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Semipalatinsk Test Site: Radioecological Situation of the Northern Lands

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The book provides present-day knowledge on radio-ecological situation in the northern part of the test site with unbiased description of present and forecasted ecological situation in the region. The book was prepared by editing group and is designed for professionals in the field of radiation safety, environmental protection, radioecology, as well as for those interested in issues related to ecological situation at the former Semipalatinsk test site.

Preface

The Republic of Kazakhstan - a country that is widely represented in all types of events related to nuclear energy. These are both military nuclear tests and peaceful nuclear explosions, as well - mining and processing of uranium. Naturally, all these activities, against the backdrop of the tragic events of the last century (Hiroshima-Nagasaki, Chernobyl and other accidents), has led to considerable public vigilance and alertness, especially toward to the Semipalatinsk test site (STS). This wariness is often exaggerated and sometimes biased. The society is sick with radiophobia. Psychological rehabilitation of society - the procedure that is very complicated and lengthy, and is achievable only if there is objective study of the situation and the availability of these results for the general public through all forms of media.

This monograph is the first of a series of books "Topical issues in radioecology of Kazakhstan", which later assumed to represent as the results of radioecological studies of the former nuclear test sites in Kazakhstan, the venues of peaceful nuclear explosions and radiation hazardous objects, and the results of basic and applied radioecological studies.

One of the main activities of the National Nuclear Centre of Kazakhstan (NNC) and its subsidiaries is the provision of radiation and nuclear safety of the former STS and arrangement of activities taking into account the peculiarities of its territory.

Since the shutdown of the test site, Kazakhstani scientists in cooperation with international scientific community have been gaining extensive information on the current radiological situation at STS and its vicinity. There have been revealed all significant areas of radioactive contamination, major pathways and mechanisms for current and potential migration of radioactive substances. The whole set of obtained data makes us confident to assume that STS does not adversely impact on the population living in the surrounding areas, except the people living in the zone of the Shagan River. One can definitely affirm that compliance with the law and rules that are applicable to activities on the territory of STS, provides radiation safety in the exercise of economic activities at the Semipalatinsk test site.

However, the radioecological situation is not stable; there were found migration processes of radioactive substances, which cause the need for regular monitoring of radiation situation at the test site and further research. We can say that, given the scale of STS and diversity of tests, the available information is not exhaustive, but allows us to offer a science-based plan for research and practical liquidation (remediation) activities.

One of the main objectives and ultimate goal of works at the STS should be a gradual transfer of STS lands for national economy. Transfer of lands is possible only after a comprehensive environmental research and rehabilitation measures at the most dangerous areas of radioactive contamination.

According to already obtained NNC data one can reasonably assume that up to 90% of the STS territory can be returned to economy. As the first phase of this lengthy work there was chosen "northern" part of STS, as for this area from 1995 to 2007 there has been accumulated much information about the content of artificial radionuclides in the environment; this area is very close to the main locality of this region (Kurchatov town), and here agricultural activities are going on, which are currently regarded as unauthorized. Further comprehensive ecological survey will be carried out for the whole territory of the test site.

Alongside with that, we can not lose valuable scientific material on STS. Some of its areas should be preserved as museum exhibits, reflecting the most important stage of human development - a stage of development of the atom and creation of the most formidable weapon in the history of mankind. STS can be regarded as the world's laboratory for studying the behaviour of artificial radionuclides in the natural environment.

Some STS areas neither currently nor in the foreseeable future will be suitable for traditional economic activities. In addition, these areas can be successfully used to host the production of atomic complex. In particular, it is a very urgent problem of disposal of radioactive wastes accumulated in Kazakhstan. The territory of the test site can become such a place for a long-term radioactive waste disposal in special containers.

Thus, at the present time the former Semipalatinsk nuclear test site has so many special properties and qualities, the development and proper use of which will inevitably lead to a world-class scientific achievements and to the significant industrial achievements of Kazakhstani economy.

Director General of the National Nuclear Center of the Republic of Kazakhstan, Academician of NAS RK, RK State Prize winner in Science and Technology in 2009, Professor **K.K. Kadyrzhanov**

Introduction

The whole set of experimental data that have been obtained to date makes us confident to assume that concentrations of artificial radionuclides in certain parts of STS are at the levels of global fallout and those lands could, therefore, be used for economical purposes without any restriction. The decision on the need for systematic work on the gradual transfer of STS lands for economic circulation has been supported by the Government as reflected in the Security Council resolution from April 06, 2009 and in the Protocol of the Interdepartmental Commission under the Security Council dated May 7, 2009.

According to the state legislation, currently the whole territory of STS is included into lands reserve (Decree No. 172 dated February 7, 1996). Article 143 of the RK Land Code says: "... the Government can transfer the lands where tests of nuclear weapons were previously performed into ownership or tenure only upon completion of all measures aimed at elimination of nuclear tests consequences and after over-all ecological studies performed there with positive expert conclusion issued by State ecological authorities." Thus, a necessary step in the transfer is to conduct a comprehensive environmental survey of the lands.

The northern part of STS was chosen for the first phase of this long work. The map (see Figure 1.1 coloured block) outlines this area with red border.

This choice was based on several considerations:

– these are the lands where the most extensive information on artificial radionuclides in environment was obtained during 1995 – 2007;
– these lands are most close to the main inhabited locality in the region - city of Kurchatov;
– and, these are the lands where unauthorized agricultural activities are currently performed.

At the same time, available information was insufficient for making a decision on the possibility of land transfer due to:

– lack of sampling statistics at studies of transuranium isotopes in soil as well as lack of reliability of these data;
– lack of reliable experimental data or substantiated calculations of radionuclide contents in certain medias (water, air);
– lack of dose load calculations for the population;
– absence of data on contents of some radionuclides which can make significant contribution to the dose loads (such as tritium, plutonium-241 and others).

Based on the foregoing, it was decided to conduct a comprehensive environmental study of the northern territory of STS as follows:

- perform theoretical assessment of possible radionuclide contamination of northern territories with calculation of possible concentrations for the full range of radionuclides generated at nuclear explosions including samarium-151, technetium-99, plutonium-238, -241, tritium;
- assess main technological factors that could affect current radio-ecological situation;
- determine experimentally the nature and levels of soil contamination; at that, surveying is to be performed on different grids – in increments of 1.5 km to the west, 1 km to the east; preliminary assessments should specify sampling grid for the central part;
- assess general characteristics of soil cover and the nature of distribution for major radionuclides in soil, as well as presence forms for main artificial radionuclides;
- study hydrogeological conditions of the region, nature of water contamination and forecast the contamination dynamics;
- study the nature of air contamination in the region;
- describe geo-botany and evaluate both theoretically and experimentally the levels and nature of vegetation contamination for the territory of concern; evaluate possible radionuclide concentrations in local agricultural crop products;
- assess fauna of the region and contents of radionuclides in major wild and domestic animals;
- evaluate of dose loads on population and personnel at activities in the territory of concern, including the scenario, "subsistence farming" based on obtained experimental data;
- based on international and national requirements to contamination of environment, prepare recommendations on utilization of northern territories in national economy.

Comprehensive radio-ecological studies of the territory have been performed by organizations of the State Enterprise "National Nuclear Center of the Republic of Kazakhstan" (NNC RK): Institute of Radiation Safety and Ecology, Institute of Nuclear Physics, Institute of Geophysical Research. Assessments of radionuclide contents in environment were carried out with verified and certified instruments included in the State Register of measuring devices in compliance with approved methods. Instrumentation and methods available in subsidiaries of NNC RK made it possible to measure contents of artificial radionuclides at levels for many times less than allowable those of radionuclides in soil, water, air and vegetation and those in the regulations. Present system of quality control in the laboratories assured continuous control over the research and reliability of the data.

Description of instrumentation and methods used for determination of radionuclides in environment of the northern part of the former Semipalatinsk test site is given in Annex A.

Chapter 1
General characteristics of studied area
1.1 Socio-economic characteristics
1.1.1 Brief description of landscape, geography and climat

The studied "northern" lands of the test site are located in the southern part of Mayskiy district of Pavlodar oblast. The territory borders with Karaganda oblast in the south-west and, behind the Irtysh River, Beskaragai district of East Kazakhstan oblast in the east.

The territory occupies the extreme north-eastern part of Kazakh melkosopochnik (a highly eroded plateau) switching to a flat plain, sloping gently towards the valley of the Irtysh River. Relative elevation of relief is 10-15 m, the absolute elevation varies from 150 to 300 m above sea level. The landscapes are represented by low-hill terrain, individual mountain ranges, knolls and bald intermountain plains, depressions under dry and desertificated steppes. The following types of landscapes were identified:

1. Granite low-hill terrain: mountains Arshaly and Dostar with elevation marks of 343 and 336 m above sea level, composed mattress shaped granites.
2. High ridgy and ridged bald mountain (melkosopochnik) with granite out-cropings and quartzite on the tops of hills.
3. Low bald mountain (melkosopochnik). Low-level bald mountains with out-crops of bedrock (granite and quartzite) are typical.
4. Deluvial-proluvial plains, for which rich in herbs steppe vegetation is typi-cal.
5. Deep depressions, occupied by drying up partially or completely (in summer) lakes, which constitute saline. Soils are saline.
6. Anthropogenically destroyed territories which are formed around the winter stays, where due to excessive grazing and man-caused interruption the soil and vegetation are degrading.

In the northern parts of STS, brown and light-brown normal soils prevail being typical zonal soils of the region. In general, the soils of surveyed territory are used as grazing land, since the extreme aridity of the climate and the instability of crop makes non-irrigable farming there impractical. Vegetation there is dominated by feather – fescue grass, wormwood-feather – fescue grass and wormwood – feather grass, often shrub steppe.

Hydrographic pattern of the STS northern part is formed by Irtysh River, several unnamed streams and quite a large number of lakes. The Irtysh river gets water from several sources – snow, subsoil water and precipitation supply. The river valley is cut by numerous meandering canals with permanent and seasonal streams. During the flood the water rises up to 5-6 m, the lowest level is observed in August-September. The Irtysh water is fresh. There is water in stream channels in periods of spring snowmelt only.

Kettles and hollow of lakes are filled with snowmelt, which in summer dries up; there is a gradual filling of the kettles with silt and their salinization takes place. The largest salt lakes in the investigated territory are Toresor, Kutansor, Kumansor, Bayansor, Sulusor, Degebasor, Maisor, Karakol, Marzabay.

The studied area is characterized by extremely continental arid climate type determined by the amplitude of diurnal and annual air temperatures, considerable evaporation prevailing precipitation, alternation of dry years with a fairly moist, unstable weather conditions during vegetation season, abrupt change in summer and winter weather patterns. Winter (November-March) is cold with little snow. In the first half of the season the weather is mostly cloudy, in the second remains clear and frosty. Snow cover is observed in the middle of November; its thickness by the end of the season rarely exceeds 25-30 cm. During winter, snowstorms are frequent causing snowdrift on roads; severe fogs are observed in heavily cold weather. Spring (April-May) is cool and overcast in the first half of the season, warm and clear in the second, at the end of the season there are frequent storms. Light frosts are observed at nights in May. Snow cover goes down in the beginning of April. Summer (June-August) is hot and dry; short rains are mostly quite intensive with thunderstorms. Autumn (September-October) in the first half is warm and clear, in the second – cool and overcast with drizzle. Snowfalls begin in late October. Winds in winter are mainly from south-east, in summer – from north-west. Hot dry winds are typical for summer season.

Types of synoptic processes

The climate in Kazakhstan is stipulated by global synoptic processes, the main ones are [1]:

- Western intervention (WI);
- North-west intervention (NWI);
- Northern intervention (NI).

WI is characterized by the transfer of polar or, less frequently, arctic air to the territory of Kazakhstan from the west. A characteristic feature of WI is prefrontal warm loss. WI is accompanied by a continuous cloudiness, precipitation, strong winds and cooling in the summer, although less intense than in the north and north-west invasion. Dangerous weather phenomena occur over a large area of Kazakhstan, including the East Kazakhstan region.

At NWI the arctic air mass (AM) or AM of temperate latitudes, limited by the cold front, penetrate into the territory of Kazakhstan from the north-west, bringing weather deterioration.

NI is characterized by penetration of very cold poor-moisture air into the territory of Kazakhstan from the north and north-east. With the passage of this front, there is no rain, or the rains are weak. Behind the cold front there is very significant drop in air temperature. Thus, in the autumn after the invasion of cold air masses in the eastern part of Kazakhstan there are light frosts strengthened due to cooling.

In the cold seasons when Siberian anticyclone is dominating, its western spur, spreading to the territory of Kazakhstan, brings a steady freezing weather. It often brings a continuous band of high pressure crossing Kazakhstan from west to east, makes sharp wind division during most of the year.

In summer the openness of area from the west and south-west promotes the free penetration of dry tropical air of Central Asia deserts, causing more dryness, hot weather and long periods without rain.

Southern cyclones bring abrupt changes of weather, both in winter and summer. In winter, southern cyclones cause heavy snowfalls and blizzards. Often, these events begin with a sharp increase of air temperature and formations of ice-slick-hoarfrost phenomena, and the ends with the invasion of cold air masses, accompanied by a sharp decrease of temperature. During the summer, southern cyclones also cause abrupt changes in weather patterns with wide fluctuations in temperature, wind speed and associated weather phenomena (dust and sand storms, dry winds).

Temperature conditions

Peculiarities of the geographical location stipulate expressed continentality and aridity of the climate.

Temperature regime is mainly determined by solar radiation factors, as well as by the influence of atmospheric circulation expressed in complex alternations of cold and warm air masses transfers and their interaction under a variety of seasonal baric conditions. Continental temperature regime, which is characterized by high contrast, large diurnal and annual amplitude is typical.

To characterize this region, the data obtained by meteorological station of the Institute of Geophysical Research NNC RK (Kurchatov) in the period 1997-2004 were used and prepared in the framework of the implementation of the ISTC project K-414 "Development, implementation and demonstration of the information set of systematic data on the Semipalatinsk test site".

Average monthly air temperature, absolute maximum and minimum of temperatures are presented in Figure 1.2.

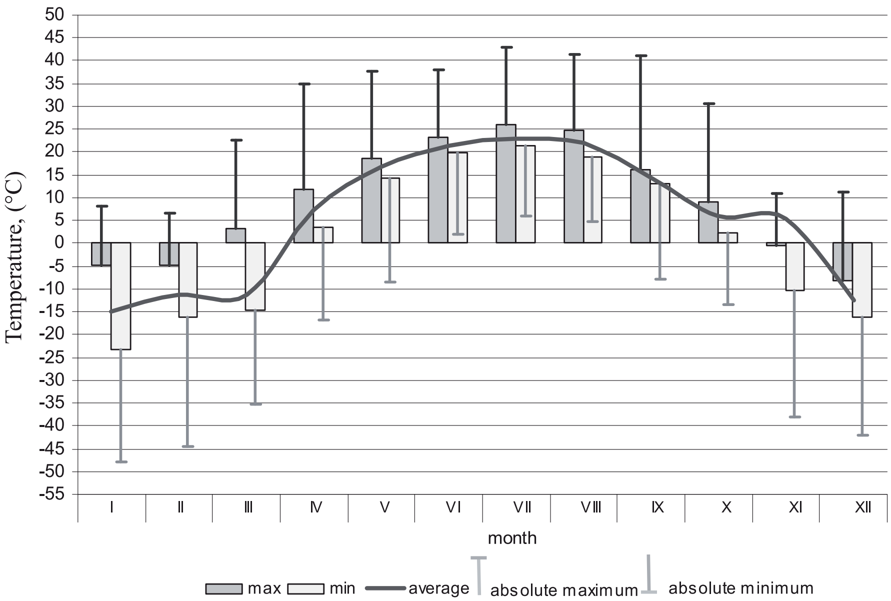


Figure 1.2. Average monthly air temperature, absolute maximum and minimum of temperatures

Wind conditions

The wind condition is predominantly continental in nature and is determined mainly by local barometric circulation conditions. In the cold season, wind condition is formed under the influence of the Siberian anticyclone, which causes sustained freezing weather. In winter, as per longstanding data, the south-east (33.1%) and south winds (19.7%) dominate. The opposite direction of the winds is observed much less frequently (7.9% – the north-west, 1.4% – the northern, 0.8% – the north-east).

Winter conditions are characterized by high frequency of anticyclones, therefore calms are observed so often.

During the summer, the wind suddenly changes, the north-west winds (25.3%), west (15.8%) and northern (15.3%) parts of the horizon dominate and there is an increased frequency of calm. The wind conditions in spring and autumn are intermediate between winter and summer, what is associated with the change in pressure fields during cold and warm seasons. May is tended to turn the prevailing wind directions from south-east to north-west. In June and July this changes are fully completed.

In October, a summer wind system is redeveloped to the winter one, what causes commence of the seasonal development of the Siberian anticyclone and a sharp weakening of the thermal depression.

Average wind speeds vary during the seasons (Figure 1.3). The form of these changes can be traced in the annual average wind speeds.

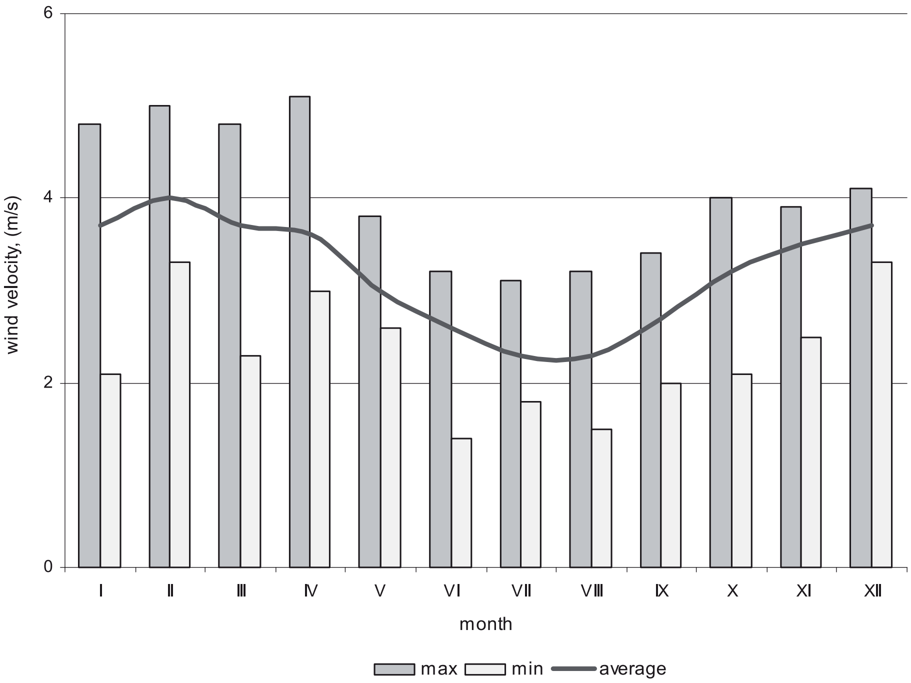


Figure 1.3. Average wind speeds over a period from 1997 through 2004

The annual variation curve for average wind speeds has a maximum and a minimum. The highest average monthly wind speed of the year is observed from January to April (3.7-4.0 m / s), the lowest - in July – August (2.3 m/s).

Strong winds occur mainly in spring (April, May), as well as in February and October. According to observation diaries, it was revealed that the maximum wind speed reached 35-40 m/s. Calm weather was observed in 10.2% of the total number of observations; most frequent calms were observed in summer - early autumn (1.0-1.3% of the total number of observations).

Dust storms happen at very strong and sustained winds [2]; at that, wind speed reaches 20-30 m/s and more. The rise of soil particles occurs more rapidly on the dry rough surface with poor vegetation in conditions that are typical for arid/semiarid areas and surface roughness of the soil combined with destruction of soil by grazing animals, vehicular traffic and human activities increase the wind dust raise.

Most often dust storms occur in May – July. On an average, dust storms were observed 4 times a year, maximum – 9 times, at least – none.

Average wind speed during dust storms varies from 15 to 20 m/s (Figure 1.4); several cases of beginning of dust storms at rather low values of wind speed (6-8 m/s) were registered.

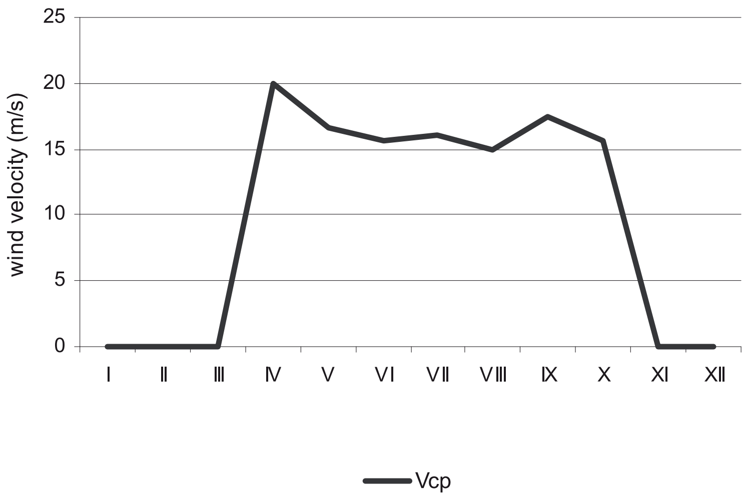


Figure 1.4. Average wind speed (m/s) at dusty storms for the period from 1997 to 2004

Storm winds occur on average 78-79 times a year. According to the winds gradation, the winds of 12-15 m/s are most frequently observed with average of 53 times per year, 16-20 m/s winds – 23 times per year, 21-25 m/s ones – 2 times a year, 26-30 m/s – 1 case per year. Winds of 30 m/s are registered very rarely (Figure 1.5).

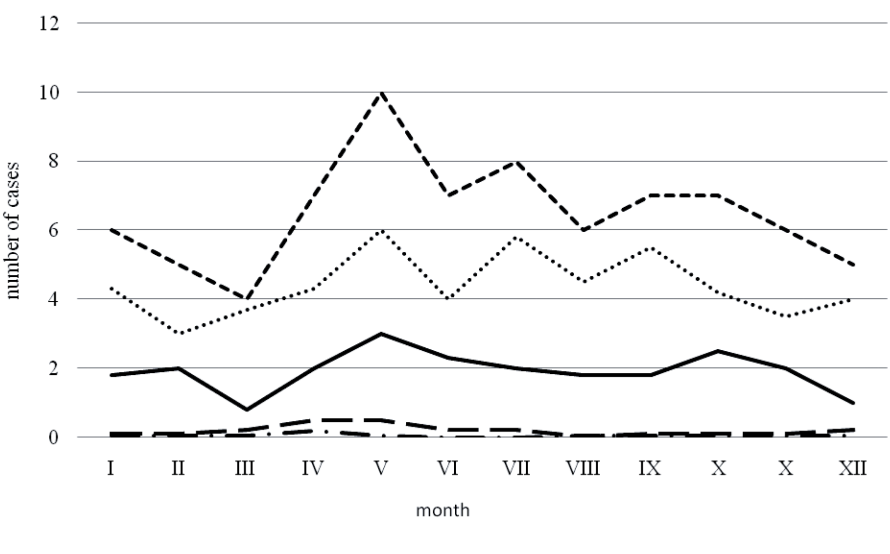


Figure 1.5. Frequency (number of cases) of >12m/s storm wind by groups for the period from 1997 to 2004; average storm winds

Precipitations

The studied area is among the areas that have insufficient precipitation. This is explained by the fact that pressure-circulation features of Eurasia determine the flow of mainly arctic air and temperate air masses of continental origin, lean moisture. Aridity of the local climate is also enhanced through the deserts of Central Asia and southern Kazakhstan. In addition, the eastern part of the steppe zone of Kazakhstan is often exposed to the influences of anticyclones and, therefore, gets less moisture than the Western part.

Continental local conditions considerably determine the instability of the rainfall fluctuations from year to year. A feature of Kazakhstan is that in any month of a year there could be no rain or some negligible precipitation, but in a different year monthly precipitation is considerable.

Annual precipitation rates vary from 117.4 mm to 275.0 mm. Maximal precipitation was registered in 2000 – 275.0 mm/year, minimal – in 1997 (117.4 mm/year). Monthly distribution of precipitation (maximum, minimum and average) for the period from 1997 to 2004 is presented in Figure 1.6.

Summer precipitation maximum is obvious. Baric-circulation conditions of the warm half-year favor a significant precipitation from May to August, when torrential rains make up from 50 to 60% of the annual amount. But the warm season precipitation is combined with high temperatures reducing their value as a factor in air humidifying. In the warm period at increase of volatility, natural moisture of the soil is not significant.

In the autumn period, compared with the summer months, precipitations are low. But since in these months the air temperature is lowering significantly reducing evaporation, rainfalls moisten the soil quite well.

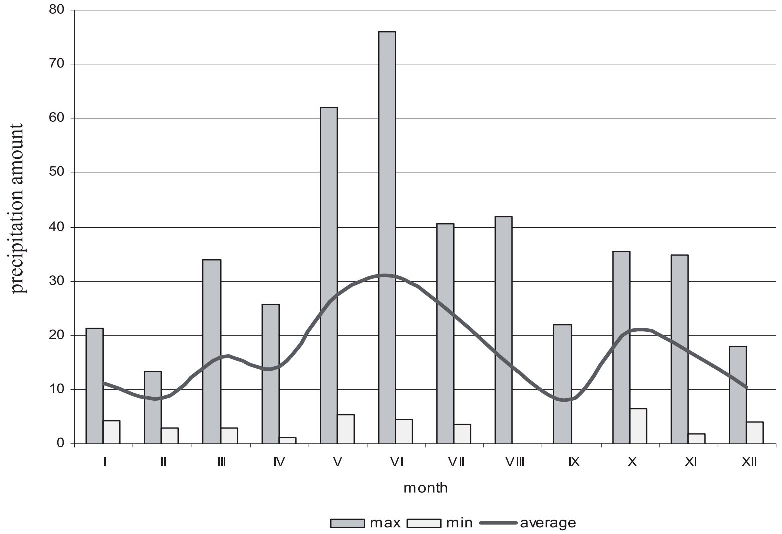


Figure 1.6. Distribution of precipitation by month for the period from 1997 to 2004

1.1.2 Administrative characteristics of the studied area

"Northern" part of STS territory belongs to Maiskiy district in south-eastern part of Pavlodar oblast. The district was established by the Decree of the Presidium of the Supreme Soviet of the Kazakh Soviet Socialist Republic on 16.10.1939 with the center in Maiskiy village. Based on the Decree of the Presidium of the Supreme Soviet of the Kazakh Soviet Socialist Republic of 02.01.1963, Maiskiy district was eliminated and its territory was included in Yermakov and Bayan-Auldistricts. By the decree of the Presidium of the Supreme Soviet of the Kazakh SSR from 31.12.1964 the district was established again with the center in the village of Belogorie (since 1992 named as – Koktobe).

Information on inhabited settlements of the studied area was obtained in many years of observations over economic activities at STS and was updated in 2009 by visiting all wintering sites and interviewing of their residents.

As of 2009, 28 wintering sites were located at the northern lands of the former STS (Figure 1.7 coloured block). Among them, only 10 were used that year: Arshaly, Bolta, Bulak, Jana-Zharkyn, Bapai, Shanyrau, "Poselok 30 kilometers", Koksh, Saba and Saba-2 (Table 1.1).

Table 1.1

Inhabited wintering sites

№	Wintering	Population number, (people)	Building availability, (pcs.)		Livestock (heads)			Water consumption objects
			Habitable	Household	Black cattle	Small cattle	Horse	
1	Arshaly	7	1	1	50	170	5	wells 3 pcs
2	Bolta	5	1	1	51	280	25	wells 2 pcs
3	Bulak	4	1	1	50	300	15	Well
4	Jana-Zharkyn	4	1	2	60	500	7	watering livestock well, drinking water is imported
5	Bapai	2	1	1	50	150	1	well
6	Shanyrau	2	1	1	76	282	3	imported
7	"Poselok 30 kilometers"	29	5	5	400	1800	600	watering livestock well, drinking water is imported
8	Koksh	5	1	2	50	200	10	watering livestock well, drinking water is imported
9	Saba	3	1	1	40	150	5	Well
10	Saba -2	4	1	1	30	180	10	Well
Total:		65	14	16	857	4012	681	

The remaining 18 wintering sites Algabas, Bayansor, Dostyk, Zhamankuduk, Tortkuduk, Tulpar, Kemaly, Aktas, Balashykan, Karabudyr, Nygmetkora, Ukkuduk and 6 winterings with no names (wintering No1, wintering No 2, wintering No 3, wintering No 4, wintering w/o No., wintering abandoned) are not used.

Winterings Shanyrau, Saba and Saba-2 are located outside the studied area, but activities for grazing and haymaking are held within the boundaries of the test site.

Used wintering are run by few people with the number of residents varying from 2 to 7 on each, except for settlement "Poselok 30 kilometers", inhabited by 29 people. The average population density for the "northern" lands (including settlements Shanyrau and "Poselok 30 kilometers") are 2 people per 100 sq.km. The population of the settlements lives there year round. Ethnicity of the population – Kazakhs.

At the wintering areas the mud-brick buildings are dominating. Objects of water (for drinking and household needs) consumption are the wells located in close proximity to the winterings. At the winterings "Poselok 30 kilometers", Jan-Zharkyn and Koksh imported drinking water is used. Of all the settlements only "Poselok 30 kilometers" has electricity supply line, other wintering operate low-power diesel stations.

The main activities at these winterings are cattle ranching and haymaking. Grazing is carried on adjacent to the wintering areas (cattle pasturing at distances ≤2 km; small cattle ≤5 km, horses ≤10 km). Since it is a free type of grazing without continuous looking after, the territory of grazing may increase. Cattle ranching products are sold at nearby settlements (details in the chapter "Agricultural activities" below).

Food ration of the residents consists mainly of their own animal products (meat, milk). Some products (flour, cereals, canned goods) are periodically purchased in retail outlets of nearby settlements.

Uninhabited winterings mainly consist of 2-3 buildings, one of which was intended for accommodation. Currently, buildings are in dilapidated condition.

1.1.3 Economic activities at the area

1.1.3.1 Agricultural activity

1.1.3.1.1 Current status of agricultural production

To assess the possible radionuclide contents in domestic agricultural products, first of all, some work has been undertaken to identify and record all the facilities (livestock farms, wintering sites, summer pastures) producing agricultural products, located in the northern part of the STS. Studies conducted in 2009 found 10 winterings with agricultural activities at this territory (Figure 1.7 coloured block).

Current status of livestock farming

In interviews of the wintering residents it was found that 4000 sheep, 680 horses and 860 heads of cattle pastured at these lands, i.e. small cattle comprise 72% of the total number of farm animals, cattle - 16%, horses - 12% (Figure 1.8).

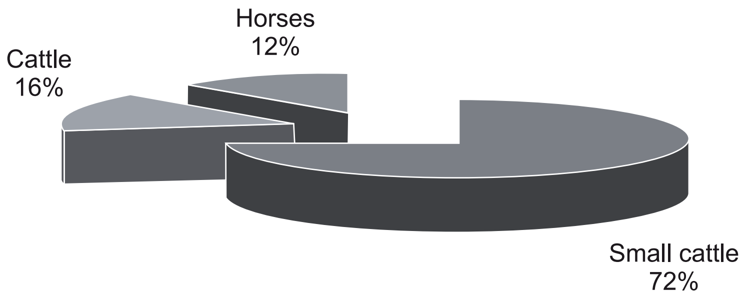


Figure 1.8. Farm livestock at the studied STS lands

Some quantitative data on the current state of winterings are available in Table 1.1.

Mostly mongrel hybrid coarse-wool sheep are bred there. Neat cattle are mainly represented by a mixture of unproductive meat and dairy breeds. In horse breeding the main horse population is mongrel. Breeding of pedigree is not performed. The main owners of the livestock farms are the farmers of Maiskiy district.

People use stalled keeping of cattle and pasturing. The system of cattle grazing is freestyle or haphazard. Pastures are used year-round. Some parts of this territory are used only in summers, where cattle grazing on natural pastures begin in early May and ends in early October.

The main products are lamb, beef and horse meat. Dairy production is unprofitable, and is made only for the working personnel and their families.

Some quantitative data on the current state of winterings are available in Table 1.1.

Current status of crop production

Difficult dissected terrain, small and imperfectly developed petrous-rubble soils of the steppe zone of Kazakh bald mountains limit the ploughing up, and arid climate - a set of cultivated pasture lands forage grasses at the studied area. Therefore, crop production (agriculture) within the studied area is absent. In small amounts, in the southern part of the investigated territory the works on the harvesting of roughage are carried out. Harvesting of succulent fodder (silage, haylage, root crop, etc.) is not performed. The main type of produced roughage is hay, which is used as a supplementary feed in winter and is an essential component of the diet to ensure the full feeding of cattle.

Of the existing methods of haymaking the crumbled hay of field curing is used. Dried to 30% moisture the mass in rolls with the pick-stacker is collected in cocks and leave for a few days in the field. In the cocks the hay finally dried to 20% moisture, and then transported to stacking by drags, cocklifter. Grass cutting for hay is commenced depending on the vegetative stage, for graminaceous plants (fescue (*Festuca valesiaca*), hairworm feather grass (*Stipa sareptana, S. capillata*), wheatgrass (*Agropyron cristatum*), cheegrass (*Achnaterum splendens*), wild rye

(*Leymus angustus*), June grass (*Koeleria cristata)*) - this is the beginning of earing (June-July).

1.1.3.1.2 Prospects of agricultural production

Prospects of livestock farming

Virtually all the studied lands (300,000 hectares) by their natural features (soil and vegetation characteristics, topography) are grazing lands. Therefore, the main agricultural activity in the future is seemed to be livestock farming. However, as a result of unsystematic grazing the degradation of vegetation takes place and, consequently, forage resources, because at this territory pastures give at least 80-90% of the annual amount of forage [3]. Therefore, under scientifically based organization of pasture lands the development of small-scale livestock farms engaged in breeding for this region traditional farm animals such as sheep, cows and horses is promissory. The list of animal products, which may be got in the investigated area, is presented in the Table 1.2.

Table 1.2

Type of primary promising livestock products for production at the studied lands

Horses	Black cattle	Small cattle		Poultry
		Sheep	Goat	
milk (koumiss)	milk	milk	milk	meat
meat (horse meat)	meat (beef)	meat (lamb)	meat	eggs

Prospects for crop production

Should complex methods of amelioration (mineral and organic fertilizers, micronutrients, irrigation, etc.) be used at the investigated area, grain cereals (rye, wheat, barley, oats) may be produced there. Also the steppe grasslands can be developed as well: periodically mowed agricultural land with zonal vegetation of the steppe type.

Farmers can also grow for themselves some products at vegetable gardens arranged at their farms. A list of such potential major crop products for the investigated area is presented in Table 1.3 below.

Table 1.3

A list of prospective crop products to cultivate at the studied lands

Grain crops	Forage	Garden crop			
		Leafy vegetables	Fabaceous	Fruited vegetables	Tuberous root
Rye Wheat Barley Oat	Hay Corn	Cabbage Spinach Leafy smallage Lettuce	Pod Pea	Tomato Cucumber Paprika Eggplant	Potato Beet Carrot Garden radish

Thus, a possible branch of agriculture in the studied area is livestock based on the principle "farmer with subsidiary plot". Garden plots can be developed, arranged on these farms to ensure the needs of the farms population of garden products.

1.1.3.2 Industrial activities

At northern part of STS industrial activities are currently carried out by the following organizations: the East-Kazakhstan Regional Energy Company and Limited Liability Partnership (LLP) Degelen Semey Tau.

East Kazakhstan Regional Energy Company runs of electricity distribution substation No. 51 and the four power lines of total length 92 km located at the northern territory of the test site (Figure 1.7 coloured block). Work at the substation No 51 is carried out by daily shifts of 5 people.

LLP Degelen Semey Tau operates the building stone mine and a sand/gravel production at the fields "Pridorozhnoe" and "Kovylnoe" (Figure 1.7 coloured block). Works are carried out the by 5-man shifts of 15 days.

There are asphalt roads Kurchatov - Reactor Complex "IGR" and Kurchatov - *Degelen* testing ground. The following companies are the main users of these roads: LLP "FML Kazakhstan", an affiliated state-owned enterprise (ASE), Institute of Atomic Energy, LLP "Degelen", "ASE Institute of Geophysical Research", ASE "Baikal", ASE "Institute of Radiation Safety and Ecology" and RSE "National Nuclear Center of the Republic of Kazakhstan". All these organizations are licensed to carry out works on the territories of the former nuclear test sites and other areas contaminated due to nuclear explosions. These are free-access roads to public.

The enterprise "Balapan Koligi" transports hard coal by rail from the coal deposits "Karazhyra" on the route: "Ugolnaya" station - "Degelen" station. This company also has a license for operation at the STS.

No case of unauthorized gathering of scrap metal or dismantling of structures at northern part of former STS has been registered.

1.2 General characteristics of the natural environment and conditions

1.2.1 Geological conditions of the area. Mineral resources

STRATIGRAPHY

The geological structure of the territory is determined by two large heterogeneous structures of different ages. Caledonides of Chenghis Tarbagatai geotectonogene is joined by deep Kalba - Chingiz fault with Hercynids of Zharma-Saur geotectonogene. Accordingly, the geological structure of Chenghis Tarbagatai geotectonogene has igneous-sedimentary rocks from the Precambrian to Lower Carboniferous visa system, as well as a young volcano-plutonic formation of tectonic-magmatic activation.

Zharma-Saur geotectonogene is composed of rocks from Tournaisian stage of the Lower Carboniferous to Middle Jurassic. Younger formations are common to the two geotectonic structures (Figure 1.9 coloured block).

MINERAL RESOURCES

The stance of the northern lands of test site at the junction of two major structures of different ages – Chenghis Tarbagatai and Hercynian Irtysh-Zaisan fold systems caused a linear metallogeny zoning and diversity of minerals of southwestern and northeastern parts of the territory (Figure 1.9 coloured block).

Solid fossil fuels

Fossil coal

Occurrence of Kotansor (17). In the old ruined the goaf with the section of 4 by 2 m at a depth of 2.5 m there is bright black coal shed with capacity of 0.4 m, lying among the carbonaceous siltstones. At a distance of 500m along the strike there were noted small goafs with coaly carbonaceous black in the dumps.

Metallic minerals

Ferrous metals

Iron

Ore occurrence of Kyzyldar (3). Genesis is sedimentary. Among the shales and siliceous rocks of Devonian the strata of hematites and iron-encriched bauxite overlie. Layer thickness is 1-5 m, length is up to 1,000 m. Iron content is 29.41%, alumina is 12,64%. Because of the small scale of mineralization, ore occurrence is futile in terms of iron and bauxite.

Ore occurrence of Maisor (9) is located 6.5 km to north-west of the eponymous lake. This is an eluvial accumulation of sediment-genesis hematite iron ore among the calcareous and siliceous siltstones of the Lower Carboniferous. Due to the small size, the field does not have commercial value.

Non-ferrous metals

Copper

Ore occurrence of Shangirau West (5). Endocontact zone of granitoid massif with remnants of volcanic-sedimentary rocks. Granodiorites in places, is altered to greisen. The copper content is 0.04%, molybdenum – 0.01-0.03%, silver – 1.3 g/t, gold – 0.005 g/t. In the zone of oxidation, developed to 23 m, the content in grab samples is much higher. Due to low mineralization, the occurrence has no independent commercial value.

Ore occurrence of Toresor (15). Located 4 km to south-west of the eponymous lake. Nothwest Zone of crushing, silicification and limoniting process in porphyrites at capacity of 40 m, northwest. The copper content is up to 1%, zinc is up to 0.3%, silver is up to 6 g/t, gold is up to 0.15 g/t, molybdenum and led are up to 0.01%, bismuth is up to 0.0006%, barium is 1%. The Occurrence needs further in-depth study.

Rare metals and trace elements

Molybdenum

Ore occurrence of Shangirau East (6). Among the fine-grained biotite granites field of quartz veins. There are molybdenite and pyrite impregnated in quartz. Molybdenum content is 0.01-0.8%. In individual samples there is 0.02% of tungsten and gold is in amounts 0.01-1.5 g/t: not of any practical interest.

Ore occurrence of Uzynbulak (10). A hydrogeological well has revealed uncovered a clarified leucocratic granite with veinlet of quartz at depth 51-53 m. Molybdenum content in samples is 0.01-0.03%, there are some increased contents of lead, zinc, silver, copper, tin of no practical interest.

Ore occurrence of Koytas (11) is located 8.9 kilometers to east-northeast of Dastar Mountain. Among the alaskite granites there are series of quartz veins of north-east outstretch. The thickness of veins is 0.2-6 m, length is 4-200 m. Totally there are 13 quartz veins. In three of them the molybdenum content is 0.01-0.02%. In the first tungsten constitutes 0.02%. In two others gold content is at the level 0.2 g/t. Ore occurrence represents no commercial interest.

Ore occurrence of Northern Kuzgan III (14) is located 15 km to north-west of the ore field Kuzgan. Mineralization in quartz veins is progressing among late carboniferous granites. The molybdenum content is 0.04%, bismuth is 0.1%, tungsten is up to 0.1%. The ore occurrence represents no commercial interest.

Niobium

Ore occurrence of alluvial type Archaly (12) is located 6.6 kilometers to east-southeast of Maisor Lake and contents tantalum and niobium in columbite bearing alaskites. Columbite content in proluvial and placer deposit is up to 250 g/t. In the west part of massif in residual soil the thickness is 8 m, columbite content is up to 69 g/t, 48-61 g/t in proluvial deposits. Niobium and tantalum ratio is 40:1. Due to low tantalum content, the occurrence is of no practical value.

Rare earths

Ore occurrence of Dostar (13) is located 6 km to east of Dostar Mountain being a silicified crushing zone among the coarse-grained alaskite granites with cerium contents of 0.04-0.06%, lanthanum 0.005-0.01%, yttrium – 0.02%, ytterbium – 0.003%. The ore occurrence represents no commercial interest due to low mineralization and concentrations.

Ore occurrence of Agirek (4). It is a complex secondary diffuse halo with cerium content of 0.08%, lanthanum – 0.06%, yttrium – 0.05%, beryllium – 0.001%, zirconium – 0.04%. The size of the halo is 150×300 meters. Further exploration is needed.

Precious metals

Gold

Ore occurrence of Zhamantuz (7). It is a quartz veining zone with a length of 1,300 m and width of 50-200 m. According to spectral analysis, gold content is 0.1-1 g/t while assay estimate is up to 415.9 g/t. Gold to silver ratio is 1:2. Gold is accompanied with arsenic, copper, zinc, tungsten, molybdenum, less bismuth, lead and antimony. Because of the great depth of erosion section, the prospects are unpromising.

Ore occurrence of Zhamantuz II (8). It is a quartz veining zone, east-northeast strike with length of 300 m. There are 22 quartz veins. Content of gold is 0.1 g/t, in two samples is 3.2 g/t and 5.2 g/t. There are arsenic, bismuth, molybdenum, tungsten, and antimony. There is no practical interest in this occurrence.

Ore occurrence of Sulusor (1). It is a quartz veining zone in the granodiorites. Its span is in north-northeast, with the length of 300 m and width 20m. Content of gold is 0.3 g/t and silver >100 g/t, copper >1%, 0.3% of molybdenum, bismuth >0.1%. Further exploration is needed.

Ore occurrence of Saryadyr (2) is located 5.5 km to the west-southwest of Saba summer pasture. It is a quartz veining zone with size of 1500*500 m in endocontact of biotite-hornblende granite massif. Gold content is 1.7 g/t and silver exceeds 100 g/t. There are arsenic, antimony, bismuth, lead, copper. A hydrogeological borehole has uncovered quartz vein at depth of 53.5-54 m with high silver content of more than >100 g/t, 1% of lead, 1% is zinc, copper is 0.3%, gold – 0.04 g/t. There are arsenic, antimony, bismuth, molybdenum, and cadmium. Ore occurrence has shallow erosional truncation and needs further exploration.

Construction and refractory materials

Seat clay

Deposit of Zharkyn (16) is located 10.5 kilometers to east-northeast of Arshaly Mountain. 2.5 m-deep ditches uncovered 5 intervals of clay residual soil with width of 7 - 35^0 m. Estimated thickness of residual soil is over 5 m. The length to the north-west is a few kilometers. According to the analysis of two samples it is kaolin clay (bentonite number is 10). Plasticity is very high, up to 30 units what is not typical for kaolinite [4, 5, 6, 7, 8, 9].

Within the northern part of STS, two deposits are currently in operation: the "Kovylnoe" deposit of building stone, and "Pridorozhnoe" deposit of gravel-sand mixture (Figure 1.9 coloured block).

"Kovylnoe" deposit

The deposit of building stone "Kovylnoe" is located 12 kilometers to south-east of Kurchatov, 1 km to north of the site No 5, and 4 km to the east of Degelen railway station – Ugolnaya station at Maiskyi district of Pavlodar oblast.

Granite massif which includes "Kovylnoe" deposit has been revealed in the process of Conditioning Geological Survey at a scale 1:200 000 (Figure 1.9 coloured block). The deposit was found in 2001. The main consumer of granite gravel of "Kovylnoe" deposit is a railroad Semipalatinsk – Degelen station – Ugolnaya station.

"Pridorozhnoe" deposit

Pridorozhnoe deposit of gravel-sand mixture is located in the Maiskyi district of Pavlodar oblast 4 km to south-east of Kurchatov in close proximity to the railroad Kurchatov–Balapan village.

The geological structure of the deposit involves sediments of Paleogene and Quaternary systems. Minerals in the deposit are alluvial deposits of proluvial upperquaternary age, presented by gravel-sand mixture.

1.2.2 Soil cover

The studied area of the Semipalatinsk test site occupies the north-eastern part of Kazakh bald mountain (melkosopochnik) and plains of pre-bald mountain, provided with deluvial-proluvial train. General characteristics of the soil cover are available in literature [10, 11, 12] (Figure 1.10 coloured block).

Landscapes are low-mountain, individual mountain ranges, bald mountains and plains between them, depressions under dry and desert steppes in the zonal chestnut and light chestnut normal, short matured and undeveloped soils that are most widespread. There are meadow-chestnut, meadow soils in the complex and coupled with alkaline and solonchak-like soil, salt-marsh and solonchak. Small thickness of mantle loose deposits, rank soil, small amounts of organic matter are typical for soil cover of the area.

Chestnut and light chestnut zonal short matured and undeveloped soils occur on slopes of hills, formed by dense bedrock, yields of which are often observed at the tops. Soil-forming rocks for them are thin eluvial-talus detrital clay loam, the thickness of which gradually increases from the top of the hills to their foot, but at the same time the gritty consistency of soils is being reduced. It is usual there that with fully developed shapes, chestnut soils rarely occur, mostly at deluvial-proluvial plume outlining the hills at the north and north-east.

The main morphological features of short matured and undeveloped soils are low thickness humus horizon (15-25 cm), with the thickness of a loose layer of no more than 40-60 cm. In subzone of chestnut soils there is no occurrence of loess with lime nodules, whereas in the light chestnut soils, directly under the humus horizon the carbonate illuvial horizon is observed. All the soil are light or medium loamy, but usually sandy. The most common among chestnut soils are medium-humic (3-4% of humus) types. The humus content in the light chestnut soils in the upper horizon reaches 2-3%. The reaction of soil solution on the surface is close to neutral, but further down the shape changes to a slightly alkaline or alkaline, which is especially typical for the light-chestnut soils.

Meadow-chestnut soils are matured under additional moisture from the slope runoff or groundwater recharge in interhill depressions or on the plains often in complexes and combinations of alkaline and solonchak shaped, as well as salt-marsh. The meadow-chestnut soil with well matured shape is spread at pre-bald mountains band, which is a blanket of deluvial-prolluvial deposits bordering bald mountains. These soils at the top of the blanket are not saline, but at the switching to the plains under low drainage becomes alkaline (the amount of absorbed Na is over 5% of exchange capacity) or salt marsh if the content of freely soluble salts in soils is more than 0.6%.

Saline soils occupy a lower position in the relief and are matured in parent rocks that are heavy in terms of mechanical composition. Meadow-steppe alkaline lands are widely spread among Solonchak soil where there clearly can be seen the natric horizon with absorbed Na in quantities of 10 to 20% of exchange capacity and high-lying salt horizon.

Alkaline lands often occupy microrelief heights among depressions occupied by meadow or alkaline soils, saline soils. The most common of them in the investigated territory are common salt marshes formed on the low terraces of the salada lakes composed of lacustrine deposits of heavy texture.

1.2.3 Hydrogeological conditions

Hydrogeological structure of the territory is determined by geological and structural-tectonic features of the region. Hydrogeological system of the territory includes the water-bearing horizon of groundwater and a regional complex of fracture water. Groundwater is represented by pore waters of alluvial terraces deposits in the valley of the Irtysh River, and subterranean waters of alluvial- proluvial deposits of the plains, valleys of temporal ephemeral streams (Figure 1.11 coloured block).

Subterranean water of quaternary alluvial terraces are free-flow, lie at a depth of 1.0-1.2 m. They are sulfate, chloride, and mixed types waters. Total mineralization is 0.4-6.0 g/l, reaching in some cases up to 12.0 g/l (in the drainageless depressions and in areas of increased evaporation), flow rate is 0.04-1.6 l/sec. Subterranean water of quaternary alluvial-prolluvial deposits is non-pressure, lie at a depth of 1.0-10.0 m. The water is fresh, transparent, type of water is hydrocarbonate, sulfate-hydrocarbonate, sometimes sulfate. Total mineralization is 0.1-0.6 g/l, flow rate is 0.1-1.6 l/sec.

Mixed subterranean-fissure water is represented by the water-bearing horizon, in the structure of which there are paleogene sand and sandstone sands and sandstones, mesozoic residual soil, a zone of exogenic fracturing of paleozoic rocks. The thickness of paleogene water-bearing sand is negligible and usually comprises not more than 2.0-2.5 m. Thickness of water-bearing horizons of mesozoic residual soil is 3.0-12.0 m and thickness of zone of exogenous fracturing ranges from 5.0 to 40.0 m. Thus, the overall thickness of the water-bearing horizon of mixed type of water varies between 10 – 50 m. When the water-bearing horizon is shut off by neogene water-impermeable clays, the groundwater becomes subartesian. Sometimes it reaches 20-30 m [13, 14].

Fissure water is mostly widespread and adapted to the zone of exogenic fracturing of the basement rocks of different ages and origins. Chemical composition and salinity of water depends on the composition and properties of the surrounding rocks. Recharge of fissure water is carried out both from precipitation and from above-located water-bearing horizons. Hydrocarbonate water with low salinity of 0.1-1.0 g/l dominates in mountainous areas, particularly in areas of granitic intrusive rocks. At the foot of mountain slopes and in the valleys the water comes to the surface in form of springs making it easily available for household and technical needs. At sites of drainageless basins there is often observed chloride water with high mineral content (20-70 g/l). For the transition regions sulfate and mixed types of water with a salinity of 1.0-25.2 g/l is typical. Fissure waters, as a rule, are artesian, their discharge varies from 0.01 to 10.6 l/sec. Water-bearing structures occur at 4-10 m in the foothills and in depressions, on plains – at 10-60 m and deeper. A variety of fissure waters is the "vein" water circulating in powerful zones of deep faults.

1.2.4 The vegetable world (Flora) of the area

Vegetation cover of studied area is represented by dry xerophytic-forb-gramineous-bunchgrass steppes. Dominant plants are turf grasses: feather grass (*Stipa capillata, S. sareptana, S. lessingiana)* and fescue (*Festuca valesiaca*). Associated species are mainly represented by wormwood (*Artemisia marschalliana, A. gracileccens, A. Frigida, A. dracunculus*).

Within the xerophytic forbs we can find Ancathia (*Ancathia igniaria*), blueflag (*Iris scariosa*), cinquefoil (*Potentilla acaulis*), bedstraw (*Galium ruthenicum, G. Verum*), Galatella (*Galatella tatarica, G. villosa*), cereals - wheat grass (*Agropyron cristatum*), cleistogenes (*Cleistogenes squarrosa*), bluegrass (*Poa stepposa, P. angustifolia*), fatuoid (*Helictotrichon desertorum*), herd grass (*Phleum phleoides*), June grass (*Koeleria cristata*). Among the steppe shrubs pea shrub (*Caragana pumila*) and meadowsweet (*Spiraea hypericifolia)* are widely spread.

Soil-geo-botanical surveys performed for the entire area have revealed there granite low-hill terrain ecosystems, ecosystems of high bald mountains (melkosopochnik) and low bald mountains, deluvial-proluvial plains, with deep degradation and anthropogenically destroyed lands, as well as accumulative plain of the Irtysh. A schematic map of the distribution of these ecosystems with typical productivity of the grass stand is shown in Figure 1.12 coloured block. Legend to the map is presented in Annex B.

1. Granite low-hill terrain ecosystems: Arshaly and Dostar mountains with altitude of 343 and 336 m above sea level, composed mattress shaped granites.

The vegetation cover consists of a series of communities: juniper (*Juniperus sabina*), rockmat-rich-in-herbs (*Thymus marschalliana, Ephedra distachya, Carex pediphormis, Patrinia intermedia, Potentilla acaulis*), rich-in-herbs-cold-wormwood-bunchgrass (*Stipa kirgisorum, Helictotrichon desertorum, Festuca valesiaca, Artemisia frigida, Centhaurea sibirica , Hieracium echioides*) with shrubs (*Caragana pumila, Spiraea hypericifolia*) on hights and slopes of granite gravel and fine grained soil accumulations between the slabs (soil - chestnut, mountain- chestnut, underdeveloped, detrital); cold-wormwood-fescue- stipa (*Stipa sareptana, Stipa capillata, Festuca valesiaca, Koeleria cristata, Artemisia frigida, Iris scariosa*) over inter-bald mountain narrows on undeveloped and short-developed chestnut soils, often meadow-chestnut. Productivity of vegetation areas of Granite low-hill terrain varies from 0.2 to 3.1 t/ha.

2. Ecosystems of bed-formed high and ridgy bald mountains (melkosopochnik) with granite outcrops and quartzite on the tops of hills.

The distribution of plant communities is usually as follows: the dominance of rockmat-rich-in-herbs - spiraeic - pea shrub (*Caragana pumila, Spiraea hypericifolia, Patrinia intermedia, Sedum hybridum, Orostachys spinosa, Veronica pinnata*) communities on the tops of hills and feather grass-fescue-stipa (*Stipa sareptana, Festuca valesiaca, Stipa lessingiana, Artemisia frigida, Carex supina, Galim ruthenicum*) on slopes and inter-bald mountain steppe depressions on chestnut short-developed and undeveloped gravelly soils.

In the case of quartzite outcrops on hill tops the vegetation cover consists of a series of communities: sagewort-bunchgrass-cold-wormwood (*Artemisia frigida, Stipa lessingiana, Festuca valesiaca, Ajania fruticulosa, Ephedra distachya, Veronica pinnata, Patrinia intermedia*) on the tops and fescue-lessingiana (*Stipa lessingiana, Festuca valesiaca, Ephedra distachya, Galatella tatarica*) with pea shrub (*Caragana pumila*) on slopes and steppe inter-bald mountain depressions on chestnut short-developed gravelly soils. Extensive inter-bald mountain depressions in such hillocks with granite outcrops mainly are xerophytic- bunchgrass with feather grass (*Stipa sareptana, Stipa capillata, Stipa lessingiana*), fescue (*Festuca valesiaca*), wormwood (*Artemisia frigida, Artemisia marschalliana, Artemisia gracileccens*), sedges (*Carex supina*), forbs (*Galatella tatarica, Ancathia igniaria, Iris scariosa, Potentilla acaulis, Galim ruthenicum*) community. Species composition of phytocenoses generally depends on the environmental conditions of specific habitats such as: on sandy and light loamy soils the following will dominate: feathers - capillary feather grass or Stipa (*Stipa capillata*), wormwoods - Marshall wormwood (*Artemisia marschalliana*), at increasing of soils alkalinity feather is replaced by S. lessingiana (*Stipa lessingiana*), wormwoods - thin wormwood (*Artemisia gracileccens*).

In alkaline soils of inter-bald mountain depressions of high ridgy hills there is expansion of complexes with Egnatioides (*Artemisia gracileccens, Artemisia pauciflora*) and hastata (*Atriplex cana*). In the eroded areas Anabasis (*Nanophyton erinaceum*) is also present in the communities.

Micro zonal variety of communities inhabits depressions on the meadow or meadow-chestnut soils in places where additional moisture is available: reed (*Phragmites australis*), reed grass (*Calamagrostis epigeios*), licorice- wild rye (*Leymus angustus, Glycyrrhiza uralensis*), alfalfa- salinitegrass-meadowgrass (*Poa triviali, Medicago falcata, Galatella biflora*).

On sors salines in inter-bald mountain depressions with temporary ephemeral ponds the following micro zonal range of communities is formed: wild rye (*Leymus angustua, L. paboanus*) - Lasiagrostis splendens (*Achnatherum splendens*) - Halimione (*Halimione verrucifera*) - camphor-fume (*Camphorosma monspeliaca*) - schrenkiana -wormwood (*Artemisia schrenkiana*).

Productivity of vegetation cover at high ridge and ridges hills varies from 0.3 to 2.0 t/ha depending on the composition of the soil-plant complexes.

Productivity of vegetation cover of areas of high bed-formed and ridgy hills varies from 0.3 to 2.0 t/ha depending on the composition of the soil-plant complexes.

3. Ecosystems of low bald mountains (low melkosopochnik) are characterized by low hills with outcrops of rocks, both granite and quartzite.

Rockmat vegetation of hills with outcrops of bedrock is differentiated into the shrub-forb-rockmat *(Orostachys spinosa, Sedum hybridum, Ephedra distachya, Ajania fruticulosa, Caragana pumila, Atraphaxis frutescens*), into chestnut gravelly soils and undeveloped pea shrub sagebrush-bunchgrass (*Festuca valesiaca, Stipa sareptana, Artemisia frigida, Spiraea hypericifolia, Caragana pumila*) and chestnut short developed gravelly soils.

Widely-spread steppe vegetation can be represented by a series of communities: pea srub-artemisia-stipa (*Stipa capillata, Caragana pumila, Artemisia frigida*), wormwood-fescue-stipa (*Stipa capillata, Festuca valesiaca, Artemisia marschalliana*) and cold-wormwood (*Artemisia frigida*) on chestnut gravelly loamy soils. Sometimes the communities have spirea (*Spiraea hypericifolia*).

Over interhillocky meadow depressions of low bald-mountains on the meadow-chestnut soils there are shrub-forb-grass communities with domination of *Festuca valesiaca, Poa stepposa, Agropyron cristatum, Leymus angustus, Achillea asiatica, Medicago falcata, Spiraea hypericifolia, Caragana pumila.*

Over interhillocky depressions in the meadow-chestnut soils in the complexes and combinations of alkaline and brackish soils in the low hillocks a number of ecological communities are formed: Lasiagrostis (*Achnatherum splendens*), salt tree (*Halimodendron halodendron*), sagebrush- wild rye (*Leymus angustus, Artemisia nitrosa*).

Productivity of vegetation cover of low hillocks for the different plant communities ranges from 0.4 to 4.3 t/ha.

4. Ecosystems of deluvial-prolluvial plains. Vegetation cover is mainly represented there by zonal xerophilous-rich in herbs-bunchgrass steppe (*Stipa capillata, Festuca valesiaca, Artemisia frigida, Galatella tatarica, Ephedra distachya*). Frequently there are observed steppe shrubs of Caragana (*Caragana pumila*) and meadowsweet (*Spiraea hypericifolia*).

For the meadow-steppe depressions the combination of zonal steppe vegetation and microzonal range of meadow-steppe communities are typical: alfalfa-fescue (*Festuca valesiaca, Medicago bifurca*) - rich in herbs-crested grass (*Agropyron cristsatum, Potentilla impollita, Galium ruthenicum*) - liquorice-wild rye (Leymus angustus, Glycyrrhiza uralensis) on meadow-chestnut soils, often graveled.

Over depressions in saline soils there are systems of wormwood-fescue-feather grass (*Stipa lessingiana, Stipa capillata, Festuca valesiaca, Artemisia gracilescens*) communities with thin-wormwood (*Artemisia gracilescens*) and hastata (*Atriplex cana*) communities.

At deluvial-prolluvial plains with non-perennial channels around the pond in saline soils (meadow chestnut alkaline, saline, salt marshes) a microzonal range of halophytic communities is formed: sea blite (*Suaeda prostrata*) - halimione (*Halimione verrucifera*) - camphor-fume (*Camphorosma monspeliaca*) - alkaligrass (*Puccinellia distans*) - reed (*Phragmites australis*) - Lasiagrostis (*Achnatherum splendens*) - liquorice-wild rye (*Leymus muiticaulis, Glycyrrhiza uralensis*).

Productivity of vegetation cover of deluvial-prolluvial plains varies from 0.4 to 4.9 t/ha depending on the composition of plant communities.

5. Ecosystems of depositional plains are spread all over the north-eastern half and the north-western half of the investigated area, confined to the valley of the Irtysh and the complex of three upper-quaternary erosional-depositional above flood-plain terraces, the latter of which merges with the Central Kazakh melkosopochnik.

Spatial distribution and depositional plains ecosystems structure are closely linked with the composition of the surface of the territory. Ecosystems of the first above flood-plain terraces, which is characterized by a flat topography with numerous catholes and deep depressions, elongated in the north-westerly direction (the direction of the ancient flow of the Irtysh River) are characterized by a large garishness of soil-vegetation cover. The second above flood-plain terraces have a more smoothed relief and a more uniform soil and vegetation cover. The third above flood-plain terraces - undulating plain with extensive, but shallow depressions. There are widespread variations of upland steppes.

On sandy and light loamy chestnut normal soils of the elevated sections there is wide spread marshal wormwood-fescue-stipa (*Stipa capillata, Festuca valesiaca, Artemisia marschalliana*) steppe.

The chestnut normal soils, well-drained sites of large depressions are associated with forb-bunchgrass (*Stipa capillata, Festuca valesiaca, Galatella tatarica, Medicago bifurca*) steppe in normal chestnut soils, sometimes in conjunction with the forb-grass-bush (*Spiraea hypericifolia, Rosa acicularis, Festuca valesiaca, Bromus inermis, Galium ruthenicum, Medicago romanica*) communities on meadow-chestnut free-salined soils of deep depressions.

In the chestnut normal soils of the flat land, sagebrush-fescue-stipa (*Stipa capillata, Festuca valesiaca, Artemisia compacta*) steppe is typical, in conjunction with them on chestnut soils of catholes there are wormwood-hastata (*Atriplex cana, Artemisia nitrosa*) cenoses.

At chestnut loamy saline soils of surveyed upland areas, sublessingiana-fescue-feather-grass (*Stipa lessingiana, Festuca valesiaca, Artemisia sublessingiana*) steppe is dominated.

At chestnut alkaline soils of vast flat depressions communities of brittle spike-fescue-wormwood are formed (*Artemisia gracilescens, Festuca valesiaca, Psathyrostachys juncea*).

At solonchakous and alkaline soil halophytic forb-grass communities composed of *Puccinellia dolicholepis, Leymus paboanus, L.angustus, Aeluropus litoralis, Saussurea amara, Limonium gmelinii* are formed.

At the outcrops of Paleogene sediments, communities of oliganthous wormwood (*Artemisia pauciflora*) and perennial saltworts are typical: *Nanophyton erinaceum, Anabasis eriopoda, Anabasis salsa, Atriplex cana, Limonium suffruticosum.*

Intrazonal lignose of Irtysh floodplain is associated with riverine parts. At the young emerging shallows with stratified alluvium a motley-reed-willow (*Salix pentandra, S. triandra, S. alba, Calamagrostis epigeios, Bidens tripartita*) conenoses is typical. On the floodplain forest-meadow soils of the channel bank a willow-poplar (*Populus* *nigra, P. alba; Salix alba; Rhamnus cathartica; Rosa pisiformis*) forest grows. On the alluvial-meadow soils of riverine floodplain flat lands there are mesophytic-shrub cenoses of wild roses (*Rosa pisiformis, R. acicularis, R. spinosissima*), honeysuckle (*Lonicera tatarica*), hawthorn (*Crataegus sanguinea*), sometimes with blackberries (*Rubus caesius*). On the alluvial-meadow dry soils of higher levels of the floodplain out of the trees there is elaeagnus (*Elaeagnus oxycarpa*) and out of shrubs salt trees are common (*Halimodendron halodendron*).

Intrazonal Irtysh floodplain meadow vegetation is very dynamic, its spatial distribution is associated with rapidly changing environmental conditions in the floodplain.

Grasslands are variants of wetlands (*Phalaroides arundinacea, Carex acuta, Cirsium incana, Lathyrus pratensis, Veronica longifolia*) in marsh soils standing (*Elytrigia repens, Bromopsis inermis, Alopecurus pratensis, Glycyrrhisa uralensis, Ptarmica cartilaginea, Poa pratensis*) on alluvial-meadow unsalinized soils, halophytic (*Puccinellia distans, Leymus paboanus, Artemisia nitrosa, Limonium gmelinii, Plantago salsa*) of salt-marsh soils in meadow and steppe grasslands (*Carex praecox, Stipa capillata, Festuca valesiaca, Agrostis tenuis, Centaurea adpressa, Artemisia pontica, Leymus ramosus*) on meadow soils that is becoming steppe.

Intrazonal scrub vegetation of small watercourses are represented mainly by salt tree (*Halimodendron halodendron*), and meadow vegetation, predominantly, by halophytic meadows variants (*Pragmites australis, Puccinellia distans, Achnatherum splendens, Leymus angustus, Plantago salsa, Limonium gmelinii, Artemisia schrenkiana*) on meadow salt marshes.

For depositional plains of north-east and the north-western half of the investigated area, vegetation usually demonstrates high productivity of not less than 1.5 kg/ha and up to 4.7 t/ha.

6. Ecosystems of the deep depressions. Depressions are occupied by intermittent salada lakes which dry up partially or completely in summers. Soils are salinized. This is mainly salina salt marshes, which are occupied with chenopodiaceae (*Halocnemum strobilaceum*) communities or salty meadow and solonchakous on the foreshore under halimione (*Halimione verrucifera*) - camphor-fume (*Camphorosma monspeliaca*) - shrenkov-wormwood (Artemisia schrenkiana) communities. The productivity of the vegetation cover of deep depressions in the average does not exceed 0.2 tons per hectare.

7. Ecosystems of man-disturbed territories. Anthropogenic processes of a certain land are directly linked to human activities there. Man-influenced ecosystems at the studied area can be considered in three main groups: ecosystem of deposits, ecosystems of urbanized territories and pascual ecosystems.

Vegetation at deposits in the northern parts of STS is characterized by various stages of restoration of natural steppe vegetation zone, dependent primarily on the age of deposits, specific location of the deposit, edaphic conditions, etc. Generalized demutation series of communities in the subzone xerophilous- rich in herbs-bunchgrass steppes are as follows: groups of biennial weeds (*Avena fatua, Lactuca altaica, Artemisia sieversiana, Barbarea stricta, Ceratocarpus arenarius*) → weed group of creeping-rooted and Rhizome perennial plants (*Cirsium arvense, Convolvulus arvensis, Artemisia procera, Artemisia austriaca*) grouping → Community of bunchgrass-wormwood (*Artemisia marschalliana, A. dracunculus, Agropyron cristatum, Festuca valesiaca*) → Community of motley-Artemisia-bunchgrass (*Agropyron cristata, Festuca valesiaca, Stipa lessingiana, Artemisia sublessingiana, A.marschalliana, Medicago romanica*) of anthropogenically-disturbed agricultural lands.

Ruderal and adventive weed species are widely present at urban areas: *Vexibia alopecuroides, Amaranthus retroflexus, Carduus nutans, Cyclachaena xantifolia, Xanthium strumarium, Capsella bursa-pastoris, Lepidium ruderale, Echinochloa crusgalli, Polygonum aviculare, Datura stramonium.*

Pasturing – the oldest form of vegetation usage by human. Pascual (pasture) digression of soil and vegetation cover at the northern part of the STS is confined to wintering sites. Distribution and rate of anthropogenic pascual disorders vary widely. Indicator species of pasture digression are ebelek (*Ceratocarpus arenarius)*, the Austrian wormwood (*Artemisia austriaca*), bur buttercup (*Ceratocephala testiculata*), koelpinia linear (*Koelpinia linearis*), mock wormwood (*Artemisia scoparia*), brunets (*Vexibia alopecuroides*), mock kochia (*Kochia scoparia*), white pigweed (*Chenopodium album*), Climacoptera ciliate (*Climacoptera brachiata*).

Productivity of vegetation cover of man-made territories on average does not exceed 0.2 tons per hectare.

1.2.5 The animal world (Fauna) of the area

The species composition of the fauna at the investigated territory

The fauna of vertebrates and invertebrates at studied area is quite rich and diverse because of low anthropogenic influence, reservation conditions, availability of abundant stable food supply and large-area land, favorable for the habitat and breeding of various species of animals.

Detailed seasonal studies on the comparative assessment of species diversity of fauna complexes at the STS [15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27], as well as analysis of the literature revealed that the fauna of vertebrates at the northern part of STS is represented by 221 species, including birds – 147, mammals – 45, fish – 18, reptiles – 7, amphibians – 2, cyclostomes – 2 species. 15 species were included in the Red Books both of the International Union for Conservation of Nature and of Kazakhstan.

One should note that presence of a number of animal species on the studied STS lands must be considered as probable based on literature data on the habitats and registration of these species in the past.

Ichthyofauna

Ichthyofauna at the investigated territory, inhabiting, mainly in Irtysh River, and in many salt lake are mainly 2 types of cyclostomes and 18 kinds of bony fishes (out of 104 living in Kazakhstan). Most numerous representatives of the order

Cypriniformes are 11 species. Valuable commercial fishes are Sturgeons (Siberian sturgeon, sterlet), Salmoniformes (pike) and Gadiformes (burbot). One representative of the Salmoniformes order – sheefish is entered in the Red Book of Kazakhstan.

Class of Terraqueous or Amphibians

Amphibians of the area are represented by 2 species (out of 12 known for Kazakhstan) from the order of acaudate: lake frog (*Rana ridibunda*) and moor frog (*Rana arvalis*). Moor frog lives in stagnant fresh water. The lake frog is the dominant species of amphibians; it inhabits the Irtysh River and its reservoirs.

Class of Reptilia

Reptiles at the STS are represented by 7 species (49 species in Kazakhstan). The most numerous of them are lizards: takyr toad agama, multicolored lizard and sand lizard, the population density of which can reach significant values. Suborder of snakes is represented by 4 species; the most common and widely spread is Pallas' coluber, rest 3 are rare and few in number [26].

Birds Class

Avifauna of the studied STS area is extremely diverse with 147 species of birds from 15 orders (total in Kazakhstan – 488 species of birds). Semi-aquatic birds are the most diverse ones. 13 species of the anseriformes and 23 charadriiformes species are nesting on the banks of the Irtysh River, freshwater and salt lakes. Also, there are many small passerines – 51; representatives of the order of diurnal predator (Falconiformes) – 19 species. There is a great number of rare and protected birds, 14 species are listed in the Red Book of Kazakhstan [15, 19, 28, 29, 30].

Mammals

Of the 178 species of mammals living on the territory of Kazakhstan, 45 species of 6 orders were found at the studied STS area; most of the species belong to rodents. Only two species are listed in the Red Book of Kazakhstan: mottled polecat of the order of prey and argali from the order of artiodactyls [19, 23, 29].

Chapter 2

Major man-caused factors for radiation conditions in the region

2.1 Factors due to activities at former SNTS

2.1.1 Historical information about tests at former SNTS responsible for the radiological conditions

In order to determine the sources which formed radioactive contamination of the STS northern part, it is necessary to examine all places where nuclear and non-nuclear tests were made. Technical grounds "5", "8" and "9" are located directly on the studied area. However, no tests which could cause radioactive contamination of the environment were made there; therefore it is possible to exclude them from the following consideration. The radiological weapons testing ground *"4a"* is partly situated on the studied territory. The closest experimental sites to the boundary of the studied area (within 15 km) are the grounds *Opytnoye Pole* and *"4"*. Other testing grounds are more than 60 km away from the studied area.

Analysis of available data showed that radiological conditions in the region could be mainly formed as a result of the following tests:

1. Atmospheric nuclear tests and model tests (hydronuclear and hydrodynamic) on the *Opytnoye pole* ground.
2. Tests of radiological weapons on the test ground *"4a"*.
3. Underground nuclear test on the site *Sary-Uzen* in the test well No.1003.

Tests at the "Opytnoye Pole" ground (Experimental field)

During 1949-1962, 30 ground and 86 aerial nuclear explosions were performed at the testing grounds P-1, P-2, P-3, P-5 and P-7. In 1958-1989, total 85 various-type hydronuclear experiments were performed at the Site with 40 of them at the *Opytnoye Pole* ground (mainly testing grounds P-2 and P-7 (P-2G)).

To quite diverse extensions, each of these tests resulted in radioactive contamination both within the Site limits and in adjacent regions.

Surface and near-surface tests

Thirty surface nuclear explosions were made on the *Opytnoye Pole* ground (table 2.1.), and in 5 cases the nuclear device did not explode. Radiological conditions in the areas adjacent to the STS were mainly affected by 11 surface tests as the other 14 tests were made in the regime of maximal precipitation of the nuclear explosion products directly within the STS area [31].

No quantitative data on radioactive fallouts on the ground surface within the STS territory at the moment of tests are available. Such information obtained by the Meteorological Service of Kazakhstan since 1954 is only available for the areas beyond the STS boundaries.

The open to public sources [32, 33, 34, 35, 36, 37] contain information about the time, power, other conditions of nuclear explosions, average wind directions at the moment of tests, fallouts beyond the STS boundaries, trajectories of motion for radioactive clouds away from the STS limits and traces of radioactive fallouts. However, different literature sources give different information. An analysis of the available information enables us to make a conclusion that 11 surface tests could be the sources of radioactive contamination of the area. Of 11 tests only 4 nuclear tests had power exceeding 1 kt TE. The other tests were characterized by low power ranging from 0.004 to 0.4 kt TE.

Based on the available information we reconstructed possible traces of radioactive fallouts from the surface nuclear tests (Figure 2.1 coloured block).

The main direction of radioactive clouds migration from the nuclear test sites was in the sector north – northeast. Therefore, contamination of the STS northern part from surface nuclear tests should be expected to be detected in this area.

Information on the power of nuclear tests, average wind direction and the results of previous radiological investigations on the STS area led to the conclusion that of all considered surface nuclear tests only 2 tests could produce a considerable impact on the area: the first test made on 29.08.1949 (power ~22 kt) and the test made on 07.08.1962 (power ~9.9 kt).

The first nuclear explosion was made on 29 August 1949 under unfavourable meteorological conditions. A strong wind caused fast motion of the radioactive cloud in the northeast direction. This circumstance led to the formation of a radioactive trace on the ground surface up to a distance of 300 km from the epicenter of the explosion.

In the tests of the nuclear device on 7 August 1962 a surface nuclear explosion occurred instead of expected aerial explosion, which caused relatively high radioactive contamination of the area in the direction of *Altay Kray*. The axis of the trace of radioactive fallout is located to the north from the trace produced by the first nuclear test (1949). The weather on the test day was stable, it was practically calm, even when the wind occasionally arose, its speed was not more than 10 km/h. The registration of radioactive fallouts in Kurchatov-city started in about 12 hours after the explosion. Hence, all that time the cloud of nuclear explosion was over the area between the *Opytnoye Pole* ground and Kurchatov-city.

The contaminations caused by the above tests could form stripes of radioactive contamination from the epicenter of nuclear explosion over the STS area reaching the width of 10 km at the boundary.

Table 2.1

Main information on surface nuclear explosions

No.	Test date [32]	Testing point (ground) [32]	Purpose [32]	Energy release, kt TNT equivalent [32]	Explosion elevation, m [32]	Average wind direction, grad [33]	Explosion type	Dose rate at maximal distance, 3 h after the explosion, mR/h [33]	Maximal distance for which experi-mental data are available, km[33]
1*	29.08.49	P -1	NWD	22	tower 30	74		15	635
2	24.09.51	P -1	NWD	38	tower 30				
3	12.08.53	P -1	NWD	400	tower 30	130 [35]		LRC insignificant	
4	05.10.54	P -3	NWD	4	0				
5	19.10.54 (failed)	P -2	NWD	0	tower 15				
6	30.10.54	P -3	NWD	10	Discharge from a plane with explosion at altitude 50 (55 [37])				
7*	29.07.55	– (P-2 [34])	NWD	1,3	2.5	97 [35]		1 [36]	200 [36]
8	02.08.55	P-2	NWD	12 (11.5 [34])	2.5				
9*	05.08.55	P-2	NWD	1.5 (1.2 [34], [37])	1.5				
10	16.03.56	– (P-2 [34])	NWD	14 (13.2 [34])	0.4				
11	25.03.56	– (P-2 [34])	NWD	5.5	1				
12	24.08.56	P-5	NWD	27 (26.5 [34])	tower 100	105 [35]	Surface ([35] low-altitude aerial)	20 [36]	660 [36]
13*	09.09.61	P-7	EST	0.38 (0.4 [34])	0	60 (70 [35], 75 [36])		No LRC ([36] background)	400 [36]

No.	Test date [32]	Testing point (ground) [32]	Purpose [32]	Energy release, kt TNT equivalent [32]	Explosion elevation, m [32]	Average wind direction, grad [33]	Explosion type	Dose rate at maximal distance, 3 h after the explosion, mR/h [33]	Maximal distance for which experi-mental data are available, km[33]
14*	14.09.61	P-7	NWD	0.4	0				
15*	18.09.61	P-7	EST	0.004	1				
16	19.09.61	P-7	EST	0.03 (0.003 [34], [37])	0				
17	03.11.61 (failed)	P-7	EST	0	0				
18	04.11.61	P-7	NWD	0.2 (0.15 [34],[37])	0	104			
19*	07.08.62	P-5	NWD	9.9 (10 [34])	0	80(72 [35])		5	340
20	22.09.62	P-3	EST	0.21 (0.2 [34])	0				
21	25.09.62	P-5	NWD	7	0				
22	30.10.62	-	NWD	1.2	0				
23	05.11.62	P-1	IDE	0.4	tower 15				
24*	11.11.62	P-3	NWD (EST [34])	0.1	tower 8	98 [35]		background [36]	320[36]
25	13.11.62 (failed)	P-7	NWD (EST [34])	0	0				
26	24.11.62 (failed)	P-7	EST	0	0				
27*	26.11.62	P-7	EST	0.03	0	80 (88 [35])		1	180
28	23.12.62 (failed)	P-7	EST	0	0				
29*	24.12.62	P-7	EST	0.007	0	40-100		No LRC	
30*	24.12.62	P-7	EST	0.028 (0.03 [34])	0	40		No LRC	

Note: * *surface nuclear explosions which could potentially result in radioactive contamination of studied lands*

NWD – tests for the purpose of nuclear weapons development
EST – emergency simulations and tests
IDE – investigations of NE damaging effects and their impact on military and civil objects
LRC – local radioactive contamination

Aerial and high-altitude nuclear tests

Atmospheric aerial and high-altitude nuclear tests (86 tests on the STS and similar tests made on the other nuclear test sites all over the world) were performed high in the atmosphere.

An aerial explosion is a nuclear test in the atmosphere with explosion altitude not lower than 100 m/kt$^{1/3}$ with the fireball formed in such a test not reaching the earth surface. A high-altitude explosion is a nuclear explosion in the atmosphere when the size of a "fireball" is comparable with the size of inhomogeneities in the atmosphere (~7 km).

In case of an aerial explosion, materials of the underlying surface do not take part in formation of radioactive products as the "fireball" does not touch them. The carriers of radionuclides of fission fragments are particles of evaporated construction material of the tested device. A considerable part of produced activity rises to the upper atmosphere (stratosphere) and remains there for many months or even years gradually precipitating on the earth's surface. In determining the average global radioactive fallouts it is supposed that 20% of activity is concentrated in the areas of local fallouts, i.e. in the vicinity of sites of nuclear explosions and 80% contribute to the global fallouts. Therefore, one can conclude that aerial nuclear tests caused formation of global fallouts on all territory of Northern Hemisphere including the STS area.

It is necessary to take into account that the above-described and similar tests as well as various nuclear incidents (accidents) made the main contribution to the radioactive contamination of the area at the level of background of global fallouts.

Model experiments (hydronuclear and hydrodynamic)

Hydronuclear tests

When the amount of released nuclear energy at an explosion experiment with nuclear charge is comparable with the energy of chemical explosive less than 1 ton, such tests refer to the category of hydronuclear tests and do not refer to nuclear tests except the cases when such result occurred in a specially planned nuclear test. Hydronuclear experiments were an important method used to study physical processes in nuclear charges, and they were widely used in the USSR in 1958-1989. The experiments were carried out to solve the problems related to physics of radiological weapons including the problem of security and safety of storage and usage of nuclear weapons. All the experiments were made on the ground surface, mainly, in 3m-deep pits.

In 1960, 1961 and 1963, surface hydronuclear experiments (table 2.2) were made on the ground P-2G of the STS site. The experiments differed by the amount of radiation released to the atmosphere and the height of the upper level of the explosion cloud. Another two model experiments were made on 01.08.65 and 12.08.65.

The experiments differed in the amounts of emitted alpha-particles; the difference was up to 400 times, the height of explosion clouds ranged from 250 m (the experiment of 01.10.1963) to 1280 m (01.07.1961) [38]. The total plutonium activity dispersed during all hydronuclear experiments (mainly, experiments Nos. 7-12, 21-

38 and two experiments made in 1965 – in total, 26 experiments) is estimated as 800 – 900 Ci, which may cause radioactive contamination of the area around the testing ground. According to the data of [39] in 1960-1963, 11 kg of plutonium were used for carrying out 38 hydronuclear experiments on the Semipalatinsk Test Site.

Since hydronuclear experiments are not accompanied by a considerable power release, the main radiation impact of such experiments on the environment is caused by the dispersion of fissionable materials from the explosive devices. In some experiments uranium was dispersed, in the others – plutonium. As plutonium has 1000 times higher specific activity than uranium and higher radio-toxicity (approximately 3 times higher per activity unit for inhalation), the experiments with plutonium dispersion mainly determined the level of radiation contamination on the STS territory [37].

Plutonium contamination of the studied territory could occur only if the azimuth directions of the axes of test traces were located in the sector from 295° to 68° (from northwest to northeast direction) and the traces were longer than 25 km – the distance from the ground P-2 to the boundary of the studied area. According to the available data [40], of 24 tests which caused the main dispersion of plutonium only 4 tests had azimuth directions of trace axes 338°, 52°, 68°, 68°, in which the length of the areas with plutonium contamination 0.1 Ci/km^2 (specific activity in soil 46 Bq/kg at the depth of 0-5 cm) could be 12.5, 6.9, 4 and 5.4 km, respectively, whereas the length of the areas with plutonium activity 2.25*10^{-2} Ci/km^2 (specific activity in soil 10.4 Bq/kg at the depth of 0-5 cm) could be 37, 23, 10.5, 19.5 km (Table 2.2). Such characteristics could, most probably, correspond to only one test with emission of 46 Ci of plutonium made on 24.07.1961 (azimuth 338°, distance 37 km (solid part of the line in the figure)) (Figure 2.2, coloured block) which could contribute to the radioactive contamination of the studied area with plutonium isotopes.

Table 2.2

Model experiments at testing grounds P-2G (P-7) in 1960, 1961 and 1963

No.	Date	E	C	V	A	H	D	Type	C α	L_1	S_1	L_2	S_2
1	20.05.60	1	1	18	142	840 (220)	300	S	-	-	-	-	-
2	22.05.60	1	1	11	328	810 (170)	250	S	-	-	-	-	-
3	24.05.60	1	1.1	14	137	400 (100)		S	-	-	-	-	-
4	26.05.60	1	1.1	14	65	790 (270)	320	S	-	-	-	-	-
5	31.05.60	1	1.2	29	81	410 (160)	340	S	-	-	-	-	-
6	01.06.60	1	1.2	18	102	640 (190)	540	S	-	-	-	-	-
7*	06.06.60	1	76.5	50	68	440 (180)	480	P	10.5	4	1.4	10.5	6
8	08.06.60	1	92.5	47	81	460 (150)	380	P	12.5	4.25	1.65	13	9
9	10.06.60	1	104	72	74	920 (150)	500	P	14	4	1.4	10	5.4
10*	11.06.60	1	112	25	52	890 (220)	420	P	15	6.9	3.5	23	30
11	13.06.60	1	132	7	209	680 (210)	450	P	17.5	22	28	66	230
12	16.06.60	1	143	29	86	890 (250)	570	P	19.5	7.7	4.2	25	35
13	27.06.61	1	1	25	304	730 (135)	320	S	-	-	-	-	-
14	29.06.61	1	1.1	25	132	490 (225)	350	S	-	-	-	-	-
15	01.07.61	1	1.3	11	143	1280 (250)	500	S	-	-	-	-	-
16	04.07.61	1	1.1	43	342	360 (120)	260	S	-	-	-	-	-
17	06.07.61	1	1.6	32	70	420 (103)	280	S	-	-	-	-	-
18	08.07.61	1	1.3	47	93	580 (97)	210	S	-	-	-	-	-
19	13.07.61	1	1.3	29	83	660 (120)	220	S	-	-	-	-	-
20	15.07.61	1	1.8	7	104	280 (70)	200	S	-	-	-	-	-
21	20.07.61	0.35	223	7	173	630 (220)	320	P	30	32	58	97	475
22	21.07.61	0.35	249	18	200	520 (125)	260	P	33.5	17.5	17	53	149
23	22.07.61	0.35	278	25	79	350 (130)	150	P	37.5	15	12	44	107

No.	Date	E	C	V	A	H	D	Type	C α	L_1	S_1	L_2	S_2
24	22.07.61	0.35	303	25	162	590 (165)	330	P	41	16	14	47.5	122
25*	24.07.61	0.35	340	40	338	370 (130)	180	P	46	12.5	8.5	37	76
26*	19.09.63	1	150	43	68	320 (70)	160	P	20.5	5.4	2.5	19.5	21
27	20.09.63	1	158	29	113	620 (345)	610	P	21.5	8.2	4.6	26.5	40
28	24.09.63	1	178	13	94	730 (300)	340	P	24	17.5	17	52	145
29	25.09.63	0.35	294	47	93	300 (115)	300	P	40	9.5	5.5	29.5	49
30	26.09.63	0.35	332	32	153	290 (170)	160	P	45	14	11	42	99
31	30.09.63	0.35	370	18	223	330 (130)	220	P	50.5	23.5	32	70	260
32	01.10.63	0.35	370	11	232	250 (180)	350	P	50.5	34.5	67	105	550
33	02.10.63	0.35	406	14	226	290 (155)	180	P	54.5	30.5	52	92	430
34	10.10.63	0.35	225	24	79	250 (87)	220	P	30.5	13	9.5	39	85
35	11.10.63	0.35	250	40	84	-	-	P	33.5	9.5	5.5	29.5	49
36	12.10.63	0.35	285	25	137	290 (70)	130	H=3 m	38	15	12	46	112
37	12.10.63	0.35	300	14	123	380 (175)	200	P	40.5	24	33	72	270
38	15.10.63	0.35	320	14	104	-	-	H=3 m	43	26	36	76	300

Note: * experiments. which could potentially cause contamination with plutonium at studied lands.
E – relative energy release at explosion
C – relative release of α–activity
V – average wind velocity (km/h) in the range of altitudes h=0-1 km at the time of explosion
A – azimuth direction of the trace axis (grad)
H – altitude of upper explosion cloud boundary (m) at the time t (s)
D – horizontal diameter of the explosion cloud (m)
Type – explosion types: "S" – surface explosion; "P" – explosion in pit; H=3 m – explosion at wood pedestal 3 m above surface
C α – Pu activity release during the experiment (Ci)
L_1. S_1 – assessed extent (km) and area (km^2) of contaminated lands with activity density q α> 0.1 μCi/m^2
L_2. S_2 – assessed extent (km) and area (km^2) of contaminated lands with activity density q α> $2.25*10^{-2}$ μCi/m^2

Hydrodynamic tests

Explosion experiments with nuclear charges which do not release nuclear energy refer to the category of hydrodynamic tests and they do not refer to nuclear tests except the cases when such result occurred in a specially planned nuclear test. In such experiments, the character of radioactive contamination of the territory is similar to the contamination observed in model explosion (hydronuclear) experiments accompanied by plutonium dispersion.

The hydrodynamic tests were made on the grounds P-2 and P-7. The grounds are situated at a distance of about 25 km from the studied area. In the period 1954-1962, 5 tests were made on the test grounds as a result of which 1000 Ci of plutonium were released to the atmosphere (Table 2.3).

Table 2.3

Main characteristics of hydrodynamic tests

No.	1*	2	3	4*	5*
Date	19.10.54	03.11.61	13.11.62	24.11.62	23.12.62
C	200-400	200-400	200-400	100-200	200-400
A	18	213	176	320	296
V	8.3	3.5	3.3	6.1	4.5

Note: * experiments, which could potentially cause contamination with plutonium at studied lands.
No. – conventional number of the experiment
C – amount of α-activity from Pu dispersed at explosion (Ci)
A – azimuth direction of the trace axis (grad)
V – average wind velocity (m/s)

In order to estimate possibility of contamination of the studied area, we considered the same sector (from 295° to 68°). According to [40], in three tests out of 5 the azimuthal directions of trace axes were 296°, 320° and 18°, and the length of zones with plutonium contamination 0.1 Ci/km^2 (specific activity in soil 46 Bq/kg at the depth of 0-5 cm) could be 68, 40, 44 km (table 2.4) (solid line in the figure), respectively, and for area activity 2.25*10^{-2} Ci/km^2 (specific activity in soil 10.4 Bq/kg at the depth of 0-5 cm) they could reach 100 km (Figure 2.2 coloured block).

Table 2.4

Characteristics of contaminated zones

Experiment		1*	2	3	4*	5*
q_1	L (km)	7	16	15.5	6	12.5
	S (km^2)	3.4	14.5	14	2.8	8.9
q_2	L (km)	44	88	86.5	40	68
	S (km^2)	105	390	375	90	240

Experiment		1*	2	3	4*	5*
q_3	L (km)	>100	>100	>100	>100	>100
	S (km^2)	(670)	(970)	(960)	(640)	(880)

Note: * experiments, which could potentially cause contamination with plutonium at studied lands.
q_1 – alpha activity density >1µCi/m^2 (specific activity in soil >463 Bq/kg at depth 0-5 cm)
q_2 – alpha activity density >0.1 µCi/m^2 (specific activity in soil >46 Bq/kg at depth 0-5 cm), характеризующий зону отселения населения
q_3 – alpha activity density >2,25*10^{-2} µCi/m^2 (specific activity in soil >10.4 Bq/kg at depth 0-5 cm)
L – contamination area length
S – contamination area

All three tests (19.10.54, 24.11.62, 23.12.62) may therefore be considered as sources of plutonium contamination of the studied area.

Underground nuclear test on the test ground Sary-Uzen in the test well No. 1003

In the underground nuclear tests the major part of radionuclides remains under the ground. The excavation explosions (tests with soil outbursts) and non-standard situations which occurred during underground tests caused considerable local contamination directly on the test grounds and formation of radioactive traces. Of all considered tests the contamination of the studied area could be caused by the underground explosion with soil outburst made on the test ground *Sary-Uzen* in test well No. 1003.

The tests were made on the testing ground *Sary-Uzen* located 70 km away from the studied area. In order to study the process of soil outburst, at a depth of 48 m the explosion of yield 1.1 kiloton was made. The underground explosion in the test hole with soil outburst made on 14 October 1965 caused a considerable contamination of the area. The investigations carried out in test hole No. 1003 showed that in the vicinity of the epicenter, the explosion caused precipitation of not only aerosol particles but also 4% of the total amount of radioactive particles formed in the explosion and about 3.5% in the near part of the tail [41]. The ratio of the fission products precipitated in the far tail to the total amount of radioactive particles was estimated as 0.66% [42].

The maximal height of the soil cupola 6 seconds after the charge explosion was 190 m and the diameter was 240 m. The outburst column fully disappeared in 10-12 seconds after the explosion. The maximal height of the dust column was not more than 300 m because of the inversion layer in the atmosphere. The cloud formed after the explosion moved in the northeast direction at speed 40 km/h [43]. For a few days the weather conditions favored motion of the explosion products in the northeast direction (Figure 2.1 coloured block) [43]. Table 2.5 presents the data characterizing radiation levels along the trace axis.

Table 2.5

Gamma-radiation dose rates ("T+24" after the explosion) along the axis of the trace due to underground nuclear explosion in the test hole No. 1003 with soil outburst

Distance to epicenter, km	**0.75**	**1.5**	**3**	**7**	**12**	**20**	**30**	**40**	**60**	**80**	**100**
Radiation level, mR/h	700	240	80	23	9	2.4	1.0	0.5	0.25	0.1	0.05

The values of cumulative doses formed both by the cloud radiation D_{cl} and by the radiation from the radioactive fallouts D_{trace} were calculated using the data on dynamics of trace formation at different distances from the epicenter of the explosion and the results of measurements of the total radiation doses with photodosimeters along the direction of motion of the radioactive cloud. The main results of calculations are presented in the table (table 2.6).

Table 2.6

Calculated doses for the explosion in the testing well 1003

Distance to epicenter, km	**8**	**11**	**25**	**44**	**49**
Value D_{cl}/ D_{tr}	0.5	1.2	5.7	13.8	23.5

The table shows that the ratio D_{cl}/D_{tr} increases with increase of the distance from the epicenter and at distances 8-50 km along the trace axis it changes from 0.5 to 24. The measurements of D_{cl}/D_{tr} in the trace cross-section show that the minimal values of D_{cl}/D_{tr} are registered along the axis, and the values increase as the distance from the axis increases [43]. It means that the main part of radioactive substances precipitated near the epicenter and along the axis of the trace of radioactive fallouts.

The main parameters of radioactive contamination of the territory of Moldary village, located ~3 km to north-east of Kurchatov town including radioisotope composition of fallouts were determined during the first two days after the explosion. 24 hours after the explosion gamma-radiation dose rate was 0.03 mR/h. Table 2.7 presents the data on the levels of radioactive contamination of the pasture by biologically harmful radionuclides 24 hours after the explosion in the test hole 1003 [44].

Table 2.7

Contamination rates of the dairy farm pasture situated near the village of Moldary with biologically harmful radionuclides, 24 hours after the explosion

Radionuclide	**Half-life, ($T_{1/2}$)**	**Surface contamination of the area, Bq/m²**	**Specific activity at depth 5 cm, Bq/kg**
Sr-90	29.1 years	93	1.2
Cs-137	30 years	150	1.9

The dose distribution in the trace of the radioactive fallout (Figure 2.1 coloured block) enables to make a conclusion that radionuclide contamination in the STS northern past caused by the test in the hole 1003 is comparable with the level of radioactive contamination near the village of Moldary, which is also situated within the studied territory. Hence, at the present time additional radioactive contamination of the territory by radionuclides ^{137}Cs and ^{90}Sr may amount to several units of Bq/kg.

Tests of radiological weapons at the ground "4a"

Nuclear explosions are not the only type of tests made on the territory of STS. In the period from 1954 to 1957 this territory was used for tests of radiological weapons with military radioactive charges (MRC) [45].

The main elements of such types of mass destruction weapons - radiological weapons - are radioactive substances used as liquids or powders. The radioactive substances were mainly made from the wastes of radiochemical industry. In the tests on the STS the main radioactive preparation was "preparation 904", its specific activity varied from several tenths of Ci to several Ci per liter. The total activity of dispersed "preparations" mainly containing long-lived radionuclides could be as high as 10,000-12,000 Curie.

The RW tests were made on the STS by detonation of individual charges, bombing from the airplane IL-28, using artillery bombardment or pouring-out aviation devices. Chemical properties of the radiological weapons made them very aggressive, and only stainless steel was resistant to them. As it was very difficult to decontaminate all the equipment used in the RW tests (tanks, pipelines, pumps, etc.), it was disposed under the 5m layer of soil. The places of disposal are not known.

The RW tests were made on the two sites – *"4"* and *"4a"* located in the northwest part of the STS (Figure 2.1 coloured block). One of the test sites – *"4a"* is partially situated on the studied territory. The RW tests caused formation of local zones of radioactive contamination, mainly, within the test site. The tests could also contribute to the radioactive contamination of all studied territory.

2.1.2 Theoretical assessment of possible radionuclide contamination of the territory. Main radionuclides and isotopic ratios

As no nuclear tests were made in the northern part of the former STS, contamination of the area may only be caused by local and global fallouts. The local fallouts are large-size dispersed particles formed in surface and atmospheric explosions spread at a distance up to 100 km from the epicenter of the explosion. Global fallouts are caused by small-size dispersed particles staying for a long time in the troposphere or stratosphere.

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

Surface contamination of the studied areas caused by the tests at the former Semipalatinsk Test Site can mainly be caused by the nuclear tests on the testing ground *Opytnoye Pole*, the place where surface and atmospheric nuclear tests were performed, as the tests in tunnels and wlls gave very little contribution to the contamination of the environment (including the global scale).

Radioactive contamination of the area adjacent to the test ground can include the following groups of artificial radionuclides:

1. Radionuclides formed as a result of nuclear fission (fission fragments).
2. Remainders of the fissionable substance.
3. Radioactive isotopes – activation products of the environmental nuclei by fission neutrons.

In order to estimate all levels of possible radionuclide contamination of the territory the following scheme was chosen:

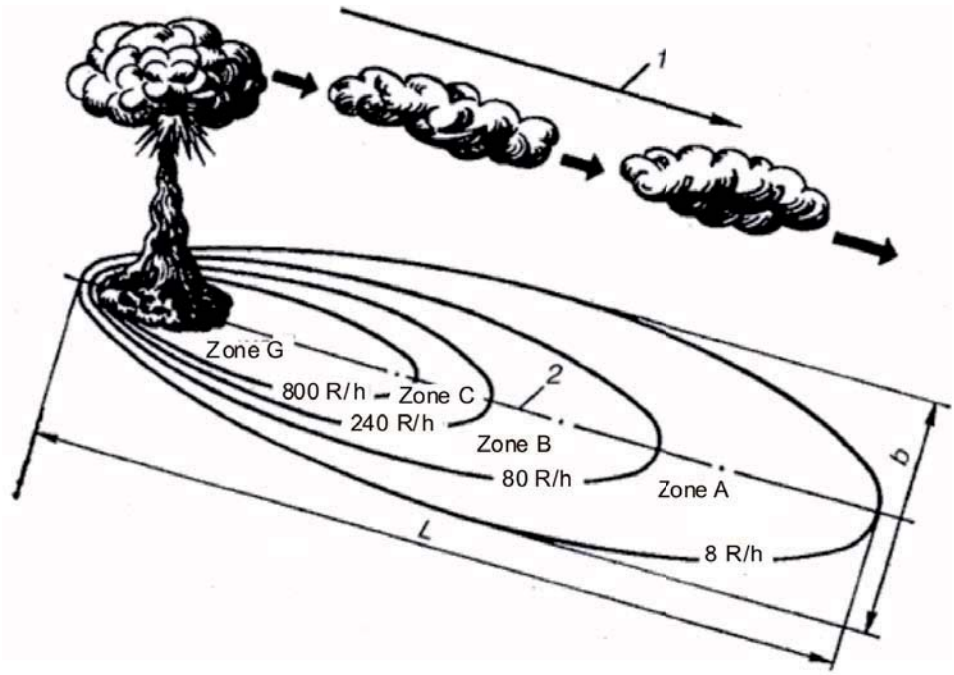
– Determination of the number and characteristics of explosion by literature data.
– Rejection of explosions whose characteristics unambiguously show impossibility of their influence of the surface contamination of the studied areas.
– Calculation of maximal possible amount of produced radionuclides and isotopes based on the principal laws of nuclear physics and data on the power of explosions.
– Calculation of maximal possible amount of produced radionuclides and isotopes which could fallout on the studied areas based on the classical model of formation of radiation trace as a result of nuclear explosion.
– Calculation of maximal possible "average" concentrations of radionuclides and isotopes on the studied areas based on the assumption of their uniform distribution and half-life period.

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

In order to estimate possible contribution of nuclear tests to the surface contamination of the studied areas we used a "classical" model of formation of radioactive trace zones as a result of nuclear explosion. The model is based on the experimental data obtained during the nuclear tests, and it is given in any textbook on military defence. According to the model, some part of radioactive substances precipitates on the earth's surface near the epicenter but most part falls out along the direction of cloud movement forming so-called radioactive trace characterized by length L and width d (radioactive contamination zone) on the surface. Hence, on the territory subjected to the radioactive contamination after nuclear explosion two zones – the explosion zone and the radioactive trace – are formed (Figure 2.3). The trace of the cloud, in its turn, depending on the level of radioactivity is divided into four zones of radioactive contamination. Literature sources also contain data on the sizes of contamination zones depending on the power of explosion and wind strength.

Based on the assumption that all radioactive substances in the explosion cloud and over the territory of the fallout zone are distributed uniformly and using the ratios of radiation levels in different zones given in the figure (Figure 2.3), one can calculate the amount of radioactive substances falling out in a certain zone. Thus, zone A contains 0.71% of all radioactive fallouts, zone B – 7.1%, zone C – 21.3% and zone B – 71.6%. The model of contamination distribution only gives general description and cannot be used for precise calculations as it does not take into account radionuclide fractioning depending on the distance from the epicenter and nonuniformity of radionuclide distribution along the length and width of the zone.

Open literature sources on the nuclear tests made on the test ground *Opytnoye pole* contain the data on energy release; some explosions are provided with such characteristics as height of explosion and wind direction during the nuclear test and observed radioactive contamination of the area. In our calculations we only used the tests during which the wind direction was in the sector 280^0 to 80^0. If the test data did not contain information about the wind direction, we assumed the worst variant – northern wind of an average speed of 5 km/h (the average wind speed in Kurchatov is 4-6 km/h). In our calculations we did not take into consideration the explosions which did not produce any contamination of the area or such contamination was insignificant.



Radiation level 1 h after explosion: 1 – average wind direction; 2 – trace axis; 3 – windward side; 4 – leeward side; A – zone of moderate contamination; B – zone of heavy contamination; C – zone of hazardous contamination; G - zone of extremely hazardous contamination; L – trace length; b – trace width

Figure 2.3. Trace of the radioactive cloud formed by a surface nuclear explosion

In further calculations it is accepted that all nuclear charges were made on the base of ^{239}Pu.

Now we can determine energy release from nuclear tests which could contribute to surface contamination of the studied areas. A total of 86 aerial and 30 surface tests was made on the STS territory. All tests can be divided into 5 groups: 1) tests with energy release up to 1 kiloton (26 tests), 2) tests with energy release up to 10 kilotons (12 tests), 3) tests with energy release up to 20 kilotons (4 tests), 4) tests with energy release up to 40 kilotons (26 tests), 5) tests with energy release 100 kilotons (1 test. To increase the "stability coefficient" of the estimate let us assume that all explosions in the group had maximal energy release for this group. Based on the literature data on the sizes of contaminated zones depending on the explosion power and wind strength we can determine which part of the four contaminated zones could be located on the studied areas. In this case we are interested in the area located at a distance of more than 17 km (distance to the southern boundary of the studied area) and less than 36 km (distance to the northern boundary of the studied area) from the center of the test ground *Opytnoye pole*. The results show that from the first group of explosions none of the four zones could belong to the studied areas. In the second group of nuclear tests 25% of zone A refer to the studied areas. In the third group 62% of zone A refer to the studied areas, in the fourth group – 75% of zone A and 22% of zone B belong to the studied areas and in the fifth group – 65% of zone A, 36% of zone B and 9% of zone C (Figure 2.4). Therefore assuming uniform distribution of radionuclide in a 5-cm soil layer on the area of 3000 km^2, one can calculate potential "average" specific activity of radionuclides. In calculations the soil density was taken equal to 1600 kg/m^3.

Calculation of maximal possible "average" concentrations of produced radionuclides – fission fragments

The main factor causing radiation impact on the environment after a nuclear explosion is decay of fission fragments. This impact depends both on the total activity of fragments, on activity of individual radionuclides and on their variation with time. In order to calculate the amount (activity) of an isotope with given values of the mass number A and charge Z in a moment of time t after termination of the chain reaction one must know:

a) the amount of the isotope and the amount of all its predecessors at the moment of time t = 0;

б) schemes of decay and half-life periods for all chains giving contribution to the formation of the isotope.

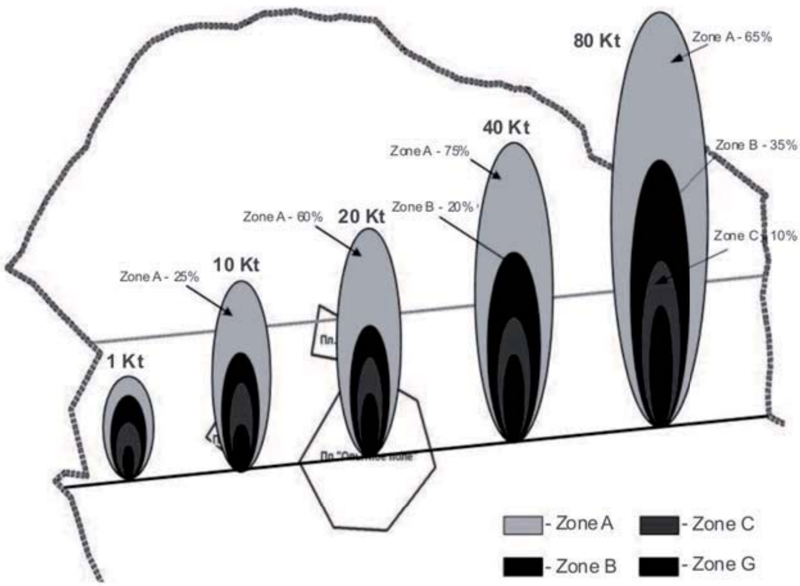


Figure 2.4. Schematic location of differently contaminated zones for explosion groups depending on their power

The amount of isotope produced during fission is characterized by the value of absolute independent yield (probability of its formation taking into account neutron emission) Y(A,Z) with normalization 200% for yields of all isotopes including stable ones. Direct measurements of Y(A,Z) meet hardly resolvable experimental problems and give high experimental errors. More precisely Y(A,Z) can be determined from a well-known expression:

$$Y(A,Z) = Y_f(A,Z) * Y_t(A), \text{ where}$$

$Y_t(A)$ – are total (cumulative) yields of all isotopes with given mass number A,

$Y_f(A,Z)$ – are relative independent yields (probability of formation of a given isotope after emission of fission neutrons) with normalization:

$$\Sigma\, Y_f(A,Z)\Big|_{A=const} = 1.$$

The papers [46, 47]. present extensive experimental information on $Y_t(A)$ values for ^{239}Pu splitting by fission and heat neutrons and tables with recommended values. The relative independent yields $Y_f(A,Z)$ are usually determined based on the results of measurements or an empirical expression obtained from them:

$$Y_f(A,Z) = (c\pi)^{-1/2}\exp(-(Z-Z_p)^2/C), \text{ where}$$

Z_p – is the most probable charge for a given isobar chain,

$C = 2*(\sigma^2+1/12)$.

Here σ^2 is dispersion of the Gaussian distribution, 1/12 is Sheppard's correction for discreetness of variations in Z. The data for Z_p and σ^2 ^{239}Pu were also tabulated and presented in [46]. The values of absolute independent yields calculated using the above-described method for 290 radioactive nuclides produced at a moment of time t = 0 in splitting of ^{239}Pu by fission neutrons are given in [48]. Comparison of these data with the results of later investigations for individual isobar chains shows high precision of the Y(A,Z) data presented in [46], therefore we did not revise these data in our calculations.

Knowing the value of Y(A,Z), we can determine activity of any isotope for a 1-kiloton explosion at t = 0 from the following formula:

$$Q(A,Z) = N_f * \ln(2) * Y(A,Z) /(T_{1/2} * 3.7 * 10^8) \text{ Curie, where}$$

$T_{1/2}$ is measured in seconds and Y(A,Z) is in %. Substituting numerical values we get:

$$Q(A,Z) = 2.59 * 10^{10} * Y(A,Z) /T_{1/2} \text{ for } ^{239}Pu$$

For a nuclear explosion variation of activity of all isotopes in the linear isobar chain of length k with time is described by a chain of differential equations:

$$dQ_1(t)/dt = -\lambda_1 * Q_1(t)$$
$$dQ_2(t)/dt = -\lambda_2 * Q_2(t) + \lambda_2 * Q_1(t)$$
$$. \quad . \quad . \quad . \quad . \quad .$$
$$dQ_к(t)/dt = -\lambda_к * Q_к(t) + \lambda_к * Q_{к-1}(t)$$

For the k^th member of the chain the solution can be written as:

$$Q_к(t) = \sum C_{ki} * \exp(- \lambda_i * t), \text{ где } i = 1,2, . . k.$$

The coefficients at the exponent are determined from the recurrent relations:

$$C_{ki} = C_{k-1,i} * \lambda_k /(\lambda_k - \lambda_i) \quad \text{for } k \neq i$$
$$C_{kk} = Q_k(t=0) - \sum C_{ki} \quad \text{for } k = i$$

This scheme of calculations is described in more details in [46] which also gives the main initial experimental fission data for ^{239}Pu. The paper [49] presents the results of calculations which we used in our further work after checking the results of calculations for three isobar chains.

This method was used to calculate activities of all produced radionuclides taking into account their half-life period at the initial moment of time and at the present time; it was also used to estimate variations in the radionuclide concentrations in the next 25 and 50 years. We take into account only radionuclides whose contribution to the total activity at the present time is not less than 1%.

Table 2.8 presents maximal possible "average" radionuclide activities on the studied area and their ratios to ^{137}Cs.

Table 2.8

Maximal possible "average" radionuclide activities on the studied areas

Nuclide	Initial time		1.09.2009		25 years		50 years	
	Bq/kg	Ratio	Bq/kg	Ratio	Bq/kg	Ratio	Bq/kg	Ratio
^{137}Cs	194	1.00	61.5	1.00	34.5	1	19.4	1.00
^{90}Sr	72	0.37	22.1	0.36	12.2	0.35	6.7	0.35
^{151}Sm	7.3	0.04	4.9	0.08	4.0	0.12	3.3	0.17
^{99}Tc	1.0	0.005	1.0	0.016	1	0.028	1	0.05

Calculation of maximal possible "average" concentrations of fragments of fissionable substance

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

For a 1-ton explosion of efficiency η the amount of non-fissioned substance can be calculated as follows:

$$N_{RES} = N_f * (1/\eta - 1 - \sigma_{n,\gamma} / \sigma_f), \text{ where}$$

$\sigma_{n,\gamma}$, σ_f are cross-sections of radiation capture and fission for neutrons in the charge substance.

For ^{239}Pu the value of $\sigma_{n,\gamma}/\sigma_f \approx 0.11$. Knowing the values N_{RES} and half-life periods for α-particles ($T_{1/2} = 2.411*10^4$ years for ^{239}Pu), one can easily calculate activities of non-fissioned nuclei

$$A(\text{Curie}) = \{N_{RES} * \ln(2)/ T_{1/2}(c)\}/3.7*10^{10}$$

From this equation for a 1 ton explosion at the moment of time t = 0 we get

$$A = 13.2 \text{ Curie/kt} = 4.8*10^{11} \text{ Bq/kg for } ^{239}Pu$$

Further, knowing typical isotope composition of weapon Pu, it is not difficult to calculate activities of its other isotopes present in the charge substance. This method was used to calculate activities of all Pu isotopes taking into account their half-life period at the initial moment of time and at the present time; it was also used to estimate variations in Pu concentrations in the next 25 and 50 years. Table 2.9 presents maximal possible "average" activities of Pu and ^{241}Am on the studied area and their ratios to the sum of ^{239}Pu and ^{240}Pu.

Table 2.9

Maximal possible "average" activities of Pu and ^{241}Am on the studied area and their ratios to the sum of ^{239}Pu and ^{240}Pu.

Nuclide	Initial time		1.09.2009		25 years		50 years	
	Bq/kg	Ratio	Bq/kg	Ratio		Bq/kg	Ratio	Bq/kg
^{239}Pu + ^{240}Pu	15.4	1	15.4	1	15.4	1	15.4	1
^{238}Pu	0.51	0.03	0.35	0.02	0.28	0.018	0.23	0.014
^{241}Pu	129	8.5	11.6	0.75	3.5	0.23	1.0	0.065
^{242}Pu	$2.2*10^{-05}$	$1.5*10^{-06}$	$2.2*10^{-05}$	$1.4*10^{-06}$	$2.2*10^{-05}$	$1.4*10^{-06}$	$2.2*10^{-05}$	$1.4*10^{-06}$
^{241}Am	-	-	3.7	0.24	3.8	0.25	3.7	0.24

In practice, the activity of ^{241}Pu may be a little higher due to activation of ^{240}Pu by fission neutrons but the cross-section of this reaction is very small to make a considerable contribution.

Calculation of maximal possible "average" concentrations of radionuclides formed as a result of activation of environmental nuclei by fission neutrons

In order to estimate the activity of artificial raduonuclides created at the boundary of the studied area we used the IRSE database and made sampling of the results of gamma-spectrometric measurements of specific activities of ^{152}Eu and ^{60}Co in the soil samples taken from the ground *Opytnoye pole*.

The following initial conditions were taken:

– All surface and aerial nuclear tests were made at the northern boundary of the ground *Opytnoye pole*, minimal distance to the boundaries of the studied area is 6 km;
– According to the available information the total energy release from the explosions (surface and aerial) is about 6900 ktons;
– The total number of neutrons is $\sim 1.5*10^{27}$;
– The fluence at a distance of 1m is $\sim 10^{25}$ cm^{-2};
– The fluence at the boundary of the studied area (6 km from the epicenter) is about
– $\sim 4*10^{5}$ cm^{-2}.

Taking into account a direct dependence of the accumulation of activation products on neutron fluence one can estimate specific activity of artificial raduonuclides at the boundary of the studied area.

That is

$$A_1/\psi_1 = A_2/\psi_2 \quad \Rightarrow \quad A_2 = A_1 * \psi_2/\psi_1$$

The results of the assessment are given in table 2.10.

Table 2.10

Assessment of maximal possible "average" activities of artificial radionuclides produced as a result of activation by neutrons on the studied area

No.	Isotope	Maximal specific activity at epicenter, Bq/kg	Neutron fluence ratio 1m/6km	Maximal possible activity of isotopes at distance 6 km, Bq/kg
1	^{152}Eu	150000	$2.5*10^{11}$	$6*10^{-7}$
2	^{60}Co	1000	$2.5*10^{11}$	$4*10^{-9}$

Conclusions:

The results of the above analysis and calculations with high degree of certainty bring to the conclusion that contamination of the studied areas could be caused by local precipitations in the form of stripes of tens of kilometers in length and several kilometers in width. Therefore, probability to find contaminated spots with concentrations of artificial radionuclides many times exceeding the concentration of global fallouts is very small.

To estimate radiation conditions on the studied areas it is necessary to take into account not only well-known radionuclides such as ^{90}Sr and ^{137}Cs but also ^{151}Sm and ^{99}Tc, as nowadays their concentrations make 8% and 1.6% of ^{137}Cs concentration, respectively. It should be noted that contribution of ^{151}Sm and ^{99}Tc will increase with time and in the 50-year period it will reach 17% and 5%, respectively.

The concentration of ^{241}Am will increase with time and will reach its maximal value in 26 years, however, even in case of reaching its maximal value its activity will not exceed 25% of that of $^{239+240}Pu$.

Radionuclides formed as a result of activation of the environmental nuclei at the moment of explosion could not make any considerable contribution to the radionuclide contamination of the studied areas.

2.1.3 Present-day radiological conditions in the areas which can affect radiological situation in the STS northern part

Test ground Opytnoye pole

The radiation conditions on the test ground *Opytnoye Pole* were estimated by the results of the pedestrian gamma survey and laboratory analyses of the radionuclide concentration in soil samples. The results of the pedestrian gamma survey enabled to contour spots with high level of radioactive contamination which were mainly situated within the test grounds where surface nuclear tests and model experiments were made (P-1, P-2, P-3, P-5, P-7). The equivalent dose rate (EDR) maximal values are located directly within the holes formed by the nuclear explosions. As one moves away from the epicenter of tests the EDR decreases and at a distance of 1-2 km its values decrease to the background level on the territory equal to 0.10-0.15 μSv/h. The figures (Figure 2.5 coloured block) show the profile (red dashed line) crossing the ground P-1 from southwest to northeast and the distribution of the exposure doses along the profile (Figure 2.6).

The results of laboratory analysis were used to determine specific activities of man-made radionuclides in soil, whose values are given in table 2.11. Radioactive contamination of soil on these grounds is comparable with solid radioactive wastes (in some spots – with middle-active RAW).

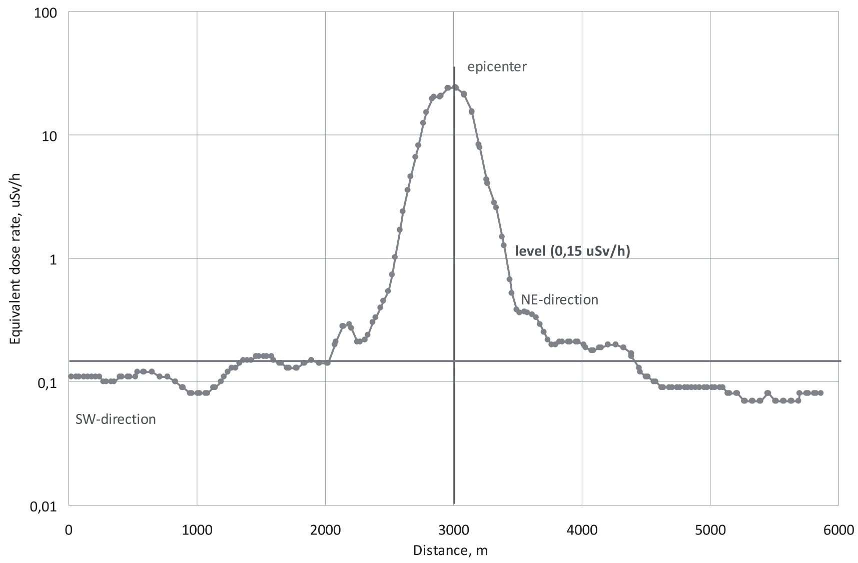


Figure 2.6. EDR distribution at the ground P-1

Table 2.11

Specific radionuclide activity in the soil cover around technical zones of the test ground *Opytnoye pole*

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*10^1	n*10^3	n*10^3	n*10^1	n*10^0	-	n*10^3	no change
P-5	n*10^2	n*10^5	n*10^4	n*10^3	n*10^2	n*10^2	n*10^4	no change
P-7	n*10^2	n*10^4	n*10^4	n*10^3	n*10^1	n*10^1	n*10^3	no change

The distribution of ^{137}Cs radionuclide in soil along the profile (blue solid line) from the epicenter of the ground P-1 in northeastern direction to the boundary of the STS northern part is shown in figures 2.5 (coloured block) and 2.7. At a distance of 1 km from the epicenter of the ground P-1 sharp decrease (one order of magnitude) in the specific activity of ^{137}Cs in the upper 5-th soil layer is registered. Beyond the area of the ground P-1 (2 km from the epicenter) ^{137}Cs specific activity is less than 100 Bq/kg and at a distance of more than 10 km it decreases to the level of global fallouts (30 Bq/kg).

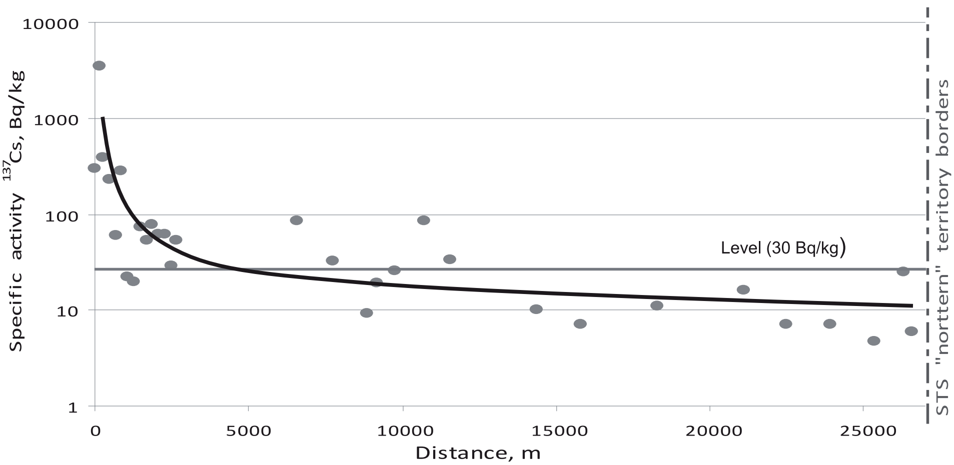


Figure 2.7. Distribution of ^{137}Cs specific activity in northeastern direction from the epicenter of the ground P-1

Therefore radioactive contamination caused by nuclear tests on the test ground *Opytnoye pole* is concentrated directly around the epicenters forming traces of short-range radioactive fallouts and decreases to background values with the distance from the epicenter.

At the present time the territory of the test ground *Opytnoye pole* may be a potential source of radioactive contamination of the studied areas. In order to prevent access of people and animals to the local spots of radioactive contamination it is wise to create physical barriers.

Test hole No. 1003

Previous investigations of the radiological conditions on the territory of the test ground *Opytnoye pole* failed to register location of the trace of radioactive contamination formed during underground nuclear explosion in the test well No.1003. The ^{137}Cs specific activity in soil at a distance of 1 km corresponds to the background values (figure 2.8). Figure 2.8 shows MED distribution around the soil heap in the place where the test was made.

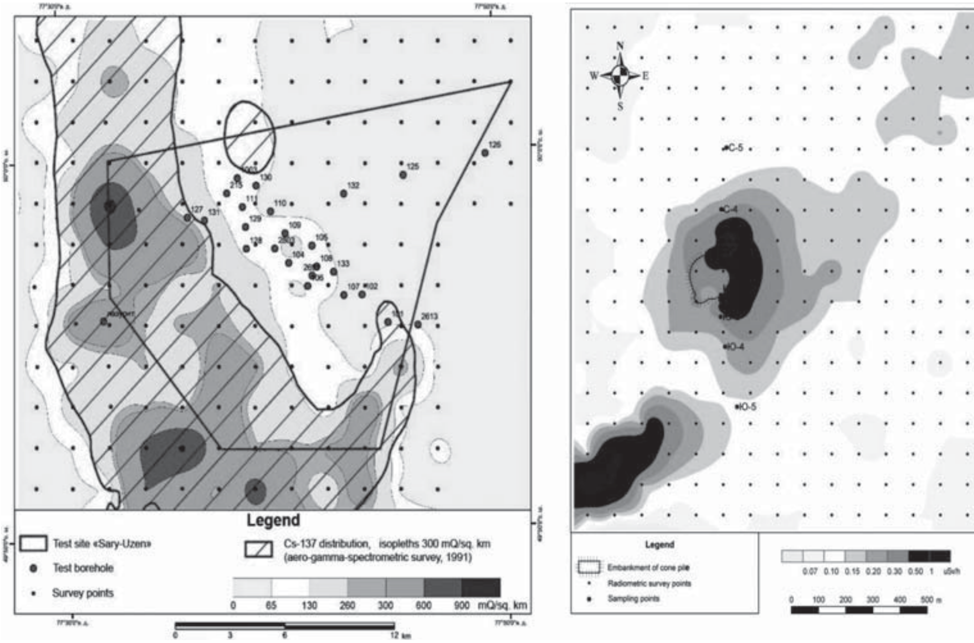


Figure 2.8. Distribution of ^{137}Cs (left) and MED (right) around the test hole No. 1003 over the test ground *Sary-Uzen*

The pedestrian gamma survey enabled to register a slight elevation over the gamma-background (up to 0.2 μSv/h) at a distance of 1 km from the epicenter of the test in the northeastern direction. Most probably, this spot of radioactive contamination was caused by the fallouts which followed the nuclear explosion in the test well No. 1003.

The results of laboratory analysis gave specific activities of man-made radionuclides in soil, the values of which are presented in table 2.12.

Table 2.12

Specific activity of radionuclides in soil cover in the vicinity of the test well No. 1003

Sample type	Specific activity, Bq/kg							
	^{60}Co	^{90}Sr	^{137}Cs	^{152}Eu	^{154}Eu	^{155}Eu	^{241}Am	$^{239+240}$Pu
soil	n*10^1	n*10^3	n*10^3	n*10^1	n*10^1	n*10^1	n*10^3	n*10^3

Taking into account very low level of radioactive contamination near the test epicenter and information about the character of radioactive fallouts presented in section 2.1.1, it is natural to suppose that this sector does not cause impact on current radiation situation of the northern part territory.

Test ground "4a" and the adjacent area

The radiological investigations enabled to determine the contours and level of radioactive contamination on the test ground territory. Over 30 spots of radioactive contamination were detected, which according to their mutual location were united into 25 sectors (Figure 2.5 coloured block). The length of the sectors varies from several tens to thousands of meters. Two sectors in the northern part of the ground test *"4a"* are located directly on the studied area. Tests of radiological weapons whose traces are directed to the northeast could also cause contamination of the studied area. It is also necessary to take into account the fact that in the vicinity of the other test ground for radiological weapons – *"4"* were detected spots of local radioactive contamination located at a distance of several kilometers from the boundaries of the test ground.

The radioactive contamination of soil and vegetation on the examined areas of RW tests is comparable with solid radioactive wastes (in some places – with liquid radioactive wastes). The results of laboratory analysis enabled to determine specific activities of some man-made raduonuclides in soil, whose maximal values are given in table 2.13.

Table 2.13

Specific activity of radionuclides in the soil cover around local radioactively contaminated spots on the test ground *"4a"*

Sample type	Specific activity, Bq/kg							
	^{241}Am	^{137}Cs	^{60}Co	^{152}Eu	^{154}Eu	^{155}Eu	^{90}Sr	$^{239+240}$Pu
soil	$n*10^3$	$n*10^5$	$n*10^2$	$n*10^2$	$n*10^3$	$n*10^3$	$n*10^8$	$n*10^4$

Maximal concentration of ^{90}Sr in the vegetation samples was $4*10^7$ Bq/kg. In soils the radionuclide ^{90}Sr is distributed practically uniformly up to a depth of 20 cm. The most hazardous sources as sources of secondary radioactive contamination are radionuclides ^{90}Sr and $^{239+240}$Pu present in the soil-vegetation cover.

Figure 2.9 (coloured block) shows distribution of radiation parameters in local sectors No. 1and No. 2 located directly on studied territory of the STS northern part.

A detailed examination of the distribution of beta-flow density along the south-west-northeast profile shows that radioactive contamination spreads in the northeast direction to a distance of 800 m from the place of maximal contamination of the ground where RWs were tested. Beyond the limits of the test ground, at a distance of 100m the flow of beta-particles decreases to the background values (Figure 2.10). Therefore there is a possibility of radioactive contamination beyond the area of the test ground *"4a"* at a distance of several hundreds of meters.

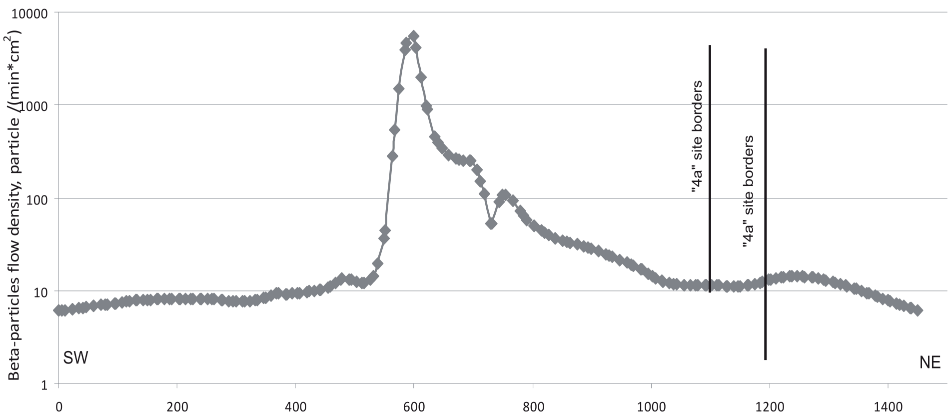


Figure 2.10. Distribution of the flow density of beta-particles (part./cm^2*min) along the SW-NE profile

In order to estimate the level of radioactive contamination the scientists made radiological survey of the territory adjacent to the boundary of the test ground *"4a"* at a distance of up to 1 km. The survey was made with a regular mesh of the size of 200×200 m, and when three spots with high radiation parameters were detected, they were examined using the mesh 40×40 m. The scheme of examination of the territory is shown in the maps (Figure 2.11 coloured block).

In sector No. 1 the MED does not exceed the background values (0.13-0.15 μSv/h) and the flow density of beta-particles insignificantly (less than 2 times) exceeds the background values (<10 part/(min*cm^2)) and does not have a character of clearly pronounced local contamination. This anomaly could be formed after precipitation of heavy aerosols from the cloud formed during RW tests on the test ground *"4a"*. Unlike the spot No. 1 the MED on the spot No.2 exceeds the background values by a factor of 1.5 and the flow density of beta-particles is as high as 90 part/(min*cm^2), which is 9 times higher than the background values and has clearly contoured localization. The area of the detected spot with radioactive contamination does not exceed 500 m^2. By the character of local contamination it is possible to suppose that it was formed as a result of tests of one of radiological weapons beyond the test area.

In order to prevent access of people and animals to the areas of local contamination it is wise to create physical barriers.

Ground for nuclear wastes disposal (disposal site)

One of the potential sources of radioactive contamination of the STS northern part is the area of near-surface disposal of industrial wastes located at a distance of 15 km away from Kurchatov-city in the direction of the test ground *Opytnoye pole*. The location of the ground for nuclear wastes disposal (disposal site) is shown in the map (Figure 2.1 coloured block).

The ground for nuclear wastes disposal is fenced by wire along the perimeter, at a distance of 3.5 m from the fence the area was protected by a ditch which is now almost fully destroyed. Primary examination (2002) of the ground territory discovered the presence of 4 man-made embankments and three dig-ups near which aluminium caps from unknown tanks, replaceable filters from gas masks, metallic meshes, metallic containers and bones of cattle and small animals were found (Figure 2.12, figure 2.13).

Figure 2.12. Embankment with remnants of animal bones

Figure 2.13. Destroyed fence

Aside of all dug-ups the researchers discovered a metallic container for keeping the sources of ionizing radiation with traces of partial destruction and without a locking cap. At a distance of 35-40 cm from the neck of the container radioactive contamination was registered – MED values showed 160 μSv/h and the flow density of β-particles was about 10, 000 part/(min*cm^2). It was supposed that the container contained radioactive substances. The circumstances which caused local surface radioactive contamination of the area are not known. The content of the containers is also not known. One cannot exclude that the containers could keep sources of ionizing radiation which were disposed in soil.

Present-day radiation conditions on the territory of the "disposal site"

Additional examinations of the territory of the "disposal site" have been made in 2009. The external examination enabled to discover 4 breaks in the protective fence. The map-scheme of the "disposal site" was made (Figure 2.14).

On the territory of the "disposal site" the pedestrian gamma-survey with a 10X10-m mesh was made. The MED values vary from 0.10 to 0.13 μSv/h (beyond the areas of radioactive contamination). The examination in the regime "search" and the pedestrian gamma-survey enabled to detect the areas of radioactive contamination shown in the figure (figure 2.14).

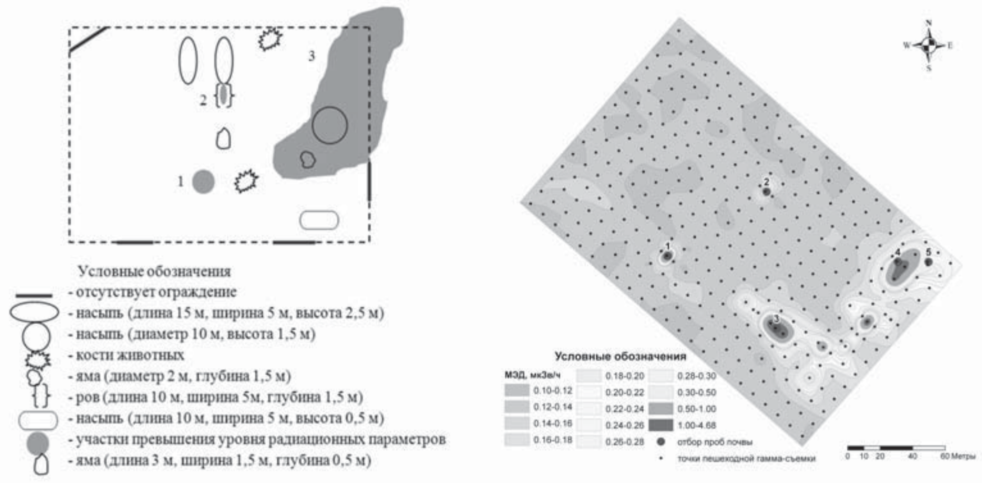


Figure 2.14. Scheme of location of man-made objects and areas of radioactive contamination on the territory of the "disposal site"

In the areas of high radioactive contamination 5 soil samples (figure 2.14) were taken, and laboratory analyses were made to determine the presence of man-made radionuclides (table 2.14). Examination of the territory in the vicinity of point No. 4 detected a black spherical man-made object (subject) of about 15 cm in diameter. The MED on the surface of the object (subject) was 1.06 μSv/h.

Table 2.14

Specific activity of radionuclides in soil sampled on the "disposal site"

Sample type	Specific activity, Bq/kg						
	^{241}Am	^{137}Cs	^{60}Co	^{152}Eu	^{154}Eu	^{155}Eu	^{90}Sr
Soil	$n*10^0$	$n*10^5$	$<n*10^1$	$<n*10^2$	$<n*10^1$	$n*10^4$	$n*10^2$

Radioactive contamination of the territory of the "disposal site" is mainly caused by ^{137}Cs with low concentrations of other artificial radionuclides. In point No. 1 the radioactive contamination is caused by ^{90}Sr with low concentration of ^{137}Cs and ^{241}Am. Such distribution of radionuclides demonstrated the presence of different sources of radioactive contamination of the territory of the "disposal site". Most probably, the radioactive contamination occurred during removal of the upper soil cover by unknown persons and extraction of radioactive substance to the soil surface. The examination did not provide enough information about the volumes and activities of disposed sources of ionizing radiation which can be identified only after disclosure of the disposal site and their extraction.

At the present time the territory of the "disposal site" is not guarded. The IRSE specialists periodically carry out visual examination of the territory. In the period from 2002 no additional infringements of the territory of the "disposal site" have been registered.

Therefore, prior to taking a decision on lands transfer to agricultural usage it is necessary to fence and not to transfer for economic usage the territory of near-surface disposal of radioactive substances ("disposal site") as it is possible that radioactive materials are disposed under the soil layer and it is not possible now to estimate their volume. It is also necessary to foresee creation of a sanitary-protective zone around it at a distance of 500 m until works on reclamation of the "disposal site" are carried out. In order to prevent access of people and animals to the test ground *Opytnoye pole* and to create physical barriers in order to prevent access of people and animals to the territory of the "disposal site" it is reasonable to reconstruct the wire fence and to make a physical barrier in the form of a ditch.

2.1.4 Man-caused factors forming radiation conditions

Secondary radioactive contamination of the studied area may be caused by natural and man-caused (anthropogenic activities) processes. Further, in the other sections we will consider in more detail the influence on formation of present-day radiation situation of such natural migration processes as radionuclide migration with groundwaters and wind transfer of radioactively contaminated soil particles.

Man-caused factors which can form secondary radioactive contamination of the studied areas are earthworks carried out in order to collect metal scrap on the areas of former nuclear tests (Figure 2.15) and its removal beyond the territory of the test site and agricultural activities (cattle grazing and hay making) on the radioactively contaminated areas. During the time which passed after withdrawal of Russian troupes as a result of uncontrolled anthropogenic activities on the territory of the test site large-scale works on unauthorized removal of cable and gathering of black metal scrap were carried out on the test ground *Opytnoye pole*. The above works caused destruction of soil cover on radioactively contaminated parts of test grounds which could cause intensification of migration processes connected with wind transfer. Radioactively contaminated automobiles and tractors periodically crossed the studied area.

Figure 2.15. Unauthorized activities on metal scrap mining near the epicenter of surface nuclear explosions on the test ground *Opytnoye pole*

Large areas, not used in distant-pasturing for a long time became attractive territories for grazing of domestic farm animals. More than 10 farms which pasture their domestic farm animals and make hay on contaminated areas appeared near the former test grounds (Figure 2.16). As a result, food stuffs (milk, meat) produced by farmers farming on the studied area and places where animals are kept got contaminated with radionuclides. There are separate, not confirmed facts of ^{90}Sr concentrations exceeding MPC in the samples of small cattle from winter pastures Tulpar, Bayansor, Dostyk and Tortkuduk, the nearest to the former test ground *"4a"*. ^{90}Sr concentration in meat exceeding MPC is most likely caused by cattle grazing on the territory of the former RW grounds.

Figure 2.16. Unauthorized activities on metal scrap on cattle pasturing and hay making in the northern part of the STS territory

It does not seem possible now to estimate volumes of transfer of radioactive substances. In order to reduce the level of radioactive contamination of the areas located close to the former test grounds it is necessary to restrict the unauthorized access of people and domestic animals to radioactively hazardous areas of the STS territory.

2.2 Factors due to global fallouts

In the aerial nuclear tests a considerable part of radioactive products is released to the stratosphere, where mixing of different layers is very weak and precipitation is slow. Radioactive aerosols of microscopic sizes (~$4*10^{-5}$ cm) remain in the radioactive cloud in the stratosphere for several months or even years and winds carry this cloud over the earth (stratospheric transfer).

Especially high was contamination of the Earth's atmosphere by the products of nuclear fission before signing in 1963 of the Agreement on Banning of Nuclear Tests in Atmosphere, Outer Space and under Water. As a result of realization of the requirements of the document, the radioactivity of the atmosphere gradually decreased, and so far it has decreased by hundreds of times. A short-term increase in the radioactive pollution of the Earth's atmosphere in the last decade was registered in 1986 as a result of accident on the Chernobyl NPP.

Atmospheric precipitations and dry fallouts transfer artificial radionuclides (ARN) from the atmosphere to the surface soil layer. Such fallouts are called global. The density of global fallouts depends on the geographical latitude of the area, time passed since the ARN emission to the atmosphere, season and, to a high extent, meteorological factors. The density of fallouts caused by local sources (spatial distribution and time dependence) has even stronger dependence on the characteristics of the ARN source and meteorological parameters.

Total (cumulative) ARN depositions gradually redistribute in the natural landscapes. It is caused by the following processes:

- Horizontal migration – washing out by atmospheric precipitations from elevations to lower places and wind transfer;
- Vertical migration – ARN gradually move deeper into the soil and the part contained in the leaf cover transfers into the upper soil layer (after plant dying off).

Natural migration causes even higher difference in the concentrations of artificial radionuclides in the upper (as a rule, studied) soil layer. Therefore one can without any doubt extend the natural range of radionuclide concentrations minimum 2-3 times of the average value.

It is impossible to give a general picture of soil contamination with global fallouts not only because of extremely high spatial nonuniformity of ARN fallout densities on the earth surface but also because of complicated processes of vertical and horizontal transfer (migration).

A certain difficulty in determining of the range of concentrations of the main radionuclides produced by global fallouts is caused by different units of measurements used by different authors. For example, the author [50] presented the following values of the density of global fallouts in the northern hemisphere without giving the depth of sampling: ^{137}Cs – 140 μCi/km^2, ^{90}Sr – 89 μCi/km^2. In order to transfer these data into specific activity in mass it is necessary to know the depth of soil sampling, in different sampling methods this value ranges from 5 to 30 cm, it means that there is uncertainty in the normalizations which can give results differing by a factor of 6. An additional source of errors is caused by the fact that many sources of information do not contain the date when activity was measured and do not give the mode of radioactive decay.

In collecting information we used all sources, both publications and Internet resources. If the source did not contain information on the depth of sampling, we assumed it to be equal to 5 cm and as the date of activity measurement we used the date of publication. The range of concentrations of the main radionuclides due to global fallouts in northern hemisphere is given in table 2.15.

Table 2.15

The range of concentrations of the main radionuclides due to global fallouts in northern hemisphere [50, 51, 52, 53, 54, 55, 56, 57]

Radionuclide	^{137}Cs	^{90}Sr	$^{239+240}$Pu
Concentration, Bq/kg	4-29	1-19	0,02 – 5,0

The isotope ratios for plutonium radionuclides in soil of different regions differ considerably because they were formed in different ways (global fallouts, emissions of nuclear-fuel cycle enterprises, Chernobyl accident). For example, we can compare the ratios ^{240}Pu/^{239}Pu caused by different factors: nuclear explosions – (0.05 ÷ 0.06), global fallouts – about 0.176, emissions of nuclear-fuel cycle enterprises plus global fallouts – (0.049 ÷ 0.150), Chernobyl fallouts – (0.30 ÷ 0.35).

The isotope ratios for plutonium radionuclides for different regions range within the limits given in the table (table 2.16).

Table 2.16

Isotope ratios for Pu for different regions

Radionuclides	Ratios
^{238}Pu/(^{239}Pu+^{240}Pu)	0.027 ÷ 0.44
^{238}Pu/^{239}Pu	$1.1·10^{-4}$ ÷ $3.7·10^{-3}$
^{240}Pu/^{239}Pu	0.049 ÷ 0.35
^{241}Pu/^{239}Pu	0.003 ÷ 0.090
^{242}Pu/^{239}Pu	$4.4·10^{-3}$ ÷ $4.0·10^{-2}$

In order to get a theoretical estimation of the density of global fallouts let us use the following initial data:

- $5.99*10^{17}$ Bq of ^{90}Sr (out of $6.04*10^{17}$ Bq released to the atmosphere) and $9.6*10^{17}$ Bq of ^{137}Cs (out of $9.64*10^{17}$ Bq released to the atmosphere) had fallen out on the earth's surface by 1990 [50].
- The total area of the earth's surface is 510 Tm^2.
- The main fraction of fallouts (~75 %) was in northern hemisphere.
- The distribution of radionuclides on the globe surface is assumed to be uniform.
- The depth of radionuclide distribution in the lithosphere is 0.05 m.
- The soil density is taken equal to 1600 kg/m^3.

Therefore the avearge specific activity of global fallouts is:

$$A(Bq/kg) = A\ (Bq)*75\%/510\ Tm^2/0.05\ (m)/1600(kg/m^3)/100\%$$

It is 23.5 Bq/kg for ^{137}Cs and 14.7 Bq/kg for ^{90}Sr.

Taking into account the half-life period we get the following values for the year 2009: ^{137}Cs – 15.2 Bq/kg, ^{90}Sr – 9.4 Bq/kg, which approximately corresponds to the middle of the range of values presented in literature.

It should be noted that literature data contain no information on such radionuclides as ^{151}Sm and ^{99}Tc, as now their concentrations are 8% and 1.6% of that of ^{137}Cs, respectively. It means that based on theoretical calculations on can, with high degree of certainty, suppose that activity of ^{151}Sm and ^{99}Tc in global fallouts is 1.2 Bq/kg and 0.2 Bq/kg, respectively.

Chapter 3
State regulations in the field of environment contamination

Radiation risk assessment is currently based on the colloquial model stipulated in the RK State legislation: the model of no threshold influence of ionizing radiation with effective dose as a risk factor (Radiation Safety Norms NRB-99, i. 2.8 [58]). According to these Norms, "Main objective of radiation safety is the health protection for people and personnel against harmful radiation through establishing and following main principles and norms of radiation safety without unfounded restriction of useful activities where radiation is involved in various spheres of industry, science and medicine."

Current status of STS territory and requirements for activities at locations of nuclear explosions

Present status of STS was defined in the governmental decree of the Republic of Kazakhstan from Feb.07 1996 #172 "About transfer of former Semipalatinsk Nuclear Test Site lands into State reserve".

The Government has enacted the following:

1. Accept the proposal of the State Committee of the Republic of Kazakhstan on lands and land planning coordinated by authorities of Karaganda, Pavlodar and Semipalatinsk oblasts, Ministry of Ecology and Bioresourses, Ministry of Agriculture and Ministry of Economics about transfer of the lands of the former Semipalatinsk Nuclear Test Site into the lands reserves of Karaganda, Pavlodar and Semipalatinsk oblasts.

Definition for the lands reserve is available in the Land Code of the Republic of Kazakhstan from June 20 2003 (Code No. 442)

Article 137. Land reserve composition

Any land under the authority of local executive authority and not in ownership or land tenure comprises land reserve.

According to the governmental decree, lands where tests of nuclear weapons were performed are to be transferred into the land reserve. Legal status of these lands is defined by the article 143 of the present Code.

Authorized commercial and research activities are currently in progress at those lands: mining and prospecting of minerals, scientific research of environment, seismicity; there are two research nuclear reactors in operation there. As it is defined in Article 5 "Main activity types in the field of atomic energy utilization" of the State Law "On Atomic Energy Utilization" from Apr. 14, 1997 No. 93-I (with amendments made on 20.12.2004 No.13-III), any activity in places of nuclear explosions is considered as activity related to atomic energy utilization and is subject to permanent direct state control.

Activities related to atomic energy utilization are subject to state licensing (Article 11. Licensing of activities related to atomic energy utilization).

State Law "About Licensing" (with amendments dated 27.07.2007) in the Article 13 "Licensing of activities related to atomic energy utilization" also establishes that a license is required for the following: clause 8) "activities at territories of former nuclear test sites and other territories contaminated due to nuclear explosions".

It is almost impossible for a farm to comply with conditions for such a license, so for legal agricultural activities on the lands of former STS it is necessary to transfer part of its lands (which satisfy the conditions set by the Land Code) into economic circulation.

Land transfer order

State reserve lands can be transferred into private ownership or land tenure for agricultural, industrial or other activities in compliance with the order and under conditions established in the Land Code of the Republic of Kazakhstan from June 20 2003 (Doc. No.442).

The order of such transfer for lands where nuclear explosions had been performed is established in Article 143 "Lands subjected to radioactive contamination and those where nuclear explosions were performed":

– lands previously subjected to exceeding radioactive contamination or those imposing a threat in any other way to human life or health cannot be transferred to ownership, permanent or temporal land tenure.
– lands previously subjected to exceeding radioactive contamination that cannot assure production on them in compliance with State sanitary requirements and norms are to be excluded from agricultural activities and are subject to preservation. Agricultural production and sales of produced there agricultural outputs is prohibited.
– the Government can transfer the lands where tests of nuclear weapons were previously performed into ownership or tenure only upon completion of all measures aimed at elimination of nuclear tests consequences and after over-all ecological studies performed there with positive expert conclusion issued by State ecological authorities.
– state and local environment protection programs, land protection, rational land use and other special programs include measures aimed at elimination of consequences from nuclear weapons tests at those territories.

The notion about State ecological expertise, its order, terms and conditions are described in Chapter 7 "Ecological Expertise" of Ecology Code of the Republic of Kazakhstan.

As stated in clause 3 of Article 143 of the Land Code, over-all ecological research of the STS northern part had been performed with the purpose to transfer these lands to ownership or land tenure.

Acceptable dose loads for population

Let us consider two classes of norms for population:

– major maximal allowable doses (MD) from Table 3.1 of NRB-99
– acceptable levels of multifactor impacts due to main dose limits: limits for annual intake (AIL) and allowable annual average volume activities (AVA).

Main dose limits do not include doses from background irradiation and medical irradiation as well as doses due to radiological accidents: special limits are set for these types of irradiation. Limits of effective doses for population comprise for artificial radionuclides 1 mSv per year in average for any consequent 5 years, but not than 5 mSv in a year.

Governmental Decree No. 653 from July 31, 2007 "About criteria for environmental assessment of territories" establishes the indexes for assessment of radiological safety for people. According to Part 6 of the Decree, the main criterion for radio-ecological safety of people inhabiting contaminated territory is the annual average effective dose due to a sum of all ionizing radiation sources including those in the nature. "Lands with annual average values of additional (i.e. over natural background) effective dose on humans do not exceed 1 mSv, … are classified as territories with relatively favorable ecological conditions. Those lands with annual average values of effective dose (additional, over natural background) can exceed 5 mSv and be up to 10 mSv are to be considered at territories of emergency ecological situation and those lands with more than 10 mSv – as territories of ecological disaster."

According to IAEA docs (BSS – Basic safety norms) "International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources" (Series 115) the following doses limits on population are established in Clause II-8: "The estimated average doses to the relevant critical groups of members of the public that are attributable to practices shall not exceed the limit of effective dose of 1 mSv in a year". So, the effective dose of 1 mSv in a year is a maximal acceptable level in Kazakhstan as well as in the international documents.

Requirements of the State regulatory documents to levels of radioactive contamination of environment

All established levels for contamination of environment and food are derivatives from main effective dose limit to population. In case of known radionuclide composition, the radiation safety norms NRB-99 (Annex 2) establish acceptable levels of mono-factor impact to evaluate pollution levels of air, drinking water sources, food produced at contaminated territories:

– limits for annual ingestion and inhalation (annual intake – AI)
– allowable average annual volume activities (AVA) in inhaled air and in water.

The values of AI and AVA for the main man-caused radionuclides are presented in Table 3.1 below. We consider here those radionuclides which can be potential contaminants of the environment due to tests at former STS and can contribute considerably into expected effective dose on population.

Table 3.1

Maximal annual ingestion and inhalation of radionuclides, acceptable volume activities for inhaled air and specific activity in water for certain radionuclides (for population)

Radionuclide	Intake due to air (inhalation)		Consumption with water and food
	Maximal annual intake, Bq/year	Acceptable average annual volume activity, Bq/m^3	Maximal annual intake, Bq/year
^{3}H	3.7*10^{6}	1.9*10^{3}	2.1*10^{7}
^{90}Sr	2.0*10^{4}	2.7	1.3*10^{4}
^{99}Tc	2.0*10^{5}	2.7*10^{1}	2.1*10^{5}
^{137}Cs	2.2*10^{5}	2.7*10^{1}	7.7*10^{4}
^{151}Sm	2.5*10^{5}	3.1*10^{1}	1.6*10^{6}
^{238}Pu	2.2*10^{1}	2.7*10^{-3}	2.5*10^{3}
^{239}Pu	2.0*10^{1}	2.5*10^{-3}	2.4*10^{3}
^{240}Pu	2.0*10^{1}	2.5*10^{-3}	2.4*10^{3}
^{241}Pu	1.1*10^{3}	1.4*10^{-1}	2.1*10^{5}
^{241}Am	2.4*10^{1}	2.9*10^{-3}	2.7*10^{3}

Acceptable levels of radionuclides in more than 20 types of food products have been established for food products the Sanitary Rules and Norms "Hygienic requirements for safety and nutritional value of food products" [59]. Table 3.2 below contains hygienic safety requirements for those food products which could be most likely produced at the lands of our interest.

Table 3.2

Hygienic safety requirements for food products

Food class	Acceptable levels, Bq/kg, (not more)	
	^{137}Cs	^{90}Sr
Meet of domestic and edible animals (without bones)	160	50
Milk, cream, liquid sour milk products, etc.	100	25
Vegetables, melons and gourds	600	200

This document contains no requirement to acceptable levels of plutonium isotopes in food products, so assessment of plutonium content can be based on annual intake of plutonium with food established in NRB-99.

Regulation of soil contamination

Up to 2007 the data on global fallouts or those on radioactive waste were used for evaluation of radioactive contamination of soils. According to the State HydroMeteo Committee in 1990 the country-average contamination density of soils with ^{137}Cs (except polluted areas) comprised 2.4 kBq/m^2 (65 mCi/km^2), and for ^{90}Sr – about 1.4 kBq/m^2 (39 mCi/km^2) [60]. These numbers are typical for whole territory of former USSR and can vary for different regions. By now these values might change due to natural decay. Assessment of global fallouts is available in literature.

By the Governmental Decree # 653 from July 31 2007 "On establishing the criteria for assessment of ecological situations at territories" [61], there were established the indexes for evaluation of ecological conditions of soils. Part 7 of the Decree "Criteria for changes in natural environment", paragraph 7 "indexes for soil state assessment" states that the choice of ecological assessment of soils is determined by location, genesis, buffering and diversity of soil use. The table below presents soil types based on surface contamination with long living products of nuclear explosions:

Table 3.3

Indexes of radioactive contamination of soil

Index	Parameter		Relatively satisfactory condition
	Ecological disaster	Emergency situation	
Radioactive contamination, Bq/kg*			
Cesium-137	over 18,500	6,938 – 18,500	up to 6,938
Strontium-90	over 1,388	462 – 1,388	up to 462
Plutonium (all isotopes)	over 46.3	23.1 – 46.3	up to 23.1
Note: * specific activity is calculated for 5 cm-deep soil layer at soil density 1.6 kg/dm^3			

One should use careful approach to norm soil contamination with plutonium. The norms are established for the sum of isotopes what in terms of their radiation hazards is not correct since specific activities of minimal value from Pu-239 (238, 240) are for two orders of magnitude less than those for Pu-241.

Regulation of vegetation contamination

Contents of artificial radionuclides ^{137}Cs and ^{90}Sr in vegetation is regulated by "Provisional Acceptable Levels for Radionuclide Contents in Objects under Regulatory Control of the Ministry of Agriculture" [62]; this document has been developed for those objects which were not covered by the regulatory list of the Ministry of Public Health from Feb.22 1994. So, acceptable contents of radionuclides in grass, grain crops, hay, haylage, and others has been established at the level 74 Bq/kg for ^{137}Cs and 111 Bq/kg for ^{90}Sr. This document does not consider specific activity of other radionuclides.

Chapter 4

Present radio-ecological situation of the environment

4.1 Radiological conditions at the studied lands

Radiation parameters such as EDR and flux density of beta particles have been measured for a preliminary assessment of the radiological status of the northern part of STS. Total radiation parameters in 2,459 points were measured during the studies. Depending on the area and the goals, sampling grid density varied from 1 measurement per 1 km^2 to 1 the measurement per 2.6 km^2 with average density of the survey 1 measurement per 1.8 km^2.

Distributions of DER and flux densities for β-particles at the studied area are shown on the maps (figure 4.1, figure, 4.2 coloured block).

Statistical data processing of radiation survey results

Data were selected for statistical processing to cover all measurements of radiation parameters performed at the STS northern part in 2008-2009. Total number of measurements within the studied area was 2,459. Since the measurements were made employing various instruments of different detection limits of the measured values, correct interpretation of the data required us to withdraw from consideration the readings below the detection limits of the used instrumentation.

Measured DER values vary from 0.05 to 0.23 μSv/h with the arithmetic mean of 0.12 μSv/h.

A variation curve has been plotted to assess the distribution of EDR values (see figure 4.3).

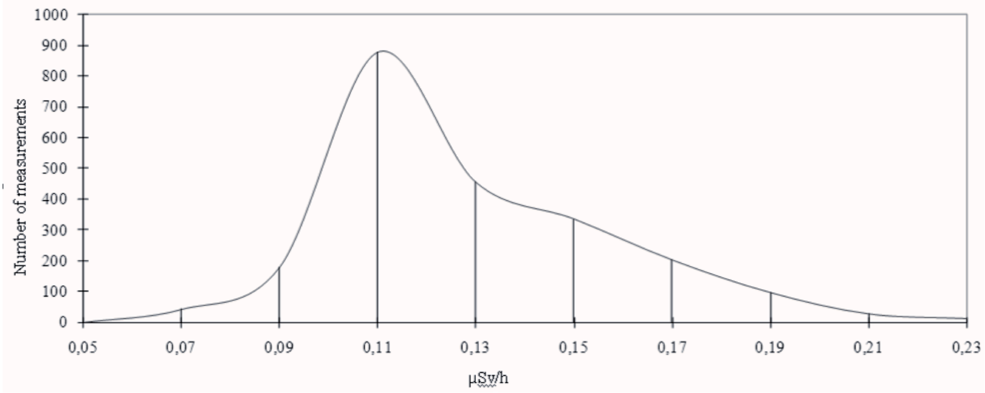


Figure 4.3. EDR distribution at the studied territory

The variation curve shows that the distribution of radiation parameters is of a nature close to normal (natural) distribution with a small asymmetry to the right. This right asymmetry determines the range of values above the normal distribution and may be a consequence of using different instrumentation with different characteristics in the survey. Also, increased activities of natural radionuclides in soil and fluctuations of the measured radiological parameters could provide their contribution to the values above the normal distribution.

Similar analysis was conducted for the values of the β-particles' flux density. Flux density of β-particles varied from 3 to 19 particles/(min·cm²); the arithmetic mean value was 9 particles/(min·cm²).

To assess the distribution of values in the flux of β–particles, a similar variation curve has been plotted (figure 4.4).

This variation curve shows that the distribution of radiological flux values of β-particles is of a nature close to normal (natural) distribution. Like in the case of EDR, there is much less right asymmetry in the range of values making the curve to exceed the normal distribution. This particular exceeding may rise up due to some factors influencing the values and due to increased activity of daughter products from radon decay at soil surface.

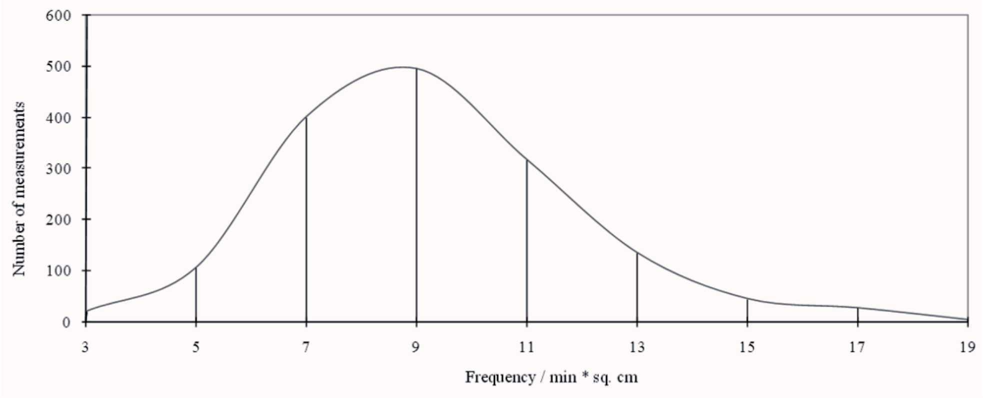


Figure 4.4. Distribution of β-particles flux density at the studied territory

Discussion of the results

Statistical analysis of the obtained results showed that the distribution of radiation parameters in the studied area is of a nature close to normal (natural) distribution. It was also determined the range of values that form right asymmetry (beyond the normal distribution).

We assessed the likely factors that form the high values area of the results. The following are factors, ranked according to the degree that determines their contribution to the formation of higher values.

1. Measurement uncertainty

Since the studies were conducted at different times and by different research groups, dosimeters and radiometers used in the measurements differed in principles of registration of ionizing radiation and in other characteristics which affect the measurement results (type and size of the detector, detector anisotropy, energy nonlinearity of the detector efficiency, etc.). While doing measurements of the values that are close to the detection limit, all this can rise up the uncertainty of the results up to ± 30%.

2. Fluctuation of the measured radiation parameters

Radiation background due to cosmic radiation is responsible for up to 40% (0.04-0.05 μSv/h) of external irradiation received by population from natural radiation sources. The intensity of cosmic radiation depends on geographical location of the object and increases at higher elevations. Intensity of cosmic radiation varies with time; such variations have periodic and aperiodic nature, terrestrial or extraterrestrial origin. Variations of terrestrial origin mainly happen because of meteorological factors. They have a non-periodic nature and are limited in time (barometric and temperature effects) or periodic seasonal variations with amplitudes up to 2÷3% in mid latitudes. Variations of extraterrestrial origin are mainly associated with variations in solar and magnetic activity, disturbances of the Earth's magnetic field.

As a consequence, number of particles and gamma-quanta through certain volume (detector) per unit of time at fixed equivalent dose rate is in itself a random value.

3. Increased activity of natural radionuclides in the lithosphere

Natural radioactivity of the lithosphere is caused by the presence of radioactive isotopes U, Th, K, Rb, etc. in geological formations. The main contribution to the radioactivity of rocks, ground and soil is made by potassium-40 and by the group of uranium-radium and thorium radionuclides.

The radioactivity of soils primarily depends on the activity of parent rocks and the intensity of radionuclide exchange processes between soil and groundwater, soil moisture, content of organic composites in soil and other factors. Rocks of volcanic origin (especially granite) have greater activity than sedimentary ones (excluding shale). Thus, the sierozems have the highest radioactivity while the peatlands – the smallest (Table 4.1) [63].

Table 4.1

Concentration of some radionuclides in soils and their expected effective dose rates

Type of soil	Concentration of radionuclide, Bq/kg			Dose rate, μSv/h
	^{40}K	^{238}U	^{232}Th	
Sierozems	660	31	48	0.074
Grey-brown	770	27	41	0.069
Chestnut	450	26	37	0.06
Chernozem	410	21	36	0.051
Gray forest	370	17	27	0.041
Sod- spodosol soils	290	15	22	0.034

Type of soil	Concentration of radionuclide, Bq/kg			Dose rate, μSv/h
	^{40}K	^{238}U	^{232}Th	
Podzol	15	9	12	0.028
Peaty	88	6	6	0.011
World average	370	26	26	0.046
Typical range	100-740	11-54	7-48	0.014-0.09

Gamma-rays from rocks and soils due to natural isotopes of radium, thorium (and their decay products) and potassium usually varies from 0.07 to 0.20 μSv/h, averaging to 0.08-0.10 μSv/h. Effective dose of external radiation due to all the natural radionuclides ranges from 3.2 to 8.1 mSv/year.

4. Increase of activity for radon decay daughter products

Increase in activity of radon daughter products decay registered at soil surface may be caused by increased exhalation of radon isotopes from the soil. Since release of radon from soil is strongly dependent on the type of soil in the area and weather conditions, the flow of radon from the soil and its concentrations in the near-surface atmosphere vary greatly depending on location and time of day [64].

Assessment of radiological parameters at the northern part of STS did not reveal exceeding over natural background values, both compared with the world averages and with those typical for Kazakhstan.

Average expected annual dose from external photon radiation at the northern part of STS is about 1 mSv. According to numerous studies and observations worldwide, it has been found that natural background radiation varies from locality to locality. The levels of natural radiation vary within quite wide limits, forming average annual dose of about 2-2.5 mSv with its third part contributed by external radiation [65].

In some areas of our planet, natural radiation background is much higher than the average one for the globe (due to abnormally high content of natural radionuclides in the soil). Thus, in the monazite areas of India, the dose rate reaches 3.2 μSv/h (0.028 Sv/year), in Brazil – 1.15 μSv/h, in areas of volcanic extrusion – 13.70 μSv/h (0.12 Sv/year), granite-rock areas of France – 0.4 μSv/h [63].

In some areas of the CIS (Borjomi, Khmelnik and Mironovka) where radioactive (radon-radium) waters reach the day surface, natural background radiation is quite high. Effective dose rate is as high as 10-30 mSv/year with up to 40-80 mSv/year in some places, i.e. exceeds the average value for more than ten times [63].

In orderto assess the level of radiological parameters at the northern parts of the STS in relation to the adjacent territories; it can be compared with data of the radioactive pollution monitoring performed for lower atmosphere at weather stations of KazHydroMet. For instance, figure 4.5 shows the EDR values in settlements of Eastern Kazakhstan in 2008 [66]. Average dose rates of γ-radiation in the regions of Kazakhstan are within 0.10-0.16 μSv/h [67].

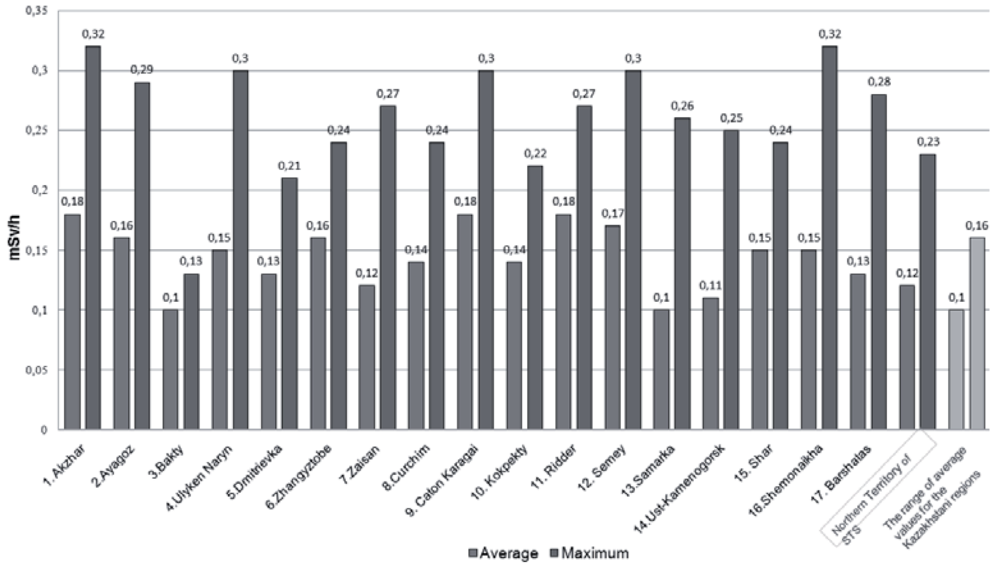


Figure 4.5. Equivalent dose rates in East Kazakhstan oblast for 2008

As seen from the histogram, the level of EDR at the northern parts of the STS is on the level of background radiation parameters in Kazakhstan and inhabited localities of the region.

Based on the foregoing, it can be concluded that the radiological parameters of the northern part of STS do not exceed the background values typical for both Kazakhstan and the world.

4.2 Areal radionuclide contamination of soils

Developing a plan for areal surveying the following main factors were taken into consideration:

– information available on radionuclide contents in soils of studied lands;
– recommendations of IAEA experts who proposed the survey grid of 1 km;
– general regularities in formation of radioactive contamination at nuclear explosions such as typical scales of contamination spots, required sampling depth.

Survey plan

The following plan for the surveying has been developed (see figure 4.6 below). The studied territory was divided into 3 parts – Western, Central and Eastern ones. Sampling grid of 1.5 km density was taken for the Western part and 1.0 km – for the Eastern. In the Central part it was proposed to run profile studies first (grid 0.2

km) crossing expected traces of radioactive contamination in order to reveal and evaluate their main radiological parameters. And after that, based on obtained profile information, additional areal study of the Central part with the grid of 1 km has been completed.

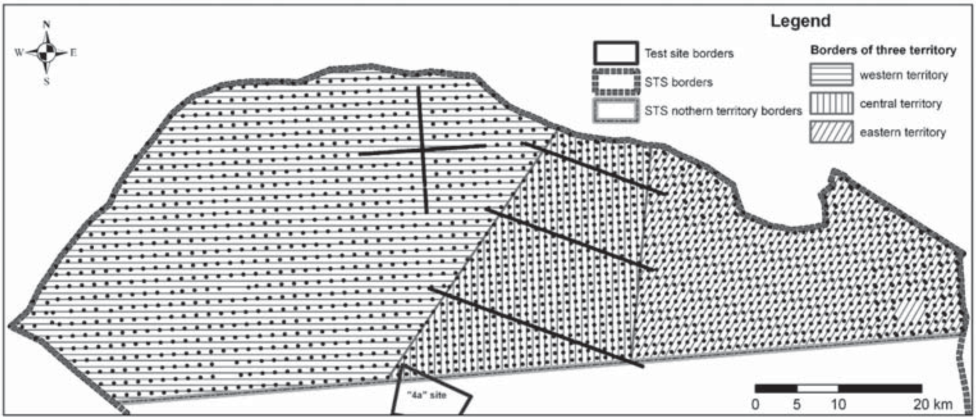


Figure 4.6. Surveying the northern part of STS

The studies included radiometric survey in selected points, measurement of their coordinates, taking of point samples at 5 cm depth within the area 10x10 cm. Then the samples were delivered to laboratory for further analyses. Upon required preparation (drying, screening, quartering) the samples were analyzed for presence of main radionuclides, both natural (^{232}Th, ^{40}K, ^{226}Ra) and artificial (^{137}Cs, ^{241}Am, ^{60}Co, ^{152}Eu). Some samples were then taken for radiochemistry in order to evaluate ^{90}Sr, $^{238,\ 239+240}$Pu there. Samples which showed $^{238,\ 239+240}$Pu were, as a rule, then analyzed for ^{241}Am content upon additional homogenizing in order to evaluate the ratios of the radionuclides.

4.2.1 Areal distribution of natural radionuclides

Radiation background at the studied area is mainly determined by natural radionuclides of uranium and thorium decay series as well as potassium ^{40}K. Upon analysis of 2,450 soil samples taken from upper soil (0-5 cm), there have been determined such natural radionuclides as ^{40}K, ^{232}Th and ^{226}Ra. Based on these studies, maps of ^{40}K, ^{232}Th and ^{226}Ra areal distribution was composed (Figure 4.7 – Figure 4.9 coloured block). Distribution of ^{40}K, ^{232}Th and ^{226}Ra readings is presented in form of histograms at figures 4.10 – 4.12).

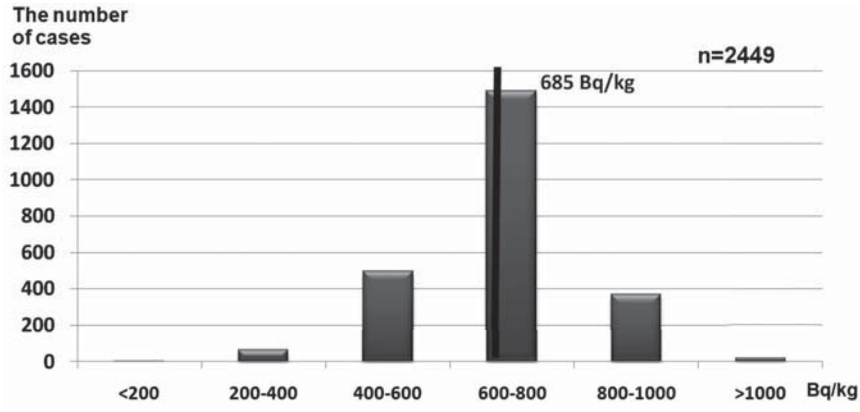


Figure 4.10. Distribution of ^{40}K values concentrations in soils

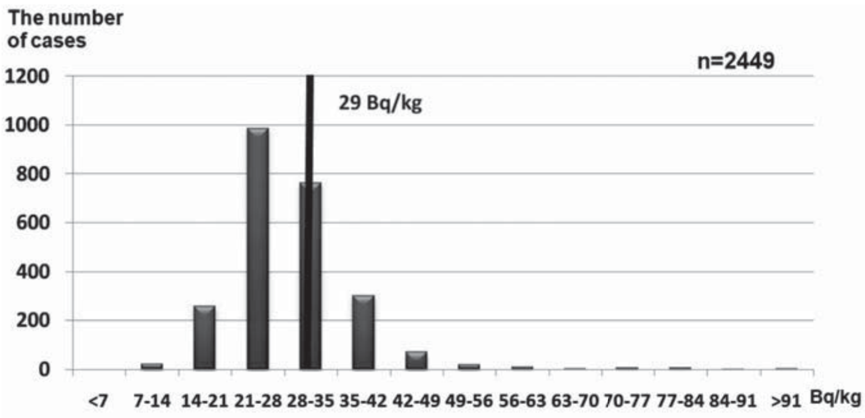


Figure 4.11. Distribution of ^{232}Th values concentrations in soils

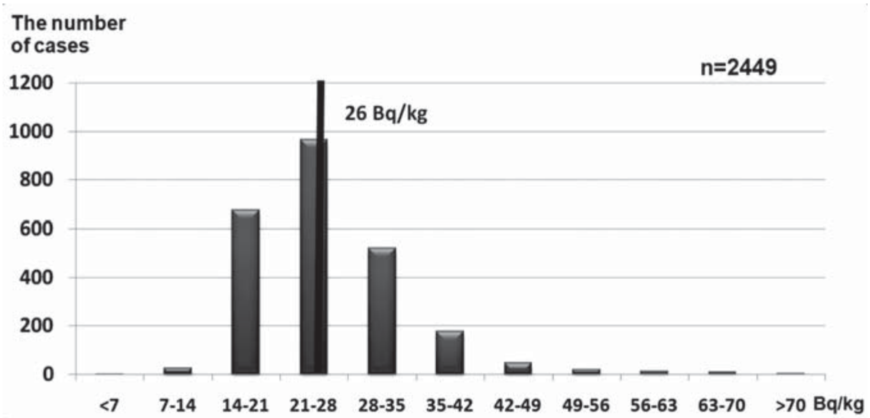


Figure 4.12. Distribution of ^{226}Ra values concentrations in soils

Average content of natural radionuclides at the studied territory was as follows: ^{40}K – 685, ^{226}Ra – 26, ^{232}Th – 29 Bq/kg. Such contents are typical for soils in Kazakhstan; no any geo-chemical abnormality has been revealed.

Maximal and minimal values of natural radionuclide specific activities in Kazakhstani soils as well as their average values are presented in table 4.2 for comparison [68].

Table 4.2

Activity of natural radionuclides in soils in Kazakhstan

	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 uranium and thorium ores have radioactive equilibrium close to one and specific activities of uranium and radium are equal			

Analysis shows that these samples from western part of the lands (sour granitoid rocks typical for low hills) with the highest specific activities of ^{40}K, ^{226}Ra and ^{232}Th which nevertheless remain within average numbers for soils in Kazakhstan (maximal value was registered for potassium-40).

4.2.2 Areal distribution of aretificial radionuclides

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

Contamination of the investigated lands with ^{137}Cs

Total samples analyzed – about 2500. A map of ^{137}Cs areal distribution has been plotted based on the research (Figure 4.13 coloured block).

Concentrations vary within the range 1 ÷ 75 Bq/kg at average value 17 Bq/kg; at that, number of points with maximal concentrations (>60 Bq/kg) constitutes less than 0.8% of the total number. This pattern can be explained by natural redistribution of this radionuclide. The histogram at Figure 4.14 shows the distribution of the number of samples with specified concentrations which is close to lognormal distribution.

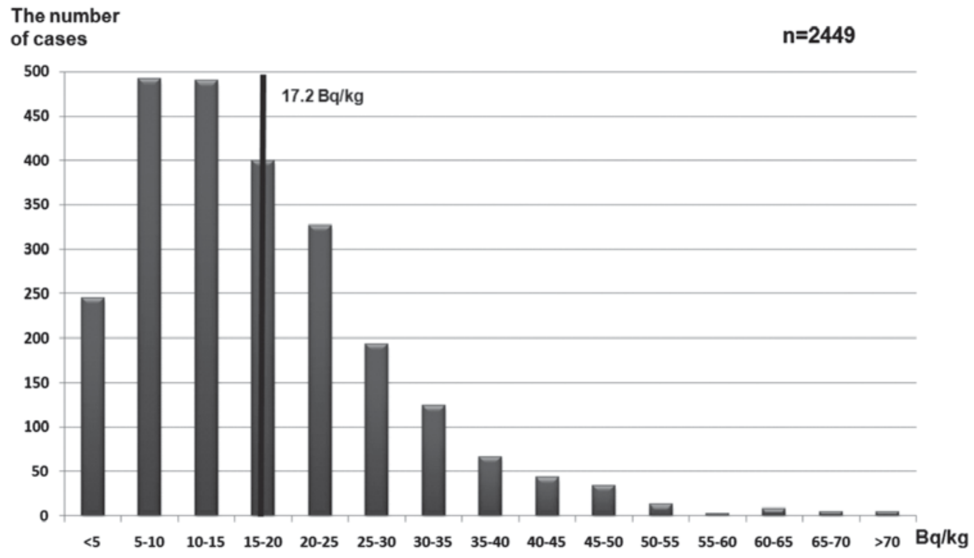


Figure 4.14. Distribution of ^{137}Cs values concentrations in soils

The range of concentrations for main radionuclides due to global fallout in the northern hemisphere is presented in table 18 (section 2.2). according to this table, in our case average ^{137}Cs concentration does not exceed maximal values for the global fallout background for this radionuclide

Contamination of the investigated lands with ^{241}Am

A map of ^{241}Am areal distribution has been plotted based on our research (Figure 4.15 coloured block).

Assessment of average for the investigated land concentration of ^{241}Am represents a problematic task since in the majority of samples ^{241}Am was below determination threshold (minimal registered activity) of the methods and instruments used (about 40% of all measurements). Still, withdrawal of these results would lead to a considerably higher number. That is why in the evaluation of ^{241}Am average concentration in such cases we accepted the concentrations to be equal to the determination threshold. Also, we excluded a set of non-quantitative data with determination threshold of more than 1.8 Bq/kg). So, presented "average" concentration of ^{241}Am is actually an upper possible value and comprised 0.8 Bq/kg based on 2,300 individual data (Figure 4.16).

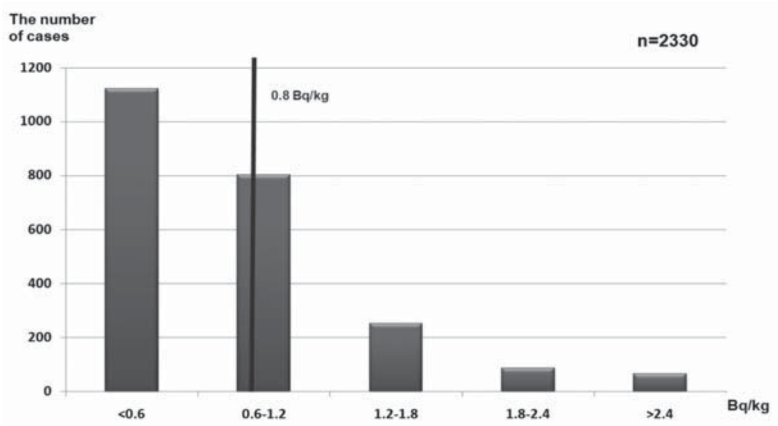


Figure 4.16. Distribution of ^{241}Am values concentrations in soils

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

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

A dependence diagram of $^{239+240}$Pu on ^{241}Am (Figure 4.17) has been plotted as a result of our research. In order to determine the ratio $^{239+240}$Pu / ^{241}Am, soil samples were prepared following a special procedure with several bucking stages each controlled by evaluation of ^{241}Am content in aliquot samples. Concentrations of ^{241}Am were determined as average over three readings of these samples.

Average ratios $^{239+240}$Pu / ^{241}Am at the intermediate stage was found to be 5.6, what is quite close to the expected value; correlation coefficient comprised 0.76 for the total number of samples – 79. When the number of laboratory results increases the average value was equal to 5.1, that later was used in our calculations of the dose loads.

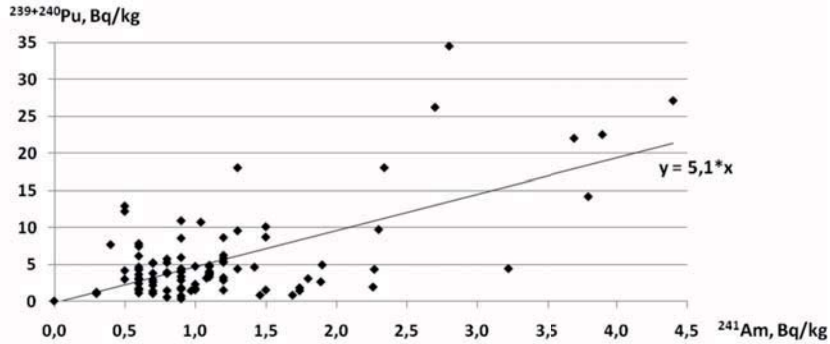


Figure 4.17. Dependence diagram of $^{239+240}$Pu in soils on ^{241}Am concentrations

So, contamination with plutonium isotopes is like contamination with americium; average concentration of $^{239+240}Pu$ comprised 4.1 Bq/kg. Based on the research outcomes, we plotted a map of $^{239+240}Pu$ distribution (Figure 4.18).

Figure 4.18. $^{239+240}Pu$ determined in soils in 2008-2009

As well, ^{238}Pu was determined employing α-spectrometry with preliminary radiochemical extraction. It was found that additive systematic error appears at determination of ^{238}Pu, particularly at low concentrations, and leads to extra 0.14 Bq/kg in the assessment. This error happens due to insufficient separation of natural α-emitting isotopes. The graph for ^{238}Pu / $^{239+240}Pu$ ratio is presented at figure 4.19 below.

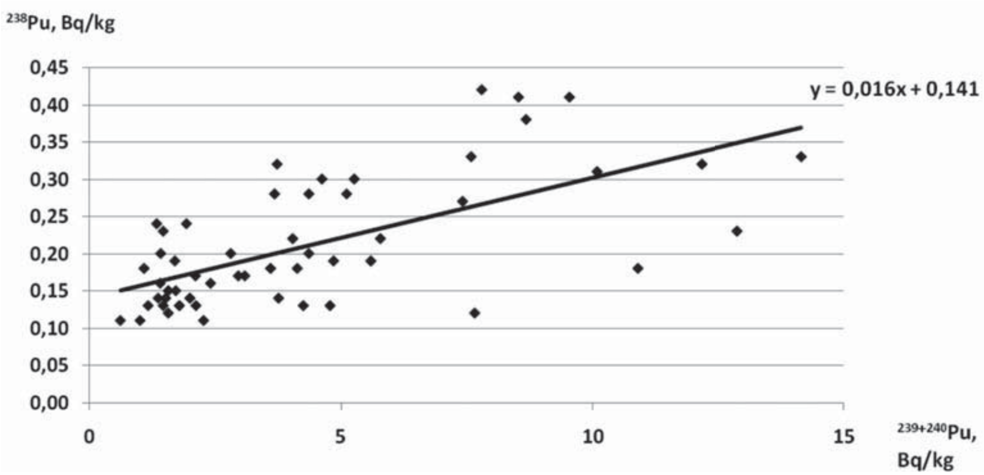


Figure 4.19. ^{238}Pu concentrations dependence in soil on $^{239+240}Pu$ concentration

So, average ratio ^{238}Pu / $^{239+240}Pu$ comprised 0.016, average concentration ^{238}Pu – 0.07 Bq/kg and the value 0.1 Bq/kg was conventionally taken in calculations of the dose loads. The calculated value of ^{241}Pu / $^{239+240}Pu$ ratio equal to 0.75 was taken for ^{241}Pu.

Contamination of the investigated lands with ^{90}Sr

In the assessment of contamination with ^{90}Sr we used the whole set of data accumulated by present time. A map of areal distribution was ^{90}Sr plotted (Figure 4.20 coloured block).

The histogram at Figure 4.21 shows the distribution of the number of samples with specified concentrations of ^{90}Sr.

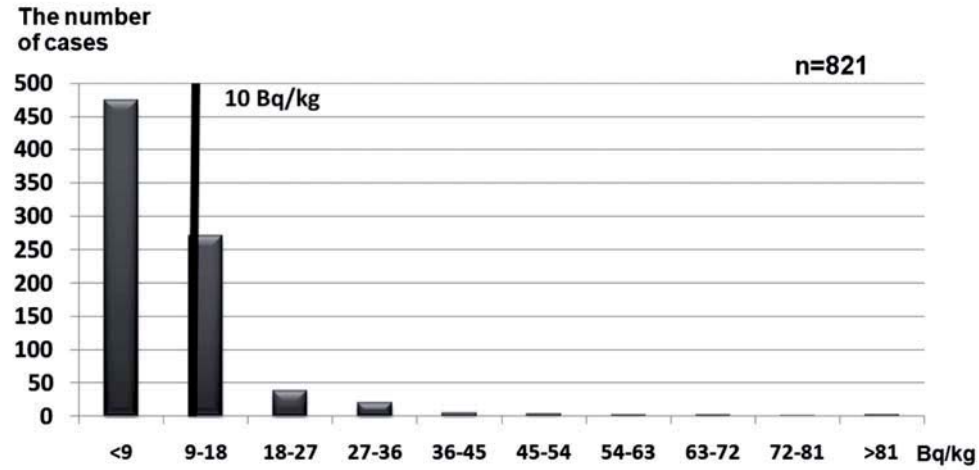


Figure 4.21. Concentration values of ^{90}Sr in soil for two profiles

Different methods were used and the main difference was in sampling depth (0-5, 0-10, 0-15 cm) what represented the main difficulty in our research. So, all results were transformed into a single format of 0-5 cm based on data for ^{90}Sr distribution within in-depth soil profile. Analysis of the whole data on ^{90}Sr distribution within soil profile makes us certain in the assumption that in-depth strontium proliferation into soil should not exceed 15 cm. Such pattern is explained by lack of atmospheric precipitation and boosted evaporation from soil surface. In general, ^{90}Sr distribution over the area is quite even, but one should note that in the vicinity of RW-site "*4a*" there are increased concentrations of this radionuclide.

Average concentration of ^{90}Sr accepted to be 10 Bq/kg according to the table (see section 2.2, Table 2.15) does not exceed the values for global fallouts.

Contamination of the investigated lands with other radionuclides

Concentrations of other radionuclides such as ^{151}Sm, ^{99}Tc, which were not measured but which are quite probable to present, were theoretically assessed based on average concentrations of ^{137}Cs and theoretical correlations between these radioisotopes. The following values were taken for our calculations: ^{151}Sm – 1.4, ^{99}Tc – 0.3 Bq/kg.

Obtained with this method average concentrations of artificial radionuclides at these territories was as in the table below and was later used in further calculations (Table 4.3).

Table 4.3

Average concentration of artificial radionuclides in northern part of the STS

^{137}Cs	^{90}Sr	^{241}Pu	^{238}Pu	^{241}Am	$^{239+240}$Pu	^{99}Tc	^{151}Sm
17.2	10	3.1	0.1	0.8	4.1	0.3	1.4

4.2.3 Zonation of the lands based on areal distribution of radionuclides

In order to reveal possible zones with artificial radionuclides of increased concentrations over average levels for these areas we plotted ^{137}Cs and ^{241}Am concentration curves along the profiles.

Then, data along the profiles perpendicular to expected traces from radioactive fallouts (Figure 4.22 coloured block) were selected and ^{137}Cs, ^{241}Am specific activity distributions were made for each profile (Annex C).

For example, figures 4.23 and 4.24 below present two typical profiles for ^{137}Cs and ^{241}Am.

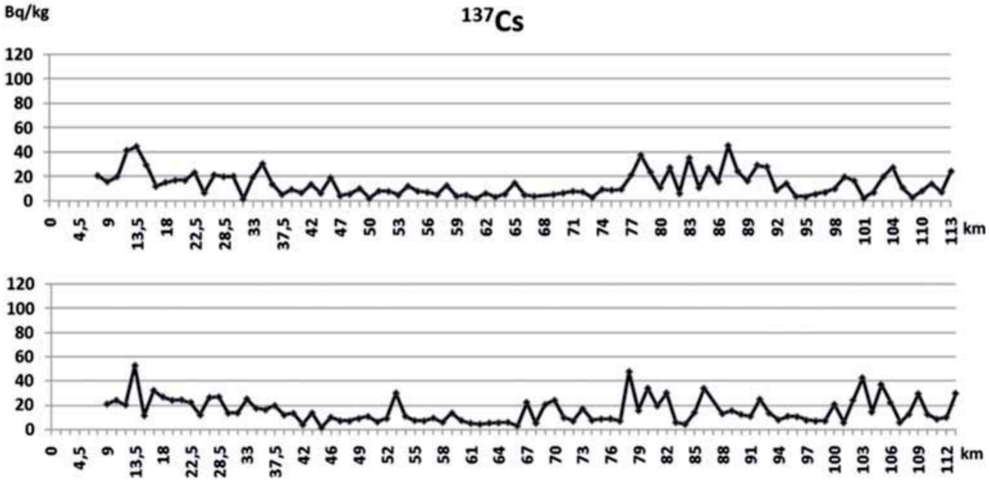


Figure 4.23. Concentration values of ^{137}Cs in soil for two profiles

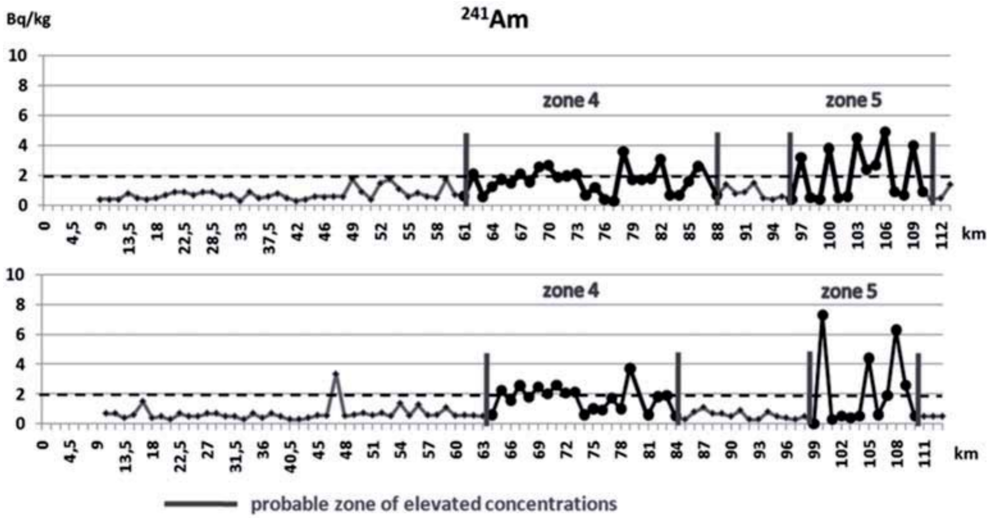


Figure 4.24. Concentration values of ^{241}Am in soil for two profiles

Distribution pattern of ^{137}Cs did not reveal any significant regularity. The values of ^{137}Cs concentrations exceeding the average ones for 2-3 times can be stipulated by natural redistribution of this radionuclide.

At the same time, ^{241}Am distribution did show several zones with increased concentrations (Figure 4.25 coloured block). Outlining these zones we took into consideration the correspondence of the increased values zone to the zone of possible fallout from radioactive clouds known from previous studies (see section 2.1.1).

So, total 6 zones were identified with the following average concentrations of ^{241}Am: zone 1 – 1.2 Bq/kg; zone 2 – 1.5 Bq/kg; zone 3 – 1.2 Bq/kg; zone 4 – 1.5 Bq/kg; zone 5 – 2 Bq/kg; zone 6 – 1.6 Bq/kg.

Zone 5 is the most evident one located in the south of the Eastern part of the studied lands,; the less evident – zone 3 in the middle of the Central part.

At that, average concentrations of ^{241}Am within the specified contours do not exceed 2 Bq/kg.

So, the following concentrations of transuranium elements (determined as increased 1.5 times average concentration in the most contaminated zone) will be used in further calculations of the dose loads (Table 4.4).

Table 4.4

Accepted concentrations of artificial radionuclides in the area of higher contents of transuranium elements in soil

^{241}Pu	^{238}Pu	^{241}Am	$^{239+240}$Pu
11.6	0.35	3.7	15.4

4.3 Condition of soils

4.3.1 Types of soils contamination with artificial radionuclides

Contamination of the soil surficial horizon with radionuclides ^{137}Cs and ^{90}Sr within the studied part of STS has been mainly registered at the level of 10-20 Bq/kg (Section 4.2.2). Several surveying points, where the ^{137}Cs content exceeds 15-20 Bq/kg, were found in some wintering areas. In single points, the levels of ^{137}Cs and ^{90}Sr reach 15-20 Bq/kg and higher. So, high concentrations of radionuclides have been registered near the south boundary of the site, and these areas are referred to the ground *"4a"* impact zone (radiological weapons-ground). The highest ^{241}Am contents have been detected nearby the southern boundary of the eastern part of the studied lands reaching 5.0-8.5 Bq/kg in some points, while the average value remains at the level of 1.0 Bq/kg.

Distribution of artificial radionuclides in soils of the STS northern part hardly depends on the relief, type or sub-type of soil. Detailed study of radionuclides required us to choose the points of highest activity within soil profile taking into consideration the necessity of obtaining the characteristic features of various soil types.

Distribution of artificial radionuclides within soil profile. In order to survey the distribution of radioactive contaminants at soil surface due to fallouts after nuclear explosions at the test sites, fourteen small trenches (Figure 4.26 coloured block) were made at the profile depth within the studied area. So, there various types and sub-types of soils characteristic for the surveyed area were covered, including zonal chestnut and light-chestnut soils, as well as azonal solonchak and saline lands.

Eight of the fourteen small trenches are located in the areas of zonal soils, developed on the hill slopes, and water parting flat lands. The soils, in general, are developing or underdeveloped, with not more than 40-60 cm of poorly-consolidated sediments and a sub-layer of solid rocks or their weathering crust. Zonal soils are formed in moisture conditions by the atmospheric precipitation only. Azonal soils, unlike the zonal ones, develop in topographic low areas and get the extra moistening through the slope flow. They are characterized by the increased number of fine particles in the soil, what leads to the formation of a compacted illuvial horizon (B-horizon) common for alkaline soils. Extra moistening combined with close groundwater table in the subsoil, readily soluble salts can accumulate in the soil body, particularly, in the surficial soils forming saline soil types. Fluffy consistency of surficial soils may be considered as the most specific morphological feature. Four and two small trenches were laid in alkaline and saline lands, respectively, in order to describe the azonal soils.

We did sampling of data on soil types, including zonal (chestnut and light chestnut), alkaline and saline soils. Distribution of ^{137}Cs, ^{241}Am and $^{239+240}Pu$ radionuclides in upper layers (0-2, 2-5, 5-10 and 10-15 cm) of these soils is presented in Table 4.5.

Table 4.5

Contents of artificial radionuclides in top soil of small trenches made in the northern part of STS

Trench №	Sampling Depth, cm	^{241}Am, Bq/kg	^{137}Cs, Bq/kg	$^{239+240}$Pu, Bq/kg
1 Ск	0-2	1.0 ± 0.3	40.2 ± 1.3	3.7 ± 0.3
	2-5	< 0.4	11.8 ± 0.5	1.8± 0.3
	5-10	1.8± 0.2	3.2 ± 0.3	< 0.2
	10-15	1.4± 0.2	1.5 ± 0.3	< 0.4
2 К$_2^\wedge$	0-2	2.8 ± 0.3	55.5 ± 1.5	18.2 ± 0.5
	2-5	< 0.5	3.7 ± 0.6	1.5 ± 0.2
	5-10	< 0.4	< 0.3	< 0.2
	10-15	1.8 ± 0.2	1.4 ± 0.2	1.7 ± 0.1
3 К$_2^\wedge$	0-2	1.3 ± 0.3	43.9 ± 1.4	7.4 ± 0.3
	2-5	0.8 ± 0.2	19.2 ± 0.9	6.3 ± 0.4
	5-10	< 0.2	3.2 ± 0.3	0.4 ± 0.1
	10-15	< 0.3	1.0 ± 0.2	< 0.3
4 Сн	0-2	< 0.4	0.9 ± 0.4	<0.2
	2-5	0.7 ± 0.3	< 0.6	<0.3
	5-10	< 0.3	5.5 ± 0.4	0.9 ± 0.1
	10-15	1.6 ± 0.3	38.4 ± 0.8	5.6 ± 0.4
5 К$_1$	0-2	< 0.4	8.9 ± 0.7	1.6 ± 0.2
	2-5	3.4 ± 0.2	19.7 ± 0.6	19.8 ± 1.0
	5-10	1.6 ± 0.2	2.0 ± 0.3	< 0.2
	10-15	1.8 ± 0.2	1.0 ± 0.2	< 0.3
6 Сн	0-2	8.6 ± 0.5	55.0 ± 1.6	33.3 ± 1.1
	2-5	1.2 ± 0.1	22.0 ± 0.4	8.0 ± 0.5
	5-10	< 0.4	1.0 ± 0.2	< 0.2
	10-15	< 0.4	< 0.2	< 0.2
7 Сн	0-2	3.0 ± 0.3	30.3 ± 1.2	19.6 ± 0.5
	2-5	< 0.3	2.2 ± 0.2	1.2 ± 0.3
	5-10	< 0.3	< 0.3	< 0.2
	10-15	< 0.4	< 0.6	< 0.1
8 К$_2^\wedge$	0-2	3.6 ± 0.3	33.8 ± 0.8	23.6 ± 0.7
	2-5	3.3 ± 0.3	7.8 ± 0.7	34.3 ± 1.2
	5-10	0.5 ± 0.3	2.2 ± 0.5	1.1 ± 0.2
	10-15	< 0.4	1.0 ± 0.4	0.8 ± 0.1
9 К$_2^\wedge$	0-2	2.1 ± 0.2	51.8 ± 1.0	23.5 ± 0.7
	2-5	0.5 ± 0.3	15.8 ± 0.9	5.4 ± 0.6
	5-10	1.3 ± 0.2	1.8 ± 0.3	< 0.2
	10-15	1.8 ± 0.2	0.4 ± 0.2	< 0.2

Trench №	Sampling Depth, cm	^{241}Am, Bq/kg	^{137}Cs, Bq/kg	$^{239+240}$Pu, Bq/kg
10 Сн	0-2	< 0.4	16.2 ± 0.6	1.8 ± 0.2
	2-5	< 0.4	2.0 ± 0.5	<0.4
	5-10	< 0.4	2.2 ± 0.5	< 0.1
	10-15	< 0.4	< 0.6	< 0.1
11 $К_2^{\wedge}$	0-2	2.2 ± 0.3	63.2 ± 1.6	10.4 ± 0.6
	2-5	< 0.3	3.5 ± 0.3	0.7 ± 0.2
	5-10	< 0.4	< 0.4	< 0.1
	10-15	< 0.5	< 0.4	< 0.1
12 $К_2^{\wedge}$	0-2	1.7 ± 0.2	34.0 ± 0.8	8.2 ± 0.5
	2-5	0.5 ± 0.3	9.7 ± 0.8	2.2 ± 0.3
	5-10	< 0.4	2.5 ± 0.3	< 0.2
	10-15	0.4 ± 0.2	1.2 ± 0.2	0.2 ± 0.1
13 Ск	0-2	< 0.3	12.2 ± 0.5	0.9 ± 0.2
	2-5	< 0.4	4.6 ± 0.3	< 0.3
	5-10	2.0 ± 0.2	1.8 ± 0.3	< 0.1
	10-15	< 0.4	1.9 ± 0.3	< 0.2
14 $К_2^{\wedge}$	0-2	1.6 ± 0.3	54.1 ± 1.0	5.3 ± 0.3
	2-5	< 0.4	3.3 ± 0.3	<0.5
	5-10	< 0.5	0.9 ± 0.2	< 0.1
	10-15	< 0.5	0.4 ± 0.2	< 0.1

Note: $К_2^{\wedge}$ - brown, rubble; $К_1$ - light-brown; Сн – solonetzic soils; Ск – saline soil

The Table data demonstrates that the ^{137}Cs and $^{239+240}$Pu distribution in zonal soils basically agrees with the common mechanism when maximal concentration is associated with upper soil, while its value rapidly decreases down the depth. Behavior of ^{137}Cs and $^{239+240}$Pu in alkaline soils is sometimes quite different: so, their maximal concentration in the small trench 4 was registered at the depth 10-15 cm. This fact could be explained by presence of surface cracks in loamy soil which allow radionuclides migrate to subjacent layers through water that stays long in topographic lows. The behavior of ^{137}Cs and $^{239+240}$Pu in saline soils is in line with the common regularities.

Since the level of radioactive contamination for these soils was quite low, the data, based on which a conclusion on the ^{90}Sr in-depth distribution could be made, have not been obtained. But, assessment of this radionuclide distribution is still possible using the earlier gathered data on the ground *"4a"* in immediate vicinity of the studied area. According to those data, the ^{90}Sr distribution is governed by the common mechanism, when contents of radionuclides reach the highest level in the uppermost soil layers and gradually decrease with depth.

Percentage of ^{137}Cs, ^{241}Am and $^{239+240}$Pu contents in a layer against their total amount in soil profile is presented in bar charts (Figures 4.27 – 4.29). When values were below some detection limit, maximal possible contents were taken for calculations, i.e. those detection limits.

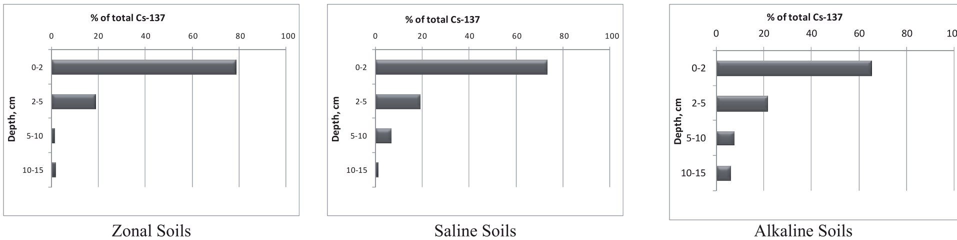


Figure 4.27. Distribution of ^{137}Cs radionuclide in soil

One can see from the Figure 4.27 that the main ^{137}Cs concentration (60-80%) was registered in the upper layer, represented by the superficial crust. The values slump down the cross-section. Due to the fluffy consistency of surficial soils, considerable amounts of ^{137}Cs (8-10%) can reach the depth of 15 cm in saline soils only.

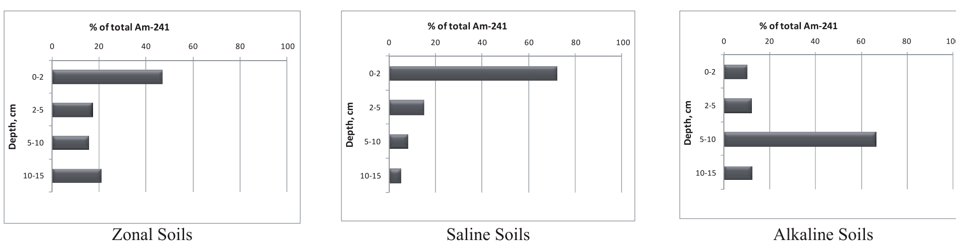


Figure 4.28. Distribution of ^{241}Am radionuclide in soil

Figure 4.28 demonstrates that the maximum concentration of ^{241}Am radionuclide is not always limited to the topsoil interval of 0-2 cm, and a continuous decline of concentration deeper in soil has not been observed at all, which is typical for ^{137}Cs. The maximal ^{241}Am content in the 5-10 cm saline soil interval corresponds to 65% of the total americium amount in the soil profile.

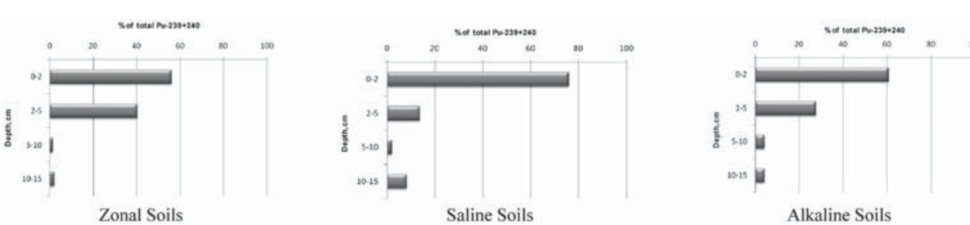


Figure 4.29. Distribution of $^{239+240}$Pu radionuclide in soil

One can see from Figure 4.29 that $^{239+240}$Pu distribution in soil is similar to the ^{137}Cs depthwise distribution. In most instances, the highest concentration in surficial layers of all soil types is typical for the $^{239+240}$Pu.

Forms of artificial radionuclides presence in soil. Determination of the radionuclides presence forms ratios in soils is of great practical importance for environmental assessment of the area and for the forecasting of radionuclide transfer into vegetation. The proportion of certain artificial radionuclides composite forms should be studied as a unified system, which may help to work out an integral estimate of the radionuclide mobility in the soil. A traditional approach to the determination of mobility characteristics and bioavailability of radioactive contaminants in the soil includes the application of consequential extraction methods. The applied methods are based on the successive usage of gradually more aggressive chemicals, which individually are expected to leach out a part of the contaminant, tied with specific soil components. Selectivity and reproducibility of chemical extraction procedures vary depending on extracting agent type and characteristics of a subject of research – so, due attention should be paid to ensure a reliable qualitative judgment of bioavailability.

In evaluation of the degree and mechanisms of radionuclides presence,the standard methods select of the great variety the following radionuclide forms, including: water-soluble, exchange, mobile, nonexchangeable (immobile) and the well-bonded ones. The water-soluble (water-extractable) and exchange (1M acetic ammonium solution extractable) forms are referred to forms easy available for plants. The mobile radionuclide forms, 1M HCl-extractable, can be absorbed by plants only partially, but represent their potential accessible reserve. Fixed radionuclide forms can be released just on treatment with 6M HCI solution. Similar to the well-bound forms they are unavailable for plants.

A provisional estimate of the radionuclide presence forms proportion in the studied soils can be made based on the ^{137}Cs, ^{90}Sr and $^{239+240}$Pu integrated data available, as well as on the proxy ^{241}Am data obtained in different STS areas (areas were surface, subsurface and excavation explosion had been performed). Taking into consideration physical and chemical properties of radionuclides, types and characteristics of soils and the local conditions, it was assumed that the proportion of radionuclide occurrence forms in the studied soils should coincide with the existing consolidated findings, allowing for an admissible variation. The average proportion values of radionuclide presence forms and their ranges are indicated in the following diagrams (Figure 4.30):

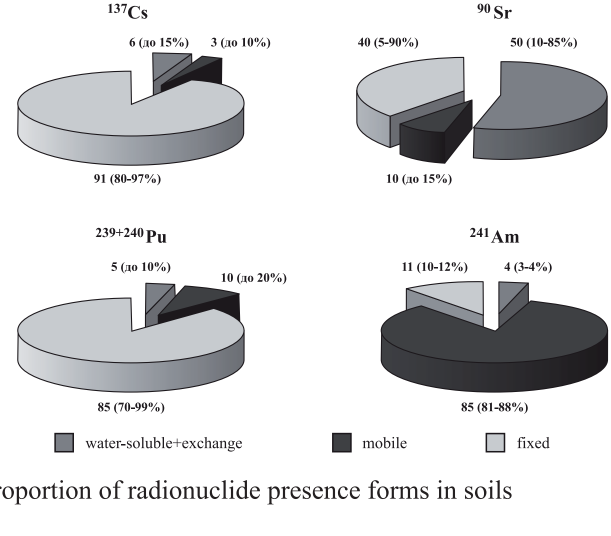


Figure 4.30. Proportion of radionuclide presence forms in soils

The presented consolidated data on the proportion of ^{137}Cs and ^{90}Sr presence forms based on the results of ecosystem soil surveys accomplished in vicinity of adits No.176 and 177 (Degelen range), show that ^{137}Cs occurs mainly in the fixed form, while the ^{90}Sr – in the exchange form. The $^{239+240}Pu$ presence forms data were obtained through the radioactive contamination study accomplished in areas of the *Opytnoye pole* site and the Shagan Lake. One can see that the fixed form of radionuclides is dominant for the soils in the region. According to the preliminary ^{241}Am presence forms data gathered in the process of investigation of the soil ecosystems in the area of adit No.177 located within the *Degelen* test site, it can be expected that the majority of radionuclides occur in the mobile and well-bound forms.

In order to evaluate soil contamination with artificial radionuclides in the northern part of STS, the presence forms proportion study was conducted for that area. Ten testing contours were allocated in areas of maximal contamination. A sampling points plan is represented in figure 4.26, coloured block. The sampling was performed in selected points to a depth of 0-3 cm and covered the total area of 600 sq.cm. Soil samples of 2500 g each, on an average, were dried-up until air-dry condition, mashed in a porcelain jar, cleared out of stones, roots and other inclusions and then bolted through a 1 mm screen. To determine radionuclide presence forms, 100 g weighs were taken from the initial samples by quartering. Assuming that contents of water-soluble and fixed (6M HCI solution extractable) forms in the investigated soils do not differ fundamentally from the global levels, it was decided to perform leaching in accordance with a reduced plan, selecting only the exchange, mobile and well-bound forms, which, in general, characterize by their content the readily accessible (available), potentially-available and unavailable for plants forms. A 1M acetate-ammonium buffer extensively exploited in the sequential fractionating practice was used as an extractive agent of the exchange form. The mobile form was extracted through the soil treatment with 1M HCI solution. The soil – leaching solution ratio was maintained at the level of 1:5 through all test stages. The well-bound form was separated directly from the soil remained after the leaching. The ^{137}Cs and ^{241}Am content in soil samples and extracts was determined employing instrumental gamma-spectrometry.

Data on presence forms for the radionuclides ^{241}Am, ^{137}Cs, $^{239+240}Pu$ and ^{90}Sr are available in Tables 4.6-4.9 in terms of radionuclide specific activity per 1 kg of soil.

Table 4.6

Specific activity values for ^{241}Am in various drawings

Sample No.	Exchange Form, Bq/kg	Mobile Form, Bq/kg	Well-Bound Form, Bq/kg
1	<1.9	4.8±1.4	<0.5
2	<1.8	<2.2	<0.6
3	<1.9	4.6±1.5	<0.6
4	<2.0	<1.9	<0.5
5	<1.7	<4.3	1.9±0.4

Sample No.	Exchange Form, Bq/kg	Mobile Form, Bq/kg	Well-Bound Form, Bq/kg
6	<2.7	<2.2	<0.7
7	<1.7	<2.5	<0.5
8	<2.3	<3.1	2.5±0.4
9	<1.8	<1.7	<0.4
10	<2.7	6.5±1.4	<0.5

Table 4.7

Specific activity values for ^{137}Cs in various drawings

Sample No.	Exchange Form, Bq/kg	Mobile Form, Bq/kg	Well-Bound Form, Bq/kg
1	<6.0	<5.5	50.2±1.8
2	<5.5	<5.5	23.3±1.2
3	<5.5	<5.0	23.0±1.3
4	<6.0	<4.5	19.6±1.3
5	21.5±4.0	<5.5	45.1±1.7
6	<5.0	<5.0	13.5±1.0
7	<5.0	<6.0	18.4±1.2
8	<5.5	<5.0	26.0±1.3
9	<5.5	<4.5	17.2±1.1
10	<6.0	<5.5	20.0±1.3

Table 4.8

Specific activity values for $^{239+240}$Pu in various drawings

Sample No.	Exchange Form, Bq/kg	Mobile Form, Bq/kg	Well-Bound Form, Bq/kg
1	<0.1	<0.1	2.5 ± 0.3
2	<0.1	0.5±0.1	6.9 ± 0.4
3	<0.1	0.3±0.1	2.3 ± 0.3
4	<0.1	0.3±0.1	1.1 ± 0.2
5	<0.2	<0.2	19.6 ± 0.8
6	<0.1	<0.2	2.0 ± 0.2
7	<0.2	0.4±0.1	7.0 ± 0.3
8	<0.1	0.4±0.1	20.2 ± 0.7
9	<0.1	<0.2	3.2 ± 0.3
10	<0.2	0.7±0.1	8.9 ± 0.4

Table 4.9

Specific activity values for ^{90}Sr in various drawings

Sample No.	Exchange Form, Bq/kg	Mobile Form, Bq/kg	Well-Bound Form, Bq/kg
1	31.5±3.0	<15.0	2.5 ± 0.7
2	34.0±3.0	<8.0	< 1.9
3	290.0±6.5	76.5±5.0	3.2 ± 0.9
4	31.0±3.5	<10.0	< 2.1
5	40.0±4.5	16.5±4.5	< 2.5
6	25.5±3.0	<9.0	< 1.7
7	22.0±3.5	11.5±4.5	< 2.4
8	30.0±3.5	<9.5	< 1.7
9	24.5±3.0	<5.5	< 1.4
10	26.5±3.5	<8.0	< 1.4

Since the studied soils have low level of radioactive contamination, in many instances the numeric data on specific activity of radionuclides in drawing-out have not been obtained.

The ^{137}Cs presence forms relation data show that in all cases a considerable amount of ^{137}Cs occurs in the well-bound form. At that, significant exchange form, in addition to the major well-bound form, has been observed as a single event.

Data of $^{239+240}Pu$ forms specific activity for all 10 cases show that the majority of radionuclides exist in the well-bound form. The mobile form is less significant in case of $^{239+240}Pu$.

The analysis of radionuclide ^{90}Sr occurrence forms balance speaks for the predomination of exchange forms. The mobile form content is considerably lower, while the well-bound form is the least in proportion.

The results of qualitative assessment of soil contamination with ^{241}Am, ^{137}Cs, $^{239+240}Pu$ and ^{90}Sr at the studied area agree with the integrated data on other STS areas and can be used in forecasts of the radioactive contamination level dynamics for the investigated lands.

Radionuclides distribution in granulometric fractions of soil.

A study of the artificial radionuclides distribution in granulometric fractions of soil allows assessing contribution of soil in the atmospheric pollution through the dusting with wind and forecasting of a secondary redistribution of radionuclides with horizontal migration due to wind erosion.

At a moderate wind velocities (v = 2-3 m/sec), dependent on the ordinary weather typical for middle latitude regions, the finest radioactive dust particles levitate from the surface due to stochastic breakthrough of turbulent vortexes to the ground surface. At the mentioned wind velocity, the dust does not settle down under the action of gravity since such dust particle have sizes of hundredths and tenths of a micrometer never exceeding 1-2 µm. At short-term winds with velocities 10 to 12 m/sec, which is occasional for this region, the size of levitating dust particles may reach 100 µm. At the same time, large particles with diameters of about 500 µm and more can just roll over, while fractions of more than 1 mm in size remain immobile. Fine dust particles of up to 100 µm in diameter are therefore of the primary concern in the assessment of radionuclides ingress from the soil surface to atmosphere.

In order to investigate the radionuclides distribution, ten point samples were taken from a depth of 0-3 cm. The sampling layout is represented in Figure 4.26, coloured block. The sampling was performed in areas of maximal radioactive contamination with radionuclides of concern as well as in vicinity of Kurchatov.

Distribution of ^{137}Cs, ^{241}Am, ^{90}Sr and $^{239+240}$Pu radionuclides was studied in soil fractions of 1000-500 µm, 500-250 µm, 250-100 µm and <100 µm segregated by wet screening in water flow. After drying-up until the air-dry condition and weighting radionuclide contents were measured in the segregated soil fractions. Concentrations of ^{137}Cs and ^{241}Am in samples was determined by gamma-spectrometry; $^{239+240}$Pu content was determined employing α-spectrometry with a prior radiochemical extraction, and ^{90}Sr was measured with radiochemical method.

Average values for distribution of ^{137}Cs, ^{241}Am, ^{90}Sr and $^{239+240}$Pu radionuclides within granulometric soil fractions are indicated in Tables 4.10 and 4.11.

It was revealed that in the northern part of STS a large-grain 1000-500 µm fraction is prevalent in the upper 0-3 cm soil, making, in average, 50% of the total weight, while 23% fall on a small-grain (<100 µm) fraction. Contribution of 500-250 µm and 250-100 µm fractions constitute, in average, 11% and 16%, respectively. It is therefore expected that at average wind velocity of 4-6 m/sec, typical for the region under investigation, it is exoected that an insignificant portion of the fine fraction that is able to be raised up from the soil surface will take part in wind-driven transportation that should not affect considerably the radionuclide contamination of the atmosphere.

Table 4.10

^{137}Cs and ^{241}Am distribution in granulometric fractions in the near-surface soil (0-3 cm)

Fraction Size, µm	Percentage of radionuclides in granulometric soil fractions, %						Average fraction content in the soil, %
	^{241}Am			^{137}Cs			
	Range		Average	Range		Average	
	min	max		min	max		
1000-500	6.4	19.5	12.6	10.1	19.9	13.7	50
500-250	7.0	65.8	33.4	17.5	25.2	22.7	11
250-100	11.9	65.0	35.7	22.7	26.9	24.1	16
<100	12.1	29.3	18.3	31.7	44.2	39.5	23

Table 4.11

$^{239+240}Pu$ and ^{90}Sr distribution in granulometric fractions in the near-surface soil (0-3 cm)

Fraction Size, µm	Percentage of radionuclides in granulometric soil fractions, %						Average fraction content in the soil, %
	$^{239+240}Pu$			^{90}Sr			
	Range		Average	Range		Average	
	min	max		min	max		
1000-500	4.9	63.8	22.9	8.0	17.3	12.6	50
500-250	11.7	48.3	22.6	28.1	34.0	31.0	11
250-100	10.3	47.3	24.1	22.5	23.3	22.9	16
<100	11.7	49.8	30.5	26.2	40.6	33.4	23

The presented data show that about 18% of the total ^{241}Am and 40% of the total ^{137}Cs concentrations in the soil are bind within the fine fraction (<100 µm) which can be raised up from the surface by the wind of 10-12 m/sec. On average, 47-69% of the total ^{137}Cs and ^{241}Am contents belong to particles of 100-500 µm in diameter which are the most easy to involve into the soil deflation process. The 500-1000 µm fraction makes 13-14% of the total radionuclides content, which does not seriously contribute to the radionuclides transfer with wind.

Preliminary results of the $^{239+240}Pu$ distribution study and the ^{90}Sr distribution data demonstrate that their contents in the fine fraction (<100 µm) comprises in average 31% and 33% of the total radionuclide contents, respectively. The lowest level of radionuclides was registered in the largest fraction and totaled, on the average, to 14% of ^{90}Sr and 23% of $^{239+240}Pu$. Percentages of $^{239+240}Pu$ and ^{90}Sr in the 100-500 µm fraction, which can hardly be involved in wind transfer of radionuclides, amount to 47% and 53%, respectively.

The data on radionuclides distribution in granulometric soil fractions reveal differences in $^{241}Am/^{239+240}Pu$ ratios for all fractions. So, an equal ratio of $^{241}Am/^{239+240}Pu$ has been registered though all fractions in a sample taken at point 4 with average $^{241}Am/^{239+240}Pu$ ratio of specific activities within each fraction of one sample proved to be equal to 0.3. No relationship between the ^{241}Am and $^{239+240}Pu$ distribution in fractions have been observed in samples taken from points 1, 2, 3, 5, 6 and 7; on the contrary, the distributions are essentially different.

Different nature of the relationship between ^{241}Am and $^{239+240}Pu$ distributions in fractions of soil samples taken from the "northern" areas can be explained by the difference in nature and contamination specifics within the area. Presumably, contamination of zones, where the sampling points 1-3 and 5-7 are located, is of superimposed character. The ^{241}Am and $^{239+240}Pu$ distribution relationship, observed through all fractions within the sample taken from the point 4, one may well explain by the input from one source to the pollution of a zone within which the given point is located.

4.3.2 Soil quality assessment

Natural conditions of the studied area determine the agrochemical characteristics of soils and, as a consequence, usability of the lands. The region is entirely a cattle-breeding one. Broken relief, frequently covered with a thin layer of melkozem soil and extensive broken stone formations, prevent from arable activities on these lands. Slopes of ridgy spurs, as well as high and low bald hills, covered with chestnut and light-chestnut soils, are the most suitable for pastures, as the plant associations, such as the Motleygrass (Artemisia frigid) bunchgrass with shrubs, Artemisia frigid (Festuca sulcata), Stipa tirsa and Stipa- Festuca sulcata, developing on slopes, not only constitute the most valuable livestock feeds in the region [69], but also are the most degradation-resistant.

Meadow chestnut, meadow alkali and saline soils, alkaline and saline soils covered by halophytic vegetation, including Egnatioides, are common for the deluvial-proluvial plains. Such feedings are considered as less valuable for livestock.

The field studies have proved steady degradation of pastures in the North-Western part of the surveyed area, where about 25 wintering stays were stationed over the last ten years. One can observe the ruins and traces of winterings survived from the past. Within recent years the population of many wintering stays was relocated to other districts of the region what is considered as a positive factor. Alongside with overgrazing, the climatic and natural conditions of the region are of significance for that process. The relief irregularity and dehumidified soils under the arid climate conditions predetermine the projective vegetation cover degree within 30-50% only, which, in turn, causes the soil vulnerability, wind erodibility and soil blowing.

Soil deflation contributes to the fast degradation of soil cover. The unlimited and uncontrolled pasturing results in complex recovery of upper soil, its dispersion, decrease of wind-resistance and soil exhaustion. "According to the principle of feedback in a genetically coupled system of the soil-plant natural complex, the wind-eroded soil is unable to provide favorable conditions for effective reproduction of feeds, plant species diversity and to rehabilitate plant associations closer back to their original, virgin conditions, while the sparse vegetation, in turn, cannot contribute to the soil enrichment" [70].

Most obvious is degradation of pastures in a 2-3 km-wide strip along the wintering sites. This area in some places is completely stumbled to baldness with pasturage brought down. Saying "pasture bringing down" we understand degradation of vegetation cover and soil distortion. Upper soil layers are packed what leads to deterioration of their hydro-physical properties, increase in the apparent density, moisture content decrease, thinning of a humus-accumulated horizon, disturbance of structure and blowing-out of fine soil particles. Blow-out of the finest soil fractions results in loss of the humus and fertility of soil. The acreage of land, removed from the agricultural operations due to soil degradation, constitute less than 30% of the total farmland area in the northern STS, which makes it possible to consider this situation as relatively satisfactory [71].

One of the signs of soil wind-erosion is the presence of debris on its surface, which proves that the fine particles have been blown away with the wind. On the other hand, the debris cover on the surface prevents soil from further wind erosion. Soil density at the studied lands, in general, does not exceed the conventional limit of 1.3 g/cm^3 [71], what allows considering the situation as relatively satisfactory one.

So, non-degraded or poorly degraded forage lands with non–eroded soils are prevailing within the studied area. At the same time, watering sites, wintering areas, as well as the cattle terraces may be associated with the moderately degraded lands with some places of highly-degraded pastures and wind-eroded soils. Thereat, the projective vegetation cover rate goes down to 35%, humus horizon (A+B) thickness decreases to 25 cm, while debris layer over the surface reaches 400-500 g per 1m^2 [70].

4.3.3 Forecast for changes in radionuclide contamination in soils

Radionuclide contamination of upper soil within the "northern" part of Semipalatinsk Test Site has occurred as a consequence of fallouts from radioactive clouds, formed in the process of nuclear tests performed at testing grounds of *Opytnoye Pole* site. There are some insignificant amounts of ^{137}Cs, ^{90}Sr and $^{239+240}$Pu radionuclides registered in the surficial soil horizons. Thus, the ^{137}Cs and ^{90}Sr concentrations rarely exceed 15-20 Bq/kg, while the $^{239+240}$Pu level reaches 10 Bq/kg. According to the data in 4.3.1, the radionuclide content in the soil declines with the depth, while the maximal concentration, as a rule, is observed in the top layer.

So, in spite of the long time (50-60 years) passed after atmospheric nuclear tests, the maximum in concentration of radionuclide fallout at the soil surface, mainly, remains in the upper soil, and their proliferation deeper into the soil is still limited with the upper 15-20 cm. Such behavior of radionuclides is determined by the high moisture deficit (annual precipitation rate of about 200-250 mm) what prevents the radionuclides migration with solutions or water flows to the lower horizons. On the other hand, the volume of evaporating moisture is 4-5 times greater than the precipitation one what leads to accumulation of soluble salts, including soluble forms of radionuclides, in the upper soil layers. Based on these, one can reasonably predict that distribution of radionuclides in the future would remain similar, but radionuclides content in the upper soil will decrease with some deeper proliferation since, in spite of the moisture deficit, redistribution of substances and elements in soils is ongoing on a geological time scale. It can be assumed that, as long as the artificial radionuclides reached down 15 cm through the soil in 50 years, their further penetration rate will remain virtually the same, i.e. some 0.3 cm per year. The radionuclide proliferation rate may decrease as soon as they reached dense rocks, which may happen in developing and underdeveloped soils prevailing in the surveyed area.

Eolation, as the key relief-forming factor, will still contribute to the spatial redistribution of radionuclides under the continental region development conditions. For example, almost 30% of the artificial radionuclides can be suspended in the surface layer associated with < 100 μm dust particles and may be drifted far away with tornado storms and strong winds since wind velocities there can reach 10 m/s and more. Dust particles of 100 to 500 μm prevail in dust storms most frequent in spring and autumn. About a half of all radionuclides is associated with dust particles. Hence, that amount of radionuclides can, even very seldom, participate in the "spatial relocation". Soil particles of 500 μm in size can be moved to short distances by trailing (sliding) over the surface or intermittently by force of turbulent processes and winds of 10-12 m/s and more. In summary, the eolian erosion processes may decrease the radionuclides content in the epipedon and blur the previous boundaries of radioactive fallouts.

4.4 Condition of waters

General Description of Waters in the Studied Territories

A survey of water objects located in the area of interest has been conducted within the framework of this program. Water objects of the studied territories are represented by both surface and ground waters. Surface water is mainly represented by saline lakes, while ground water (pits and wells) was considered as potential source for drinking and technical water.

4.4.1 Assessment of water quality based on general chemical characteristics

Water bodies that potentially constitute drinking and industrial use water facilities have been monitored in the course of this program in 2008-2009. Since cattle breeding is the main economic activity in the northern region, utilization of ground and surface water for stock watering is of great importance. Surface water within the survey area is represented by saline and high-salt-water lakes and, normally, cannot be used for stock watering. Wells or pits have been arranged for drinking and industrial needs in livestock breeding areas. Hereafter they will be referred to as the water use facilities. The appropriate research, including the identification and inventory (assessment) of water bodies, as well as the laboratory chemical and radionuclide water analyses was performed in order to evaluate the usability of water facilities for drinking and industrial purposes.

It should be noted that currently there are no officially registered water use facilities in the STS area. Therefore, identification and inventory (assessment) of water bodies implied preliminary studying of detailed local maps with outlining all existing water bodies, including temporary surface watercourses, lakes, as well as domestic livestock breeding zones. After that, we conducted further ground investigations of these objects.

Additionally, a route survey was carried out to delineate the surface-stream flows as a result of which ten small lakes have been disclosed and examined in the course of the survey. Herewith, no any surface watercourses have been found during the survey, conducted in July 2009. At the same time, more than 100 water facilities, including the water supply wells and pits, were identified in the "Northern" zone.

Laboratory analyses of water samples were conducted for the preliminary assessment of water quality in the water use facilities, situated in the "northern" zones of STS, in order to determine the following characteristics: content of chlorides and sulfates, total hardness, total water salinity (salt content). Besides, works were done to determine basic elements, such as natrium, potassium (kalium), calcium, strontium, barium, cesium, molybdenum, zinc and beryllium.

By the salt content (according to Vernadsky's classification) those waters with 1,000 mg/dm^3 of salt are referred to fresh (soft) waters, 1,000-10,000 mg/dm^3 - to saltish water, 10,000-50,000 mg/dm^3 - to salt water, and water with salt concentration reaching 50,000 mg/dm^3 and more is associated with salt brines.

Figure 4.31 coloured block represents a map of ground water of various salt contents. Analyses of water samples revealed that their major part (57.9 %) belongs to saltish water (1,020 – 9,700 mg/dm^3), and the lesser part (38.6 %) to fresh (soft) water (up to 1,000 mg/dm^3). An inconsiderable part of the investigated samples, taken from a lake in the northern part of STS, falls into the category of salt water (up to 13,200 mg/dm^3) and the brines (53,600 mg/dm^3). According to the Sanitary Rules and Norms (SanPiN), the total potable water salinity level shall not exceed 1,000 mg/dm^3.

By its anion content water is mostly associated with the hydrocarbonate-chloride-sulfate, hydrocarbonate-sulfate-chloride and sulfate-chloride-hydrocarbonate types of water. Chloride content varies from 53 to 29,000 mg/dm^3. Figure 4.32 coloured block demonstrates the chloride ion areal distribution pattern (areal behavior) in ground water.

Based on these data, one can notice that water of higher chloride contents and maximum salinity level is predominant, mainly, in the south-eastern part of the surveyed site. This fact is related to the presence of a ground water recharge area in the western part of the site, where, as a rule, more fresh (soft) water occurs.

The sulfates content in ground water ranges from 17 to 6200 mg/dm^3 (Figure 4.33 coloured block). By contents of sulfates and chlorides (up to 500 mg/dm^3 and 350 mg/dm^3, accordingly) 63.2 % of water correspond to the Sanitary Regulations and Norms (SanPiN). The hydrocarbonates content varies from 100 to 4,400 mg/ dm^3. By its cationic structure the studied waters can mainly be referred to the sodium-calcium-magnesium ones. Total content of sodium and potassium ions makes within 23 and 13,600 mg/dm^3. Calcium level varies from 4 to 1,500 mg/dm^3. Magnesium content fluctuates from 7.3 to 3,400 mg/dm^3.

Areal distribution of various hardness water is represented in Figure 4.34 coloured block. The presented data suggest that 31.6% of water samples tested are associated with soft water (below 4 mg-eq/l), 33.4% – with water of medium hardness (4-8 mg -eq/l), 7% – with hard water (8-12 mg-eq/l), 28% – with water of high hardness (above 12 mg-eq/l). The majority of water objects conform to the Sanitary Rules and Norms (SanPiN) (7 meq/l maximum).

Water pH level varies from 4 to 10 (the average value – 6.5). Almost 60% of studied objects are within the limits established in the Sanitary Rules and Norms (within 6-9 pH units). In addition, some major nutrient and micronutrient elements have been defined in a number of water bodies.

Magnesium. Concentration of magnesium in water taken from pits ranges between 11 mg/l and 74 mg/l, which remain within the maximum allowable limits of 10 mg/l to 85 mg/l (SanPiN), set for this element content in potable water. The exception should be made for the Bajansor well, where the magnesium amount in water reaches almost 300 mg/l, which is three times more than the permissible rates.

Natrium (Sodium). Concentration of sodium in all selected water samples is not more than the permissible level and varies from 2 mg/l to 15 mg/l (the maximum permissible concentration of sodium in potable water is 200 mg/l).

Potassium (Kalium). Potassium concentration in the test water samples ranges between 2 mg/l and 8 mg/l that is within the regulatory limits (up to 12 mg/l).

Calcium. Concentration of calcium in all analyzed water samples does not exceed 130 mg/l, which is less than the allowable norm (up to 140 mg/l).

Strontium. Strontium content in pit water remains within the limits of 0.5 mg/l and 4 mg/l that is not to exceed the allowable limit established for this micronutrient element content in potable water equal to 7 mg/l.

Barium. Barium concentration in all the analyzed water samples is considerably lower than the maximum permissible concentration of 0.1 mg/l and ranges within 0.002 mg/l and 0.05 mg/l.

Cesium. Concentration of cesium in the investigated samples corresponds to the SanPiN requirements for drinking water and does not exceed 0.0005 mg/l.

Zinc. Concentration level of zinc varies from 0.006 mg/l to 0.5 mg/l, which is significantly lower than the set limits for potable water (5 mg/l).

Beryllium. Beryllium concentrations exceeding the permissible level have been detected in two water bodies, viz. in the Bulak pit (0.014 mg/l) and Zhamankuduk pit (0.02 mg/l). The obtained values of beryllium content in water samples excessively overcome the prescribed norms of this minor nutrient element (microelement) concentration in potable water. The maximum permissible concentration (MPC) of beryllium in drinking water is 0.0002 mg/l. Concentration of beryllium in the remaining water samples is less than 0.0005 mg/l. Considering that the sensibility of a method, used for determining the Be content in water samples, is insufficient in this context. We recommend to repeat water bodies testing in order to define the Be content in their water samples.

Therefore, the microelement analysis of water showed that the values of some chemical parameters the concentrations of some elements variously exceed the maximum permissible limits, set for potable water. Especially, we should make a point of the beryllium content. Its concentration in some analyzed water samples is in large excess of the SanPiNs limits established for drinking water. At the same time, it is necessary to emphasize that the above mentioned data is to be considered as some additional information and, therefore, shall not influence the decisions on the lands transfer since these data simply describe natural conditions of those lands.

4.4.2 Contents of natural and artificial radionuclides in surface and ground water of the studied region

Fifty eight water use facilities have been surveyed with the purpose to determine levels of artificial radionuclides contamination in those, situated within the "northern" part of STS. A map with location of the examined facilities, including wells, pits and some water reservoirs, is represented in Figure 4.35 coloured block. Samples of water, taken from all facilities, were tested to identify tritium, ^{137}Cs and ^{90}Sr contents. In addition, concentrations of $^{239+240}Pu$ were determined in some samples. Determination thresholds for instrumentation and methods used comprised for ^{90}Sr and ^{137}Cs 0.02 Bq/l, concentration of tritium – 15 Bq/l and $^{239+240}Pu$ content – 0.001 Bq/l what is 10-1,000 times lower than the maximum permissible concentration limits for these isotopes. None of the studied radionuclides have been found in the investigated water facilities, which allow us to believe that utilization of water from the mentioned facilities is reliably safe for the population.

Two research techniques, such as the direct measurement of water samples and determination after the physical concentration of water samples by evaporation out of large volume were used to study contents of natural radionuclides (NR) in water bodies within the survey area.

Direct measurements were performed immediately after the delivery of samples to the lab. Water samples were placed, without preliminary preparation, into the measuring cell for gamma-ray spectrometry to determine concentrations of ^{40}K, ^{232}Th and ^{226}Ra. The second research technique was applied as follows: a large volume water sample (50-100 liters) was taken from a water body, then it was reduced (boiled down) by evaporation to the size of a measuring cell (50-100 milliliters) and then analyzed for concentrations of major NRs, such as ^{226}Ra, ^{223}Ra, ^{227}Th, ^{234}Th, ^{232}Th, ^{40}K and ^{235}U, using gamma-ray spectrometry. The results are presented in Table 4.12.

Table 4.12

Contents of natural radionuclides in water samples

№	Name of pit / well	NR Specific Activity, Bq/kg		
		^{226}Ra	^{232}Th	^{40}K
1	Arshaly	< 1	< 1	< 15
2	Bolta	< 1	< 6	< 15
3	Zhana-Zharkyn	< 1	< 2	< 15
4	Shanyraz	< 2	< 1	< 10
5	Wintering №1	< 2	< 1	< 10
6	Karabudyr	< 2	< 1	< 15
7	Nygmektora	< 3	< 1	< 10

№	Name of pit / well	NR Specific Activity, Bq/kg		
		^{226}Ra	^{232}Th	^{40}K
8	Balashykan	< 1	< 5	< 15
9	Algabas	< 1	< 1	< 10
10	Bajan Sor	< 1	< 1	< 20
11	Dostyk	< 1	< 1	< 2
12	Tulpar	< 1	< 1	< 10

The analysis suggests that in all instances the contents of natural radionuclides in the test water samples are lower than the quantification limit of techniques and instrumentation used. Unfortunately, the detection limit of instrumentation and methods used for the determination of studied radionuclides is 5-10 times greater than the intervention level specified by the Radiation Safety Norms (NRB-99 doc) for the population. Judging from the worst conditions and assuming that concentrations of natural radionuclides correspond to the upper detection limit of the instrumentation used these concentrations shall be considered allowable for the intake with water by people. Content of ^{40}K nuclide shall be under regulatory control only if potassium (K) isotopes are additionally introduced changing natural proportion of the isotopes.

According to the lab analysis of water samples, concentration of artificial radionuclides intaken by human body is not higher than the Interventional limit and, in general, is far less than the established standards. Specific activities of ^{137}Cs and ^{3}H in all tested water samples are less than detection limits of the instrumentation used and amount to <0.07 Bq/kg (Intervention Level of 11 Bq/kg) and 8 Bq/l (IL=7,700 Bq/kg), respectively. Specific activity of $^{239+240}$Pu in test samples varies from <0.0004 to 0.0045 Bq/kg (IL=0.6 Bq/kg). ^{90}Sr specific activity varies from <0.068 to 0.1 Bq/kg (IL=5 Bq/kg).

Contents of the studied radionuclides in all examined water samples are therefore not in excess of the maximum permissible limits established in NRB-99.

4.4.3 Expected changes in radioactive contamination for surface and ground water

To evaluate proliferation of contaminated ground water from the nuclear test sites to subsurface water of the "northern" areas we shall consider characteristics of radioactive contamination of water within the main STS grounds, major possible pathways of the artificial radionuclides transport with ground water, as well as to conduct an assessment of the migration pathway parameters.

Atmospheric nuclear explosions (ANE)

Opytnoye Pole Ground. The possibility of contaminated ground water entry from the ANE and radiological weapon (RW-site) sites to subsurface water of the "northern" areas is being investigated in the context of potential ingress of artificial radionuclides to ground water from the surface. The results of survey performed at *Opytnoye Pole* suggest that radioactive fallout formed as a consequence of the atmospheric nuclear explosions migrate to the ground sublayers, but not as deep as to reach the ground water table. The Graph below (Figure 4.36 a) demonstrates the vertical mode of artificial radionuclides distribution within the *Opytnoye Pole* ground.

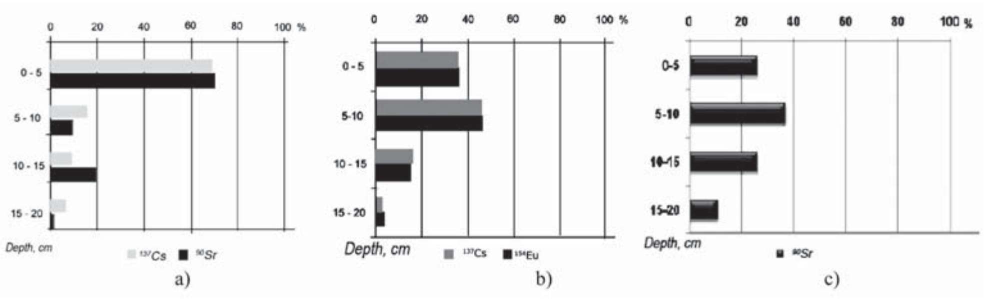


Figure 4.36. In-depth distribution of radionuclides: a) *Opytnoye Pole*; b), c) RW-site

Analyzing the Graph data, one can see that 90% of ^{137}Cs and ^{90}Sr radionuclides are distributed in the upper 10 cm layer of the *Opytnoye Pole* area. However, it should be noted that proliferation of radionuclides to that mentioned depth have taken 60 years at a speed of <0.1 cm/year. According to the estimates, the radionuclide contamination front will reach the ground water depth of 5 m at *Opytnoye Pole* site not earlier than in $5*10^3$ years.

Absence of artificial radionuclides in underground water within the *Opytnoye Pole* was confirmed by drilling of a water well. The well was drilled in 2009 in the northern part of the site, nearby of an estimated surface aqueous runoff area (Figure 4.37 coloured block). A geophysical study for more precise determination of geological and groundwater conditions had been conducted to chose the well location.

Figure 4.38, coloured block shows vertical resistivity profile, based on interpretation of the obtained data. One can see from the Figure that the geological cross-section of the studied northern part of the *Opytnoye Pole* is represented by original rocks (Carboniferous age), characterized by the electrical resistance of 140-185 Ohm. The rocks are overlapped by the interbedded clays and sandy loam mantle (Quarternary period), defined by the electrical resistance of 11-23 Ohm. It was decided to drill wells in the interval between PK 50 and PK 100 with a view to obtain more reliable groundwater data (Figure 4.38 coloured block). The well has accessed ground water in the delluvial-proluvial deposits at a depth of 7 m. The lab analysis showed that values of the artificial radionuclides concentration in the well water samples are below the minimal detectable activity level of instrumentation used.

Thus, the data obtained confirm that proliferation of radioactive fallouts from ANE into the ground water and their further migration to the northern area boundaries are not feasible in the near future.

Radiological weapon sites (RW-sites). The situation with regard to the above process is different within the RW-sites (Figure 4.36 b, c). The graphs demonstrate that 90% of the major gamma-emitting radionuclides, such as ^{154}Eu and ^{137}Cs, occur in the upper 20 cm layer. At the same time, the concentration of ^{90}Sr remains at a quite high level. According to the existing data, the vertical migration of ^{90}Sr to soils within the RW sites area reaches 1 m. In such circumstances we shall not exclude a possibility of the ^{90}Sr proliferation to the ground water. However, if to take the ^{90}Sr indepth migration velocity, which in this case is 2.0 cm/year, as a basis of the estimate calculations, then a possible time of ^{90}Sr transport to the ground water level (5 m) will approximate to 250 years.

Based on the above, we propose to locate a monitoring water well in the immediate vicinity of radioactive contamination sources within the ground *"4a"* in order to control possible ^{90}Sr proliferation to underground water of the site, with due consideration of an eventual rising of underground water.

Underground nuclear explosions (UNE)

Degelen Ground. Degelen mountains generally represent a granite massif of isometric form covering the area of about 200 km^2. Actual elevation of the mountain peaks reaches 1,100 m and overtop the surrounding area by 500 m max. Underground nuclear explosions resulted in a significant rock mass deformation, building-up of multiple zones of crush, collapsed craters and open fissures. As a consequence, the rock permeability has considerably increased, that contributed to the enhancement of downward filtration and partial transfer of the surface-stream flow to underground watercourse. Therefore, a totally new underground water type has been formed in the Degelen rock massif area due to nuclear explosions, which combined the fissure-vein and fracture water flows of the atmospheric precipitation filtration zone. This water type will hereinafter be referred to as adit water.

The radionuclide composition of adit water is formed through the proliferation of atmospheric precipitation and fissure-vein water to zones of irreversible deformation and directly to the explosion cavity. Contaminated water, traveling via the fracture system and the sprung hole (cavity), resupplies the groundwater basin or discharges to the surface in the area of adit entries. General charts of the irreversible deformation zones and filtration flow routs are represented in Figure 4.39, coloured block.

Currently, a radionuclide monitoring is being conducted in adits with continuous outflow (Figure 4.40).

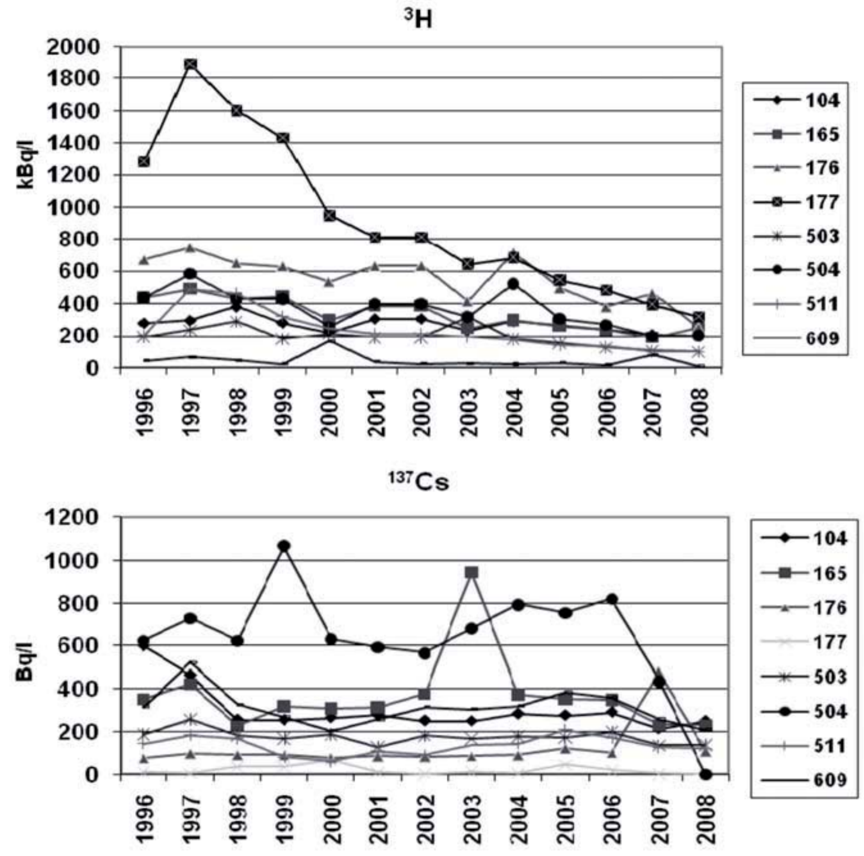


Figure 4.40. Results of ^{3}H and ^{137}Cs monitoring in adit water at *Degelen* ground

Graphs of radionuclide monitoring in adit water show the highest specific activity of tritium maintained the same in the adit № 177 through the entire monitoring period. Its maximum concentration, equal to 1,900 kBq/l, was registered in 1997. Similar situation has been observed with regard to ^{137}Cs, which the top specific activity of 1,100 Bq/l was registered in the adit № 504 in 1999.

The adit water monitoring data confirm that the process of radioactive contamination of ground water within the *Degelen* massif area is still ongoing and is relatively stable.

Groundwater studies were accomplished within the *Degelen* rock massif area in different years with the purpose of determining the radioactive contamination levels in ground water. Figure 4.41, coloured block shows water wells layout within the *Degelen* massif and its vicinity.

The findings of study conducted to define the nature of artificial radionuclides export with underground water outside of the *Degelen* area have proved that concentrations of ^{90}Sr and ^{137}Cs in different zones of export are at, approximately, the same lowest feasible levels and are not to exceed the potable water standard values. At the same time, tritium concentration levels are different in different flow course areas (figure 4.41 coloured block):

- minimal values up to 16 kBq/l have been observed in ground water flows of northern course;
- maximal values of tritium, up to 260 kBq/l, have been registered in ground water flows of south-eastern direction that are prevailing in the *Baitles* stream valley area.

Thus, we can emphasize that adit water flows do not significantly contribute to the radioactive contamination of ground water of the regional basin. Actually, in close proximity to areas of water discharge to the ground surface, the rocks perform complete decontamination for all radionuclides except tritium.

One of the main possible ways for proliferation of contaminated ground water from the *Degelen* test site to underground water of the "northern" areas lies along the regional basin ground water flow course (north-north-eastern). Therefore, flow routes formed near the boundaries of catchment basins should be considered as the most potential ground water flow courses.

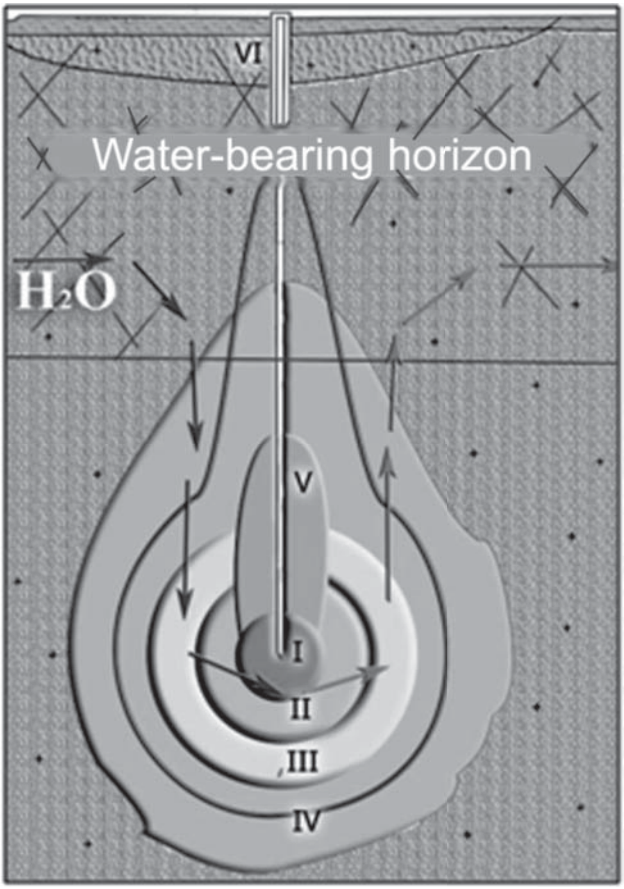
For example, the most probable water flow courses from the *Degelen* site are as follows (Figure 4.42, coloured block):

1. Water flows through the Karabulak stream catchment area and further via a drainage basins system to the boundaries of "northern" areas, then through the Kalbachingiz fracture influence zone shall be referred to the first, most potential flow routes of contaminated ground water transfer (Figure 4.43 coloured block). Tritium concentration of 0.06 kBq/l was registered in ground water of the well 32p, drilled in the Kalbachingiz fracture zone.
2. The second potential water transfer route shall be associated with the ground water flow course towards the *Sary-Uzen* ground via the Altybai valley.

A 2009 research of the above routes has proven that concentration of tritium in ground water of zones, distanced from the rock massif up to 20 km, reaches 30 kBq/l, which is 3 times higher than the permissible limits for potable water.

To estimate probable time of arrival of artificial radionuclides with ground water to the boundaries of northern areas, we shall use the Karadzhal field hydrogeology data obtained in the detailed exploration of the field region. The Karadzhal field is situated in the northern part of *Degelen* ground. Let us calculate tritium there. Tritium is known to travel with ground water in the form of tritiated water and cannot be sorbed on the enclosing rocks. In this connection, the estimated arrival time of tritium, supplied with *Degelen* mountain watercourses to the northern area boundaries, have been determined, considering the distance from the nearest adit to the south boundary of northern areas. According to the data on groundwater study, the maximum ground water proliferation rate within the field area is 2.5 m/day. Therefore, at this speed and with the distance from ground *Degelen* to the northern areas equal to 85 km, the estimated time of ground water proliferation through this area will comprise some 95 years. Taking into account that the first nuclear explosion at the *Degelen* ground was performed 35 years ago, tritium-contaminated ground water from the Degelen area may reach the southern boundary of the northern territories in, approximately, 60 years. Due to the nuclear decay and tritium dilution in ground water with atmospheric precipitations, the time of contaminated water supply to the area of interest will be significantly longer.

Balapan ground. Unlike the nuclear explosions in adits, the sprung hole blast cavities are located far below the ground water level. A general layout of the irreversible deformation zones, as well as the filtration flows to the rock massif after the UNE in hole is presented in Figure 4.44.



Irreversible Deformation Zones: I - Cavity and Melt, II – Splitting up, III – Fracturing , IV – Block Fracturing, V – Collapsed Pillar, VI – Scabbing

Figure 4.44. Ground water contamination from UNE in holes

Due to superinsulation of explosion cavities by overlapping rocks, the high temperature in there is maintained for a long time, which leads to formation around the cavity of the gradient temperature field. The occurrence of gradient temperature field is associated with the formation of a ground water heat convection process. Traveling through the fissures systems of irreversible deformation zones ground water warm up, solubilize (decompose) the radionuclides and take them back to the water-bearing horizon (aquifer).

According to the survey results, high concentrations of ^{90}Sr and ^{137}Cs can be observed only in close vicinity to epicentral zones of nuclear explosions. Concentration of radionuclides declines to mBq/liter level when the distance from mouths of "warfare" boreholes increases up to 300 m.

Thus, on the ground of the existing data we can state that no any particular issues associated with the distribution of ^{137}Cs and ^{90}Sr in underground water have arose so far, due to their low concentrations in water.

At the same time, tritium concentrations in ground water range widely from the minimal detectable activity (7 Bq/l) to maximum values, reaching 5 MBq/l. In general, a zonal character of tritium distribution has been observed within *Balapan* ground. In total, 5 zones of enhanced tritium concentrations have been defined in the area of interest (Figure 4.45, coloured block).

Maximal contents of artificial radionuclides were detected in zones of elevated tritium concentrations, which are situated in the north-eastern part of *Balapan* ground. Maximal tritium concentration level of 5,000 kBq/l and the ^{90}Sr content of 220 Bq/l were registered within this area.

The highest UNE density represents an outstanding feature of the increased tritium concentration area. Twenty three nuclear explosions of 15 to 165 kt were detonated within the 36 km^2 area. However, artificial radionuclides concentration levels in ground water of this zone stay within the permissible limits set for drinking water. One of the reasons of such situation could be associated with the predominant occurrence of free-flow groundwater in this area. In this context, much lower washout and supply of radionuclides from central explosion cavities to the ground water horizon are observed.

In general, we may note that no essential or large-scale contamination of ground water have been registered at *Balapan* ground over the years passed since the suspension of nuclear tests at STS. This fact speaks for the presence of stagnant ground water dynamics and a series of local, relatively isolated subartesian hydrogeological basins within the ground area.

The major proliferation ways for contaminated ground water from *Balapan* ground towards the northern territory of STS were defined by the following features. Figure 4.43, coloured block represents a pattern of tectonic dislocations within the Semipalatinsk Test Site.

Disjunctive dislocation traces are indicated with solid and dotted lines, while arrows represent most probable ground water proliferation paths from the *Balapan* ground via the northern lands towards the Irtysh river as to a water discharge area. It should be mentioned that the *Balapan* ground is located at the junction of several local faults of north-western strike and large fractures of north-south and north-eastern courses. In summary, a complex of factors, including subsurface geology characteristics of the area and effects of underground nuclear explosions on the geological environment, has contributed to the formation here of complicated geological and physical conditions for radionuclides migration with ground water. In this relation, location of *Balapan* is favorable for the ground water supply and active dynamics. We have established that the key role in water resources distribution in the area is played by zones of tectonic dislocations, where the ground water proliferation speed is more intensive, as compared to water of surrounding rocks. The Chinrau and Kalba-chingiz regional faults represent the major ones. Their influence zones cover hundreds of meters. Therefore, the north-western direction of water migration shall be regarded as the most probable contaminated ground water flow course from the *Balapan* ground, including further fracture water transfer towards the northern areas through zones of northern and north-eastern faults. Migration of radionuclides with ground water north-west via the Chinrauz fault zone has been confirmed by the test results of the water well № 538 (Figure 4.46).

This well is located in the north-western periphery of the *Balapan* ground, within the Chinrau fault influence zone, 4 km north-west of the nearest nuclear charge well No. 1080. Concentrations of tritium in ground water samples, taken from this hole, reach 0.7 kBq/l. At the same time, tritium concentration in ground water of all other wells, indicated at the location plan, do not exceed 0.015 kBq/l. Over the past years, studies of tritium migration pattern in the Chinrau fault influence zone were conducted in vicinity of well No. 538. During the study, several water wells were drilled in the faulted zone. No tritium indications have been registered in water samples taken from those wells. This fact speaks for the composite nature of tritium migration with fissure-vein water within the faulted zone. It should be noted that concentrations of ^{137}Cs and ^{90}Sr in ground water of this area stay within 1 Bq/l.

Three water monitoring wells: S-102, S-102/1 and S-103 (Figure 4.43 coloured block), were drilled in 2009 with the purpose of studying the potential proliferation of contaminated ground water from *Balapan* and *Opytnoye pole* grounds to the northern areas of STS. Locations of wells have been selected considering the main ground water flow courses. The depths of wells S-102, S-103 and S-102/1 are 5 m, 6 m and 25 m, respectively. Wells S-102 and S-103 accessed ground water of the delluvial-proluvial and alluvial deposits, while the S-102/1 well tapped ground water of the exogenous fissility zone. According to the laboratory data, tritium concentration in water samples taken in all wells is not higher than the minimum detectable activity equal to 7 Bq/l.

From the data presented one can assume that, taking into consideration the nuclear decay and radionuclide content dilution due to the atmospheric precipitation, proliferation of contaminated ground water to the boundaries of northern areas from this side is not forthcoming in the next few decades.

To estimate the possible access time of contaminated with artificial radionuclides ground water to the boundaries of northern areas we were based on hydrogeology data, obtained at detailed exploration of the Karazhira field. According to all findings of the groundwater study, the average ground water proliferation velocity within the field area makes 170 m/year. Herewith, if to take the ground water proliferation velocity within the Karazhira field area and the distance from *Balapan* site to the northern areas as a basis, then tritium contaminated ground water from the *Balapan* ground may reach the southern boundaries of northern areas no sooner than in 480 years.

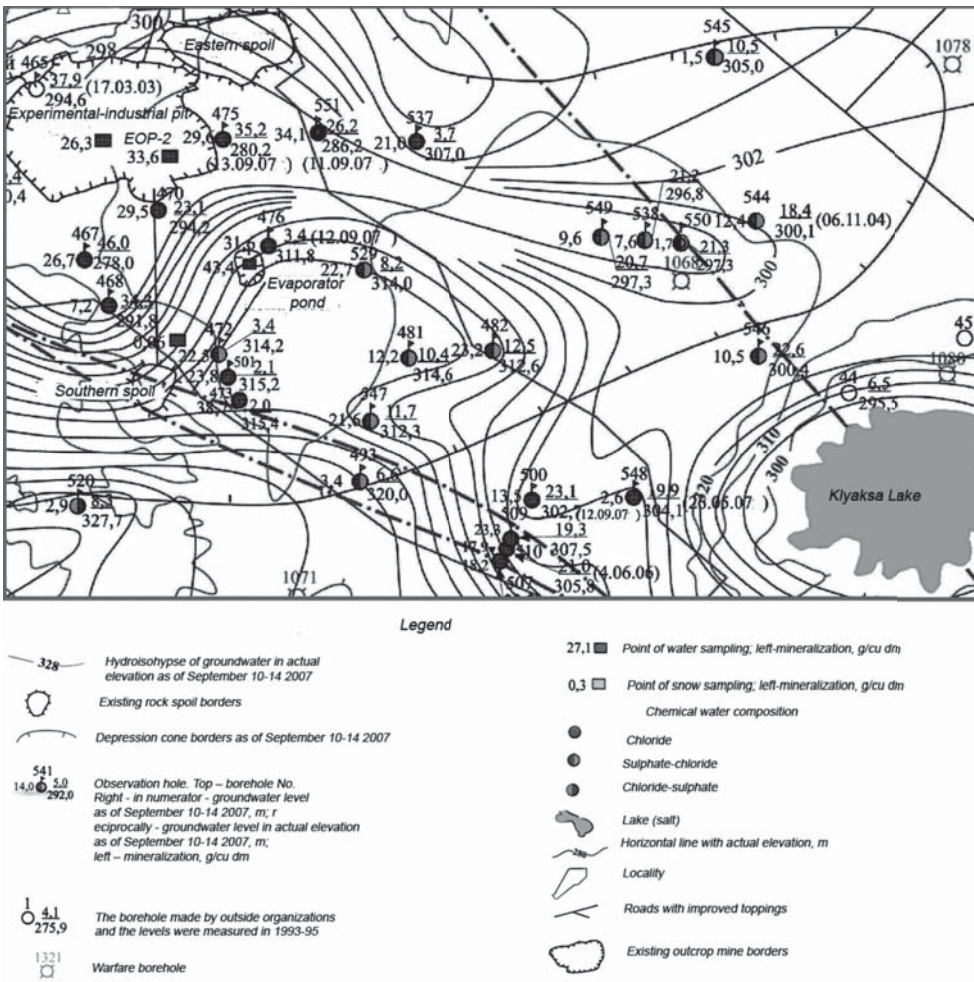
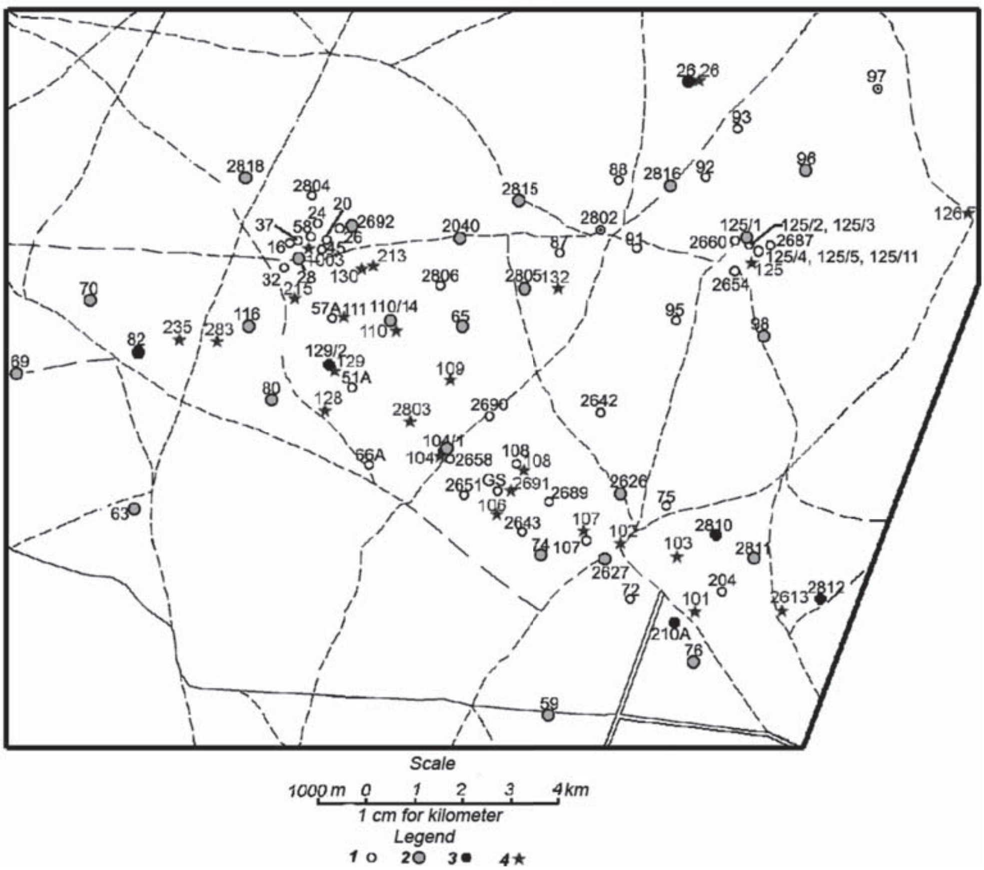


Figure 4.46. Location of monitoring wells within the *Balapan* ground

Sary-Uzen ground. Figure 4.47 below shows the layout of nuclear charge and water wells.



Wells: 1 – water wells; 2 – water wells, applicable for monitoring investigations; 3 – water wells, unfeasible for monitoring investigations; 4 – nuclear charge wells

Figure 4.47. Schematic map of warfare and hydrological wells at Ground *Sary-Uzen*

Conditions and mechanism of ground water contamination with radioactivity in this area are similar to those in the *Balapan* ground. Thereat, the main most probable ground water flow course is associated with the northern direction route running through the catchment basin of the Altybai valley. This version is currently under the intensive study and crosschecking. In fact, over 20 water monitoring wells have been located in *Sary-Uzen* area during nuclear tests era. According to 2005 data, concentrations of radionuclides in ground water within the test area were registered as follows: ^{137}Cs – up to 3 mBq/l, ^{90}Sr – up to 10 mBq/l and ^{3}H – over 500 kBq/l. Based on the data presented, we can state that tritium is the major radioactive contaminant of ground water within this area. At the same time, concentrations of ^{137}Cs and ^{90}Sr in water impose no radiological hazard and stay within the permissible limits set for potable water.

To study potential contaminated ground water proliferation from *Sary-Uzen* ground towards the "northern" areas, we currently use the test data of water wells, drilled in the "Novaya" ground area. This test site is located nearby the northern boundary of *Sary-Uzen* ground, i.e. at the possible ground water transport route towards the "northern" areas. Preparatory operations for carrying UNE in holes had been performed in the "Novaya" ground during at times of nuclear tests. For this purpose 19 water wells were arranged in the test site area. Laboratory data showed that concentrations of artificial radionuclides in underground water within this ground area are lower than the minimal detectable activity level, which values are considerably below the permissible limits set for drinking water. The above mentioned suggests that the ground water contamination front stays yet within *Sary-Uzen* ground area and, therefore, the supply of contaminated ground water from this side to ground water of "northern" areas is not feasible. Herewith, considering some similarity of hydrological conditions in *Balapan* and *Sary-Uzen* grounds, we can estimate that proliferation of tritium contaminated ground water from *Sary-Uzen* test site to the south boundary of northern lands will take 365 years as minimum, provided that the basic calculated velocity of ground water flow is 170 m/year and the distance from *Sary-Uzen* ground to the northern lands totals to 62 km.

Therefore, the findings of surveys conducted allow us to state that, in terms of radioactive contamination, ground and surface water in the "northern" areas of STS are usable for any type of activities without any limitations, taking into account the following recommendations (suggestions) below.

With the purpose to control possible proliferation of contaminated ground water from the nuclear test sites to underground water of northern lands, as well as for the prompt detection at the initial stage of any unfavorable radio-ecological situation trends, we suggest to arrange additional hydrogeology observation posts in the following STS areas and include them into the unified State ecological monitoring system:

1. *Degelen* test site – 2 wells. Examination rate – 1-2 times per year. Radionuclide under monitoring – ^{3}H. Post purposes – control over the radionuclides distribution with underground water flowing outward the *Degelen* ground.
2. Ground *Sary-Uzen* – 3 water wells. Examination rate – 1 time per year. Radionuclides under monitoring – tritium, cesium-137 and strontium-90. Post purposes – control over the radionuclides distribution directly in *Sary-Uzen* test site area.
3. Ground "*Novaya*" – 2 water wells. Examination rate – 1 time per year. Radionuclide under monitoring – ^{3}H. Post purposes – control over the radionuclides distribution with underground water flowing outward *Sary-Uzen* ground.
4. Ground "*4a*" – 2 wells. Examination rate – 1 time per year. Radionuclide under monitoring - ^{90}Sr. Post purposes – control over the strontium-90 access to ground water.

5. *Opytnoye Pole* ground – 2 wells. Examination rate – 1-2 times per year. Radionuclide under monitoring – ^{90}Sr. Post purposes – control over the potential ingress of contaminated ground water from *Opytnoye Pole* towards the "northern" lands. The selection of ^{90}Sr as cotrolled radionuclide is due to its relatively high migration abilities compared with other radionuclides, that can be found in contaminated soils of *Opytnoye Pole.*
6. 3 water use facilities located along the south boundary of northern areas. Examination rate – 1 time a year. Radionuclide under monitoring – ^{3}H. Post purposes – control over the possible showing of contaminated ground water in water use facilities.
7. *Degelen* ground – 3 wells. Examination rate – 1-2 times per year. Radionuclide under monitoring – ^{3}H. Post purposes – control over the possible ingress of contaminated ground water outside of the rock massif *Degelen*, as well as monitoring over the potential supply of contaminated ground water from the ground *Balapan* through the Kalba-Chingiz fault zone.
8. *Balapan* ground – 3 wells. Radionuclide under monitoring – ^{3}H. Post purposes – monitoring over the radionuclides distribution directly in the *Balapan* area.
9. *Balapan* ground – 2 wells. Radionuclide under monitoring – ^{3}H. Post allocations – control over the radionuclides distribution outward *Balapan* ground through the Chinrau regional fault zone.

4.5 State of the air basin

Climatic conditions of the STS region (dust storms, strong winds and steppe fires) contribute to the formation of deflation processes, i.e. secondary rise of artificial radionuclides precipitated on the earth surface. This process is also stimulated by light soils, which are most easily subjected to dust formation and are widely spread on the STS territory.

The state of the air basin in the frames of the formulated task was studied in the settlements in the STS northern part (from the northern boundary to the cut line) and for comparison in the settlements adjacent to the north region. The results of measurements were compared with the Radiation Safety standards (NRB-99) [58] and earlier obtained data for settlements of Semipalatinsk oblast [72, 73].

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

An assessment of the content of artificial radionuclides in the air of the studied region was made with account for possible additional impact of the most contaminated areas of the STS territory due to the wind transfer of radionuclides. As additional sources of radionuclide air contamination we took the contaminated areas on the territory of grounds used for radiological weapons tests (grounds *"4a"* and *"4"*) and *Opytnoye Pole* (grounds (P-1, P-2, P-5) (Figure 2.1, 2.2 coloured block).

The dust formed on the soil surface under the wind action rises to the atmosphere with different intensity [74]. The first stage in the process of secondary sedimentation is rise of particles from the underlying surface. This process is estimated by the coefficient of wind rise. The intensity of wind rise of long-lived radionuclides from the underlying surface depends on a number of factors: the level of radioactive contamination of the soil layer, physical-chemical soil characteristics, vegetation cover and micrometeorological parameters. The dependence of intensity of wind rise on the above listed factors has not been well studied yet. The authors [74] estimated the wind rise coefficient as:

$$\alpha = \frac{2 \cdot 10^{-10}}{z_0^{1,4}};$$ where

α – is the wind rise intensity, 1/s;
z_0 – is the height of underlying surface roughness, cm.

The near-surface volume activity (VA) of radionuclides caused by wind rise and further transfer of the admixture was calculated using a semi-empirical equation from the turbulent diffusion theory [74]

$$q\,(x,y,z) = \frac{aA}{\sqrt{2\pi}\,(1+m)k_1 b_y x^2}\, exp\left(-\frac{y^2}{2b_y^2 x^2} - \frac{u_1(z^{1+m} + z_0^{1+m})}{(1+m)^2 k_1 x}\right) l_0 \left[\frac{2u_1 (zz_0)^{\frac{1+m}{2}}}{(1+m)^2 k_1 x}\right]$$, where [1]

α – is the wind rise intensity, 1/s;
A – is the surface contamination density, Bq/m^2;
m – is a parameter characterizing atmosphere stability;
κ_1 – is the coefficient of turbulent diffusion for $z=z_1$, m^2/s;
b_y – is an empirical constant (0.08);
u_1 – is the wind speed at height z_1=1 m;
I_0 – is Bessel's function;
z_0 – is the height of roughness of the underlying surface, m;
z – is the source height, m;
x – is the distance from the source, m.

In order to calculate possible radionuclide contamination of the near-surface atmosphere of the studied area due to wind transfer from the grounds of radiological weapons tests *"4a"*, *"4"* and *Opytnoye Pole* (grounds P-1, P-2, P-5), we chose elementary spots with maximal surface contamination of the soil cover by artificial radionuclides.

The initial data for determining of the near-surface (average annual) volume activity of artificial radionuclides in air are presented in tables 4.13-4.14.

Table 4.13

Values of maximal radiation parameters in the sectors of the grounds of radiological weapons tests *"4a"* and *"4"* and *Opytnoye Pole*

RW-sites	**Specific radionuclide activity on the soil surface, Bq/kg**						
Ground *"4a"*	^{241}Am	^{137}Cs	^{60}Co	^{154}Eu	^{152}Eu	^{90}Sr	$^{239+240}$Pu
sector 1	56	$1.3 \cdot 10^{2}$		$8.8 \cdot 10^{1}$		$1.3 \cdot 10^{6}$	$2.1 \cdot 10^{3}$
sector 2	82	$4. \cdot 10^{3}$				$1.1 \cdot 10^{5}$	
sector 17*	$5.8 \cdot 10^{3}$	$1.4 \cdot 10^{3}$	186	$3.5 \cdot 10^{3}$	$2.3 \cdot 10^{5}$	$5.8 \cdot 10^{8}$	
Ground *"4"*							
sector 1		83				$2.6 \cdot 10^{3}$	6.7
sector 2	7	26				$3.1 \cdot 10^{3}$	$2.8 \cdot 10^{2}$
Opytnoye pole							
P-1	$6.2 \cdot 10^{2}$	$1 \cdot 10^{3}$		$4.3 \cdot 10^{3}$		$2.3 \cdot 10^{4}$	$1.5 \cdot 10^{3}$
P-2	$8.1 \cdot 10^{2}$	$2.9 \cdot 10^{3}$	$1.4 \cdot 10^{2}$	$2.6 \cdot 10^{2}$	$6.5 \cdot 10^{3}$	$3.1 \cdot 10^{4}$	$9.8 \cdot 10^{3}$
P-5	$1.9 \cdot 10^{3}$	$4.2 \cdot 10^{3}$				$8.4 \cdot 10^{5}$	
Note: * sample taken at a depth of 10 cm							

Table 4.14

Initial data for determining average annual volume activity

m	**k_1, m^2/s**	**u_1, m/s**	**I_0**	**z_0, m**	**z, m**	**α, 1/s**	**b_y**
2.1	0.2	4	1	0.1	1	$7.5 \cdot 10^{-11}$	0.08

Table 4.15 presents the results of calculation of the average annual VA and concentration of artificial radionuclides in the air at the boundary of the STS "northern" lands caused by possible additional impact of chosen sectors on the grounds *"4a"*, *"4"* and *Opytnoye Pole* calculated by formula 1 and the values of permissible volume activity of artificial radionuclides in the inhaled air [58].

Table 4.15

Average annual volume activity of artificial radionuclides in the air at a height of 1 m caused by wind transfer from RW contaminated areas and *Opytnoye pole* at the boundary of the studied area

RW-sites	**Near-surface (average annual) volume activity, Bq/m^3**						
	^{241}Am	**^{137}Cs**	**^{60}Co**	**^{154}Eu**	**^{152}Eu**	**^{90}Sr**	**$^{239+240}$Pu**
Ground *"4a"*							
sector 1	$1.17 \cdot 10^{-8}$	$2.76 \cdot 10^{-8}$		$1.84 \cdot 10^{-8}$		$2.71 \cdot 10^{-4}$	$4.44 \cdot 10^{-7}$
sector 2		$8.35 \cdot 10^{-7}$				$3.30 \cdot 10^{-5}$	
sector 17*	$2.11 \cdot 10^{-7}$	$5.03 \cdot 10^{-8}$	$6.68 \cdot 10^{-9}$	$1.26 \cdot 10^{-7}$	$8.3 \cdot 10^{-6}$	$2.08 \cdot 10^{-2}$	

RW-sites	Near-surface (average annual) volume activity, Bq/m³						
	^{241}Am	^{137}Cs	^{60}Co	^{154}Eu	^{152}Eu	^{90}Sr	$^{239+240}$Pu
Ground *"4"*							
sector 1		$5.97 \cdot 10^{-10}$				$1.87 \cdot 10^{-8}$	$4.82 \cdot 10^{-11}$
sector 2	$7.55 \cdot 10^{-11}$	$2.80 \cdot 10^{-10}$				$3.34 \cdot 10^{-8}$	$3.02 \cdot 10^{-9}$
Opytnoye pole							
P-1	$3.71 \cdot 10^{-9}$	$5.99 \cdot 10^{-9}$		$5.27 \cdot 10^{-10}$		$1.38 \cdot 10^{-7}$	$8.98 \cdot 10^{-9}$
P-2	$3.49 \cdot 10^{-9}$	$1.26 \cdot 10^{-8}$	$6.21 \cdot 10^{-10}$	$1.12 \cdot 10^{-9}$	$2.80 \cdot 10^{-8}$	$1.34 \cdot 10^{-7}$	$4.27 \cdot 10^{-8}$
P-5	$1.33 \cdot 10^{-5}$	$2.94 \cdot 10^{-5}$				$5.87 \cdot 10^{-3}$	
AVA pop, Bq/m³	$2.9 \cdot 10^{-3}$	$2.7 \cdot 10^{1}$	$1.1 \cdot 10^{1}$	2.3	2.9	2.7	$2.5 \cdot 10^{-3}$

The results of our calculations taking into account the direction of the wind rose at the boundary of the STS "northern" territory show that the values of average annual volume activities of artificial radionuclides in the near-surface atmosphere do not exceed permissible concentrations. Therefore, the additional impact of artificial radionuclides caused by the wind transfer from the most contaminated pars of the STS territory on people and personnel working on the studied territory will not make a considerable contribution to the total dose load.

The results of calculations of the average annual volume activity of radionuclides caused by wind transfer from the most contaminated STS areas to the near-surface atmospheric layers of the northern part of the studied area showed that these areas made very little contribution to the radioactive air pollution in the northern part of the test site. Similar results were obtained in the studies of possible radioactive pollution of the near-surface atmosphere in Kurchatov-city caused by wind transfer [75].

4.5.2 Experimental data on the content of natural and artificial radionuclides in air of the studied area

In order to study air quality, the Institute has recently completed a number of targeted investigations. In 2000-2001, in cooperation with researchers from Finland in the framework of an IAEA project, the Institute carried out air sampling with two filtering units (K1 and K2R) manufactured in Finland [76]. These units were operated in the automatic regime with continuous air pumping through a week-exposure filter (figure 4.48). The samples from the aliquot parts of the filters were analyzed by the methods of gamma-spectroscopic and radiochemical analyses. The results of the analyses were used to calculate volume activities of radionuclides. The figure (figure 4.49) shows the values of volume activity of $^{239+240}$Pu obtained during monitoring in the time interval from 14 to 62 weeks. These values are many orders of magnitude lower than the NRB-99 requirements.

Figure 4.48. Air sampling in Kurchatov-city

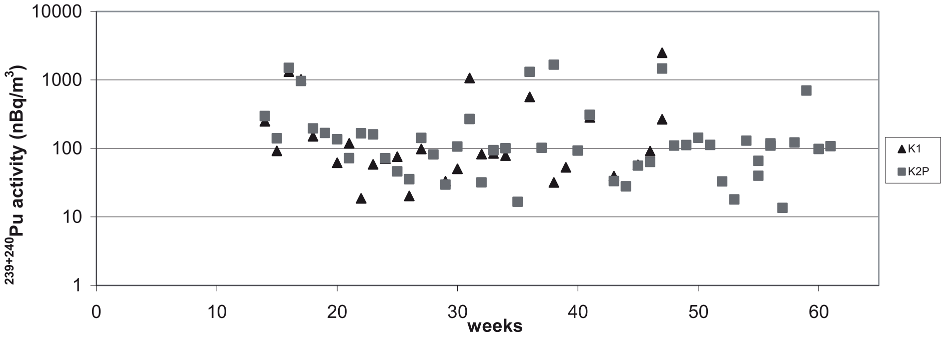


Figure 4.49. Volume activity of $^{239+240}$Pu in the air of Kurchatov-city (2000-2001)

A long-term monitoring of the near-surface atmosphere of Kurchatov-city carried out in cooperation with foreign researchers confirmed absence of any noticeable radionuclide contamination of the air environment of the region under different meteorological conditions and seasonal climatic variations.

In 2005-2006, in the framework of the scientific-technical program 0346 "Development of Nuclear Power Industry in Kazakhstan" and contracts on surveying of the Pavlodar oblast, the Institute studied pollution of the air environment. The investigations included studying of concentrations of both natural and artificial radionuclides in the near-surface atmosphere. Table 4.16 presents the experimental data on volume activity of ^{137}Cs and other radionuclides in the near-surface atmosphere of the STS northern part (ground *"8"*, Kurchatov) and some settlements situated to the northwest from the STS territory.

Table 4.16

Volume activity of natural radionuclides in air

No.	Sampling point	Geographical coordinates						Volume activity of radionuclides in air, Bq/m^3			
		latitude			longitude						
		°	'	"	°	'	"	^{40}K	^{232}Th	^{226}Ra	^{137}Cs
1	Ground "8"	50	35	21.0	77	50	50.0	<9	<0.7	<0.9	<1
2	Kurchatov-city	50	44	59.8	78	31	56.6	<9	<0.5	<0.6	<0.1
3	Kopabay winter camp	50	37	7.0	76	44	42.8	0.029	<0.00072	0.0015	<0.0004
4	Akshay w.c.	50	30	37.8	76	42	23.2	0.0127	<0.00039	0.00092	<0.0002
5	Akshiman w.c.	50	47	27.3	76	44	36.6	0.0368	<0.0008	0.0033	<0.0004
6	Lebyazhje village	51	27	56.2	77	47	4.4	0.0249	<0.0007	0.00347	<0.0003
7	Koktobe village, Maisky rayon	51	31	50.8	77	28	1.2	0.15	0.0005	<0.00063	<0.0002

Comparison of the experimental data given in the table with the permissible volume activities (NRB-99) does not show any exceeding of the normative values of natural radionuclides concentrations in the near-surface atmosphere. All obtained values for ^{137}Cs are lower than the normative values (NRB-99).

In August 2009, the Institute started regular monitoring (sampling of air aerosols) on the "ground 100" (the reactor complex IGR on the STS territory) adjacent to the *Opytnoye Pole*. The air was pumped out with a sampler AKL-2 of capacity of 300 m^3/h. Pumping cycle comprised 7 days with a filter was replaced once a week. Gamma-spectroscopy data for 11 filters with samples of air aerosols are given in table 4.17, and the results of radiochemical analysis of concentration of radionuclides ^{90}Sr and $^{239+240}Pu$ from two other filters (Nos. 1and 2) are given in table 4.18.

Table 4.17

Data from gamma-spectroscopic measurements of filters with air aerosol samples (Bq/m^3)

No.	Volume of pumped air, m^3	Sampling date	^{40}K	^{232}Th	^{226}Ra	^{241}Am	^{137}Cs	^{60}Co	^{152}Eu
1	≈35200	31.07.09	$(2±0.4)*10^{-4}$	$(3 ± 1)*10^{-5}$	$(1±0.6)*10^{-5}$	$<2*10^{-6}$	$<4*10^{-6}$	$<5*10^{-6}$	$<5*10^{-6}$
2	≈35200	07.08.09	$(8 ± 2)*10^{-5}$	$(3±0.2)*10^{-5}$	$(2±0.1)*10^{-5}$	$<4*10^{-7}$	$<2*10^{-6}$	$<6*10^{-7}$	$<6*10^{-7}$
3	≈35200	14.08.09	$(4 ± 2)*10^{-5}$	$(2±0.4)*10^{-5}$	$(4±0.6)*10^{-5}$	$<5*10^{-7}$	$<2*10^{-6}$	$<1*10^{-6}$	$<1*10^{-6}$
4	≈35200	21.08.09	$(1±0.2)*10^{-4}$	$(1±0.2)*10^{-5}$	$(3±0.6)*10^{-5}$	$<2*10^{-6}$	$<3*10^{-6}$	$<5*10^{-6}$	$<3*10^{-6}$
5	≈35200	01.09.09	$(1±0.2)*10^{-4}$	$(3 ± 1)*10^{-5}$	$(3±0.7)*10^{-5}$	$<1*10^{-6}$	$<4*10^{-6}$	$<3*10^{-6}$	$<2*10^{-6}$

No.	Volume of pumped air, m^3	Sampling date	^{40}K	^{232}Th	^{226}Ra	^{241}Am	^{137}Cs	^{60}Co	^{152}Eu
6	≈35200	07.09.09	$(1±0.3)*10^{-4}$	$(3 ± 1)*10^{-5}$	$(3±0.5)*10^{-5}$	$<2*10^{-6}$	$<5*10^{-6}$	$<3*10^{-6}$	$<5*10^{-6}$
7	≈35200	21.09.09	$(1±0.3)*10^{-4}$	$(3± 0.7)*10^{-5}$	$(3±0.4)*10^{-5}$	$<1*10^{-6}$	$<5*10^{-6}$	$<3*10^{-6}$	$<2*10^{-6}$
8	≈35200	28.09.09	$(6 ± 2)*10^{-5}$	$(2±0.4)*10^{-5}$	$(3±0.3)*10^{-5}$	$<1*10^{-6}$	$<3*10^{-6}$	$<2*10^{-6}$	$<2*10^{-6}$
9	≈35200	02.10.09	$(5 ± 1)*10^{-5}$	$(2±0.2)*10^{-5}$	$(4±0.2)*10^{-5}$	$<5*10^{-7}$	$<2*10^{-6}$	$<1*10^{-6}$	$<1*10^{-6}$
10	≈35200	16.10.09	$(1±0.2)*10^{-4}$	$(3±0.8)*10^{-5}$	$(3±0.1)*10^{-5}$	$<2*10^{-6}$	$<3*10^{-6}$	$<2*10^{-6}$	$<2*10^{-6}$
11	≈35200	30.10.09	$(1±0.2)*10^{-4}$	$(2±0.6)*10^{-5}$	$(4±0.5)*10^{-5}$	$<2*10^{-6}$	$<3*10^{-6}$	$<4*10^{-6}$	$<3*10^{-6}$

Table 4.18

Radiochemical analysis of filters with air aerosol samples (Bq/m³)

No.	^{90}Sr	$^{239+240}Pu$
1	$<8.2*10^{-5}$	$<9.8*10^{-6}$
2	$<1*10^{-4}$	$<1*10^{-5}$

In order to study the radiation conditions in more detail, the samples of air aerosols were taken in different places where people live (winter-camps, summer-camps, watering places, etc.). Sampling was made with a mobile air sampler JAP-50. In order to determine activities of natural and artificial radionuclides the samples were analyzed using gamma-spectrometers. The results of gamma-spectroscopic measurements are presented in table 4.19.

Table 4.19

Results of gamma-spectroscopic measurements of air aerosol samples (Bq/m³)

Sampling point	^{40}K	^{232}Th	^{226}Ra	^{241}Am	^{137}Cs	^{60}Co	^{152}Eu
Bapay winter camp	$(1.5±0.1)*10^{-2}$	$(3±1)*10^{-3}$	$(3±0.5)*10^{-3}$	$< 2*10^{-4}$	$< 4*10^{-4}$	$< 4*10^{-4}$	$< 3*10^{-4}$
Actas w.c.	$(1.3±0.2)*10^{-2}$	$(4±0.8)*10^{-3}$	$(4±0.5)*10^{-3}$	$< 2*10^{-4}$	$< 3*10^{-4}$	$< 4*10^{-4}$	$< 3*10^{-4}$
Bulak w.c.	$(1.3±0.2)*10^{-2}$	$(4±0.9)*10^{-3}$	$(4±0.5)*10^{-3}$	$< 2*10^{-4}$	$< 2*10^{-4}$	$< 4*10^{-4}$	$< 3*10^{-4}$
Dostyk w.c.	$(1.3±0.3)*10^{-2}$	$(3±0.8)*10^{-3}$	$(3±0.4)*10^{-3}$	$< 2*10^{-4}$	$< 4*10^{-4}$	$< 4*10^{-4}$	$< 3*10^{-4}$
Tortkuduk w.c.	$(1.2±0.2)*10^{-2}$	$(3±0.8)*10^{-3}$	$(2±0.4)*10^{-3}$	$< 2*10^{-4}$	$< 2*10^{-4}$	$< 4*10^{-4}$	$< 3*10^{-4}$

The above experimental data (tables 4.17 – 4.19) show that now the level of radioactive contamination of the air environment on the studied part of the STS territory does not differ from the global background.

4.5.3 Radon content in the air of the studied area

In 2006 and 2009, the Institute carried out comprehensive radiological survey of villages Nygmetcora, Bulak, Dostyk, Zhamankuduk, Aktas and Tortkuduk including measurements of radon (^{222}Rn) and thorone (^{220}Rn) concentrations. In the studied villages using a radon monitor "Ramon-01" which enabled to measure the equivalent equilibrium volume activity (EEVA) of radon and thorone in the open place and in the air of residential buildings. The thorone EEVA in all studied points was lower than 8 Bq/m^3, which is below the registration level of the used measuring devices. The EEVA values for ^{222}Rn are given in table 4.20.

Table 4.20

Measurements of radon and thorone EEVA (Bq/m^3)

Wintering site	Place of measurements	EEVA ^{222}Rn	
		2006	2009
Nygmetcora	living premises	22	–
	open air	<4	–
Bulak	living premises	21	52
	open air	<4	–
Dostyk	living premises	29	16*
	open air	<4	–
Zhamankuduk	living premises	32	–
	open air	<4	–
Aktas	uninhabited premises	–	20
Tortkuduk	uninhabited premises	–	26

Note: * uninhabited premises
– measurements were not performed

The results of investigations showed that during the period of observations the volume activity of radon and thorone in the atmospheric air did not exceed the values of permissible average annual volume activity for population established in NRB-99 and equal to 200 Bq/m^3. For winter camps Bulak and Dostyk the EEVA for radon and thorone measured in 2006 and 2009 practically did not differ.

4.5.4 Expected variations in radionuclide contamination of the air basin

Based on the above results one can draw a conclusion that radioactive contamination of the atmosphere may be hazardous only for people working directly on the territory of radiation-hazardous STS objects and only in case if a large amount of dust is contained in the air at the moment of people staying there (dust storms, man-made dusting, etc.). For example, studies of concentrations of artificial radionuclides in the vicinity of the test ground *Opytnoye Pole* registered considerable exceeding of permissible concentrations. It means that it is dangerous to stay and to do any works (causing dust rise) in the vicinity of such objects.

These investigations [77] enabled to conclude that transboundary transfer of radioactivity beyond the grounds and, all the more, beyond the STS boundaries is very small and cannot be a source of danger either now or in the future.

4.6 State of vegetation cover

4.6.1 Concentration of natural radionuclides in the vegetation of the studied area

One of the most widely used factors applied to determine parameters of natural radionuclides transfer from soil to vegetation is the accumulation coefficient (A_c) – the ratio of radionuclide concentration to the unit mass of vegetation and soil, respectively [78].

The concentration of natural radionuclides in the vegetation cover of the studied area was determined on the basis of the average A_c values for ^{40}K, ^{232}Th and ^{226}Ra given in the IAEA document "Quantification of radionuclide transfer in terrestrial and freshwater environments for radiological assessment" (2009) [79], and A_c values for ^{40}K, ^{232}Th and ^{226}Ra calculated using the values of specific radionuclide activity in about 140 samples of soils and herbs sampled on the studied territory in 2001-2008. The average A_c values for ^{40}K, ^{232}Th and ^{226}Ra are given in table 4.21.

Table 4.21

Average accumulation coefficient values for radionuclides in some groups of herbs

Herbs	A_c		
	^{40}K	^{232}Th	^{226}Ra
IAEA (2009)			
Motley grass	-	0.07	0.26
Gramineae grass	1.1	0.01	0.09
Pascual grass	0.7	0.37	0.19
Studied lands (2001-2008)			
Step motley grass	0.4	0.1	0.2

The above results show that in the studied area the experimental A_c values for ^{40}K, ^{232}Th and ^{226}Ra do not contradict the international concentrations, and therefore in our calculations we used the international values of specific activities (SA) of these radionuclides in plants (table 4.22).

Table 4.22

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

Average values	Natural radionuclides		
	^{40}K	^{232}Th	^{226}Ra
A_c	0.4	0.1	0.2
SA in soil, Bq/kg	685	29	26
SA in vegetation, Bq/kg	274	2.9	5.2

According to the results of calculations the highest concentration in plants is observed for ^{40}K as one of the most widely spread natural radionuclide in nature which, in its turn, is one of the main sources of natural radioactivity. The concentration of ^{232}Th and ^{226}Ra in plants in the studied area is 1-2 orders lower.

4.6.2 Type of contamination of vegetation cover by artificial radionuclides

In order to determine parameters of artificial radionuclides as well as natural radionuclides transfer from soil to plants we used literary and experimental data for A_c average values. For example, the IAEA materials (2009) [79] present generalized A_c values for radionuclide accumulation by plants. Table 4.23 gives the Ka ranges for accumulation of ^{137}Cs, ^{90}Sr, $^{239+240}Pu$, ^{241}Am, ^{151}Sm (Pm) and ^{99}Tc (Mn) in some groups of plants in soils similar by mechanical composition to the soil of the studied area.

Table 4.23

Ranges of accumulation coefficient values for radionuclides accumulation by herbs (IAEA, 2009)

Herb	A_c					
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am	^{151}Sm (Pm)*	^{99}Tc (Mn)*
Sabulous soil						
Motley grass	0.01-1.0	0.3-2.8	0.00005-0.0003	0.004-0.3	-	-
Gramineae grass	0.04-1.9	0.9-9.8	-	-	0.02-1.4	4.8-27
Pascual grass	0.01-4.8	0.1-7.3	0.0002-0.001	0.001-0.03	-	0.4-2.7
Loamy soil						
Motley grass	0.01-0.2	0.3-2.0	-	-	-	-
Gramineae grass	0.007-1.5	0.7-3.6	0.0002-0.001	-	0.3-1.2	0.2-6.2
Pascual grass	0.01-2.6	0.4-2.6	0.0001-0.003	0.001-0.02	-	0.1-1.8
Note: * – A_c values are those for Pm and Mn, see explanations below.						

A certain role in the radiological conditions of the studied area is played by radionuclides ^{151}Sm and ^{99}Tc, whose K_a data were not found. However, as the chemical properties of ^{151}Sm are close to those of Pm, and the properties of ^{99}Tc are close to M_n, one can suppose that the A_c values for them could be approximately the same.

It was established that A_c values for the considered radionuclides vary in a rather wide range and their accumulation by plants diminishes in the row:

$$^{90}Sr > {}^{137}Cs > {}^{241}Am > {}^{239+240}Pu$$

An extensive data on radionuclide accumulation by plants has been collected for the STS territory (1999-2008) – the table gives the average A_c values for radionuclides

^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am for the main biocenosis-forming plants (*Stipa, Festuca, Artemisia*) of the dry steppe zone (table 4.24).

Table 4.24

Average accumulation coefficient values for radionuclides in the main biocenosis-forming plants (stipa, festuca, Artemisia) of the dry steppe zone

Plants	A_c			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Stipa	0.37 (0.005–2.41)	0.71 (0.02–2.30)	0.05 (0.003–0.26)	0.48 (0.23–0.77)
Festuca	0.27 (0.001–1.66)	0.74 (0.27–1.66)	0.02 (0.007–0.06)	-
Artemisia	0.29 (0.004–1.30)	0.74 (0.14–1.37)	0.06 (0.005–0.22)	0.42 (0.09–0.80)
Note: brackets give range of values.				

The results of investigations show a detectable difference between the average A_c values for different radionuclides and practically the same A_c values for different plants. The patterns of radionuclide accumulation except a little higher A_c values for ^{241}Am, which in this case can be explained by the lack of statistics, in general, do not differ from the IAEA data (2009) [79] and decrease in the row: ^{90}Sr > ^{137}Cs, ^{241}Am > $^{239+240}$Pu. The frequency of detected A_c values for ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am is presented in the histograms (Figure 4.50).

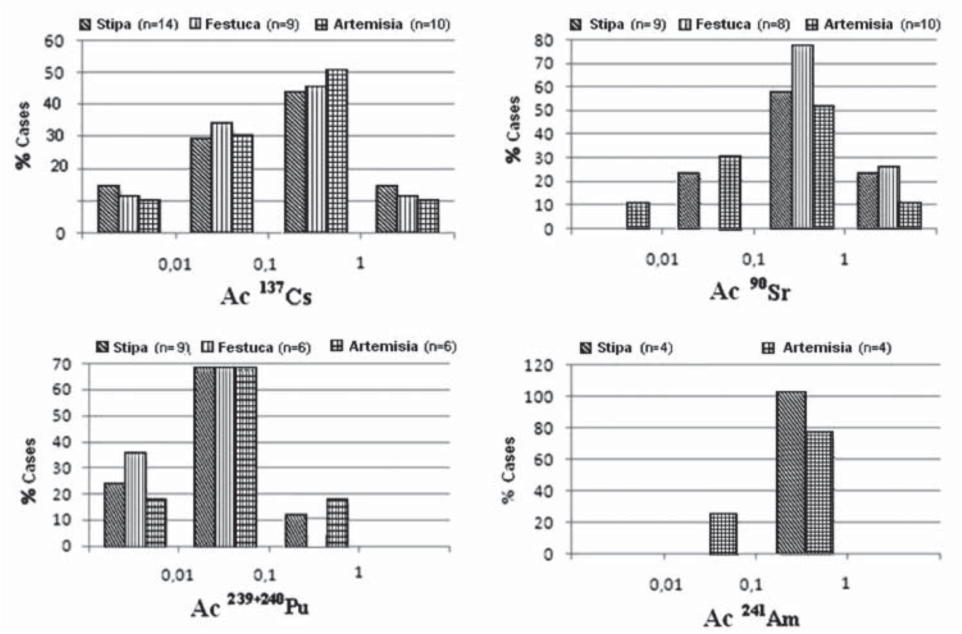


Figure 4.50. Distribution of accumulation coefficient values for radionuclides ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am in the main biocenosis-forming plants (Stipa, Festuca, Artemisia) of the dry steppe zone

As no principal differences in the A_c values for the dominant plants of the dry steppe zone have been revealed, further calculations of the average A_c values were made for the steppe motley grass. Table 4.25 presents the average A_c values for ^{137}Cs, ^{90}Sr, $^{239+240}Pu$ and ^{241}Am in the motley grass growing on the main test grounds *Balapan* and *Opytnoye Pole* and directly on the studied area.

Table 4.25

Average accumulation coefficient values for radionuclides accumulation in the steppe motley grass

Land	A_c			
	^{137}Cs	^{90}Sr	$^{239+240}Pu$	^{241}Am
Balapan	0.34 (n=41) 0.001 – 4.77	0.71 (n=31) 0.02 – 2.30	0.05 (n=30) 0.001 – 0.26	0.29 (n=2) 0.07 – 0.51
Opytnoye Pole	0.44 (n=17) 0.02 – 1.32	0.07 (n=5) 0.02 – 0.09	0.03 (n=5) 0.003 – 0.08	0.45 (n=8) 0.09 – 0.80
"Northern" Lands	0.59 (n=50) 0.03 – 2.44	0.76 (n=70) 0.01 – 4.67	0.29 (n=24) 0.01 – 1.21	0.53 (n=5) 0.10 – 1.20

Note: numerator shows average number with number of cases in brackets; denominator – range of values

The results of analysis show that the A_c values on the studied STS areas vary in a rather wide range – they reach 2-3 orders of magnitude for ^{137}Cs and ^{90}Sr, have 2 orders of magnitude for $^{239+240}Pu$ and one order for ^{241}Am. The average A_c values tend to decrease in the row $^{90}Sr > ^{137}Cs > ^{241}Am > ^{239+240}Pu$. The histogram shows the distribution of A_c values on the studied area (figure 4.51).

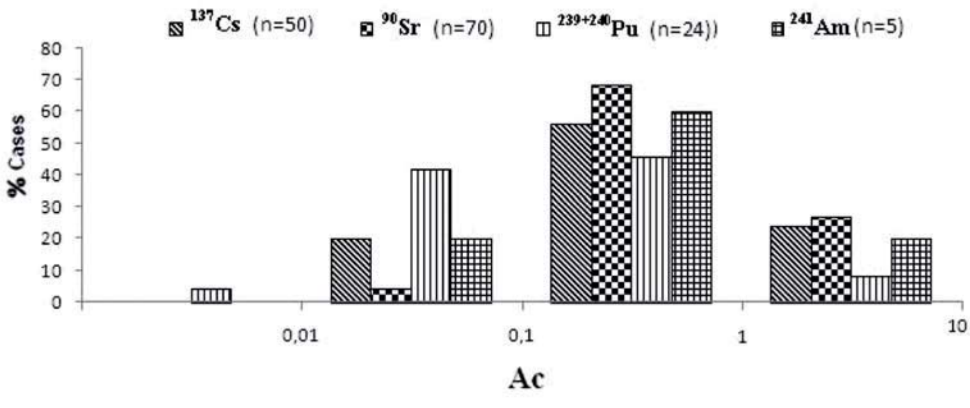


Figure 4.51. Distribution of the average accumulation coefficient values for radionuclides ^{137}Cs, ^{90}Sr, $^{239+240}Pu$ and ^{241}Am in the steppe motley grass on the studied area

In 2009, in order to obtain more precise data, the Institute carried out additional investigations of the levels and parameters of transfer of radionuclides ^{137}Cs, ^{90}Sr, $^{239+240}Pu$ and ^{241}Am from soil to plants. In the sectors with increased average activity of radionuclides in soil spread over all studied territory 14 research grounds (sampling points) were organized (figure 4.26 coloured block). On each research ground scientists simultaneously made soil sampling (sampling area – 10×10 cm, to a depth of 5 cm) and sampling of top parts of the plants (sampling area ~ 2-4 sq. m) presented by mixed samples of steppe motley grass mainly consisting of Stipa (*Stipa capillata*, *S. sareptana*, *S. lessingiana*), Festuca (*Festuca valesiaca*) and Artemisia (*Artemisia gracileccens, A. frigida*). The radionuclide specific activity in soil and plant samples was measured by gamma-spectrometric (^{137}Cs and ^{241}Am) and radiochemical techniques (^{90}Sr and $^{239+240}Pu$). ^{137}Cs concentration in plants was determined in dry, preliminary washed and chopped plant samples, concentrations of ^{241}Am, ^{90}Sr and $^{239+240}Pu$ were determined in ash with further recalculation to the dry substance. In order to determine parameters of radionuclide transfer from soil to plants the authors determined accumulation coefficients whose values for ^{90}Sr, $^{239+240}Pu$ and ^{241}Am, in case of absence of qualitative values of specific activity (below the threshold of registration) in plant samples, were estimated approximately. The results of analysis and calculations are presented in table 4.26.

According to the analysis it was revealed that the maximum values of ^{137}Cs specific activity in plants of the studied area do not exceed 4 Bq/kg, ^{90}Sr ~ 30 Bq/ kg, and the content of transuranic elements is less than one ($^{239+240}Pu$ ~ 0,6 Bq/kg, ^{241}Am ~ 0,24 Bq/kg). Upon that, the accumulation coefficient, especially for radionuclides ^{137}Cs and $^{239+240}Pu$, is lower than the results for 1999-2008, that may be related both consolidation processes of radionuclides over time soil-absorbing complexes [80], and partly to the poor quality of previously conducted analytical works.

Thus, as a result of a critical analysis of international and experimental materials for the average accumulation coefficients of ^{137}Cs, ^{90}Sr, $^{239+240}Pu$ and ^{241}Am in this work it has been assumed to cinsider values based on quantitative and evaluative data for steppe forbs of studied area in 2009 as the most adequately reflecting the situation for this area. Average accumulation coefficient of ^{151}Sm and ^{99}Tc are selected on the basis of the IAEA (2009). Given the accepted values of accumulation coeffficient and the average specific activity of radionuclides in the soil, both for the whole area and for areas with higher concentrations of transuranic elements, calculated the average content of ^{137}Cs, ^{90}Sr, $^{239+240}Pu$, ^{241}Am, ^{151}Sm and ^{99}Tc in plants (Table 4.27).

Table 4.26

Values of specific activity and accumulation coefficient for radionuclides ^{137}Cs, ^{90}Sr, $^{239+240}Pu$ and ^{241}Am on the studied area (data of 2009)

No. of site (sampling point)	Radionuclide specific activity, Bq/kg								A_c			
	^{137}Cs		^{90}Sr		$^{239+240}Pu$		^{241}Am		^{137}Cs	^{90}Sr	$^{239+240}Pu$	^{241}Am
	vegetation	soil	vegetation	soil	vegetation	soil	vegetation	soil				
1	0.88±0.12	76.6±1.7	<1.8	-*	<0.04	9.7±0.3	<0.15	1.3±0.3	0.011	-*	<0.004	<0.12
2	3.72±0.16	66.6±1.5	6.2±1.8	-*	0.20±0.02	8.4±0.4	<0.15	2.9±0.4	0.056	-*	0.024	<0.05
3	1.26±0.11	50.8±1.4	3.8±1.1	18.1±7.1	0.15±0.03	9.5±0.3	<0.15	1.3±0.3	0.025	0.21	0.016	<0.12
4	1.57±0.14	67.5±1.5	6.1±1.1	-*	0.10±0.03	8.5±0.4	0.24±0.07	2.1±0.4	0.023	-*	0.012	0.11
5	0.52±0.11	110.7±2.1	<2.7	-*	<0.03	14.0±0.7	<0.15	6.3±0.5	0.005	-*	<0.002	<0.02
6	0.56±0.11	89.7±1.9	5.0±0.9	-*-	0.14±0.02	11.3±0.6	0.15±0.07	7.3±0.4	0.006	-*-	0.012	0.02
7	1.09±0.17	23.8±0.9	<5.3	12.9±6.4	0.26±0.03	14.2±0.7	0.19±0.10	3.8±0.4	0.046	<0.41	0.018	0.05
8	1.15±0.12	49.3±1.3	3.8±0.9	-*	0.59±0.04	6.2±0.3	<0.15	4.6±0.5	0.023	-*	0.095	<0.03
9	1.85±0.25	57.4±1.4	<10.1	-*	0.58±0.14	7.3±0.3	<0.15	3.1±0.4	0.032	-*	0.080	<0.05
10	0.81±0.11	27.4±1.0	<7.9	11.1±5.5	0.22±0.07	10.9±0.4	<0.15	0.9±0.2	0.030	<0.71	0.020	<0.17
11	0.55±0.13	87.0±2.5	29.9±5.5	-*	<0.13	11.0±0.5	<0.15	1.8±0.4	0.006	-*	<0.012	<0.08
12	0.21±0.08	67.3±1.6	<9.9	-*	0.18±0.05	8.5±0.4	<0.15	1.3±0.4	0.003	-*	0.021	<0.12
13	0.28±0.04	27.7±1.0	<2.7	9	<0.08	12.9±0.6	<0.15	0.5±0.2	0.010	<0.30	<0.006	<0.30
14	0.27±0.06	75.1±2.5	<3.7	-*	<0.04	9.5±0.4	<0.15	1.1±0.4	0.004	-*	<0.004	<0.14
Average value of K_a									0.02	0.21	0.03	0.06
-* no data available												

Table 4.27

SA calculation for artificial radionuclides in plants on the studied area

Average values	Artificial radionuclides					
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am	^{151}Sm	^{99}Tc
K_a	0.02	0.4	0.02	0.1	0.5	5
Average SA in soil, Bq/kg	17.2	10	4.1	0.8	1.4	0.3
Average maximal SA in soil, Bq/kg	-	-	15.4	3.7	-	-
Calculated SA in plants (average), Bq/kg	0.344	4	0.08	0.08	0.7	1.5
Calculated SA in plants (maximal average), Bq/kg	-	-	0.31	0.37	-	-
Permissible levels in plants, Bq/kg	74	111	~10*	~10*	~1000*	~1000*
Note: * – estimated permissible levels, see below.						

The results of calculation, in general, do not contradict the analytical data – the values of average specific activity for ^{137}Cs, ^{90}Sr, $^{239+240}$Pu, ^{241}Am in plants on all studied territory are lower than the content of radionuclides in plants sampled from the areas with increased level of soil contamination.

The content of radionuclides ^{137}Cs and ^{90}Sr in plants does not exceed maximal permissible level 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) [62].

The concentration of $^{239+240}$Pu, ^{241}Am, ^{151}Sm and ^{99}Tc in plants is not standardized, but based on the general level of radiotoxicity of each radionuclide one can suppose that permissible levels for $^{239+240}$Pu and ^{241}Am will be an order of magnitude lower, and the levels for ^{151}Sm and ^{99}Tc will be an order of magnitude higher than that for ^{90}Sr [58]. It should be noted that assumed permissible levels in plants for all above listed radionuclides are much higher than the average and even maximal average values for $^{239+240}$Pu and ^{241}Am and SA values.

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

The vegetation cover of the studied area mainly consists of dry steppe vegetation. The content of artificial radionuclide ^{137}Cs does not exceed 1%, ^{90}Sr – 4 % of the maximal permissible levels [62]. The concentration of $^{239+240}$Pu, ^{241}Am and ^{99}Tc in plants is less than 1%, ^{151}Sm – less than 0.1% of expected permissible levels. No anomalously high levels of specific activity of natural radionuclides have been detected in plants on the studied area.

Level of radionuclide contamination of vegetation cover mainly depends on the ability of plants themselves to accumulate radionuclides and on their ability to extract radionuclides which depends on soil characteristics. "Fresh" radionuclides in the first period of their presence in soil may be easier accessible for their consumption by plants than in the later periods after their aging. The aging intensity depends on physical-chemical properties of radionuclides. For example, ^{137}Cs is characterized by noticeable decrease of penetration into plants with time, whereas ^{90}Sr mobility in the soil-plant system changes slowly [80].

Assessment of radionuclide accumulation parameters made for plants on the studied area in the period from 1999 up to present, in terms of accumulation coefficients, did not show any noticeable variations in the radionuclide contamination of the vegetation cover. A little decrease in the accumulation values in 2009 as compared with the data for 1999-2008 was registered for ^{137}Cs and $^{239+240}Pu$ radionuclides.

The above data with higher degree of probability predict possible decrease in the level of radionuclide contamination of vegetation cover than its increase.

Therefore, the vegetation cover of the studied area in terms of its contamination at the present time and in the far future, in general, does not cause any danger for population and may be considered suitable for some types of agricultural works (including pasturing of domestic farm animals).

4.7 Assessment of the state of wild animals in terms of radionuclide contamination. Prognosis of tendencies in radionuclide contamination of animals

Investigations of fauna of the northern parts of the Semipalatinsk Test Site including concentration of radionuclides in the organisms of wild animals enable to obtain additional information in order to take a decision about possibility of transfer of considered areas into economic usage.

Investigations of radionuclide concentrations in the organisms of some animal species inhabiting on STS areas with various levels of radioactive contamination.

No investigations of radionuclide concentrations in the organisms of wild animals were carried out directly in the northern part of STS. There were investigations which studied ^{137}Cs concentration in organisms of some species of wild animals inhabiting on the STS territory. 11 jerboa species (*Allactaga saltator Ewersm*) inhabiting directly on the banks of the "Atomic lake" (level I), where ^{137}Cs concentration in soil is as high as $3*10^4$ Bq/kg, were examined. The concentration of artificial radionuclide ^{137}Cs in this group of animals varies in a wide range – from 40 to 125 Bq/kg (Figure 4.52).

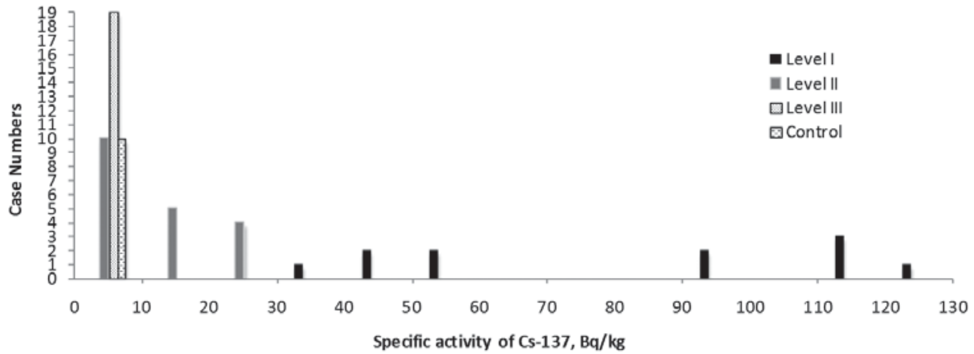


Figure 4.52. Histogram of frequency of ^{137}Cs concentrations in body of jerboa-jumpers at *Balapan* ground with different contamination levels and the territory not belonging to the STS (control)

In organisms of jerboa-jumpers inhabiting on the territory adjacent to the "Atomic lake" in a radius of 1-3 km (level II) in the places of catching, where ^{137}Cs concentration of in soil is as high as 50 Bq/kg, the ^{137}Cs concentration has lower values (<1-25 Bq/kg) (Figure 4.52). The ^{137}Cs specific activity in organisms of big jerboa (*Allactaga major Kerr*) inhabiting on the same territory (level II) is on average higher (<2-50 Bq/kg) (Figure 4.53).

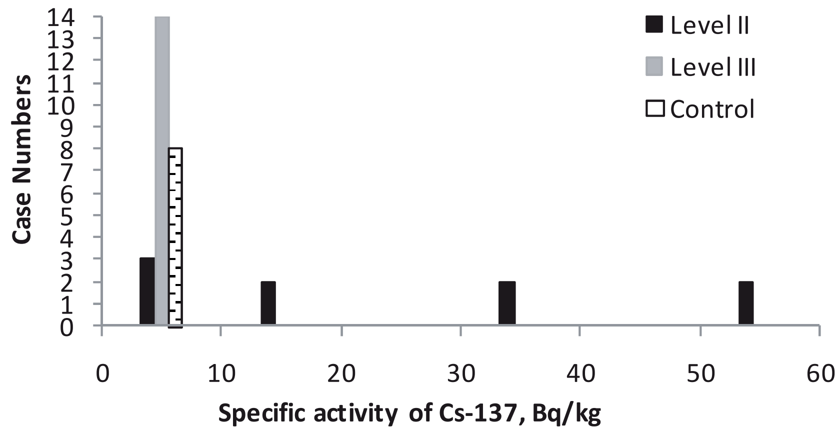


Figure 4.53. Histogram of frequency of ^{137}Cs concentration occurrence in body of great jerboa inhabiting *Balapan* ground

Artificial radionuclide ^{137}Cs was not detected in organisms of big jerboa caught on the background level (III level of the *Balapan* ground, 5-10 km from the "*Atomic lake*".)

An examination of mouse-like rodents showed that the ^{137}Cs concentration in the organisms of jerboa-jumpers inhabiting even directly on the banks of the "*Atomic lake*" did not exceed 125 Bq/kg. The ^{137}Cs concentration in the biological tissues of jerboa-jumpers inhabiting on the territory adjacent to the "*Atomic lake*" did not exceed 30 Bq/kg and the ^{137}Cs concentration in jerboa-jumpers caught on "clean" areas of the *Balapan* ground was below the detection threshold of the instrumentation used. In all cases the ^{137}Cs concentration did not exceed sanitary-hygiene standards [59], which for ^{137}Cs are equal to 160 Bq/kg in muscular and bone tissues.

Investigations of wild animals inhabiting the closest to the STS northern part radiation-hazardous object – the test ground "*4a*" (radiological weapons testing ground) showed that ^{137}Cs concentration was on average below the equipment's registration level and only in some cases was as high as 6 and 8 Bq/kg.

The ^{137}Cs concentration was also studied in the organism of the lizard *(Lacerta agilis Linn.)*. For example, ^{137}Cs concentration in the organisms of *Lacerta agilis Linn.* inhabiting on the territory adjacent to the radioactively-contaminated waterway of adit No. 176 of the test ground *Delegen* (level I) varies in the range 330-610 Bq/kg (Figure 4.54). Only in one lizard sample the specific activity was an order lower – 95 Bq/kg. Examination of the catching area showed that the highest level of radioactive contamination was registered in the bed of the waterway of adit No. 176. In this area the average ^{137}Cs concentration in soil was $2*10^5$ Bq/kg, and the maximal values were as high as $1.7*10^6$ Bq/kg.

Concentration of artificial radionuclide ^{137}Cs in the organisms of *Lacerta agilis Linn.* inhabiting the territory at some distance from the bank of the radioactively-contaminated waterway (level II) goes down to 50-10 Bq/kg.

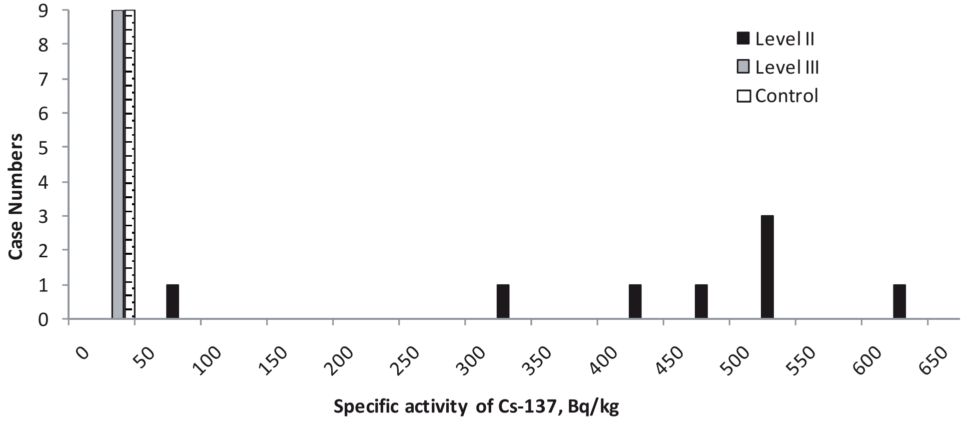


Figure 4.54. Histogram of frequency of ^{137}Cs concentration occurrence for *Lacerta agilis Linn.* inhabiting the banks of radioactively-contaminated waterway of adit No. 176 (level II) and at some distance from the radioactively-contaminated waterway (level III)

Currently, no data on the ^{90}Sr concentration in the organisms of wild animals inhabiting the STS territory is available, however, the investigations carried out on the STS test grounds [81] (the experiment is described in section 5.1.2.1) showed that in the organisms of sheep pastured in the conditions of radioactive contamination, the ^{90}Sr concentration in viscus and muscular tissues did not exceed permissible levels for ^{90}Sr content in meat, 50 Bq/kg, [59] even in case the animals only got vegetation with ^{90}Sr specific activity as high as $9.5*10^4$ Bq/kg and with total intake exceeding $3.3 *10^7$ Bq.

Assessment of radionuclide transfer to the organism of some commercial species of wild animals

As there are no data on the radionuclide concentration in the organisms of wild animals inhabiting on the studied territory, we made assessment of the radionuclide concentration in meat of commercial species based on the available data on radionuclides concentration in the environment (soil, plants).

Wild animals – objects of commercial use

Of 46 species of mammals inhabiting on the studied territory 11 refer to the objects of sport hunting, of which 9 are the objects of commercial hunting (table 4.28). Of 147 bird species 22 are objects of sport hunting, 11 – objects of commercial hunting and 28 are used for other purposes (besides hunting). 3 reptile species out of 7 inhabiting in the area are used for other purposes (besides hunting) [82].

Table 4.28

Mammals as commercial objects

Class	Objects of hunting		
	Species	Commercial hunting	Sport hunting
Predators	Corsac (*Vulpes corsac*) Fox (*V. vulpes*) Steppe polecat (*M. eversmani*) Badger (*Meles meles*)	+ + + +	+ + + +
Artiodactila	Siberian roedeer (*Capreolus pygargus*) Saiga (*Saiga tatarica*) Elk (*Alces alces*)	+	+ + +
Rodents	Steppe matmot (*Marmota bobak*) Water-rat (*Ondatra zibeticus*)	+ +	+ +
Lepus	Brown hair (*Lepus europeus*) Lepus (*L. timidis*)	+ +	+ +

Assessment of radionuclide transfer to the organisms of commercial species of wild animals in case of their inhabitance on the studied area

As there are practically no literature data on the coefficient (C_t) of radionuclide transfer to the organisms of wild animals it was decided to use maximal C_t values found in literature and used during preparation of the research materials for assessment of radionuclide transfer to the organisms of domestic animals (table 5.10) and Ct obtained during the experiment on the STS territory.

Thus, we used the following C_t values: 2.3*10^{-1} for ^{137}Cs, 1.1*10^{-4} for ^{90}Sr (maximal C_t values obtained during the experiment with agricultural animals (table 5.10)). For $^{239+240}$Pu and ^{241}Am we took the values 6.0*10^{-5} and 5*10^{-4}, respectively (beef, mutton). These maximal C_t values were used for domestic *Artiodactyla* animals; we carried out assessment of possible radionuclide contamination in the organisms of wild Artiodactyla – saiga, Siberian roe deer and elk.

The amounts of maximal possible annual and daily radionuclide transfer to the organisms of wild animals in case of their feeding on the studied area were calculated based on estimated radionuclide concentration in soil (table 5.5) and daily consumption of pasture grass. The results of calculation are presented in 4.29.

Table 4.29

The results of possible transfer of radionuclides to the organisms of wild animals on the studied area

Species	Average animal mass, kg	Consumption of pasture grass (per dry weight), kg	Transfer of radionuclides to the organism of 1 animal, Bq							
			^{137}Cs		^{90}Sr		$^{239+240}$Pu		^{241}Am	
			annual	daily	annual	daily	annual	daily	annual	daily
Elk	350-400	18	2.3*10^{3}	6.2	26280	72	539	1.5	526	1.4
Saiga	50-60	3.5	439	1.2	5110	14	105	0.29	102	0.28
Siberian roedeer	50-60	3	377	1.0	4380	12	90	0.25	88	0.24

Based on the data on average daily radionuclide transfer to the organisms of animals (table 4.29) and chosen C_t values, we calculated possible radionuclide concentrations in the organisms of wild animals. Table 4.30 presents the results of calculated radionuclide concentrations in meat of wild animals and permissible values of radionuclide concentrations in foodstuffs according to SanPiN 4.01.071.03 [59]. However, concentrations of $^{239+240}$Pu and ^{241}Am in foodstuffs are not standardized as in the NRB-99 (Annex P-2) the limit of annual intake with food is an order of magnitude lower for population than the similar value for ^{90}Sr ($^{239+240}$Pu –2.4*10^{3} Bq/ year, ^{241}Am – 2.7*10^{3} Bq/year, ^{90}Sr – 1.3*10^{4} Bq/year), and taking into account their high radiotoxicity one may suppose that permissible levels for them are an order of magnitude lower than for ^{90}Sr [58]. Permissible levels for $^{239+240}$Pu and ^{241}Am for this calculation are given in tables 4.30, 4.34.

The values of concentrations obtained during investigations are much lower than permissible radionuclide concentrations in foodstuffs according to SanPiN 4.01.071.03 [59].

Table 4.30

Prognosis values of specific radionuclide activity in meat of wild animals

Meat type	Expected concentration, Bq/kg (acceptable concentration, Bq/kg)			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Elk	1.42 (320)	7.9*10^{-3} (100)	8.9*10^{-5} (32)	7.2*10^{-4} (32)
Saiga	0.28 (320)	1.5*10^{3} (100)	1.7*10^{-5} (32)	1.4*10^{-4} (32)
Siberian roedeer	0.24 (320)	1.32*10^{-3} (100)	1.5*10^{-5} (32)	1.2*10^{-4} (32)

Assessment of radionuclide transfer to organisms of commercial species of wild animals inhabiting areas adjacent to radioactively-contaminated objects

The nearest radioactively-contaminated objects located close to the studied area are test grounds *"4a"* and *Opytnoye Pole*. In this calculation we consider possibility of eating by commercial animals with wide range of activity (10-15 km) of radioactively-contaminated grass from contaminated areas from the test ground "*4a*" located very close to the studied area. On the territory of ground "*4a*" were determined 30 spots of local radioactive contamination of average sizes 50×100 m and total area 4.5 km^2. The average radionuclide concentrations in soil of these local spots are 10^6 Bq/kg for ^{90}Sr, 10^3 Bq/kg for ^{137}Cs and 10^3 Bq/kg for ^{241}Am.

The conventional grazing zones determined based on the radius of animals' activity during feeding fully include the ground "*4a*" (Figure 4.55). The initial data used in calculations are given in table 4.31.

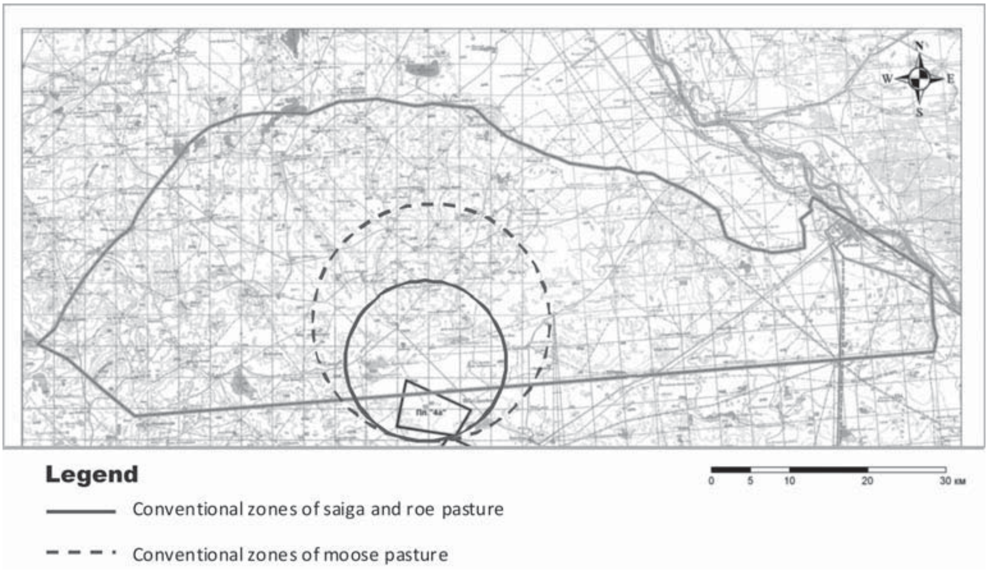


Figure 4.55. Conventional grazing zones used in the forecast

Table 4.31

Initial data used for assessment of possible activity in meat of wild animals

Species	Consumption of pasture grass (per dry weight), kg	Radius of activity during feeding, km	Grazing area, sq km	Area of local contaminated spots of ground "*4a*"		Consumption of pasture grass, kg	
				sq km	% of grazing zone	From conventionally clean areas	From conventionally contaminated areas
Elk	18	15	706.9	4.5	0.64	17.88	0.12
Saiga	3.5	10	314.2	4.5	1.4	3.45	0.049
Siberian roedeer	3	10	314.2	4.5	1.4	2.6	0.042

Table 4.31 shows the fraction of pasture grass of the daily fodder which animal can consume during feeding on the radioactively-contaminated area and on the "clean" areas. A potential concentration of radionuclides in grass on local spots of radioactively-contaminated grounds of *"4a"* were calculated based of the coefficients of radionuclides transfer from soil to motley grass (table 5.4). As the radionuclide concentration in the grass on the "clean" area we used calculated values for motley grass of the studied area given in i. 5.1 (table 5.5). The radionuclide concentrations in the grass on the conventional grazing areas are given in table 4.32.

Table 4.32

Radionuclide concentrations in the fodder on the conventional grazing areas

Radionuclide type	Radionuclide concentrations in the fodder, Bq/kg	
	Conventionally contaminated area	Conventionally clean area
^{137}Cs	$2.0*10^{1}$	$3.4*10^{-1}$
^{90}Sr	$4.0*10^{5}$	4.0
^{241}Am	$1.0*10^{2}$	$8.0*10^{-2}$

The average daily radionuclide transfer to the organism of wild animals taking into account their grazing on ground "*4a*" (table 4.33) is based on the obtained data (tables 4.31, 4.32).

Table 4.33

Average daily radionuclide transfer to the organism of wild animals

Species	Day average intake of radionuclides per 1 animal, Bq		
	^{137}Cs	^{90}Sr	^{241}Am
Elk	8.5	48072	13.4
Saiga	2.2	19614	5.2
Siberian roedeer	1.72	16810	4.4

Based on the average concentrations and accepted C_t values we calculated prognosis values of specific activity of radionuclides in meat of wild animals in case of their inhabiting on the adjacent radioactively-hazardous object – ground "*4a*" (table 4.34).

Table 4.34

Calculated values of radionuclides specific activity in meat of wild animals

Species	Expected concentration, Bq/kg (acceptable concentration, Bq/kg)		
	^{137}Cs	^{90}Sr	^{241}Am
Elk	2.0 (320)	5.29 (100)	$6.7 \cdot 10^{-3}$ (32)
Saiga	0.5 (320)	2.16 (100)	$2.6 \cdot 10^{-3}$ (32)
Siberian roedeer	0.4 (320)	1.85 (100)	$2.2 \cdot 10^{-3}$ (32)

Calculated specific activity of ^{137}Cs in meat of wild animals inhabiting on the adjacent radioactively-hazardous object – ground *"4a"* is 2 times higher than the values on the studied area, this figure is 3 times higher for ^{90}Sr and for an order of magnitude higher for ^{241}Am. However, even in this case the calculated values are much lower than permissible radionuclide concentrations in foodstuffs according to SanPiN 4.01.071.03 [59].

Analysis of the above data shows that presence of radionuclides in organisms of wild animals is directly caused by their inhabiting on the radioactively-hazardous areas (dumps of the "*Atomic lake*", banks of the radioactively-contaminated waterway). It should be noted that radionuclide concentrations in the organisms of jerboa-jumpers from the most contaminated areas are at an acceptable level. This result can be explained by a spotted pattern of radionuclide contamination of the STS territory and wide range of life activity of studied animals. For example, the radius of moving of jerboa jumpers in search of food can exceed 5 km. Due to these factors the percentage of radioactively-contaminated fodder in the ration of these animals does not cause high radionuclide concentrations in their organisms. This fact explains low radionuclide concentrations (both calculated and factual) in the organisms of wild animals inhabiting on the radioactively-hazardous object – ground *"4a"*, the area with spotted radionuclide contamination.

A quite different picture is observed for ^{137}Cs concentrations in the organism of lizards. Due to their small radius of movement (40 m, [83]) the ^{137}Cs concentration in the organism of this species is rather high (610 Bq/kg) in case of direct inhabitance on the radioactively-contaminated area. The ^{137}Cs concentration sharply decreases at a distance of about two hundred meters away from the radioactively-contaminated waterway.

From this it can be said with certainty that the concentration of artificial radionuclides in the bodies of wild animals inhabiting STS "northern" territories will be at an acceptable level, even with their migration from the nearby test grounds of STS, as almost all animals (mammals) which are the objects of hunting, the radius of activity during the feeding is more than 5-7 km, as for artiodactyls – 15-20 km and more. Animals with a small radius of activity, dwelling on the radiation-hazardous locations of test sites *Opytnoe Pole* and *"4a"*, because of their ecological features will not be able to reach the northern part of the test site.

Predicted values of radionuclide concentrations in meat of wild commercial animals, obtained through research, are far below the allowable values for radionuclide content, despite the fact that the forecast took into account the possibility of grazing in the radiation-dangerous object – the site *"4a"*.

Thus, the fauna of the studied area is not dangerous to people when using its representatives that are hunted for food.

Chapter 5
Assessment of radiation characteristics of products produced on the territory under investigation

5.1 Agricultural products

5.1.1 Theoretical estimation of contamination levels of crop products based on the experimenal data on soil contamination

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

$$K_n = \frac{C_{veg}}{C_{soil}}$$, where

products:

C_t – is the transfer coefficient;
C_{veg} – is the radionuclide concentration in vegetation (Bq/kg);
C_{soil} – is the radionuclide concentration in soil.

5.1.1.1 Choice of transfer coefficients

Choice of transfer coefficient based on literature data

In 2009 the IAEA published the report "Quantification of radionuclide transfer into terrestrial and freshwater environments for radiological assessments" containing the coefficients of radionuclide transfer into crop production (Table 5.1) [79].

Table 5.1

Transition coefficient of ^{137}Cs, ^{90}Sr and $^{239+240}$Pu and ^{241}Am into crop products

Product type	Transfer coefficient			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Grain crops	$4.3*10^{-2}$	$1.6*10^{-1}$	$4.7*10^{-5}$	$1.7*10^{-2}$
Maize	$2.3*10^{-2}$	$4.0*10^{-1}$	$3.0*10^{-6}$	$9.6*10^{-4}$

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

In order to estimate coefficients of ^{137}Cs transfer into crop products the authors generalized and analyzed the data for 7 Russian oblasts for 1987-1993. The data analysis showed that for the same type of soil the accumulation of radionuclides depended on soil granulometric composition, and the values of radionuclide accumulation differed by a factor of 1.5-7 [84]. Maximal values of ^{137}Cs transfer coefficients for light and medium loamy soils are given in Table 5.2.

Table 5.2

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

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

Choice of transfer coefficients on the basis of the STS experimental data

The investigations carried out on the steppe part of the STS territory (sites *Balapan*, Experimental field, STS northern part) enabled to obtain the values of radionuclide transfer from soil to plants for the territory covered by motley grass (Table 5.3).

Table 5.3

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

Radionu-clide	N	C_t	Radionu-clide	N	C_t
^{137}Cs	108	2*10^{-2}	$^{239+240}$Pu	59	2.0*10^{-2}
^{90}Sr	106	4.0*10^{-1}	^{241}Am	15	1.0*10^{-1}

Radionuclide migration into crop products within the STS territory has not been studied.

Accepted transfer coefficients

As no investigations of radionuclide migrations from soil cover into grain and truck crops have been carried out on the STS territory, in order to make prognosis we used maximal C_t values available in literature (Table 5.4). In order to estimate radionuclide concentration in hay the authors used coefficients of radionuclide transfer into steppe motley grass obtained in the investigations on the STS territory (table 5.4).

Table 5.4

Transition coefficient of ^{137}Cs, ^{90}Sr и $^{239+240}Pu$ and ^{241}Am into crop products accepted for forecast

Product type	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 crop				
Hay (steppe motley grass)	$2.0*10^{-2}$	$4.0*10^{-1}$	$2.0*10^{-2}$	$1.0*10^{-1}$
Maize	$2.9*10^{-1}$	$4.0*10^{-1}$	$3.0*10^{-6}$	$2.9*10^{-1}$
Leaf vegetables				
Cabbage, spinach, celery leaves, lettuce	$1.8*10^{-1}$	2.0	$2.8*10^{-4}$	$2.4*10^{-4}$
Legumes				
Beans, peas	$4.3*10^{-2}$	1.5	$6.7*10^{-5}$	$4.8*10^{-4}$
Vegetables				
Tomatoes, cucumbers, paprika, aubergine	$9.4*10^{-2}$	1.5	$8.5*10^{-5}$	$7.9*10^{-4}$
Tuberous roots (roots)				
Potatoes	$1.3*10^{-1}$	$2.0*10^{-1}$	$9.9*10^{-4}$	$9.1*10^{-4}$
Beet and carrot (roots)	$1.3*10^{-1}$	1.3	$1.7*10^{-3}$	$8.6*10^{-4}$

5.1.1.2 Assessment of radionuclide concentration in crop production

In order to estimate contamination of crop products the authors used the data on average radionuclide concentration in soils of the area under investigation and coefficients of radionuclide transfer into different types of crops accepted based on the analysis of literature data and the results of studies on the STS territory (table 5.5).

The following average concentrations of radionuclides were accepted for the investigated area at the over-all survey: 17.2 Bq/kg – for ^{137}Cs, 10 – for ^{90}Sr, 4.1 – for $^{239+240}Pu$, and 0.8 – for ^{241}Am. These values were obtained as a result of analysis of extensive radiological data.

The radionuclide concentration was calculated with the formula:

$$C_{calc} = C_{soil}\, X\, C_t, \text{ where}$$

C_{calc} is the calculated concentration (Bq/kg);
C_{soil} is the average radionuclide concentration in soil (Bq/kg);
C_t is the transfer coefficient.

Table 5.5 shows the values of calculated concentration of radionuclides in crop products, in case they are produced on the area under investigation, and permissible concentrations of radionuclides in food products according to SanPiN of 4.01.071.03 [59]. The permissible levels for $^{239+240}Pu$ and ^{241}Am in tables 5.5, 5.6 are calculated following the procedure used in s. 4.7.

Table 5.5

Estimated concentrations of radionuclides in crop products in case of their production on the studied area (calculation is based on average radionuclide concentrations in the soil of the studied area)

Product type	Estimated concentration, Bq/kg (permissible concentration, Bq/kg)			
	^{137}Cs	^{90}Sr	$^{239+240}Pu$	^{241}Am
Grain crops				
Rye	1.9 (70)	1.6 (40)	$1.9*10^{-4}$ (4.0)	$1.4*10^{-2}$ (4.0)
Wheat	1.9 (70)	1.6 (40)	$1.9*10^{-4}$ (4,0)	$1.4*10^{-2}$ (4.0)
Barley	2.9 (70)	1.6 (40)	$1.9*10^{-4}$ (4,0)	$1.4*10^{-2}$ (4.0)
Oats	3.6 (70)	1.6 (40)	$1.9*10^{-4}$ (4.0)	$1.4*10^{-2}$ (4.0)
Fodder crops				
Hay (steppe motley grass)	$3.4*10^{-1}$ (74*)	4 (111*)	$8.2*10^{-2}$ (11.1)	$8*10^{-2}$ (11.1)
Maize	5.0 (70)	4.0 (40)	$1.2*10^{-5}$ (4.0)	$2.3*10^{-1}$ (4,0)
Leaf vegetables				
Cabbage, spinach, celery leaves, lettuce	3.1 (600)	20 (200)	$1.1*10^{-3}$ (20)	$1.9*10^{-4}$ (20)
Legumes				
Beans. peas	$7.4*10^{-1}$ (50)	15 (60)	$2.7*10^{-4}$ (6.0)	$3.8*10^{-4}$ (6.0)
Vegetables				
Tomatoes, cucumbers, paprika, aubergine	1.6 (600)	15 (200)	$3.5*10^{-4}$ (20)	$6.3*10^{-4}$ (20)
Tuberous roots (roots)				
Potatoes	2.2 (120)	2.0 (40)	$4.1*10^{-3}$ (4.0)	$7.3*10^{-4}$ (4.0)
Beets and carrot (roots)	2.2 (600)	13 (200)	$7.0*10^{-3}$ (20)	$6.9*10^{-4}$ (20)

**Note*: maximal permissible concentrations for fodder crops (grass, hay) were established by the Ministry of Agriculture of the Republic of Kazakhstan (^{137}Cs – 74 Bq/kg, ^{90}Sr –111 Bq/kg) [62]

On the studied territory, the survey revealed a zone with concentration of transuranium elements exceeding the MPC. Based on the average concentrations of radionuclides in soil in this zone ($^{239+240}Pu$ – 15.4 Bq/kg, ^{241}Am – 3.0 Bq/kg) we calculated concentrations of the above radionuclides in the crop products. The results of calculations are shown in table 5.6.

Table 5.6

Estimated concentrations of radionuclides in crop products in case of their production in the zone of concentration of transuranium elements exceeding MPC.

Product type	Estimated concentration, Bq/kg (permissible concentration, Bq/kg)	
	$^{239+240}Pu$	^{241}Am
Grain crops		
Rye	$7.2*10^{-4}$ (4.0)	$5.1*10^{-2}$ (4,0)
Wheat	$7.2*10^{-4}$ (4.0)	$5.1*10^{-2}$ (4,0)
Barley	$7.2*10^{-4}$ (4.0)	$5.1*10^{-2}$ (4,0)
Oats	$7.2*10^{-4}$ (4.0)	$5.1*10^{-2}$ (4,0)
Fodder crops		
Hay (steppe motley grass)	$3.1*10^{-1}$ (11,1)	$3.0*10^{-1}$ (11,1)
Maize	$4.6*10^{-5}$ (4,0)	$8.7*10^{-1}$ (4,0)
Vegetables		
Cabbage, spinach, celery leaves, lettuce	$4.3*10^{-3}$ (20)	$7.2*10^{-4}$ (20)
Legumes		
Beans, peas	$1.0*10^{-3}$ (6.0)	$1.4*10^{-3}$ (6,0)
Vegetables		
Tomatoes, cucumbers, paprika, aubergine	$1.3*10^{-3}$ (20)	$2.4*10^{-3}$ (20)
Tuberous roots (roots)		
Potatoes	$1.5*10^{-2}$ (4.0)	$2.7*10^{-3}$ (4,0)
Beet and carrot (roots)	$2.0*10^{-2}$ (20)	$2.6*10^{-3}$ (20)

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

5.1.2 Theoretical assessment of contamination levels for livestock products

Estimation of radionuclide concentration in the domestic farm products is based on the transfer coefficients (ratio of the radionuclide concentration in the livestock products to the daily ration intake).

5.1.2.1 Choice of Transfer coefficients

Choice of transfer coefficients based on literature data

The contamination of livestock products can be calculated based on the fodder contamination using transfer coefficients taken from the IAEA reference book "On the values of parameters used to calculate migration of radionuclides in the environments of middle latitudes" published in 1994 [85].

Table 5.7

Coefficients of ^{137}Cs and ^{90}Sr transfer into livestock products [86]

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

The IAEA documents published in 2009 [79] contain transfer coefficients for radionuclide transfer into livestock products (table 5.8).

Table 5.8

Coefficients of ^{137}Cs, ^{90}Sr and $^{239+240}Pu$ transfer into farm products [84]

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

The Republic of Belarus having wide experience in farming on radioactively contaminated areas issued a guide-book on agroindustrial business in the conditions of radioactive pollution which gives the coefficients of ^{137}Cs and ^{90}Sr transfer from fodder to the farm products obtained by the Byelorussian Institute of Radiology (table 5.9) [86]. These coefficients are recommended to be used to calculate radionuclide concentration in animal products in the Russian Federation [87].

Table 5.9

Coefficients of ^{137}Cs and ^{90}Sr transfer into domestic farm products (Byelorussian Institute of Radiology) [86, 87]

Product	Transfer coefficient	
	^{137}Cs	^{90}Sr
Cattle		
Milk	$7.4*10^{-3}$	$1.4*10^{-3}$
Meat (beef)	$4.0*10^{-2}$	$4.0*10^{-4}$
Sheep		
Meat (mutton)	$1.5*10^{-1}$	$1.0*10^{-3}$
Poultry		
Chicken	4.5	$2.0*10^{-3}$
Eggs	$3.5*10^{-2}$	$3.2*10^{-2}$

The English authors [88] showed that for sheep the coefficient of ^{137}Cs transfer from the contaminated fodder into muscles was $5.7*10^{-1}$, into kidneys – $5.0*10^{-1}$, and into lever – $3.3*10^{-1}$. The authors from the Czech Republic determined that the coefficient of ^{137}Cs transfer in the fodder-milk chain was equal to $4.8*10^{-3}$, and for ^{90}Sr it was $2.4*10^{-3}$. In the fodder-beef chain the coefficients were $2.1*10^{-3}$ and $6.9*10^{-3}$, respectively [89]. The contamination of wet hay on natural grounds (England) of 550 Bq/kg gave the coefficient of ^{137}Cs transfer to the beef equal to $2.3*10^{-2}$ and the transfer coefficient to milk was $1.1*10^{-2}$ [90]. In 1977-1986, in Great Britain the coefficient of ^{137}Cs transfer from fodder to milk for livestock with pasture holding was equal to $4.0*10^{-3}$, and for ^{90}Sr – $1.0*10^{-3}$ [91]. In Great Britain the coefficient of ^{137}Cs transfer from global fallouts to milk from different types of fodder was estimated as follows: from hay – $2.0*10^{-3}$ and from green mass – $4.0*10^{-3}$. The measurements for green mass after Chernobyl fallouts gave $1.4*10^{-2}$ [92].

Choice of transfer coefficients based on STS studies

Brief description of the experiment. In order to obtain the transfer coefficients into livestock products on the STS territory the scientists carried out in-situ experiments with livestock grazing in the conditions of radioactive contamination [81]. As experimental animals the two-year-old sheep of Kazakh coarse-haired fat-tail (Edilbay) breed were chosen.

As the experimental site it was decided to choose a radioactively contaminated ecosystem of the waterway of tunnel No. 176 located in the southern part of Delegen site. The animals were brought from the farm located in the area not subjected to radioactive contamination (Maysky rayon, Pavlodar oblast). The animals grazed on radioactively contaminated pastures for 20, 30, 60, 70, 130 and 150 days.

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

Recommended transfer coefficients based on the experimental results. The data on average daily transfer of radionuclides into organisms of animals and their concentration in tissues and organs were used to calculate coefficients of radionuclide transfer from ration into tissues and organs of livestock animals. The maximal values of transfer coefficients (C_t) are given in table 5.10.

Table 5.10

Maximal values for coefficients of ^{137}Cs and ^{90}Sr transfer into sheep's tissues and organs obtained in the experiment

Organ (tissue) type	C_t	
	^{137}Cs	^{90}Sr
Meat	$2.3*10^{-1}$	$1.1*10^{-4}$
Heart	$1.2*10^{-1}$	$2.0*10^{-4}$
Lever	$1.2*10^{-1}$	$1.1*10^{-4}$
Kidneys	$1.5*10^{-1}$	$2.4*10^{-4}$
Lungs	$9.8*10^{-1}$	$3.2*10^{-4}$
Bones	$8.4*10^{-1}$	$3.4*10^{-1}$

Accepted transfer coefficients

The analysis of experimental and literature data showed that the coefficients of ^{137}Cs transfer into milk and meat of cows, sheep and goats practically had the same values. The difference was observed for ^{137}Cs transfer into chicken meat (2 orders of magnitude) and eggs (3 orders of magnitude). The coefficients of ^{90}Sr transfer into the milk of cows, sheep, goats and goat meat were practically of the same value. The coefficients of ^{90}Sr transfer into meat of cows differed from that for meat of chicken and eggs by 2 orders of magnitude and for mutton – by 3 orders of magnitude. The coefficients for $^{239+240}$Pu and ^{241}Am transfer into some types of animal products are given in one of the IAEA documents [79].

On the base of the analysis, it was decided to use for prognosis the maximal concentrations of radionuclides for different types of livestock products presented in literature. In order to calculate possible concentrations of ^{137}Cs and ^{90}Sr in mutton, the maximal transfer coefficients obtained in the STS experiment were taken. As a result, the following transfer coefficients were adopted (table 5.11).

Table 5.11

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

Product type	Transfer coefficient			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Cattle				
Milk	$2.3*10^{-2}$	$2.8*10^{-3}$	$1.0*10^{-5}$	$1.0*10^{-5}$
Meat (beef)	$5.1*10^{-2}$	$8.0*10^{-3}$	$6.0*10^{-5}$	$5.0*10^{-4}$
Sheep				
Milk	$7.7*10^{-2}$	$5.6*10^{-2}$	$1.0*10^{-4}$	-
Meat (mutton)	$2.3*10^{-1}$	$1.1*10^{-4}$	$5.3*10^{-5}$	$1.1*10^{-4}$
Goats				
Milk	$1.3*10^{-1}$	$2.8*10^{-2}$	-	$6.9*10^{-6}$
Meat	$4.8*10^{-1}$	$3.0*10^{-3}$	-	-
Poultry				
Meat	12.0	$8.0*10^{-2}$	-	-
Eggs	$4.5*10^{-1}$	$8.8*10^{-1}$	-	-

5.1.2.2 Assessment of radionuclide concentration in livestock products

$$C_{prod} = C_{ration}\ X\ C_t \quad \tilde{N}_{prod} = \tilde{N}_{ration} \times \hat{E}\ddot{i}$$, where

In order to estimate radionuclide concentrations in domestic farm animal products it is necessary to know their concentration in the daily ration of the animals and the transfer coefficients from ration to livestock products. The radionuclide concentration in livestock products (C_{prod}) is calculated according to the formula:

C_{calc} is the calculated concentration (Bq/kg);

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

C_t is the transfer coefficient.

Based on the data on estimated radionuclide concentration in vegetable fodder obtained using the average values of radionuclide concentration in soil (steppe motley grass (table 5.5)) and information on daily consumption of pasture grass [3], scientists calculated maximal possible annual (based on the conditions of year-round pasture usage) and daily radionuclide intake in the organism of pastured animals. The data are presented in table 5.12.

Table 5.12

Calculated potential transfers of radionuclides into organisms of domestic animals on the studied area (based on known average radionuclide concentration in soil)

Domestic animals	Average mass of an animal, kg	Daily consumption rate of pasture grass (per dry weight), kg	Transfer of radionuclides in the organism of one animal, Bq							
			^{137}Cs		^{90}Sr		$^{239+240}$Pu		^{241}Am	
			annual	daily	annual	daily	annual	daily	annual	daily
Horse	350-400	18	$2.3*10^{3}$	6.2	$2.6*10^{4}$	72	539	1.48	525.6	1.44
Cow	400	16	$2.0*10^{3}$	5.5	$2.3*10^{4}$	64	479	1.31	467.2	1.28
Sheep	50-60	2,5	314	0.86	$3.6*10^{3}$	10	75	$2.0*10^{-1}$	73	0.2
Goat	50-60	2	251	0.69	$2.9*10^{3}$	8	60	$1.6*10^{-1}$	58.4	0.16
Poultry	4-6	0.1*	69.3	0.19	58.4	0.16	$6.9*10^{-3}$	$1.9*10^{-5}$	$5.1*10^{-1}$	$1.4*10^{-3}$
**Note:* Daily ration for poultry is normalized to the weight of dry wheat (grain)										

Table 5.13 shows the results of estimated concentration of radionuclides in domestic farm animal products in case of their production on the studied territory and maximal permissible concentrations of radionuclides in foodstuffs according to SanPiN of 4.01.071.03 [59]. The maximal permissible concentrations of $^{239+240}$Pu and ^{241}Am in such farm products were calculated using the same procedure as in 4.7 (for meat of wild animals).

Table 5.13

Estimated values of specific radionuclide activity in farm animal products (calculation is based on average radionuclide concentrations in soil)

Product type	Estimated concentration, Bq/kg			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Cattle				
Milk	$1.27*10^{-1}$ (100)	$1.8*10^{-1}$ (25)	$1.3*10^{-5}$ (2.5)	$5.4*10^{-7}$ (2.5)
Meat (beef)	$2.81*10^{-1}$ (160)	$5.1*10^{-1}$ (50)	$7.9*10^{-5}$ (5.0)	$6.4*10^{-4}$ (5.0)
Sheep				
Milk	$6.6*10^{-2}$ (100)	$5.6*10^{-1}$ (25)	$2.0*10^{-5}$ (2.5)	-
Meat (mutton)	$2.0*10^{-1}$ (160)	$1.1*10^{-3}$ (50)	$1.1*10^{-5}$ (5.0)	$2.2*10^{-5}$ (5.0)

Goats				
Milk	$8.9*10^{-2}$ (100)	$2.2*10^{-1}$ (25)	-*	$1.1*10^{-6}$ (2.5)
Meat	$3.3*10^{-1}$ (160)	$2.4*10^{-2}$ (50)	-	-
Poultry				
Meat	2.3 (180)	$1.3*10^{-2}$ (80)	-	-
Eggs	$8.5*10^{-2}$ (80)	$1.4*10^{-1}$ (50)	-	-
* *Note:* No calculated values are given as no Ct data are available				

The estimated specific activity of radionuclides in horse-flesh is not given as literature sources contain no data on radionuclide transfer from daily fodder to 1 kg of meat.

Estimated concentrations of radionuclides in farm animal products in case of livestock pasturing only in the zone of high concentrations of transuranium elements in soil ($^{239+240}Pu$ – 15.4, ^{241}Am – 3.7 Bq/kg) were calculated based on average values of radionuclide concentrations in soil known for this zone (tables 5.14, 5.15).

Table 5.14

Calculated possible transfers of radionuclides $^{239+240}$Pu and ^{241}Am into animals in case of their pasturing in the zone of high concentrations of transuranium elements

Livestock	Average mass of an animal, kg	Consumption rate of pasture grass (per dry weight), kg	Radionuclide transfer into the organism of 1 animal, Bq			
			$^{239+240}$Pu		^{241}Am	
			annual	daily	annual	daily
Horse	350-400	18	$2.0*10^{3}$	5.5	1971	5,4
Cow	400	16	$1.8*10^{3}$	4.9	1752	4.8
Sheep	50-60	2.5	281	0.77	274	0.75
Goat	50-60	2	224	0.62	219	0.6

Table 5.15

Calculated values of specific activity of radionuclides in the domestic farm animal products (calculations were based on the maximal values of radionuclide concentration in soil)

Product type	Estimated concentration, Bq/kg (permissible concentration, Bq/kg)	
	$^{239+240}$Pu	^{241}Am
Cattle		
Milk	$4.9*10^{-5}$ (2.5)	$2.0*10^{-6}$ (2.5)
Meat (beet)	$2.9*10^{-4}$ (5.0)	$2.4*10^{-3}$ (5.0)

Sheep		
Milk	$7.7*10^{-5}$ (2.5)	-
Meat(mutton)	$4.0*10^{-5}$ (5.0)	$8.3*10^{-5}$ (5.0)
Goats		
Milk	-*	$4.1*10^{-6}$ (2.5)
Meat	-	-
**Note:* No predicted values are given as Ct data are not available		

The obtained values of potential radionuclide concentration in the meat of domestic animals grazed in the zone of high concentration of transuranium elements do not exceed MPC, though calculations were made only for the animals grazed only on radioactively contaminated areas. In real conditions the animals are not pastured only in the zone with high radionuclide concentrations during a long period of time because of low productivity of steppe pastures and low percentage of their usage (40-50 %) [95].

The above investigations therefore show that agricultural production of both crop and livestock products in the "northern" part of the STS territory will not contain radionuclides in amounts exceeding the established standards in spite of the fact that the exaggerated values for the parameters have been used in the calculations. Thus, such products used as foodstuff will not cause any harm to human health.

5.2 Industrial production

There are two operating open pits on the STS territory where crushed stone for construction is mined (deposits Kovylnoye and Pridorozhnoye). In order to determine the radionuclide concentration we performed gamma spectrometric analysis of samples from ready-for-delivery lots assessing specific activity of natural radionuclides for them. The results of the analysis are given in Table 5.16 below.

Table 5.16

Specific activity of radionuclides

Deposit	**Specific activity of radionuclides, Bq/kg**						
	^{40}K	**^{232}Th**	**^{226}Ra**	**^{241}Am**	**^{137}Cs**	**^{60}Co**	**^{152}Eu**
Kovylnoye	900	50	40	<1	<2	<1	<1
Pridorozhnoye	1000	50	40	<1	<2	<1	<1

$$A_{eff} = A_{Ra} + 1,3 A_{Th} + 0,09 A_K$$

The results of gamma spectrometric analysis show that the main contribution to the radiation dose is made by natural radionuclides (K, Th, Ra), whereas the fraction of artificially produced radionuclides is negligibly small.

In order to estimate the quality of production (crushed stone for construction works) one must use the formula given in NRB-99:

Effective specific activity of natural radionuclides in crushed stone of the studied deposits comprised 186 Bq/kg (deposit Kovylnoye) and 195 Bq/kg (deposit Pridorozhnoye). The NRB-99 gives the following classification of construction materials (table 5.17):

Table 5.17

Classification of construction materials

Class of construction materials	Use of construction materials	Effective specific activity, Bq/kg
I	Materials used for construction and maintenance of living and public buildings	≤370
II	Materials used in road construction within the territory of settlements, perspective built-up areas and in construction of production premises	≤740
III	Materials used in road construction outside populated centers	≤1500

Analyzed crushed stone therefore belongs to the class I materials.

Chapter 6

Assessment of dose loads on population and personnel living and working on the studied area

6.1 Description of possible scenarios for behaviour of population and personnel at the studied area

Any activity performed at contaminated land may impose risk of exposure to radiation on people, whereas products grown and produced on such lands may contain radionuclides and be harmful for people when they use them. In order to estimate doses, the authors [93] used an approach based on the scenario "subsistence economy farmer". This approach enables to estimate annual effective dose for population and personnel living and working on the STS "northern" areas. The expected annual effective dose is a normalizable quantity, and it should not exceed 1 μSv per year for population [58]. The exposure of population and personnel is determined in scenarios which enable to estimate usage of contaminated areas with account for possible exposure pathways.

In order to estimate dose loads produced by artificial radionuclides on people living in the northern part of STS, the following exposure pathways which make the main contribution to the total exposure dose were considered:

– External exposure from the soil surface layer (5 cm) by artificial radionuclides;
– Internal exposure from inhalation of contaminated dust;
– Internal exposure from food consumed.

It is necessary to take into account that there are other ways of exposure which include:

– External exposure from the contaminated soil stick to the skin;
– Internal exposure from unintentional oral intake of contaminated soil;
– Possible additional internal exposure from inhalation of radionuclides from most contaminated STS areas.

It is supposed that radioactive contamination spreads over the area uniformly and its distribution in the soil horizon is exponential.

This research does not consider such exposure pathways as:

– external exposure from cosmic radiation;

– external and internal exposure from radon and thoron daughter products;
– external and internal exposure from natural radionuclides in upper soil.

Our dose estimates did not take into account individual radiation protection means or reduction of dose rate from external radiation due to snow cover over soil in winters.

Also, the authors did not take into account doses of internal exposure by radionuclides from water intake by people living and working on the contaminated area as the concentration of artificial radionuclides is several orders of magnitude lower than the maximal permissible concentrations for drinking water (see i.4.4 *State of water objects* above). Contents of artificial radionuclides in water is < 0.07 Bq/kg for ^{90}Sr, < 0.5 Bq/kg for ^{137}Cs, < 0.015 Bq/kg for $^{239+240}Pu$ and < 15 Bq/kg for ^{3}H, which is 1-3 orders of magnitude below the maximal allowable concentrations. Even for maximal concentrations of artificial radionuclides in the water objects in the STS northern areas the contribution of drinking water into the integral dose does not exceed 5%.

It is assumed that local population eats crop and animal products produced in the area. The following crop products grow there: leaf vegetables, legumes, fruit vegetables, and tuberous roots (potatoes, beets, carrots). The livestock products produced on the territory: meat (horse, cattle, sheep, poultry), milk (kumiss) [i.1.2.2.1 *Agricultural production* (livestock farming, fodder production, plant growing)]. Doses gained from imported products were not taken into account in the estimates of internal exposure from food.

Effective dose rates were estimated by summing up of the expected effective dose from external exposure gained during a calendar year and expected effective dose of internal exposure due to intake of artificial radionuclides during the same year.

The effective exposure dose for a man living in the area is expressed as the sum of partial doses E_{efi} for all *i*-th factors of radiation impact:

$$E_{ef}=E_{\gamma}+E_{\beta}+E_{skin}+E_{inh}+E_{mg}+E_{ing} \text{ , where}$$

E_{γ} – dose of external gamma-exposure;
E_{β} – dose of external beta- exposure;
E_{skin} – dose of external gamma-exposure from contaminated soil stick to the skin;
E_{inh} – dose of internal gamma-exposure caused by inhalation intake of radionuclides;
E_{mg} – dose of internal exposure from oral intake of radionuclides with food;
E_{ing} – dose of internal exposure from unintentional transfer of radionuclides to the digestion system.

Dose of external beta- and gamma-exposure from soil

Effective dose of external exposure by β- and γ- radionuclides was determined from the formula:

$$E_\gamma = A_s \cdot B_{sg} \cdot t \cdot K_{tc}\text{ , where}$$

E_γ – is the effective dose of external γ – radiation;
t – exposure time;
B_{sg} – dose coefficient equal to effective dose rate of γ – radiation of surface-contaminated soil at a height of 1 m, $Sv \cdot m^2/s \cdot Bq$ [94];
K_{tc} – conversion coefficient of equivalent dose into effective dose [95];
A_s – contamination density for upper (0-5 cm) soil, Bq/m^2.

$$A_s = A_m \cdot \rho \cdot h,\ (\text{Бк/м}^2)\text{ , where}$$

A_m – is the specific activity of radionuclides in upper soil, Bq/kg;
ρ – density of soil cover, kg/m^3;
h – depth of the surface soil layer (0-5 cm).

$$E_\beta = (1/2 \cdot A_m \cdot n_i \cdot \exp(-\mu_{sEi} \cdot 1.3 \cdot 10^{-4} / \mu_{si}) \cdot e_\beta \cdot t \cdot W_t \cdot K_{\beta 0}\text{, where}$$

E_β – is the effective dose of external beta–exposure;
T – exposure time;
W_t = 0.01– weighted coefficient for skin;
$K_{\beta 0}$ = 0.5 – coefficient of beta-exposure reduction by clothes;
A_m – specific activity of radionuclides in upper soil, Bq/kg;
n_i – yield of beta-particles of average energy, part./decay;
$\exp(-\mu_{sEi} \cdot 1.3 \cdot 10^{-4})$ – correction on reduction of the number of beta-particles in air;
μ_{si} – mass coefficient of attenuation of β-particles in soil;
e_β – dose equivalent to the unit fluence of beta-particles of Ei average energy E (NRB-99)

Dose of internal gamma-exposure caused by inhalation of radionuclides

Estimating doses of internal exposure from inhalation intake of artificial radionuclides from contaminated surface soil, we considered 2 cases:

Effective annual dose from intake of artificial radionuclides contained in the surface soil layer of the STS "northern" area through inhalation (through respiratory apparatus) was determined by the formula:

$$E_{ih} = A_m \cdot V \cdot e_{inh} \cdot \rho_{sus}\text{, where}$$

A_m – is the specific soil activity, Bq/kg;
V – volume of inhaled air with which radionuclides are transferred to organism during a calendar year – (NRB-99), m^3/year;
e – dose coefficient of the *i*-th isotope when it transfers to the organism through inhalation (NRB-99), Sv/Bq.
ρ_{su} – average annual air dustiness, kg/m^3.

Average annual air dustiness was taken equal to $1\cdot10^{-7}$ kg/m^3 [96]. In order to estimate the expected effective dose, it was assumed that in the places of people's activities air dustiness increased by a factor of 10, that is up to $1\cdot10^{-6}$ kg/m^3.

Effective annual dose from possible inhalation intake of radionuclides from other more contaminated areas of the STS territory taking into account wind transfer of radioactive dust is determined as:

$$E_{inh}=q\cdot V\cdot e_i\cdot\eta \text{ , where}$$

q – is the average annual (near-surface) volume activity of the radionuclide, Bq/m^3;
V – volume of inhaled air with which radionuclide gets into the organism during a calendar year (NRB-99), m^3/year;
e_{inh} – dose coefficient of the *i*-th isotope when it transfers to the organism through inhalation (NRB-99), Sv/Bq;
η – elongation of the wind rose in a given direction, % [i.4.5 *State of air basin*];

$$\eta=n/n_0 \text{ [94], where}$$

n – repeatability of the wind direction in a given azimuthal sector for the real wind rose;
n_0 – the same picture for the round wind rose.

Calculation of the average annual (near-surface) volume activity caused by the wind rise and further transfer of dust particles was made using analytical solution of the semi-empirical equation of turbulent diffusion [74]:

$$q\,(x,y,z) = \frac{aA}{\sqrt{2\pi}\,(1+m)k_1 b_y x^2}\, exp\left(-\frac{y^2}{2b_y^2x^2} - \frac{u_1(z^{1+m}+z_0^{1+m})}{(1+m)^2k_1x}\right) l_0 \left[\frac{2u_1(zz_0)^{\frac{1+m}{2}}}{(1+m)^2k_1x}\right], \text{ where}$$

α – intensity of winds rise, 1/s;
A – surface density of soil contamination, Bq/m^2;
m – a parameter characterizing atmosphere stability;
κ_1 – coefficient of turbulent diffusion for $z=z_1$, m^2/s;
b_y – is an empirical constant (0.08);
u_1 – wind speed at height z_1=1 m;
I_0 – Bessel's function;
z_0 – height of roughness of the underlying surface, m;
z – source height, m;
x – distance from the source, m.

To calculate the wind rise coefficient the authors [74] used the following formula:

$$\alpha = \frac{2\cdot10^{-4}}{z_0^{1.4}} \text{ , where}$$

z_0 - is the height of roughness of the underlying surface, cm.

In this case, roughness of the underlying surface (z_0) is a parameter characterizing the degree of maturity of vegetation cover.

Internal exposure dose caused by intake of food produced on the contaminated area

Effective dose of radionuclides intake with food was determined by the formula:

$$E_{mg} = A_m \cdot q \cdot e_{dt}, \text{ where}$$

A_m – is the radionuclide content in the foodstuffs, Bq/kg;
q – annual intake of the *i*-th isotope with food per year, kg/year;
e_{dt} – dose coefficient of the *i*-th isotope in case of its intake through digestive tract (from NRB-99), Sv/Bq.

Internal exposure dose caused by unintentional oral intake of contaminated soil

This method enables to take into account the internal exposure dose which a member of population gets in case of unintentional swallowing of particles of contaminated soil. It occurs in case of oral intake of particles of contaminated soil from the hands' skin. The masses of swallowed soil are estimated to be 8.3, 18 and 44 g/year for adults, children and infants from 1 to 5 years, respectively [96].

The effective dose of unintentional swallowing of particles of contaminated soil is determined as:

$$E_{ing} = M_{annual} \cdot A_m \cdot e_{dt}, \text{ where}$$

M_{annual} – is annual unintentional swallowing of particles of contaminated soil, g/year;
A_m – specific activity of radionuclides in the surface soil layer, Bq/kg;
e_d – dose coefficient of the *i*-th isotope in case of its intake through the digestive tract given in the table in Appendix P2 NRB-99, Sv/Bq.

External exposure dose from contaminated soil penetrated onto skin

In these calculations we neglect the external exposure of skin surface covered by clothes from contaminated soil. Open parts of the skin (50% of the total area) are subjected to irradiation with γ– and β-particles of radionuclides present in the dust layer (0.01 cm) covering this part of the skin. The effective dose of the exposure by radionuclides present in the dust layer is equal to:

$$E_{skin} = W_t \cdot 0{,}5 \cdot 1/2 \cdot \rho \cdot A_m \cdot t \cdot n_i \cdot e_i \cdot T, \text{ where}$$

A_m – radionuclide content in the surface soil layer, Bq/kg;
n – yield of particles, particles/decay;
0.5 – correction for the fraction of exposed part of the skin;
½ – correction for the fraction of particles moving in the skin direction;
t – density of the soil layer taken equal to 0.01 cm [96];

ρ – dust density taken equal to $0.5 \cdot 10^{-3}$ kg/cm^3;
e_i – equivalent dose per unit fluence (Table 8.4 NRB-99), Sv·cm^2;
W_t – weighted coefficient of the organ (skin), 0.01;
T – exposure time during a year, s.

Initial data

The investigations carried out by the Institute detected the following artificial radionuclides: ^{137}Cs, ^{90}Sr, $^{239+240}$Pu, ^{241}Am, ^{151}Sm, ^{99}Tc, ^{241}Pu, and ^{238}Pu in the subsurface layer on the territory of the STS northern part (i.2.1 "*Theoretical assessment of possible radionuclide contamination of the area. Main radionuclides and isotope ratios*"). Experimentally determined average and maximal contents of artificial radionuclides in the subsurface (5 cm) soil layer are presented in the table below (table 6.1).

Table 6.1

Average concentrations of artificial radionuclides and increased concentrations of transuranium elements in subsurface soil of the northern part of STS

^{137}Cs	^{90}Sr	^{99}Tc	^{151}Sm	^{238}Pu	$^{239+240}$Pu	^{241}Pu	^{241}Am
Average concentrations, Bq/kg							
17.2	10	0.3	1.4	0.1	4.1	3.1	0.8
Maximal concentrations, Bq/kg							
17.2	10	0.3	1.4	0.35	15.4	11.6	3.0

In order to estimate dose loads caused by additional inhalation intake of artificial radionuclides, we considered the most highly contaminated STS areas, namely, grounds for radiological weapons explosions (*"4a"* and *"4"*), *Opytnoye Pole* (P-1, P-5, P-7) and traces of radioactive fallouts from the surface nuclear explosions. At the estimations we determined the areas which could make the highest contribution to the dose load for people living in the STS northern part –sectors No.1, No.2 and No.17 of the ground "*4a*". Sectors No.1 and No.2, grounds for radiological weapons explosions, are directly located on the studied area (figure 2.5 coloured block).

Initial data for estimation of the impact of the most contaminated grounds on the STS territory are given in tables 6.2-6.4 [77].

Table 6.2

Initial data for estimation of additional dose loads on the population of the STS northern areas from the most contaminated grounds of radiological weapons explosions

RW-testing grounds	Specific activity of radionuclides in upper soil, Bq/kg						
Gr. "*4a*"	^{241}Am	^{137}Cs	^{60}Co	^{154}Eu	^{152}Eu	^{90}Sr	$^{239+240}$Pu
Sector 1	56	$1.3 \cdot 10^2$		88		$1.3 \cdot 10^6$	$2.1 \cdot 10^3$
Sector 2	82	$4. \cdot 10^3$				$1.1 \cdot 10^5$	
Sector 17*	$5.8 \cdot 10^3$	$1.4 \cdot 10^3$	186	$3.5 \cdot 10^3$	$2.3 \cdot 10^5$	$5.8 \cdot 10^8$	
Note: *- sample taken at the depth of 10 cm							

Table 6.3

Initial data for calculation of average annual volume activity

m	k_1, m²/s	u_1, m/s	I_0	z_0, m	z, m	α, 1/c	η,%
1	0.2	4	1	0.1	1	$7.5 \cdot 10^{-11}$	2.5

Table 6.4

Average annual volume activity of radionuclides

x, km	Near-surface (volume) activity					
	^{241}Am	^{137}Cs	^{60}Co	^{154}Eu	^{90}Sr	$^{239+240}$Pu
Sector 1						
0	$4.6 \cdot 10^{-7}$	$1.1 \cdot 10^{-6}$	$7.3 \cdot 10^{-7}$	$1.1 \cdot 10^{-2}$	$1.7 \cdot 10^{-5}$	$4.6 \cdot 10^{-7}$
1	$2.4 \cdot 10^{-7}$	$5.69 \cdot 10^{-7}$	$3.8 \cdot 10^{-7}$	$5.6 \cdot 10^{-3}$	$9.2 \cdot 10^{-6}$	$2.4 \cdot 10^{-7}$
Sector 2						
0	-	$8.7 \cdot 10^{-7}$	$2.5 \cdot 10^{-8}$	$6.01 \cdot 10^{-7}$	$1.2 \cdot 10^{-2}$	-
1	-	$4.5 \cdot 10^{-7}$	$1.3 \cdot 10^{-8}$	$3.1 \cdot 10^{-7}$	$6.4 \cdot 10^{-3}$	-
Sector 17						
1	$2.5 \cdot 10^{-5}$	$6.3 \cdot 10^{-6}$	$8.02 \cdot 10^{-7}$	$1.5 \cdot 10^{-5}$	$5.0 \cdot 10^{-1}$	-
5	$5.08 \cdot 10^{-6}$	$1.2 \cdot 10^{-6}$	$1.6 \cdot 10^{-8}$	$3.1 \cdot 10^{-6}$	$3.1 \cdot 10^{-1}$	-

The values of specific activity of radionuclides in the products of livestock and crop farming are calculated using the coefficients of radionuclide transfer presented in the IAEA documents [79, 85]. The coefficients of radionuclide transfer in the steppe motley grass were calculated by the IRSE specialists in the investigations of possible radionuclide concentrations in farming products in case of their production on the studied areas. In order to estimate radionuclide concentration in the horse-meat, we used maximal coefficient of radionuclide transfer from plants to meat and milk for sheep and goats (i.5 "*Assessment of radiation characteristics of products produced on the studied territory*").

In order to estimate dose loads from intake of artificial radionuclides through food chains, we used expected radionuclide concentrations in the products of livestock and crop farming produced on the studied area (see tables 6.5-6.8).

Table 6.5

Calculated values of specific activity of radionuclides in the livestock farming products for average concentrations of artificial radionuclides in the surface soil layer

Product type	Specific activity, Bq/kg			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Cattle				
milk	$1.3\cdot10^{-1}$	$1.8\cdot10^{-1}$	$1.3\cdot10^{-5}$	$5.4\cdot10^{-7}$
meat (beef)	$2.8\cdot10^{-1}$	$5.1\cdot10^{-1}$	$7.9\cdot10^{-5}$	$6.4\cdot10^{-4}$
20% fat sour cream	$2.1\cdot10^{-2}$	$3.1\cdot10^{-2}$	$2.1\cdot10^{-6}$	$1.2\cdot10^{-7}$
low-fat curd	$7.8\cdot10^{-2}$	$1.1\cdot10^{-1}$	$7.8\cdot10^{-6}$	$3.6\cdot10^{-7}$
Horse meat				
Meat	$3.5\cdot10^{-1}$	2	$3.7\cdot10^{-4}$	$3.1\cdot10^{-3}$
Koumiss (fermented mare's milk)	$8\cdot10^{-1}$	$1.7\cdot10^{-1}$	$6.2\cdot10^{-4}$	$4.3\cdot10^{-5}$
Sheep				
Meat (mutton)	$2\cdot10^{-1}$	$1.1\cdot10^{-3}$	$1.1\cdot10^{-5}$	$2.2\cdot10^{-5}$
Poultry				
Meat	2.3	$1.3\cdot10^{-2}$	-	-
Eggs	$8.5\cdot10^{-2}$	$1.4\cdot10^{-1}$	-	-

Table 6.6.

Calculated concentrations of radionuclides in the crop farming products in case of their production on the studied area for average concentrations of artificial radionuclides in the surface soil

Product type	Specific activity, Bq/kg			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Leaf vegetables				
Cabbage	3.1	20	$1.1\cdot10^{-3}$	$1.9\cdot10^{-4}$
Legumes				
Beans, peas	$7.4\cdot10^{-1}$	15	$2.7\cdot10^{-4}$	$3.8\cdot10^{-4}$
Fruit vegetables				
Tomatoes Cucumbers Onions	1.6	15	$3.5\cdot10^{-4}$	$6.3\cdot10^{-4}$
Tuberous roots				
Potatoes	2.2	2.0	$4.1\cdot10^{-3}$	$7.3\cdot10^{-4}$
Beet, carrot (root vegetables)	2.2	13	$7.0\cdot10^{-3}$	$6.9\cdot10^{-4}$

Table 6.7

Calculated values of specific activity of radionuclides in the livestock farming products for minimal concentrations of artificial radionuclides in the surface soil layer

Product type	Specific activity, Bq/kg	
	$^{239+240}Pu$	^{241}Am
Cattle		
milk	$4.9 \cdot 10^{-5}$	$2.5 \cdot 10^{-6}$
meat (beef)	$2.9 \cdot 10^{-4}$	$2.9 \cdot 10^{-3}$
20% fat sour cream	$9.8 \cdot 10^{-4}$	$1.5 \cdot 10^{-6}$
low-fat curd	$2.9 \cdot 10^{-5}$	$2.0 \cdot 10^{-6}$
Horse meat		
Meat	$3.3 \cdot 10^{-4}$	$2.7 \cdot 10^{-3}$
Koumiss (fermented mare's milk)	$5.5 \cdot 10^{-5}$	$3.8 \cdot 10^{-6}$
Sheep		
Meat (mutton)	$4.0 \cdot 10^{-5}$	$8.3 \cdot 10^{-5}$

Table 6.8

Calculated concentrations of radionuclides in the crop farming products in case of their growing in the area of increased concentrations of transuranium elements

Product type	Specific activity, Bq/kg	
	$^{239+240}Pu$	^{241}Am
Leaf vegetables		
Cabbage	$4.3 \cdot 10^{-3}$	$7.2 \cdot 10^{-4}$
Legumes		
Beans Peas	$1.0 \cdot 10^{-3}$	$1.4 \cdot 10^{-3}$
Fruit vegetables		
Tomatoes Cucumbers Onions	$1.3 \cdot 10^{-3}$	$2.4 \cdot 10^{-3}$
Tuberous vegetables		
Potatoes	$1.5 \cdot 10^{-2}$	$2.7 \cdot 10^{-3}$
Beat, carrot (root vegetables)	$2.0 \cdot 10^{-2}$	$2.6 \cdot 10^{-3}$

We assumed that grown and consumed amount of products corresponded to the minimal standards of consumption of the main foodstuffs by the population of Kazakhstan [97]. Taking into account the real conditions of living in the STS northern areas, we introduced some changes in the standards of foodstuffs consumption and chose the products which could be produced and consumed by the local population (table 6.9).

Table 6.9

Amount of consumed foodstuffs grown and produced on the northern part of STS

Foodstuffs	Standards for foodstuffs consumption, kg/year			
	11-year-old child	infant	man	woman
Peas, beans	1	-	2.6	2
Potatoes	66.5	5	110.9	94.1
Cabbage	13.6	0.5	31.6	25
Carrot	19.2	5	23	18.2
Onion	8.5	-	26	20.6
Tomatoes	3.1	0.5	6.2	4.9
Cucumbers	3.1	0.3	6.2	4.9
Beat	3.1	0.5	6.2	4.9
Beef	12.3	2	30	25
Horse-meat	1.6	-	40	32
Mutton	5.7	-	40	32
Chicken	4.6	0.5	10	8
Milk, liters	150	180	300	150
Cream, 20% fat content	2.8	0.5	30	18
Koumiss (fermented mare's milk), liters	-	-	60	50
Cottage cheese	4.4	4.4	30	20
Eggs	205	40	200	250

6.1.1 Dose calculation for various scenarios of behaviour for population and personnel at the northern part of STS

Estimating doses loads for the people living in the winter houses in the northern part of the STS territory we considered the following behavior scenarios:

1. Agricultural scenario (farmer, shepherd).
2. Residential scenario.
3. Scientific-research scenario.

6.1.1.1 Agricultural scenario

This scenario considers two types of activities on the contaminated area.

1) This scenario considers doses received by a farmer from the contaminated area. It is supposed that the farmer spends only part of his working time on the contaminated area (8 hours). The farmer’s dose was calculated in the assumption

that he spends time on his area doing physical works, plowing and doing some other less active works (spring-summer period). As a farmer we considered only an adult. It is supposed that the farmer eats products of livestock and crop farming grown and produced on the contaminated area.

The expected effective dose for a farmer working on the contaminated area is a sum of doses obtained in the following ways:

– External exposure from ground;
– External exposure from contaminated soil stick to the skin;
– Internal exposure from inhalation of contaminated dust particles;
– Internal exposure from unintentional oral intake of contaminated soil;
– Internal exposure from foodstuffs grown on the contaminated area.

This scenario did not take into account the external exposure dose obtained during the time spent inside the premises.

The results of calculation of annual dose load for a farmer living on the contaminated area for average values of specific activity of artificial radionuclides and increased concentrations of transuranium elements in the surface soil layer are given in tables 6.11-6.12.

2) This scenario only considers doses received by a shepherd during pasturing of domestic animals on the contaminated area. The working day of a shepherd in winter (3 months, December –February): the main part of his working time, about 12 hours, he spends outside in the open air, of which 7-8 hours he works with animals. The lunch break lasts about 1-2 hours, the remaining 2 hours he cleans premises and looks after ill animals. The other 10 hours are spent on evening rest and sleeping.

In the summer-spring period the shepherd spends all light day in the open air – it is about 16-18 hours. When animals rest, he also has a rest. He takes cooked food with him and rests on the ground for about 5-6 hours lying on the waterproof cape-tent.

When autumn comes and the light day gets shorter animals stay on the pasture from 8 in the morning till 5 in the evening (about 9 hours). The lunch break lasts about 1 hour (from 13 to 14) during which the shepherd usually lies on the ground. The shepherd has practically the same order of the day in spring (March-April).

The expected effective dose for a shepherd working on the contaminated area is a sum of doses received in the following ways:

– External exposure from ground;
– External exposure from contaminated soil stick on the skin;
– Internal exposure from inhalation of contaminated dust particles;
– Internal exposure from unintentional oral intake of contaminated soil;
– Internal exposure from foodstuffs grown on the contaminated area.

The results of calculation of annual dose load of a farmer living on the contaminated area for average values of specific activity of artificial radionuclides and increased concentrations of transuranium elements in the surface soil layer are given in tables 6.11-6.12.

6.1.1.2 Residential scenario

The residential scenario considers doses for population living and working on the contaminated area. In this scenario we assume that:

– the farmer and his family has a house in the contaminated area, they grow cattle, sheep, poultry and crops (leaf vegetables, legumes, fruit vegetables, tuberous roots);
– the farmer's family consists of four people (two adults, one infant of under 1 year and 1 child of 11) who eat products of crop and livestock farming produced on the studied area;
– the farmer looks after and pastures domestic animals. The farmer's wife keeps the household, looks after the vegetable garden, helps in looking after young and ill animals;
– an infant under 1 year is always with his mother and does not spend much time on the open ground;
– adults' works in the garden cause less contact with contaminated ground than children's plays;
– all members of the family occasionally intake ground when there are particles of contaminated soil on their skin (unintentional swallowing of contaminated dust particles).

The time intervals of exposure of people living on that contaminated area are given in table 6.10.

The effective annual dose load for a farmer working on the contaminated area is a sum of doses received in the following ways:

– external exposure from ground;
– external exposure from contaminated soil stick onto the skin;
– internal exposure from inhalation of contaminated dust particles;
– internal exposure from unintentional oral intake of contaminated soil;
– Internal exposure from foodstuffs grown on the contaminated area.
– External exposure during time spent inside the premises.

Table 6.10

Time spent under the action of contamination according to the residential scenario

Factor	Measurement units	Value
Time spent in the garden	hour/year	1100 (adult, infant) 1820 (child)
Time spent on the "disturbed" ground area	hour/year	160 (adult) 540 (child) 160 (infant)
Time spent on manual dinging and playing in the garden	hour/year	120 (adult 180 (child) 80 (infant)

Factor	Measurement units	Value
Time spent with contaminated soil on the skin	hour/year	280 (adult) 615 (child) 240 (infant)
Time spent inside the house	hour/year	7100 (adult, infant) 5610 (child)

The results of calculation of the dose load received by the farmer and his family according to the residential scenario for average values of specific activity of artificial radionuclides and increased concentrations of transuranium elements in the surface soil layer are given in tables 6.11-6.12.

6.1.1.3 Scientific-research scenario (geological prospecting, research works)

The following works are carried out on the studied territory:

– Geological survey of the area;
– Scientific survey of the area.

Geological survey of the territory is carried out from April to November, in the field season. The geological party stays in the area for several days without a break. For the period of field works a field camp is made, and in the daytime, from 8 in the morning till 8 in the evening, works in the open air are carried out with 1 hour for lunch break, in the hot time of the year the break increases to 3 hours, and due to the increase of the light day, the working time in the evening increases.

Research scientific work of the STSis carried out 9-10 months a year. The trips are made 3-5 times a week, they last one day or several days with staying in caravans. Sampling is made according to the safety rules – in gloves, respirators, special clothes and with a dosimeter. The foodstuffs, drinking and technical water are brought to the place.

Any works on the STS territory are carried out with a license and radiological control. Research works are seasonal, and people practically all day long stay in the open air and are subjected to the action of not only external but also internal exposure due to aerosols.

The dose load on a person working as per this scenario is a sum of doses received in the following ways:

– external exposure from ground;
– external exposure from contaminated soil stick on the skin;
– internal exposure from inhalation of contaminated dust particles;
– internal exposure from unintentional oral intake of contaminated soil.

The results of calculation of dose load of a worker according to the research scenario of behaviour on the contaminated area for average values of specific activity of artificial radionuclides and increased concentrations of transuranium elements in the surface soil layer are given in tables 6.11-6.12.

Table 6.11

Calculated annual effective dose for different scenarios of population and personnel behavior for average concentrations of artificial radionuclides in the surface soil layer

<table>
<tr><th colspan="5">Agricultural scenario</th></tr>
<tr><th rowspan="2">Exposure pathways</th><th colspan="4">Annual effective dose, µSv/year</th></tr>
<tr><th colspan="2">Farmer</th><th colspan="2">Shepherd</th></tr>
<tr><td>External exposure from contaminated soil surface</td><td colspan="2">$2.01\cdot10^{-4}$</td><td colspan="2">$3.72\cdot10^{-4}$</td></tr>
<tr><td>External exposure from contaminated soil got on the skin</td><td colspan="2">$7.33\cdot10^{-8}$</td><td colspan="2">$1.35\cdot10^{-7}$</td></tr>
<tr><td>Internal exposure caused by intake of foodstuffs grown and produced on the studied area</td><td colspan="2">$1.16\cdot10^{-1}$</td><td colspan="2">$1.16\cdot10^{-1}$</td></tr>
<tr><td>Internal exposure from inhalation of radionuclides</td><td colspan="2">$6.66\cdot10^{-3}$</td><td colspan="2">$1.23\cdot10^{-3}$</td></tr>
<tr><td>Internal exposure from unintentional oral intake of contaminated soil</td><td colspan="2">$8.90\cdot10^{-6}$</td><td colspan="2">$1.62\cdot10^{-5}$</td></tr>
<tr><td>Additional internal exposure from inhaled intake of radionuclides from the STS contaminated areas</td><td colspan="2">$2.4\cdot10^{-3}$</td><td colspan="2">$4.4\cdot10^{-3}$</td></tr>
<tr><td>Total</td><td colspan="2">$1.19\cdot10^{-1}$</td><td colspan="2">$1.22\cdot10^{-1}$</td></tr>
<tr><th colspan="5">Residential scenario</th></tr>
<tr><td rowspan="2">Exposure pathways</td><td colspan="4">Annual effective dose, µSv/year</td></tr>
<tr><td>Man</td><td>Woman</td><td>Child</td><td>Infant</td></tr>
<tr><td>External exposure from contaminated soil surface</td><td>$9.52\cdot10^{-5}$</td><td>$9.52\cdot10^{-5}$</td><td>$1.75\cdot10^{-4}$</td><td>$9.24\cdot10^{-5}$</td></tr>
<tr><td>External exposure from contaminated soil got on the skin</td><td>$3.76\cdot10^{-8}$</td><td>$3.76\cdot10^{-8}$</td><td>$1.54\cdot10^{-8}$</td><td>$6.02\cdot10^{-9}$</td></tr>
<tr><td>External exposure inside the premises</td><td>$1.94\cdot10^{-4}$</td><td>$1.94\cdot10^{-4}$</td><td>$1.53\cdot10^{-4}$</td><td>$1.94\cdot10^{-4}$</td></tr>
<tr><td>Internal exposure caused by intake of foodstuffs grown and produced on the studied area</td><td>$1.16\cdot10^{-1}$</td><td>$9.03\cdot10^{-2}$</td><td>$4.99\cdot10^{-2}$</td><td>$6.75\cdot10^{-3}$</td></tr>
<tr><td>Internal exposure from inhalation of radionuclides</td><td>$2.0\cdot10^{-3}$</td><td>$2.0\cdot10^{-3}$</td><td>$1.28\cdot10^{-3}$</td><td>$2.47\cdot10^{-4}$</td></tr>
<tr><td>Internal exposure from unintentional oral intake of contaminated soil</td><td>$2.64\cdot10^{-5}$</td><td>$2.64\cdot10^{-5}$</td><td>$5.72\cdot10^{-5}$</td><td>$1.40\cdot10^{-4}$</td></tr>
<tr><td>Additional internal exposure from inhaled intake of radionuclides from the STS contaminated areas</td><td>$6.0\cdot10^{-3}$</td><td>$6.0\cdot10^{-3}$</td><td>$4.2\cdot10^{-3}$</td><td>$8.2\cdot10^{-4}$</td></tr>
<tr><td>Total</td><td>$1.24\cdot10^{-1}$</td><td>$9.86\cdot10^{-2}$</td><td>$5.44\cdot10^{-2}$</td><td>$8.24\cdot10^{-3}$</td></tr>
<tr><th colspan="5">Scientific-research scenario</th></tr>
<tr><td rowspan="2">Exposure pathways</td><td colspan="4">Annual effective dose, µSv/year</td></tr>
<tr><td colspan="2">Geological survey</td><td colspan="2">Scientific survey</td></tr>
<tr><td>External exposure from contaminated soil surface</td><td colspan="2">$5.96\cdot10^{-5}$</td><td colspan="2">$6.62\cdot10^{-5}$</td></tr>
<tr><td>External exposure from contaminated soil got on the skin</td><td colspan="2">$2.17\cdot10^{-8}$</td><td colspan="2">$2.41\cdot10^{-8}$</td></tr>
<tr><td>Internal exposure from inhalation of radionuclides</td><td colspan="2">$1.33\cdot10^{-3}$</td><td colspan="2">$1.66\cdot10^{-3}$</td></tr>
<tr><td>Internal exposure from unintentional oral intake of contaminated soil</td><td colspan="2">$2.64\cdot10^{-5}$</td><td colspan="2">$2.64\cdot10^{-5}$</td></tr>
<tr><td>Additional internal exposure from inhaled intake of radionuclides from the STS contaminated areas</td><td colspan="2">$4.2\cdot10^{-3}$</td><td colspan="2">$5.8\cdot10^{-3}$</td></tr>
<tr><td>Total</td><td colspan="2">$5.62\cdot10^{-3}$</td><td colspan="2">$7.56\cdot10^{-3}$</td></tr>
</table>

Table 6.12

Calculated annual effective dose for different scenarios of population and personnel behavior for increased concentrations of transuranium elements in the surface soil layer

<table>
<tr><th colspan="5">Agricultural scenario</th></tr>
<tr><th rowspan="2">Exposure pathways</th><th colspan="4">Annual effective dose, µSv/year</th></tr>
<tr><th colspan="2">Farmer</th><th colspan="2">Farmer</th></tr>
<tr><td>External exposure from contaminated soil surface</td><td colspan="2">$2.03\cdot10^{-4}$</td><td colspan="2">$3.76\cdot10^{-4}$</td></tr>
<tr><td>External exposure from contaminated soil got on the skin</td><td colspan="2">$7.06\cdot10^{-7}$</td><td colspan="2">$5.25\cdot10^{-7}$</td></tr>
<tr><td>Internal exposure caused by intake of foodstuffs grown and produced on the studied area</td><td colspan="2">$1.81\cdot10^{-1}$</td><td colspan="2">$1.81\cdot10^{-1}$</td></tr>
<tr><td>Internal exposure from inhalation of radionuclides</td><td colspan="2">$1.41\cdot10^{-2}$</td><td colspan="2">$2.61\cdot10^{-2}$</td></tr>
<tr><td>Internal exposure from unintentional oral intake of contaminated soil</td><td colspan="2">$2.56\cdot10^{-5}$</td><td colspan="2">$4.66\cdot10^{-5}$</td></tr>
<tr><td>Total</td><td colspan="2">$1.95\cdot10^{-1}$</td><td colspan="2">$2.07\cdot10^{-1}$</td></tr>
<tr><th colspan="5">Residential scenario</th></tr>
<tr><td rowspan="2">Exposure pathways</td><td colspan="4">Annual effective dose. µSv/year</td></tr>
<tr><td>Man</td><td>Woman</td><td>Child</td><td>Infant</td></tr>
<tr><td>External exposure from contaminated soil surface</td><td>$1.18\cdot10^{-6}$</td><td>$1.18\cdot10^{-6}$</td><td>$2.18\cdot10^{-6}$</td><td>$1.15\cdot10^{-6}$</td></tr>
<tr><td>External exposure from contaminated soil got on the skin</td><td>$1.46\cdot10^{-7}$</td><td>$1.46\cdot10^{-7}$</td><td>$5.99\cdot10^{-8}$</td><td>$2.34\cdot10^{-8}$</td></tr>
<tr><td>External exposure inside the premises</td><td>$2.41\cdot10^{-6}$</td><td>$2.41\cdot10^{-6}$</td><td>$1.90\cdot10^{-6}$</td><td>$2.41\cdot10^{-6}$</td></tr>
<tr><td>Internal exposure caused by intake of foodstuffs grown and produced on the studied area</td><td>$1.81\cdot10^{-1}$</td><td>$1.14\cdot10^{-1}$</td><td>$5.36\cdot10^{-2}$</td><td>$3.77\cdot10^{-3}$</td></tr>
<tr><td>Internal exposure from inhalation of radionuclides</td><td>$4.22\cdot10^{-2}$</td><td>$4.22\cdot10^{-2}$</td><td>$2.71\cdot10^{-2}$</td><td>$5.21\cdot10^{-3}$</td></tr>
<tr><td>Internal exposure from unintentional oral intake of contaminated soil</td><td>$6.67\cdot10^{-5}$</td><td>$6.67\cdot10^{-5}$</td><td>$1.45\cdot10^{-4}$</td><td>$3.53\cdot10^{-4}$</td></tr>
<tr><td>Total</td><td>$2.03\cdot10^{-1}$</td><td>$1.36\cdot10^{-1}$</td><td>$8.78\cdot10^{-2}$</td><td>$1.79\cdot10^{-2}$</td></tr>
<tr><th colspan="5">Scientific-research scenario</th></tr>
<tr><td rowspan="2">Exposure pathways</td><td colspan="4">Annual effective dose. µSv/year</td></tr>
<tr><td colspan="2">Geological survey</td><td colspan="2">Scientific survey</td></tr>
<tr><td>Internal exposure from inhalation of radionuclides</td><td colspan="2">$7.40\cdot10^{-7}$</td><td colspan="2">$8.22\cdot10^{-7}$</td></tr>
<tr><td>Internal exposure from unintentional oral intake of contaminated soil</td><td colspan="2">$8.41\cdot10^{-8}$</td><td colspan="2">$9.34\cdot10^{-8}$</td></tr>
<tr><td>Internal exposure from inhalation of radionuclides</td><td colspan="2">$2.81\cdot10^{-2}$</td><td colspan="2">$3.51\cdot10^{-2}$</td></tr>
<tr><td>Internal exposure from unintentional oral intake of contaminated soil</td><td colspan="2">$6.67\cdot10^{-5}$</td><td colspan="2">$6.67\cdot10^{-5}$</td></tr>
<tr><td>Total</td><td colspan="2">$2.82\cdot10^{-2}$</td><td colspan="2">$3.52\cdot10^{-2}$</td></tr>
</table>

Table 6.13 presents the results of calculation of changes in the total dose load caused by external exposure from contaminated soil surface and intake of artificial radionuclides with air and food gained by a member of population at the northern part of STS during 70 years.

Table 6.13

Dose accumulated by a member of population at average concentration values

Radionuclide	Dose, mSv					
	1 year	5 years	15 years	25 years	50 years	70 years
^{137}Cs	$3.26 \cdot 10^{-2}$	$1.44 \cdot 10^{-1}$	$3.26 \cdot 10^{-1}$	$4.23 \cdot 10^{-1}$	$5.11 \cdot 10^{-1}$	$5.27 \cdot 10^{-1}$
^{90}Sr	$1.11 \cdot 10^{-1}$	$4.90 \cdot 10^{-1}$	1.10	1.43	1.72	1.77
^{151}Sm	$7.37 \cdot 10^{-4}$	$3.36 \cdot 10^{-3}$	$8.08 \cdot 10^{-3}$	$1.10 \cdot 10^{-2}$	$1.44 \cdot 10^{-2}$	$1.53 \cdot 10^{-2}$
^{99}Tc	$2.59 \cdot 10^{-4}$	$1.20 \cdot 10^{-3}$	$2.98 \cdot 10^{-3}$	$4.17 \cdot 10^{-3}$	$5.70 \cdot 10^{-3}$	$6.20 \cdot 10^{-3}$
$^{239+240}Pu$	$4.08 \cdot 10^{-3}$	$1.89 \cdot 10^{-2}$	$4.70 \cdot 10^{-2}$	$6.58 \cdot 10^{-2}$	$9.00 \cdot 10^{-2}$	$9.77 \cdot 10^{-2}$
^{238}Pu	$5.28 \cdot 10^{-5}$	$2.40 \cdot 10^{-4}$	$5.79 \cdot 10^{-4}$	$7.88 \cdot 10^{-4}$	$1.03 \cdot 10^{-3}$	$1.09 \cdot 10^{-3}$
^{241}Pu	$1.01 \cdot 10^{-4}$	$4.26 \cdot 10^{-4}$	$8.77 \cdot 10^{-4}$	$1.06 \cdot 10^{-3}$	$1.18 \cdot 10^{-3}$	$1.19 \cdot 10^{-3}$
^{242}Pu	$5.69 \cdot 10^{-9}$	$2.63 \cdot 10^{-8}$	$6.55 \cdot 10^{-8}$	$9.18 \cdot 10^{-8}$	$1.26 \cdot 10^{-7}$	$1.36 \cdot 10^{-7}$
^{241}Am	$4.69 \cdot 10^{-3}$	$2.16 \cdot 10^{-2}$	$5.34 \cdot 10^{-2}$	$7.44 \cdot 10^{-2}$	$1.01 \cdot 10^{-1}$	$1.09 \cdot 10^{-1}$
Total	$1.53 \cdot 10^{-1}$	$6.80 \cdot 10^{-1}$	1.54	2.01	2.44	2.53

The estimations show that the main contribution to the accumulated dose from external exposure from contaminated soil surface and internal exposure due to intake of artificial radionuclides with air and food gained by a member of population is made by ^{90}Sr contained in the foodstuffs produced and grown in the STS "northern" areas.

Discussion of the results

The estimation of radiation doses for the population and personal living and working on the STS "northern" areas gave the following results:

1. The main contribution to the dose load on the population is made by the dose from the foodstuffs grown and produced on the studied area (94%). The dose of internal exposure from inhalation of contaminated dust particles is 5.6%; the dose due to external exposure from ground surface is 0.2%, whereas the dose of external exposure from contaminated soil stick to the skin and internal exposure from unintentional oral intake of contaminated soil is less than 0.02% of the total annual effective dose.
2. The main dose-forming radionuclide in the foodstuffs is ^{90}Sr. Table 6.14 presents the values of annual effective doses from the foodstuffs gained by the population of the northern areas of STS due to ^{90}Sr for average values of its concentration in the surface soil layer.

Table 6.14

Effective dose from foodstuffs for the main dose-forming radionuclide, ^{90}Sr

Product type	Effective dose for ^{90}Sr, µSv/year			
	Man	Woman	11-year-old child	Infant (1 year-old)
Products of crop farming	0.1	0.08	0.04	0.003
Products of livestock farming	0.018	0.004	0.002	0.003

The values in the table show that the ^{90}Sr contribution to the annual effective dose from the foodstuffs is 82% when consuming products of crop farming and 11% when consuming livestock products.

3. The main contribution to the dose load on the people working in geological and scientific parties on the territory is made by the internal exposure dose from inhalation of contaminated soil (98%).
4. The additional dose caused by the influence of the most contaminated areas of the STS territory will not make any considerable contribution to the total dose load on the population of the STS "northern" areas.

Chapter 7
Conclusion and recommendations

Comprehensive radio-ecological studies were performed in 2008-2009 at the northern part of former Semipalatinsk Nuclear Test Site at the lands of total 3,000 km^2 located in Pavlodar oblast of Kazakhstan. There was studied the environment: soils and vegetation, water and air, fauna and livestock. Investigations of 2008-2009 were based on previous radiological studies of these lands.

The following has been revealed during the research.

Radionuclide content in environmental objects at the northern part of STS is mainly stipulated by nuclear explosions and model experiments performed at the site *Opytnoye Pole* and by radiological weapons tests at the ground *"4a"* as well as global fallouts. Radionuclides formed during activation of nuclei in the environment at explosion could not contribute considerably into the radionuclide contamination of studied territories.

Currently, potential sources for secondary radioactive contamination of the northern part of STS include local spots of radioactive contamination within *Opytnoye Pole* site and the testing ground *"4a"* where radionuclide contents in soil and vegetation are comparable to those in solid radioactive waste, and within certain areas – with those of intermediate-level waste.

Radionuclide analysis of taken environmental samples showed that average contents of natural radionuclides in soils of studied territories are typical for Kazakhstani soils with no any geo-chemical anomalies revealed.

No single sample studied thoroughly employing gamma-spectrometry revealed other artificial radionuclides than ^{137}Cs or ^{241}Am; at that potential presence of ^{60}Co, ^{152}Eu, their content can not exceed 1-2 Bq/kg.

In general, distribution of ^{137}Cs and ^{90}Sr radionuclides over the territory is quite smooth; one should still remember that in the vicinity of RW-testing ground *"4a"* increased concentrations of ^{90}Sr were revealed. Six spots with increased concentrations of ^{241}Am were also revealed.

Average concentrations of ^{137}Cs and ^{90}Sr radionuclides in soils at these lands remain at the level of global fallout with maximal concentration values of ^{137}Cs, ^{90}Sr and $^{239+240}Pu$ radionuclides below the levels referred to as "relatively satisfactory conditions" in soil classifying regulatory documents (parameter of soil contamination with long-living decay products due to nuclear explosions in the Governmental Decree No.653 from July 31, 2007 "Criteria for Environmental Assessments of Lands").

Radionuclide contents in vegetation there do not exceed the levels established in the "Provisional Acceptable Levels for Radionuclide Contents in Objects under

Regulatory Control of the Ministry of Agriculture". In general, radionuclide contents in vegetation do not impose radiological risks on population making the vegetation suitable for certain types of commercial use including agricultural pasturing both in the present time and in the future.

Concentrations of artificial radionuclides in wild animals inhabiting northern part of STS will remain at acceptable levels even in case of migration through or from the nearby testing grounds of STS. Assessed during the comprehensive study radionuclide concentrations in meat of wild animals are well below acceptable levels. Consumption of meat from hunted wild animals does not impose any radiological risk on people.

The research outcomes provide forecasts for radiological parameters of goods produced at the studied lands. Expected values of artificial radionuclide specific activities in crop and cattle production is well below regulatory levels even for the cases of production at areas with increased concentrations of transuranium elements.

Expected contents of radionuclides in food products produced at these lands are, therefore, below regulatory levels established in the Sanitary Rules and Norms No. 4.01.071.03 "Hygienic requirements to safety and nutritive value of food products" set in force by the RK Ministry of Public Health on June 11, 2003 No.447.

Our studies assure that in terms of radionuclides contents in strata and surface water these "northern" territories of STS can be utilized in all types of commercial activities without any restriction, but taking into account the recommendations provided. According to the Radiation safety norms NRB-99, radionuclide contents in water within the studied lands do not exceed intervention levels at ingestion with water or food for local population.

Radionuclide contents in atmospheric air within the studied territories do not impose hazard on people inhabiting these lands. Radioactive contamination of the atmosphere impose risks on people directly at the territory of radiation-hazardous sites at the testing grounds and only in cases when there is a lot of dust in air at that particular moment, i.e. during dust storms, man-caused dusting, etc. Nevertheless, trans-boundary transfer of radioactivity outside these spot limits and even outside the test site boundaries is insignificant and does not impose hazard now nor in the future. Radionuclide contents in air of the studied territory do not exceed the level of acceptable volume activity at inhalation established for members of public in the Radiation safety norms NRB-99.

Final conclusion on applicability of the studied lands for living and commercial activities is based on assessment of dose loads on population to inhabit these lands. Maximal acceptable effective dose for population comprises 1 mSv/year. Our worst-case scenario for a subsistence farmer living within the contaminated area predicts annual effective dose per person to be below 0.3 mSv what is below the intervention level established in NRB-99.

At transfer of the lands on should take into consideration that the surveys of the STS northern part have revealed near-surface burying of radioactive waste ("a disposal"). Soil contamination at the disposal site reached in several places the acceptable levels. This site cannot be transferred for commercial use now. The other site which is not recommended for the transfer is a part of the testing ground *"4a"* (2 to 5 km away) where tests of radiological weapon were performed. The territory that is adjacent to the ground where one can find increased concentrations of ^{90}Sr must be regarded as control zone.

So, according to the assessment of integral radiological parameters and based on current regulatory requirements, almost all studied territory except two sites can be utilized without any restriction.

Annex D presents tables with geographic coordinates of vertexes of the outlined zones at the northern part of the Test Site.

The full-color insert includes a map and a layout of the lands recommended for transfer (figures 7.1 – 7.2).

At the lands transfer the following is to be taken into account:

- it is reasonable to envisage establishing a sanitary-protective zone outlining the RW-testing ground "*4a"*. In the nearest future it is reasonable to establish physical barriers to prevent access of people and animals to the local spots of radioactive contamination. Later, one should consider remediation measures for these contaminated areas removing radioactive waste to special RAW disposals;
- within the "*4a"* ground, which is not recommended for the transfer, scheduled inspections of commercial activities are to be established;
- a system of radiological monitoring is to be set in place for control over migration processes which could potentially result in delivery radionuclides to the transferred lands;
- with the purpose to control possible inflow of contaminated strata waters from the places of nuclear explosions to waters of the "northern" territories and to assure timely identification of radio-ecological risks, additional hydrogeological monitoring posts located as prescribed in 4.4.3 above are to be arranged and integrated into a State monitoring system;
- it is reasonable to envisage additional measures restricting access to the near-surface RAW disposal including reconstruction of physical barriers and warning signs since this land is not entitled for transfer because of radioactive contamination. Since this area is within the considered northern part of STS envisaged for the transfer, it is reasonable to eliminate in the near future the disposal of RAW there and implement other measures for the transfer of this land for economic activities.

Abbreviations and acronyms

RSE NNC RK	Republican State Enterprise National Nuclear Center of the Republic of Kazakhstan
ASE	affiliated state-owned enterprise
IRSE	Institute of Radiation Safety and Ecology
IGR	IGR-type research reactor in Kurchatov at the Institute for Atomic Energy NNC RK
LLP	Limited Liability Partnership
STS	Semipalatinsk Test Site
EKO	East Kazakhstan oblast
ISTC	International Science and Technology Center
ChNPP	Chernobyl Nuclear Power Plant
EDR	equivalent dose rate
γ– radiation	gamma radiation
mSv	millisieverts
μSv/h	microsieverts per hour
mSv/year	millisieverts per hour
mR/h	milliRoentgen per hour
β-particle	beta- particle
part/(min*cm^2)	particles per minute per square centimetre
SA	specific activity
Bq/kg	becquerel per kilogram
Ci	Curie
NT	nuclear tests

kt TNT eqv.	kiloton of trinitrotoluene equivalent
RAW	radioactive waste
RW-site	radiological weapons site – testing ground where radiological weapons (also known as radiological dispersion devices-RDD) were tested
NFC	nuclear fuel cycle
ARN	artificial radionuclides
NR	natural radionuclides
DL	dose limit (see also MPD)
ALI	annual limit on intake
SanPiN	Sanitary Rules and Norms – RK State regulatory doc
NRB	Radiation Safety Norms – RK State regulatory doc
MPC	maximum permissible concentration
IL	intervention level
EEVA	equivalent equilibrium volumetric activity
VA	volumetric activity
AVA	Allowable average annual volumetric activity
A_c	accumulation coefficient
$К_t$	transition coefficient
mg-eq/l	milligram-equivalent per liter
Тм	terameter
υ	speed
WI	Western intervention
NWI	North-Western Intervention
NI	Northern Intervention
NNE	North-north-east
AM	air mass
p.	point
PK	picket

Annex A
Instrumentation and methods of research

Institute of Radiation Safety and Ecology was involved in comprehensive surveying of northern part of STS based on its license for services in the field of atomic energy utilization (State license GLA No.001732, Figure A.1) in compliance with the list of licensed works and services (Figure A.2).

МИРНОЕ ИСПОЛЬЗОВАНИЕ АТОМНОЙ ЭНЕРГИИ

ЧЕЛОВЕК ПРЕВЫШЕ ВСЕГО

ГОСУДАРСТВЕННАЯ ЛИЦЕНЗИЯ

Выдана ДГП "Институт радиационной безопасности и экологии" РГП (на праве хозяйственного ведения) НЯЦ РК, ВКО, г. Курчатов, ул. Красноармейская, 2

на занятие предоставление услуг в области использования атомной энергии

согласно прилагаемому перечню - Приложение № 1.

Особые условия действия лицензии - согласно Приложению № 2

Орган, выдавший лицензию *Комитет по атомной энергетике Министерства энергетики и минеральных ресурсов Республики Казахстан*

Руководитель Т. М. Жантикин

Дата выдачи лицензии 29 ноября 2007 г.

Номер лицензии ГЛА № 0001732

Figure A.1. State license issued to IRSE

АДАМНАН ЖОҒАРЫ ЖОҚ

ЧЕЛОВЕК ПРЕВЫШЕ ВСЕГО

ӘРЕКЕТ ТҮРЛЕРІНІҢ ТІЗІМІ
ПЕРЕЧЕНЬ ВИДОВ ДЕЯТЕЛЬНОСТИ

№1 ҚОСЫМША
мемлекеттік лицензияға
2008 ж. 23 мамырға өзгерісте
Лицензияның нөмірі ГЛА № 0001732
Лицензияның берілу күні 2008 ж. 29 қараша

ПРИЛОЖЕНИЕ №1.
с изменениями на 23 мая 2008 г
к Государственной лицензии
Номер лицензии ГЛА № 0001732
Дата выдачи лицензии 29 ноября 2007 г.

Перечень лицензируемых видов работ и услуг, входящих в состав лицензируемого вида деятельности

- **Проведение экспертизы, анализа и оценки радиационной безопасности;**
- **Радиационный контроль территорий, помещений, рабочих мест, товаров, материалов, металлолома, транспортных средств;**
- **Определение содержания радионуклидов в продуктах, материалах, объектах окружающей среды, измерение концентрации радона и других радиоактивных газов;**
- **Гамма-съемка и другие радиометрические исследования территорий;**
- **Радиационная реабилитация и рекультивация территорий и объектов;**
- **Контроль качества работы приборов, оборудования, установок, генерирующих ионизирующее излучение (медицинских рентгеновских аппаратов);**
- **Индивидуальный дозиметрический контроль персонала.**

Филиалдары мен өкілдіктері: **Жоқ**
(толық аты, орналасқан жері, деректемесі)

Филиалы, представительства: **Нет**
(полное наименование, местонахождение, реквизиты)

Лицензияға қосымша берген орган: *Қазақстан Республикасының Энергетика және*
(лицензияға қосымшаны берген органның толық атауы)
минералдық ресурстар министрлігінің Атом энергетикасы жөніндегі комитеті

Орган, выдавший приложение к лицензии: *Комитет по атомной энергетике*
(полное наименование органа, выдавшего приложение к лицензии)
Министерства энергетики и минеральных ресурсов Республики Казахстан

Басшысы (уәкілетті адам):
Руководитель (уполномоченное лицо): *Т. М. Жантикин*
(басшының (уәкілетті адамның) тегі және аты-жөні)
(фамилия и инициалы руководителя (уполномоченного лица))

Лицензияға қосымша берілген күні: **23 мамыр 2008 ж.**
Дата выдачи приложения к лицензии: **23 мая 2008 г.**

Астана қ.
г. Астана

Страница 2 из 2

003077

Figure A.2. List of activities licensed to IRSE

Field research

Certified instruments and gauges that passed state verification were used during field research. Preparation for instrumental measurements has been performed in strict compliance with the procedures for corresponding instruments.

The following instruments were used in our field research.

Radiometer-dosimeter RKS-01-SOLO

This instrument is designed for complex radiation surveying of environment, work places, facilities and vehicles.

Brief specification:

- alpha-particle flow density range $0.2 \div 10^5$ particles/(min·cm^2). Energy range $1 \div 8$ MeV;
- maximal relative accuracy: ± 20%;
- beta-particle flow density range $2 \div 10^5$ particles/(min·cm^2). Energy range $0.06 \div 3$ MeV;
- maximal relative accuracy: ± 20%.

Scintillation detector unit:

- Energy range of gamma-radiation: 20 keV÷ 10.0 MeV.
- Measurement range:
- equivalent dose rate, μSv/h $0.05 \div 1 \cdot 10^2$;
- equivalent dose, μSv $0.05 \div 1 \cdot 10^{10}$.
- Maximal relative accuracy: ± 15%.

Gas discharge detector unit:

- Energy range of gamma-radiation: 40 keV ÷ 3 MeV.

Measurement range:

- equivalent dose rate, μSv/h $1 \cdot 10^2 \div 1 \cdot 10^6$;
- equivalent dose, μSv $0.05 \div 1 \cdot 10^8$.

Maximal relative accuracy: ± 20%.

Measurements were performed in compliance with the manual [98].

Dosimeter-radiometer MKS-RM1402M is designed for:

measurements of ambient equivalent dose rates of gamma- and x-ray (photon) radiation H*(10);

- measurements of surface contamination rates for alpha- and beta-emitters;
- search (revealing and localization) of radioactive materials measuring photon, neutron, alpha and beta radiation;
- registration of neutron radiation;
- accumulation, storage and transfer to PC of instrumental scintillation spectra of gamma-radiation for evaluation of radionuclide compositions.

Brief specification:

Gamma radiation detector unit BD-01.

Sensitivity – not less than 200 (pulses/s)/(μSv/h). Counting rates are indicated in the range 1 ÷ 14,000 pulses/s. MED measurement range 0.05 ÷ 40 μSv/h. Registered energies – 0.06 ÷ 1.5 MeV. Acceptable relative accuracy for MED measurements ± (20+A/H) % (MED measured in μSv/h, A – a coefficient equal to 1 μSv/h). Additional relative error ± 20%.

Gamma radiation detector unit BD-02.

Sensitivity – not less than 30 (pulses/s)/(μSv/h). Counting rates are indicated in the range 1 ÷ 8,000 pulses/s. MED measurement range 0.06 ÷ 1.5 μSv/h. Registered energies – 0.06 ÷ 1.5 MeV. Number of amplitude discrimination channels – 512. Energy resolution at registration of scintillation spectra for the line 0.662 MeV (^{137}Cs) – not worse than 10%. Acceptable relative accuracy for MED measurements ± (20+A/H) % (MED measured in μSv/h, A – a coefficient equal to 2 μSv/h). Additional relative error ± 20%.

Gamma radiation detector unit BD-05.

Flow density measurement range (φ):

– alpha-radiation – 1 ÷ $5*10^5$ $cm^{-2}*min^{-1}$);
– beta-radiation - from 10 to 10^6 $cm^{-2}*min^{-1}$).

Range of registered boundary energies of beta-radiation - from 0.15 to 3.5 MeV.

Sensitivity, not less:

– for alpha-radiation (of ^{239}Pu) – 2 pulses/cm^2;
– for beta-radiation (of ^{90}Sr+^{90}Y) – 0.5 pulses/cm^2.

Counting rates are indicated in the range:

– for alpha-radiation – from 1 to 25,000 pulses/s;
– for beta-radiation – from 1 to 14,000 pulses/s.

Acceptable relative error in flow density measurements:

– for 5.15 MeV alpha-radiation (^{239}Pu): ± (20+A/φ)%; here φ – measured flow density for α-particles in $min^{-1}*cm^{-2}$, A – a coefficient equal to10 $min^{-1}*cm^{-2}$.
– for 5.15 MeV beta-radiation (^{90}Sr+^{90}Y): ± (20+A/φ)%; here φ – measured flow density for β-radiation in $min^{-1}*cm^{-2}$, A – a coefficient equal to 100 $min^{-1}*cm^{-2}$.

The measurements were performed following the manual [99].

Dosimeter–radiometer MKS-AT6130

The device is designed for control over radioactive contamination of surfaces, skin, outwear and individual protection means.

Measured ambient dose rates for x-ray and gamma-radiation (dose rates) can vary within the range 0.1 μSv/h ÷ 10 mSv/h.

Measured ambient doses for x-ray and gamma-radiation (doses) can vary within the range 0.1 μSv ÷ 100 mSv.

Measured flow densities for beta-radiation emitted from a contaminated surface can vary within the range 10 ÷ 10^4 particles/(min·cm^2).

Energy range for registered gamma-radiation: 20 keV ÷ 3 MeV.

Energy range for registered flow density of beta-radiation: 300 keV ÷ 3.5 MeV.
The measurements were performed in accordance with the manual [100].

Dosimeter-radiometer DKS-96 is designed for:

– dose and dose rate measurements of ambient equivalent doses of continuous and pulsed x-ray and gamma-radiation;
– alpha- and beta-radiation flow density measurements;
– gamma-radiation flow density measurements;
– flow and exposition dose rate measurements of gamma-radiation in wells and liquid media;
– radiological surveillance of lands with GPS data positioning.

Flow density of beta-radiation can be measured within the range 3 ÷10^4 particles/(min·cm^2) for Sr-90 +Y-90 sources.
Registered energies of beta-radiation: 0.12 ÷3.0 MeV.
The measurements were performed in accordance with the manual.

Dosimeter-radiometer DRG-01T1
The device is designed for measurements of exposition dose rates from gamma-radiation.
Modes of operation:

– single measurements of dose rate;
– search.

Exposition dose rate can be measured within the ranges:

– mode "Search": 1 μSv/h ÷ 1 Sv/h;
– mode "Measurement": 0.1 μSv/h ÷ 0.1 Sv/h.

Energy range for gamma-radiation: 50 keV ÷ 3 MeV.
The measurements were performed in accordance with the manual.

Dosimeter-radiometer SRP-68-01
This is a geological prospecting scintillation device designed for radiometric field surveys.
Exposition dose rate: 0 ÷ 30 μSv/h.
The measurements were performed in compliance with the manual [101].

Methods of sampling and field surveying
Measurements of radiological parameters
Measurements of radiological parameters were performed in the knots of a survey grid as well as between the knots ("search" mode) in accordance with the manual of the measuring device and a procedure for measurements of gamma-background at field works [102].

Soil sampling
Soil sampling was performed in all grid knots. A single sample is taken from 100-200 cm^2 and depth 5 cm. Larger sampling area is stipulated by precision requirements

of laboratory spectrometry and radiochemistry. Environmental samples were taken and packed in accordance with the requirements for soil sampling at total and local contaminations [103].

Measurements of equivalent equilibrium volume activity of radon in atmosphere

Measurements of equivalent equilibrium volume activity (EEVA) of radon and thoron were performed with the radon monitor Ramon-01. The radon monitor Ramon-01 is designed for express assessment of radon EEVA by its daughter products RaA, RaB and RaC utilizing the possibility for spectrometric determination of thoron EEVA in air, premises and on open air during radiochemical, geological and radio-ecological investigations.

Brief specification:

EEVA measurement range:

– radon: from 4 to $5 \cdot 10^5$ Bq/м^3.
– thoron: from 8 to $5 \cdot 10^5$ Bq/м^3.

Acceptable measurement error – 30%.

Verification certificate is available in the Annex.

Radon exhalation measurements

Radon exhalation measurements in soil air were performed in the places of sampling for water vapor in compliance with [104]. These measurements are based on radon accumulation from soil surface in an airproof tank placed on the surface; then air is sampled from the tank for assessment of accumulated radon followed by calculations of exhalation with a formula operating accumulation time and tank volume.

Radon exhalation was measured with Ramon-radon-01 instrument and a radiometer RZA-01-SOLO.

Ramon-radon-01 is designed for measurements of volume activity of radon (^{222}Rn) in various media such as air, water, soil and of radon flows from various surfaces (exhalation). The instrument uses sampling into a 2l vessel and electrostatic deposition on a replaceable filter-target followed by alpha-activity measurement of the filter with an external alpha-radiometer.

Air consumption of the pumping device comprises 1÷0.1 l/min; power supply is provided by a net adapter or by a 7.2V build in battery of 1.5A capacity.

Alpha-radiometer RZA-01-SOLO is designed for measurements of flow density and surface activities of alpha-particles including those of analytical filters, smears, samplers and other objects.

Measurement range $0.2 \div 2 * 10^6$ particles/(min*cm^2), energy range – 1÷8 MeV, measurement time – 10 s.

Measurements of equivalent equilibrium volume activity of radon

The measurements were performed according to the instrument's manual and based on criteria for potential hazardousness of the territories in terms of radon [105, 106].

Sampling of air aerosols and water vapor

In order to evaluate rates of atmospheric air contamination with artificial radionuclides we used aspiration sampling which makes it possible to get data on aerosol concentrations in unit volume. The core of the method is in pumping of large air volumes through a filter; the filter then is sent to laboratory for further analyses. Samples of air aerosols were taken in the place of possible adit outlet. Volume of air pumped per one sample was calculated based on technical specifications of spectrometry instrumentation used in our laboratory measurements.

Sampling of air aerosols was performed with a special air sampler "JAP-50". Production rate of this unit is 50 – 60 m^3/h. Power supply of 220 V. "Petryanova" tissue was used as a filter. Filtering area comprised 250 cm^2. Total volume of filtered air was measured with mechanical volume gauge in m^3.

Determination of tritium concentrations in air was performed with sampling of water vapor by freezing. Samples were taken in the same places were air aerosols were sampled and above the epicenters. Upon freezing, required amount of water vapor was placed into a vial

Temperature and air humidity were recorded for sampling points; specific activities were transformed into volume one using obtained data. Samples were packed in polyethylene and provided with sampling data passports. A device consisting of Dewar bottle, vacuum flask, refrigerant supply and radiator was used for sampling of water vapor.

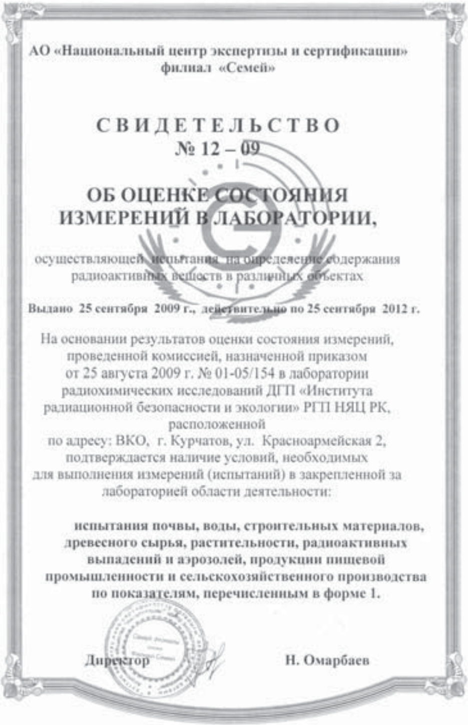
Sampling was performed in compliance with [107].

Laboratory studies

Analysis of environmental samples from northern territories of STS was performed in two analytical laboratories of NNC RK: IRSE Radiochemical Laboratory and INP Laboratory of Engineering Ecology. The Radiochemical Laboratory has been certified for determination of radioactive substances in various media (No. 12-09 dated 25.09.2009 – see Figure A.3).

The Laboratory for engineering ecology has been accredited for technical competency by State authorities (Accreditation certificate No. KZ.7100000.06.09.00703 issued Nov.05, 2007, Figure A.3).

The laboratories are equipped with necessary certified instrumentation that passed state verification (figures A.4 – A.7).



АО «Национальный центр экспертизы и сертификации»
филиал «Семей»

СВИДЕТЕЛЬСТВО
№ 12 – 09

ОБ ОЦЕНКЕ СОСТОЯНИЯ
ИЗМЕРЕНИЙ В ЛАБОРАТОРИИ,

осуществляющей испытания на определение содержания радиоактивных веществ в различных объектах

Выдано 25 сентября 2009 г., действительно по 25 сентября 2012 г.

На основании результатов оценки состояния измерений, проведенной комиссией, назначенной приказом от 25 августа 2009 г. № 01-05/154 в лаборатории радиохимических исследований ДГП «Института радиационной безопасности и экологии» РГП НЯЦ РК, расположенной по адресу: ВКО, г. Курчатов, ул. Красноармейская 2, подтверждается наличие условий, необходимых для выполнения измерений (испытаний) в закрепленной за лабораторией области деятельности:

испытания почвы, воды, строительных материалов, древесного сырья, растительности, радиоактивных выпадений и аэрозолей, продукции пищевой промышленности и сельскохозяйственного производства по показателям, перечисленным в форме 1.

Директор Н. Омарбаев

КОМИТЕТ ПО ТЕХНИЧЕСКОМУ РЕГУЛИРОВАНИЮ И МЕТРОЛОГИИ
МИНИСТЕРСТВА ИНДУСТРИИ И ТОРГОВЛИ
РЕСПУБЛИКИ КАЗАХСТАН

ГОССТАНДАРТ

ГОСУДАРСТВЕННАЯ СИСТЕМА ТЕХНИЧЕСКОГО РЕГУЛИРОВАНИЯ РЕСПУБЛИКИ КАЗАХСТАН

АТТЕСТАТ АККРЕДИТАЦИИ

Зарегистрирован в реестре Государственной системы технического регулирования Республики Казахстан
№ KZ.7100000.06.09.00703
от «5» ноября 2007 года
Действителен до
«5» ноября 2010 года

Настоящий аттестат удостоверяет, что лаборатория инженерной экологии ДГП «Институт ядерной физики» РГП «Национальный ядерный центр Республики Казахстан» (город Алматы, улица Ибрагимова, 1; Западно-Казахстанская область, город Аксай, Промзона)

аккредитована на техническую компетентность в Государственной системе технического регулирования Республики Казахстан на соответствие требованиям СТ РК ИСО/МЭК 17025-2001.

Область аккредитации приведена в приложении, являющемся неотъемлемой частью настоящего аттестата, на 15 листах.

Председатель Г. Мухамбетов

М.П.

№ 0001028

Figure A.3. Certificate of measurements conditions in IRSE laboratory and Accreditation certificate of INP laboratory

ДГП "Институт атомной энергии" РГП "Национального ядерного центра РК"
(наименование подразделений государственной метрологической службы или метрологической службы юридического лица)
Аттестат аккредитации №862 от 08.06.07 г. и лицензия МА № 0001138
(номер аттестата аккредитации и (или) лицензии)

СЕРТИФИКАТ О ПОВЕРКЕ № ЕА17-81/15
Гамма-спектрометр
наименование средства измерений (эталона)
Тип, обозначение: InSpektor 1200/GX2020 заводской № 05957529/02055186
от 50 до 2000 кэВ.
(пределы измерений)
Изготовитель: - Дата изготовления: 2006 г.
Пользователь: ДГП ИРБЭ РГП НЯЦ РК
Поверка проведена в соответствии: МИ 1916-88.
(обозначение и наименование НД по поверке)
с использованием следующих средств поверки: ОСГИ-3-2; С1-55.
(обозначение эталона и вспомогательного оборудования, использованного при поверке)
На основании результатов поверки признан годным и допущен к применению
по классу - разряду рабочий
Дата поверки "11" Января 09 г. Действителен до "11" Января 10 г.
Руководитель отдела (лаборатории) подпись Латыпова Г.Г. инициалы, фамилия
подпись Гетьман В.А. инициалы, фамилия

РГП НЯЦ РК ДГП
"Институт Атомной Энергии"
г.Курчатов, ул.Красноармейская,10
Номерной код самоклеящейся пломбы:
Y68 8 3/5

Figure A.4. Certificate of gamma-spectrometer verification

ДГП "Институт атомной энергии" РГП "Национального ядерного центра РК"
(наименование подразделений государственной метрологической службы или метрологической службы юридического лица)
Аттестат аккредитации №862 от 08.06.07 г. и лицензия МА № 0001138
(номер аттестата аккредитации и (или) лицензии)

СЕРТИФИКАТ О ПОВЕРКЕ № ЕА17-81/14
Альфа-спектрометр
наименование средства измерений (эталона)
Тип, обозначение: Canberra 7401 заводской № 2624
от 3 кэВ до 8 мэВ
(пределы измерений)
Изготовитель: Canberra industries, США. Дата изготовления: 1996 г.
Пользователь: ДГП ИРБЭ РГП НЯЦ РК
Поверка проведена в соответствии: МИ 1798-87.
(обозначение и наименование НД по поверке)
с использованием следующих средств поверки: ОСАИ; Г5-56; Ч3-38; БАММ; ПБУ.
(обозначение эталона и вспомогательного оборудования, использованного при поверке)
На основании результатов поверки признан годным и допущен к применению
по классу - разряду рабочий
Дата поверки "10" Января 09 г. Действителен до "10" Января 10 г.
Руководитель отдела (лаборатории) подпись Латыпова Г.Г. инициалы, фамилия
подпись Гетьман В.А. инициалы, фамилия

РГП НЯЦ РК ДГП
"Институт Атомной Энергии"
г.Курчатов, ул.Красноармейская,10
Номерной код самоклеящейся пломбы:
Y6 8 83/4

Figure A.5. Certificate of alpha-spectrometer verification

ДГП "Институт атомной энергии" РГП "Национального ядерного центра РК"
(наименование подразделений государственной метрологической службы или метрологической службы юридического лица)
Аттестат аккредитации №862 от 08.06.07 г. и лицензия МА № 0001138
(номер аттестата аккредитации и (или) лицензии)

СЕРТИФИКАТ О ПОВЕРКЕ № EA17-82/244
Спектрометр бета излучения.
наименование средства измерений (эталона)
Тип, обозначение: TRI-CARD 2900TR заводской № 431978
от 20 до 2000 кэВ.
(пределы измерений)
Изготовитель: USA. Дата изготовления: 2003 г.
Пользователь: ДГП ИРБЭ РГП НЯЦ РК
Поверка проведена в соответствии: МП в ТО.
(обозначение и наименование НД по поверке)
с использованием следующих средств поверки: 1CO; контрольные источники H-3; C14.
(обозначение эталона и вспомогательного оборудования, использованного при поверке)
На основании результатов поверки признан годным и допущен к применению
по классу - разряду рабочий
Дата поверки "10" Сентября 09 г. Действителен до "10" Сентября 10 г.
Руководитель отдела (лаборатории) подпись Г.Г. Латыпова инициалы, фамилия
Поверитель подпись В.А. Гетьман инициалы, фамилия
РГП НЯЦ РК ДГП "Институт Атомной Энергии" г.Курчатов, ул.Красноармейская,10
Y695943

Figure A.6. Certificate of beta-radiation spectrometer verification

Алматинский филиал АО "НаЦЭкС"
(наименование подразделения государственной метрологической службы или метрологической службы юридического лица)
Лицензия №0001015 серия МА от 22.12.00г. и аттестат №796 от 05.02.07г.
(номер аттестата аккредитации и (или) лицензии)

СЕРТИФИКАТ О ПОВЕРКЕ № ВА.17. 7613
Радиометр радона и его дочерних продуктов распада
наименование средства измерений (эталона)
Тип, обозначение: Рамон-02 заводской № 08-09
(4-500000) Бк/м.куб.
(пределы измерений)
Изготовитель: ТОО "СОЛО" ЛТД Дата изготовления: 2009
Пользователь: ДГП "ИРБЭ РГП НЯЦ РК"
Поверка проведена в соответствии: МП из паспорта на прибор. АА 1.000.000 ПС
(обозначение и наименование НД по поверке)
с использованием следующих средств поверки: плутоний-239 1-го разряда, 1П9
(обозначение эталона и вспомогательного оборудования, использованного при поверке)
На основании результатов поверки признан годным и допущен к применению
по классу соотв.ТО разряду рабочий
Дата поверки "02" Июля 09 г. Действителен до "02" Июля 10 г.
Руководитель отдела (лаборатории) подпись Канибетов К.К. инициалы, фамилия
Поверитель подпись Кареев А.В. инициалы, фамилия

Figure A.7. Certificate of radon radiometer verification

All measurements and analyses of soil, water, atmospheric air and vegetation samples were performed in compliance with state standards, regulatory and methodical documents of the Republic of Kazakhstan.

Methodical description of sample preparation for laboratory tests

Soil

Soil sample preparation for γ-spectrometry was done in compliance with the State standard GOST-17.4.4.02-84 [108] as follows:

1. removal of inclusions (vegetation and stones) from bulk soil;
2. drying of sample till constant mass;
3. sample sieving with 1 mm-fine sieve;
4. pounding with a mill of soil fraction >1 mm to reduce its mass down to 4-5% of total sample weight;
5. quartering and taking batches for measurements;

6. placing of a batch in a vessel to measure precise geometry;
7. γ-spectrometry.

Soil sample preparation for ⁹⁰Sr and ²³⁹⁺²⁴⁰Pu radiochemical analysis was performed with the following procedure:

1. removal of inclusions (vegetation and stones) from bulk soil;
2. drying of sample till constant mass;
3. sample pounding and sieving with 0.1 mm-fine sieve;
4. quartering and taking batches for measurements;
5. ashing of batches in muffle furnace for 8 hours at 600º C (^{90}Sr content determination) or at 650º C for determination of $^{239+240}Pu$ contents.
6. Radiochemical extraction of ^{90}Sr and $^{239+240}Pu$.

Water

Water samples were filtered during 3 days employing the "blue ribbon" and were acidified with nitric acid to achieve pH=2-3.

Water sample preparation for γ-spectrometry was performed as follows:

1. a sample was placed into a vessel for precise geometry measurements;
2. mass measurements;
3. γ-spectrometry.

Water sample preparation for β-spectrometry (tritium measurements) was performed according to the procedure [109] as follows:

1. water sample distillation employing rotational evaporator in order to remove interfering β-emitters and scintillation-suppressing compounds;
2. mixing of purified sample aliquot in 5 ml with scintillation agent in the ratio 1:3;
3. measurements of the prepared sample at β-spectrometer.

Water sample preparation for ^{90}Sr radiochemical analysis implied sampling of 500 ml aliquot and introducing there of ^{85}Sr isotope label of certified activity followed by radiochemical extraction of ^{90}Sr and determination of its content in water.

Water sample preparation for $^{239+240}Pu$ radiochemical analysis implied sampling of 500 ml aliquot and introducing there of ^{242}Pu isotope label of certified activity followed by radiochemical extraction of $^{239+240}Pu$ and determination of its content in water.

Air

Air aerosol sample preparation for γ-spectrometry was used to determine contents in air of natural and artificial radionuclides and implied compressing the filter (with known volume of air passed through it) in a special device to achieve the geometry suitable for the detector.

Air aerosol sample preparation for ^{90}Sr and $^{239+240}Pu$ radiochemical analysis consisted of the following stages:

1. filter weighting;
2. cutting the filter into two pieces for ^{90}Sr and $^{239+240}Pu$ analyses;
3. coalification of each piece and ashing ^{90}Sr-sample in a furnace during 5-6 hours at 550ºC (650ºC for $^{239+240}Pu$-sample);
4. radiochemical extraction of ^{90}Sr and $^{239+240}Pu$.

Vegetation

Preparation of vegetation samples was performed in compliance with Methodical instructions for testing methods [110] and Instructional procedures for Sanitary-and-Epidemiological authorities (radiation hygiene) [111].

Vegetation sample preparation for γ-spectrometry was done as follows:

1. washing out of a sample with running water, then with distilled water;
2. comminuting in a mincing machine;
3. drying at 100-110 °C;
4. coalification in an electrical furnace and ashing in a muffle furnace at 450-500°C and continuous stirring (coalification was finished when ash got white or gray-while color; prepared ash was pounded down to powder; coalification coefficient was then calculated);
5. placing of a sample into calibrated geometry;
6. γ-spectrometryспектрометре.

Vegetation sample preparation for ^{90}Sr and $^{239+240}Pu$ radiochemistry implied:

1. sample drying at 100-110 °C;
2. coalification in an electrical furnace and ashing in a muffle furnace at 450-500°C and continuous stirring (coalification was finished when ash got white or gray-while color; prepared ash was pounded down to powder; coalification coefficient was then calculated);
3. radiochemical extraction of ^{90}Sr and $^{239+240}Pu$.

Instrumentation and methods for laboratory analyses:

γ-spectrometry

In order to determine contents of gamma-emitting radionuclides in environmental samples we used gamma-spectrometers of Canberra Company. Determination thresholds were calculated based on geometry of prepared sample and measurement time.

Standard kit of γ-sources was used for energy calibrations and special volumetric activity with ^{137}Cs, ^{152}Eu, ^{241}Am – for geometry calibrations.

The measurements were performed following the gamma-spectrometry procedure No. 5.06.001.98 RK [112].

β-spectrometry of samples

Determination of ^{3}H contents in water samples was done with liquid-scintillation spectrometer TriCarb-2900 using international standard ISO 9698:1989 (E) [109]. Measurement time for prepared sample comprised ~120-180 minutes. Accounting of suppression in the sample was performed with an outside standard ^{133}Ba. Processing of spectra and calculations of specific activities for ^{3}H were performed with Quanta Smart software.

Radiochemical extraction and determination of ^{90}Sr contents in environment

Determination of strontium-90 in environmental samples (soil, water, air aerosols and vegetation) was performed in compliance with certified procedure and the method [113, 114] employing a beta-spectrometer TriCarb. Determination thresholds for ^{90}Sr in the taken samples were calculated based on batch mass, pumped air volume (for air samples) and measurement time.

The method of radiochemical analysis of environmental samples for ^{90}Sr content is based on determination of its daughter radionuclide ^{90}Y in the sample what makes it possible to calculated specific activity of ^{90}Sr there. Chemical yield of ^{90}Sr is determined by γ-spectrometric measurements of extracted label – isotopic tracer ^{85}Sr, while chemical yield of ^{90}Y is determined by weighting for assessment of introduced stable carrier (Y) amounts. In the course of analyses, strontium is transferred into solution and then, in numerous chemical operations hydroxides of interfering radionuclides and alkali-earth metals are deposited to leave ^{90}Sr in the solution. Within 14-16 days strontium reaches equilibrium with daughter ^{90}Y. Determination of ^{90}Sr activity in a sample is performed by direct measurements of ^{90}Y in the solution by Cherenkov radiation registered with liquid-scintillation spectrometer TriCarb. Liquid scintillation spectrometer TriCarb makes it possible to do measurements in the mode of Cherenkov counting, i.e. to register Cherenkov radiation in liquid samples without introduction of a special scintillator solution. Efficiency of its registration in the range 0÷30 keV reaches 50-60% depending on saline composition of analyzed samples.

Radiochemical extraction and determination of $^{239+240}$Pu contents in environment

Radiochemical analysis of environmental samples for plutonium isotopes is performed employing the radiochemical procedure [115]. Alpha-spectrometry was performed employing instruments of Canberra Company. Data were processed with software Genie-2000 designed by Canberra for alpha-spectrometer. Detection thresholds for $^{239+240}Pu$ in the studied samples were calculated based on batch mass for analysis, volume of air (for air samples) and measurement time.

The method makes it possible to obtain plutonium fraction almost free from non-radioactive macrocomponents. Total chemical yield of plutonium with this method varies within the range 30-65%. The method is based in radionuclide transfer from a sample to solution employing effective acid leaching and on preparation of leachable based on initial α-spectrometric solutions. The method also takes into account losses of plutonium radionuclides due to introduction of ^{242}Pu isotopic tracer.

The whole process of radiochemical extraction of plutonium isotopes consisted of the following stages:

1. acid leaching of plutonium radionuclides from a sample;
2. extraction and radiochemical plutonium purification employing ion-exchange resins;
3. preparation of alpha-radioactive solutions.

Obtained fraction was spread over a Ch18N10Ti-type stainless steel substrate (plate) of total area 450 mm^2 employing electrolytic coating. Sample produced with such procedure was then measured at α-spectrometer.

Sufficiency of measurement sensitivity with respect to regulated values

The methods used made it possible to achieve registration thresholds for, as a rule, an order of magnitude below those required by regulatory documents (see table A.1 below).

Table A.1.

Values for regulated values (RV) for radionuclide contents in soil, water, air and vegetation, and MASA

Object, unit of specific activity measured	^{137}Cs		^{241}Am		^{90}Sr		$^{239+240}Pu$	
	RV	MASA	RV	MASA	RV	MASA	RV	MASA
Soil, Bq/kg	15 [60]	0.2	-	0.6	9 [60]	0.06	2.7 [60]	0.2
Water, Bq/kg	11 [58]	0.3	0.69 [58]	0.08	5 [58]	0.1	0.56 [58]	0.5
Air, Bq/m^3	27 [58]	0.014	0.0029 [58]	0.002	2.7 [58]	0.001	0.0025 [58]	0.002
Vegetation, Bq/kg	74 [62]	0.7	-	1	111 [62]	0.02	-	0.01

Quality control for laboratory analyses results

There has been designed and is successfully used in the laboratories a quality assurance system. Its integral part implies verification of measuring, certification of experimental equipment, scheduled maintenance of main and auxiliary equipment, actualization of procedures and utilization of certified methods.

Both laboratories operate under technological procedure for works with environmental samples (see figures A.8-A.10 below).

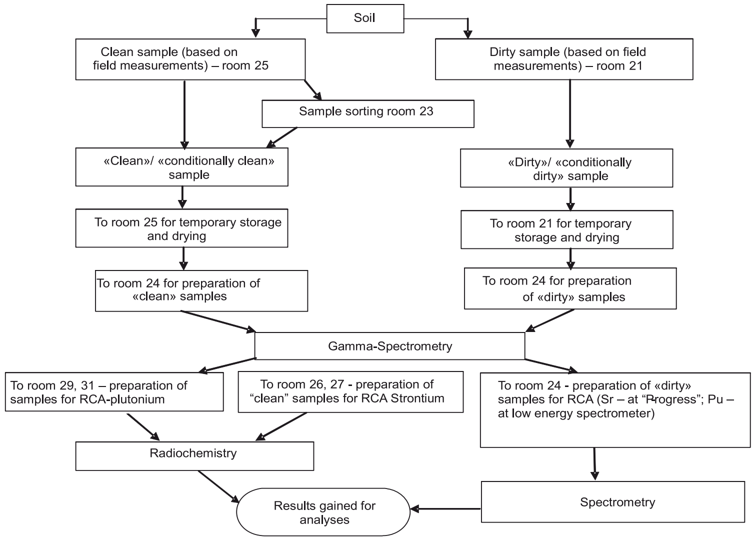


Figure A.8. Technological procedure for operations with samples of environment (soil) used by the Department of radiology and restoration of ecosystems

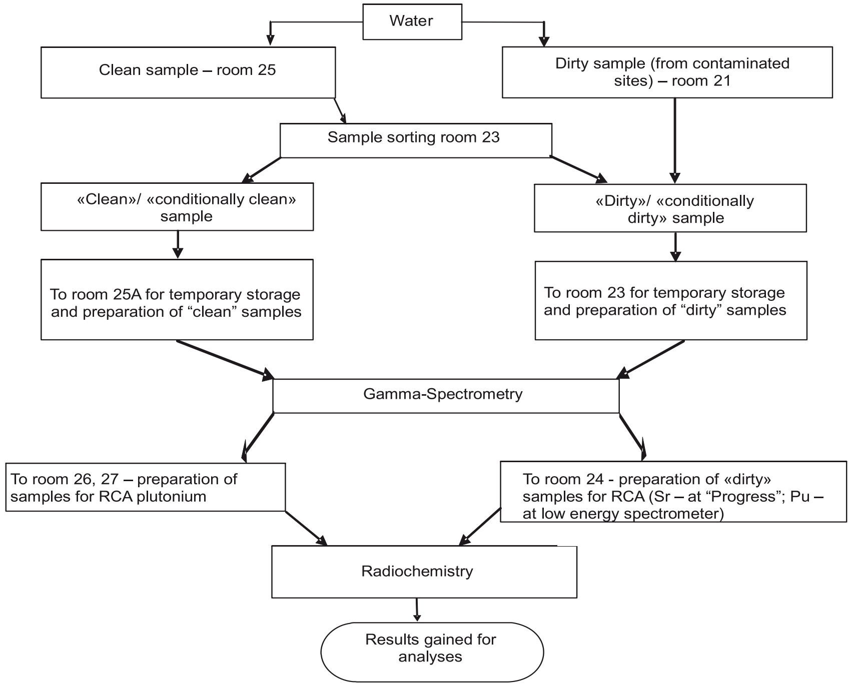


Figure A.9. Technological procedure for operations with samples of environment (water) used by the Department of radiology and restoration of ecosystems

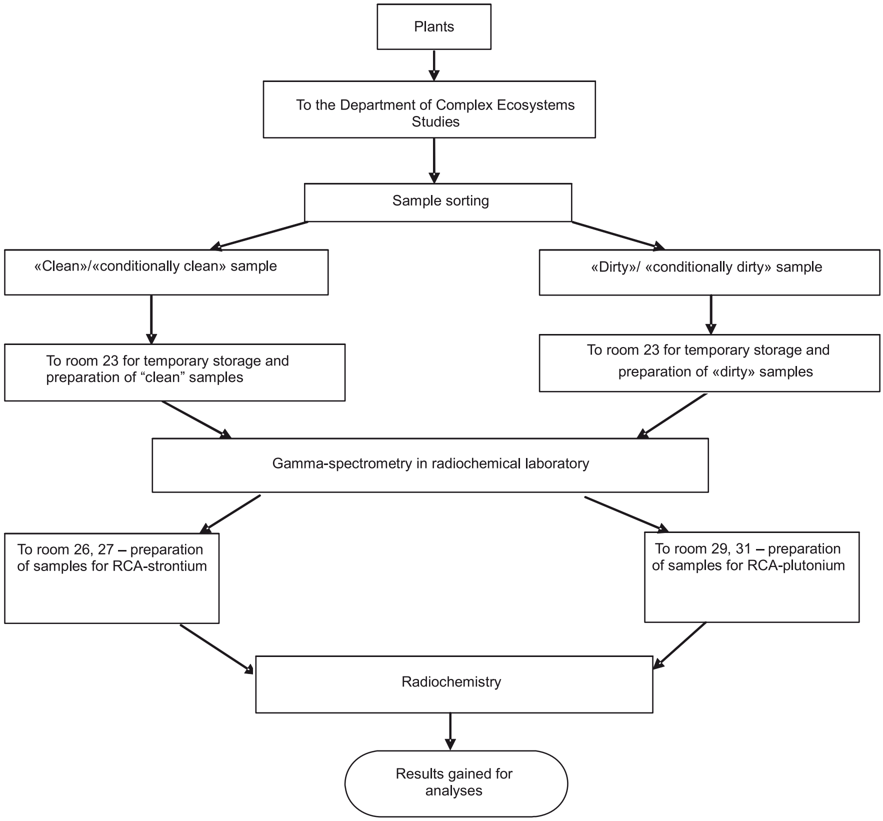


Figure A.10. Technological procedure for operations with samples of environment (vegetation) used by the Department of radiology and restoration of ecosystems

According to the procedures, sample is under control at all stages starting from sampling throughout obtaining of measurements. The procedures require segregation of samples based on their activity and prevent sample contamination in the laboratory.

Current quality control of scientific data in performed in the Radiochemistry laboratory of IRSE NNC RK according to the "Instruction manual for intra-laboratory control". This control involves control measurements performed for separately taken control sample (repeatability control) and repeated analyses of actual samples (verification of precision). So, verification of precision is performed in one series with real samples for each 10th sample. To confirm repeatability each 20th sample is measured for the second time. Interlaboratory verifications are scheduled once for each quarter. Besides, each sample batch has a dummy sample produced from distilled water to assure purity and absence of cross-contamination of samples.

Analysis of control samples shows that average inaccuracy of the results does not exceed 12% (table A.2, figures A.11 – A.16).

Table A.2

The verification results of precision and repeatability of laboratory analyses results

Analysis type	Average variation, %		
	Gamma-spectrometry	Radiochemical determination of ^{90}Sr	Radiochemical determination of $^{239+240}Pu$
Specific activity of samples up to 10 Bq/kg	10.3	10.5	12.3
Specific activity of samples 10÷100 Bq/kg	5.8	11.8	7.6

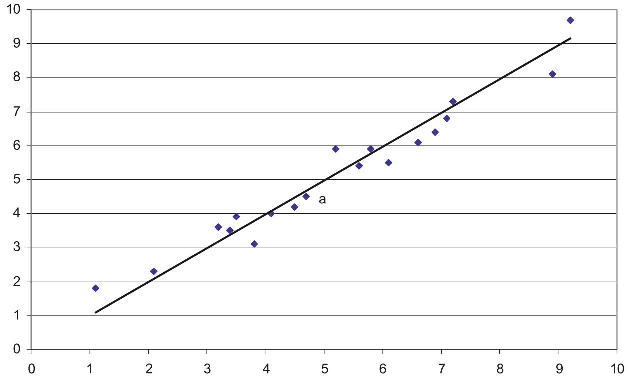


Figure A.11. Results of repeated gamma-spectrometry of soil samples with specific activity 1-10 Bq/kg

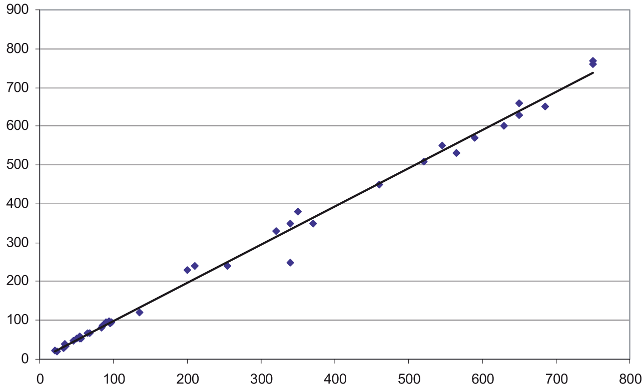


Figure A.12. Results of repeated gamma-spectrometry of soil samples with specific activity 10-1000 Bq/kg

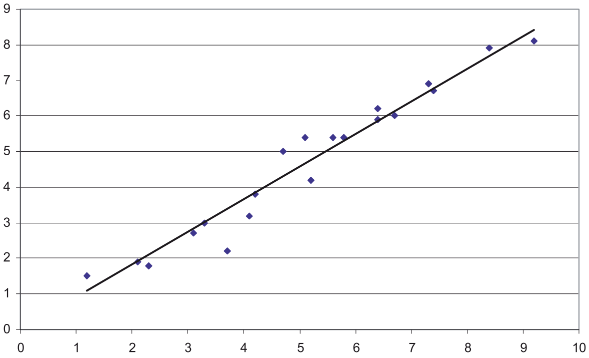


Figure A.13. Results of repeated radiochemical analysis for $^{239+240}Pu$ of soil samples with specific activity 1-10 Bq/kg

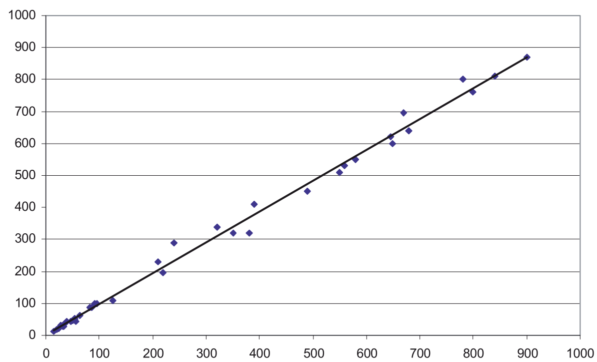


Figure A.14. Results of repeated radiochemical analysis for $^{239+240}Pu$ of soil samples with specific activity 10-1000 Bq/kg

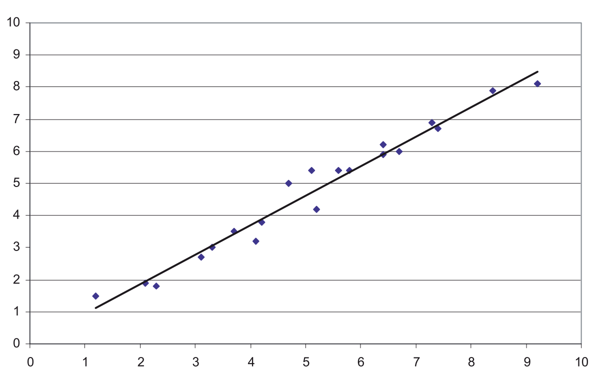


Figure A.15. Results of repeated radiochemical analysis for ^{90}Sr of soil samples with specific activity 1-10 Bq/kg

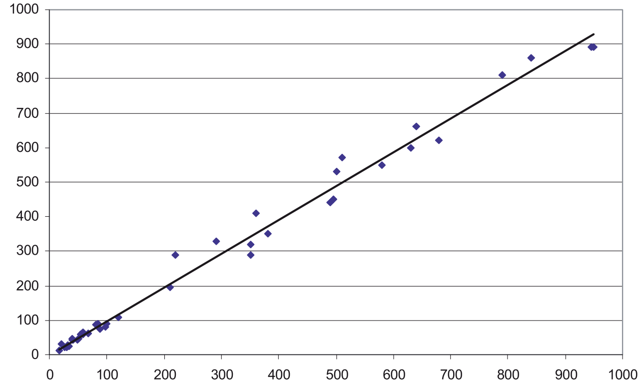


Figure A.16. Results of repeated radiochemical analysis for ^{90}Sr of soil samples with specific activity 10-1000 Bq/kg

Readings of dummy samples are almost at the levels of minimal detectable activity – more than 70% of the samples (figures A.17 – A.18).

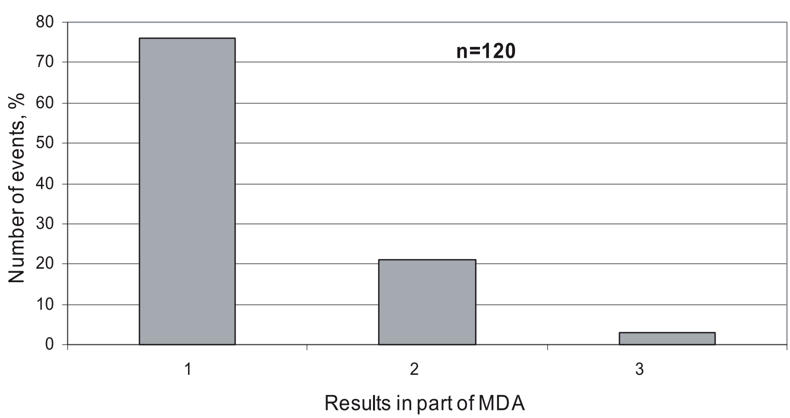


Figure A.17. Dummy sample analyses at radiochemical analyses of soil for $^{239+240}$Pu (MASA=0.2 Bq/kg)

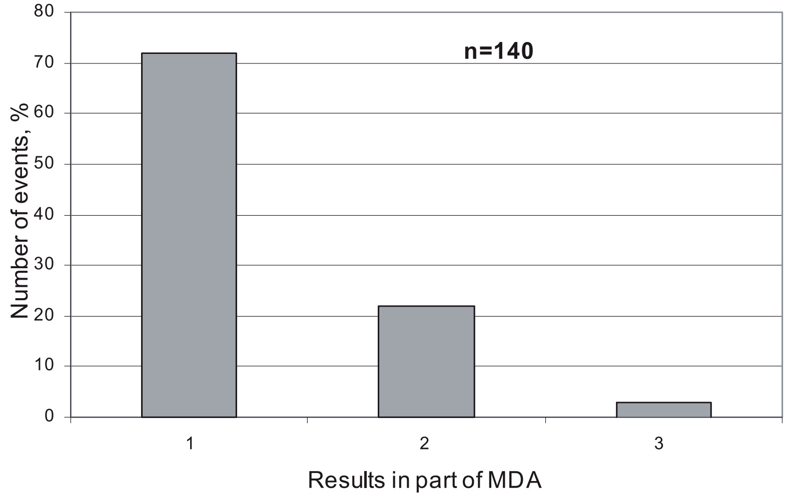


Figure A.18. Dummy sample analyses at radiochemical analyses of soil for ^{90}Sr (MASA=0.6 Bq/kg)

Outcomes of the inter-laboratory verification show that disagreement in the results does not exceed 13% (Figure A.19).

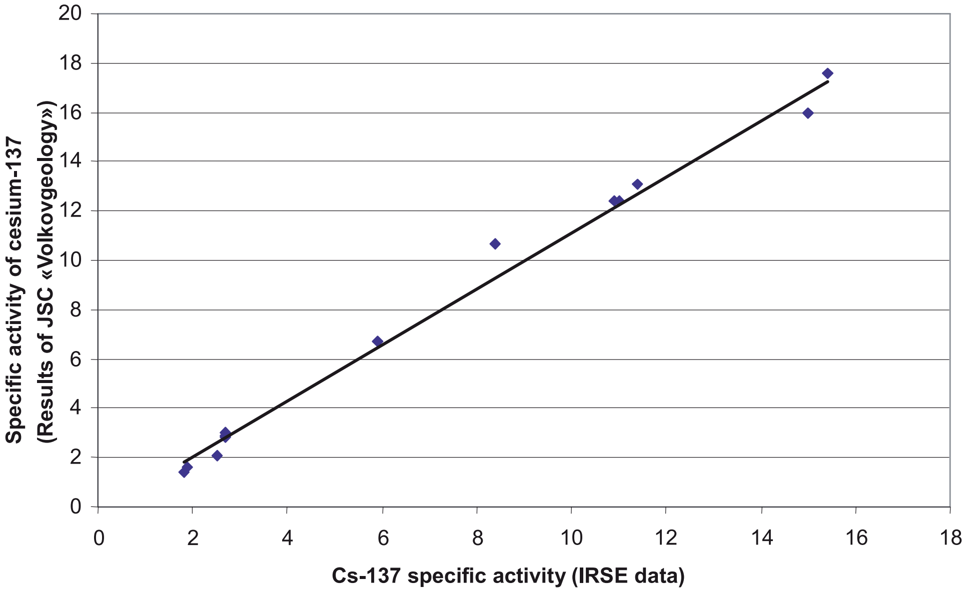


Figure A.19. Gamma-spectrometry of soil samples at inter-laboratory verification

Annex B

Legend to the schematic map of soil-vegetation complexes at the northern part of STS

	Granite low hills
1	**Series of communities:**
	Juniper (*Juniperus sabina*),
	Miscellaneous herbs (petro- phytno-herbs) (*Thymus marschalliana, Ephedra distachya, Carex pediphormis, Patrinia intermedia, Potentilla acaulis*),
	Herb bunchgrass - wormwood (*Stipa kirgisorum, Helictotrichon desertorum, Festuca valesiaca, Artemisia frigida, Centhaurea sibirica, Hieracium echioides*) communities with bushes (*Caragana pumila, Spiraea hypericifolia*) on the tops and upper parts of slopes;
	Wormwood sage -fescue- feather grass (*Stipa sareptana, Stipa capillata, Festuca valesiaca, Koeleria cristata, Artemisia frigida, Iris scariosa*), <u>on the slopes and in the inter-hill steppe depressions</u>
	High hummock - ridge hills melkosopochnik (a highly eroded plateau)
	With granite outcrops
2	**Series of communities:**
	Miscellaneous herbs (petro- phytno-herbs) -spiraeic-elm communities (Caragana pumila, Spiraea hypericifolia, Patrinia intermedia, *Sedum hybridum, Orostachys spinosa,Veronica pinnata)* on the tops;
	Feather grass- fescue (Stipa sareptana, Festuca valesiaca, Stipa lessingiana, *Artemisia frigida, Carex supina, Galim ruthenicum)* <u>on the slopes</u>
3	**Series of communities:**
	Miscellaneous herbs (petro- phytno-herbs) - spiraeic-elm communities (Caragana pumila, Spiraea hypericifolia, Patrinia intermedia, *Sedum hybridum, Orostachys spinosa,Veronica pinnata)* <u>on the tops of hills</u>;
	Feather grass- fescue-salsoa (Stipa sareptana, Festuca valesiaca, Stipa lessingiana, *Artemisia frigida, Carex supina, Galim ruthenicum)* <u>on the slopes</u>
	In combination with a complex of communities:
	Black wormwood (Artemisia pauciflora)
	with hastata (Atriplex cana) in the interhill solonetz depressions
	<u>**In some places**</u> with tasbiyurgun (Nanophyton erinaceum) <u>in eroded inter-hill depressions</u>

4	**Series of communities:**
	Miscellaneous herbs (petro- phytno-herbs) - spiraeic-elm communities (Caragana pumila, Spiraea hypericifolia, Patrinia intermedia, *Sedum hybridum, Orostachys spinosa,Veronica pinnata)* on the tops;
	Feather grass- fescue- thyrsoid communities (Stipa sareptana, Festuca valesiaca, Stipa lessingiana, *Artemisia frigida, Carex supina, Galim ruthenicum)* on the slopes
	In combination with microbelts of the following communities:
	a) reed (Phragmites australis)
	b) bluejoint (Calamagrostis epigeios)
	c) licorice-wild rye (Leymus angustus, Glycyrrhiza uralensis)
	d) lucerne-solonetz-fowl-grass (Poa trivialis, Medicago falcata, Galatella biflora), in the inter-hill meadow depressions
	With quartzite outcrops
5	**Series of communities:**
	Ajania-bunchgrass- wormwood sage communities (*Artemisia frigida, Stipa lessingiana, Festuca valesiaca, Ajania fruticulosa, Ephedra distachya, Veronica pinnata, Patrinia intermedia)* on the tops
	Fescue-feather grass (Stipa lessingiana, Festuca valesiaca, *Ephedra distachya, Galatella tatarica*) with elm (Caragana pumila) on slopes and in steppe inter-hill depressions
	Low hills
	With quartzite outcrops
6	**Series of communities:**
	Bunchgrass-wormwood-sage communities (*Artemisia frigida, Stipa lessingiana, Festuca valesiaca, Koeleria cristata, Ephedra distachya, Veronica pinnata, Patrinia intermedia)* on the tops
	Fescue-feather grass (*Stipa lessingiana, Festuca valesiaca, Ephedra distachya, Galatella tatarica*) with elm (*Caragana pumila*) and meadow-sweet (*Spiraea hypericifolia*) on the slopes and in steppe inter-hill depressions
	With grey quartzite outcrops
7	**Series of communities:**
	Ephedra- wormwood sage - bunchgrass communities (Stipa sareptana, Stipa lessingiana, Festuca valesiaca, Artemisia frigida, Ephedra distachya) on the tops
	Wormwood-bunchgrass communities (Stipa sareptana, Festuca valesiaca, Stipa lessingiana, Artemisia frigida, Artemisia austriaca, *Kochia prostrata, Carex supina*) on the slopes and in steppe inter-hill depressions

	With granite outcrops
8	**Combinations of a series of communities:**
	Bushes-petrophyto- bunchgrass (Orostachys spinosa, Sedum hybridum, Ephedra distachya, Ajania fruticulosa, Caragana pumila, Atraphaxis frutescens) tops of hills;
	Elm-wormwood- stipa (Stipa capillata, Caragana pumila, Artemisia frigida),
	Wormwood-fescue-feather grass (Stipa capillata, Festuca valesiaca, Artemisia marschalliana),
	Wormwood (Artemisia frigida)
	On slopes and inter-hill steppe depressions
9	**Combinations of a series of communities:**
	Bushes-miscelleneous grass (Orostachys spinosa, Sedum hybridum, Ephedra distachya, Ajania fruticulosa, Caragana pumila, Atraphaxis frutescens) on the tops of hills;
	Elm-wormwood-feather grass (Stipa capillata Caragana pumila, Artemisia frigida),
	Wormwood-fescue-feather grass (Stipa capillata, Festuca valesiaca, Artemisia marschalliana),
	Wormwood sage (Artemisia frigida)
	On the tops, slopes and inter-hill steppe depressions
	With inclusion of the following communities:
	Thin wormwood (Artemisia gracilescens)
	Black wormwood (Artemisia pauciflora)
	camphorosma (Camphorosma monspeliaca)
	Orache (Atriplex cana) in the inter-hill depressions on brackish-solonetz soils
10	**Combinations of a series of communities:**
	Bushes-miscellaneous grass communities (Orostachys spinosa, Sedum hybridum, Ephedra distachya, Ajania fruticulosa, Caragana pumila, Atraphaxis frutescens) on crushed undeveloped soils on the tops of hills;
	Elm-wormwood- stipa (Stipa capillata Caragana pumila, Artemisia frigida),
	Wormwood – fescue –feather grass (Stipa capillata, Festuca valesiaca, Artemisia marschalliana),
	Wormwood (Artemisia frigida)
	on the tops, slopes and inter-hill steppe depressions
	In some places with **inclusion of ecological series of communities**
	Bushes-mecsellaneous grass – grain crops (Poa stepposa, Festuca valesiaca, Leymus angustus, Achillea asiatica, Medicago falcata, Spiraea hypericifolia, Caragana pumila) on themeadow-chesnut soils in the interhill meadow depressions

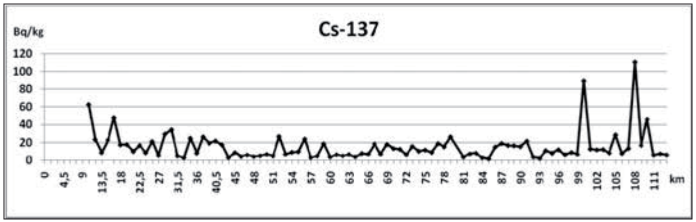
11	**Combinations of a series of communities:**
	Bushes- mecsellaneous grass communities (Orostachys spinosa, Sedum hybridum, Ephedra distachya, Ajania fruticulosa, Caragana pumila, Atraphaxis frutescens) on crushed undeveloped soils on the tops of hills;
	Elm-wormwood-feather grass stipa (Stipa capillata Caragana pumila, Artemisia frigida),
	Wormwood-fescue-feather grass - stipa (Stipa capillata, Festuca valesiaca, Artemisia marschalliana),
	Wormwood sage(Artemisia frigida) on the slopes and interhill steppe depressions
	with inclusion of ecological series of communities:
	With cheegrass (Achnatherum splendens
	Chingil (Halimodendron halodendron),
	wormwood-wild rye (Leymus angustus, Artemisia nitrosa) on halophytic meadows in the interhill depressions
	Dealluvial-prolluvial plains
12	Bunchgrass (*Stipa capillata, Festuca valesiaca, Artemisia frigida, Galatella tatarica, Ephedra distachya*) plains with inclusions of elm (*Caragana pumila*) and meadow-sweet (*Spiraea hypericifolia*) in some places.
13	Bunchgrass (*Stipa capillata, Festuca valesiaca, Artemisia frigida, Galatella tatarica, Ephedra distachya*) steppes.
	In combination with a series of communities:
	Thin wormwood (*Artemisia gracilescens*)
	Orache (*Atriplex cana)* on solonetz soils in the interhill depressions
14	Bunchgrass (*Stipa capillata, Festuca valesiaca, Artemisia frigida, Galatella tatarica, Ephedra distachya*) steppes.
	In combination with microbelts of the following communities:
	a) lucerne-fescue (Festuca valesiaca, Medicago bifurca),
	b) bunchgrass- wheat communities (Agropyron cristsatum, Potentilla impollita, Galium ruthenicum),
	c) licorice-wild rye (Leymus angustus, Glycyrrhiza uralensis) in the meadow steppe interhill depressions
15	Bunchgrass (*Stipa capillata, Festuca valesiaca, Artemisia frigida, Galatella tatarica, Ephedra distachya*) steppes, in some places with elm (*Caragana pumila*) and meadow-sweet (*Spiraea hypericifolia*)
	In combination with microbelts of the following communities:
	Suaeda (Suaeda prostrate)
	Halimione (Halimione verrucifera)
	Camphorosma (Camphorosma monspeliaca)
	Puccinellia (Puccinellia distans)
	Reed (Phragmites australis)

	Cheegrass (Achnatherum splendens)
	Licorice-wild rye (Leymus muiticaulis, Glycyrrhiza uralensis) in inter-hill depressions with drying-up water reservoirs
	Priirtyshie accumulative valley
	Floodplain vegetation
16	Ecological-dynamical series of communities: bushes and poplars (Poipulus nigra, Salix cinerea, Rosa majalis)→ herbs and grain crops (Phragmites australis, Calamagrostis epigeios, Bromopsis inermis, Glycerrhiza uralensis)→ halophytic herbs and grain crops (Aeluropus litoralis, Puccinellia dolicholepis, Limonium gmelinii, Plantago salsa)→ chingil-chegrass- Halimione (Halimione verrucifera, Achnatherum splendens, Halimodendron halodendron)→ wild rye-wormwood (Artemisia nitrosa, Leymus angustus) communities on floodlands
	Vegetation of the Irtysh floodplain terrace
17	Herb bunchgrass steppe (*Stipa capillata, Festuca valesiaca, Galatella tatarica,Medicago bifurca*) on ordinary chestnut soils, in some places in combination with micsellaneous grasses – grain crop – brushland communities (Spiraea hypericifolia, Rosa acicularis, Festuca valesiaca, Bromus inermis, Galium ruthenicum, Medicago romanica) on meadow-chestnut unsalinized soils of the Irtysh floodplain terrace
18	Complex of communities: wormwood-bunchgrass (Stipa capillata, Festuca valesiaca, Artemisia compacta) on ordinary chestnut soils and wormwood- orache (Atriplex cana, Artemisia nitrosa) plants on alkaline chestnut soils on the Irtysh floodplain terrace
19	Complex of communities: cespitose-crop-wormwood communities (Artemisia gracilescens, A.pauciflora, Festuca valesiaca, Psathyrostachys juncea) on brackish chestnut soils and halophytic herbs – grain crops (Puccinellia dolicholepis, L.angustus, Leymus paboanus, Aeluropus litoralis, Saussurea amara, Limonium gmelinii) communities on alkali saline soils on the Irtysh floodplain terrace
	Weeds
20	The Chenopodiaceae (Halocnemum strobilaceum) and areas without vegetation
	Vegetation caused by antropogenic activities
21	Demutation series of communities (rehabilitation): groups of biennial weeds (Avena fatua, Lactuca altaica, Artemisia sieversiana, Barbarea stricta, Ceratocarpus arenarius) → groups of weedy rhizomatous and proliferous perennial grasses (Cirsium arvense, Convolvulus arvensis, Artemisia procera, Artemisia austriaca) groups → communities of bunchgrass and wormwoods (Artemisia marschalliana, A. dracunculus, Agropyron cristatum, Festuca valesiaca)→ communities of motley grass-wormwood-bunchgrass (Agropyron cristata, Festuca valesiaca, Stipa lessingiana, Artemisia sublessingiana, A.marschalliana, Medicago romanica) on agricultural lands
22	Groups and communities including Elaeagnus oxycarpa, Rosa majalis, Vexibia alopecuroides, Ciclochena xantifolia, Chenopodium album, and Leymus angustus around urbanized areas
23	Groups including Austrian wormwood (Artemisia austriaca), wormwood (Artemisia scoparia), sophora (Vexibia alopecuroides), broom kochia (Kochia scoparia), Sivers kochia (Kochia siversiana), frost-blite (Chenopodium album), Climacoptera ciliated (Climacoptera brachiata), ebelek arenarius (Ceratocarpus arenarius) in the vicinity of winter camps

ANNEX C

Distribution of ^{137}Cs and ^{241}Am specific activity within the profiles

Profile №1



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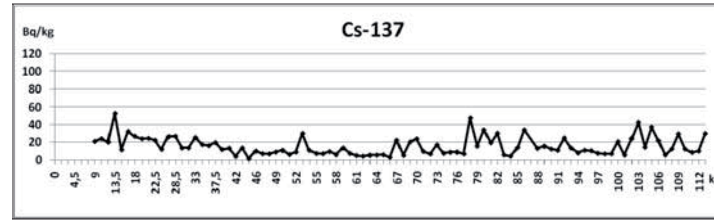

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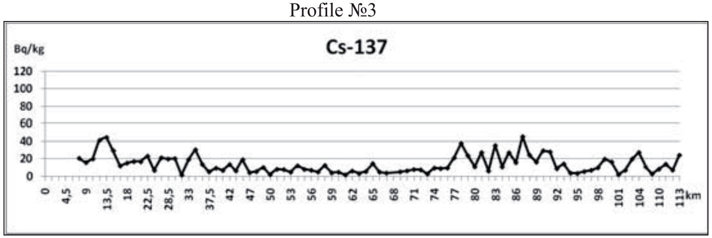

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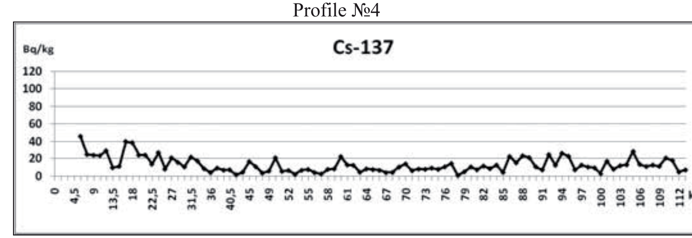

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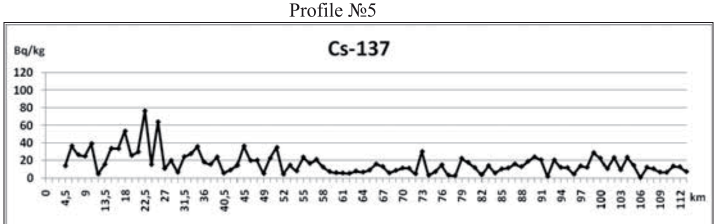

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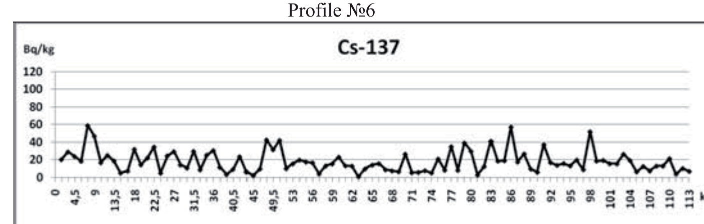

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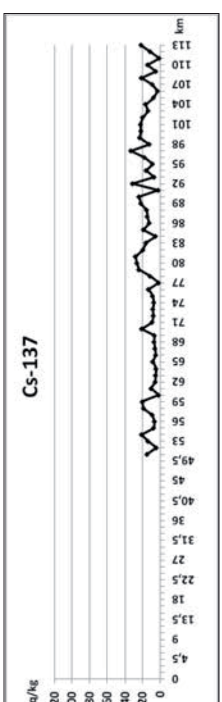

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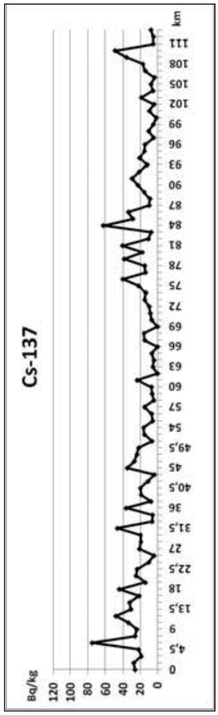

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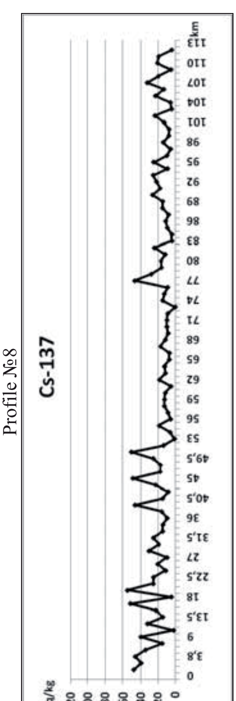

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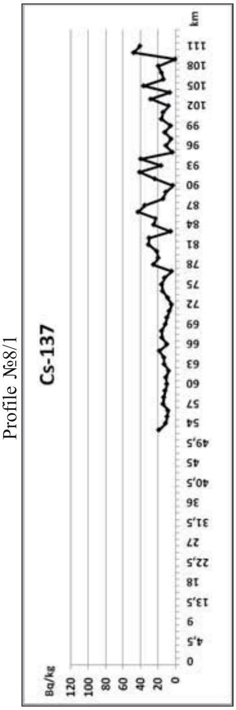

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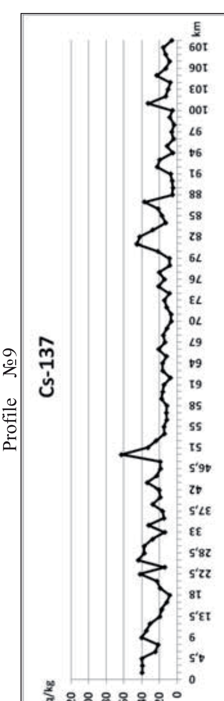

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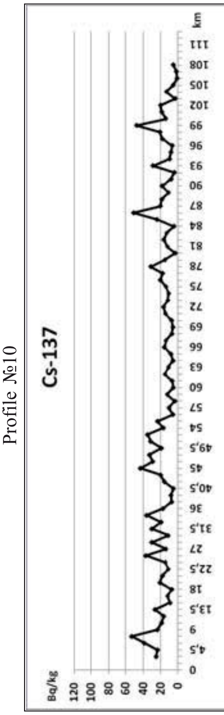

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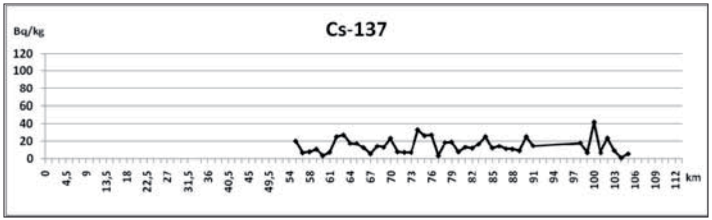

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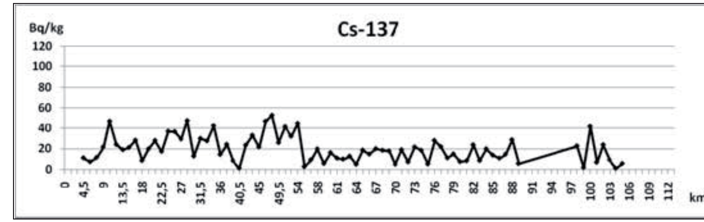

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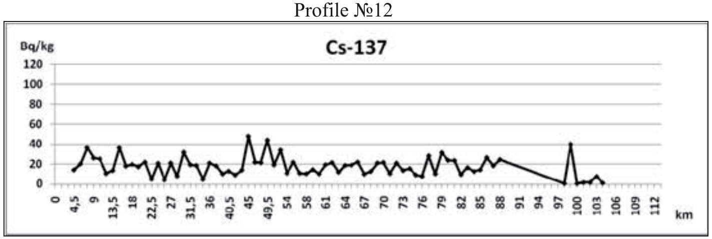

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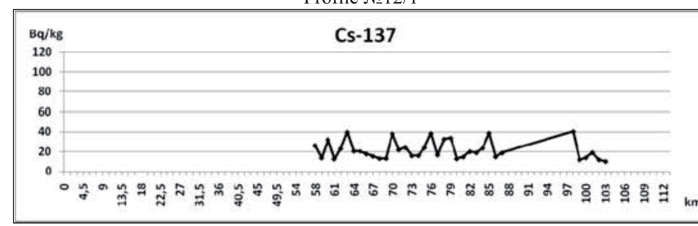

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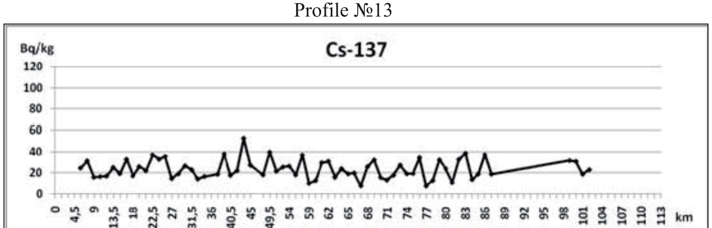

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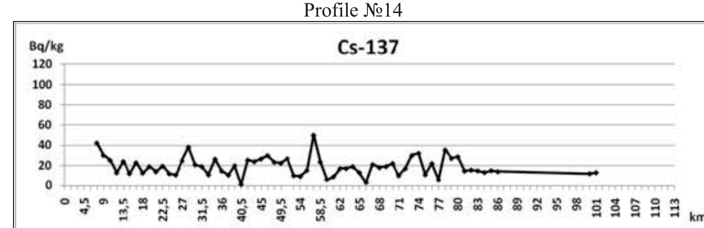

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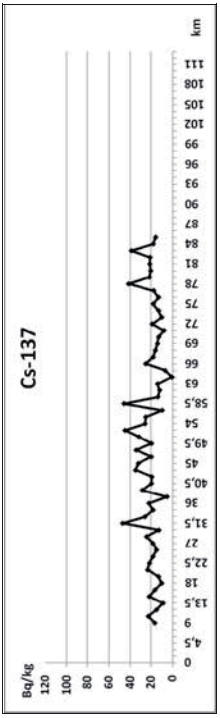

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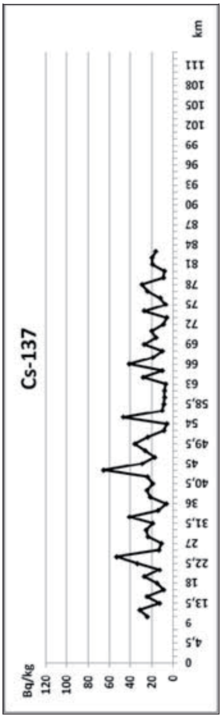

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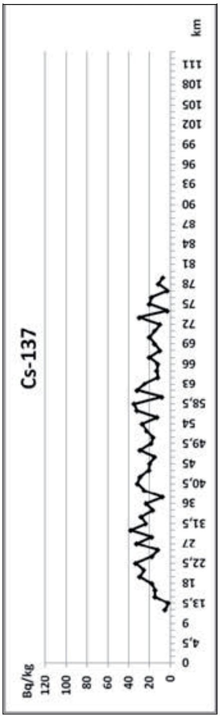

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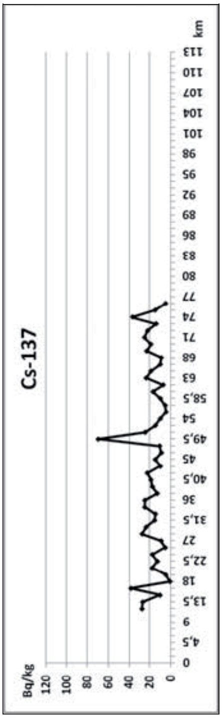

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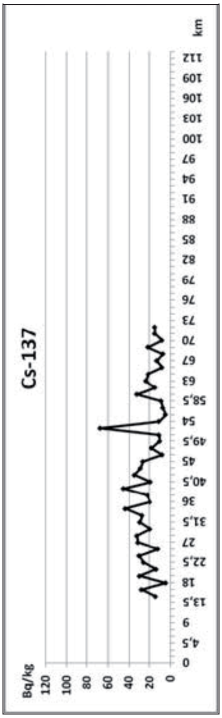

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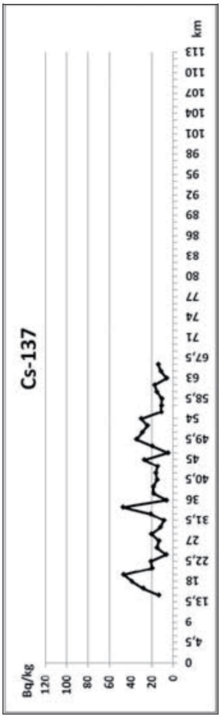

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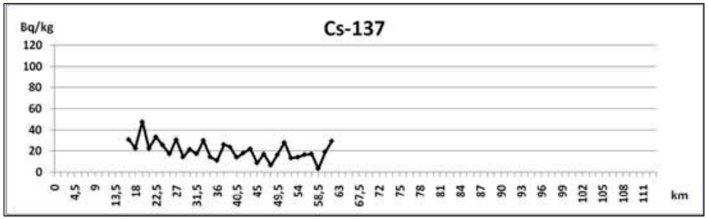

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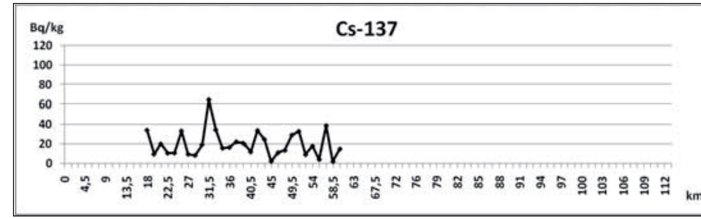

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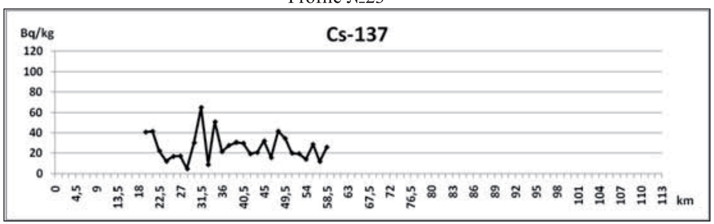

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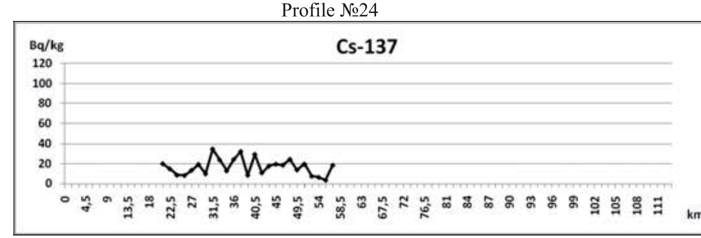

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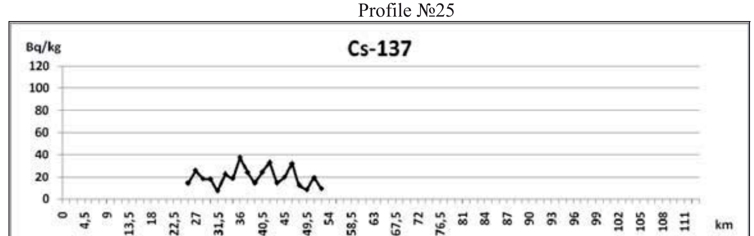

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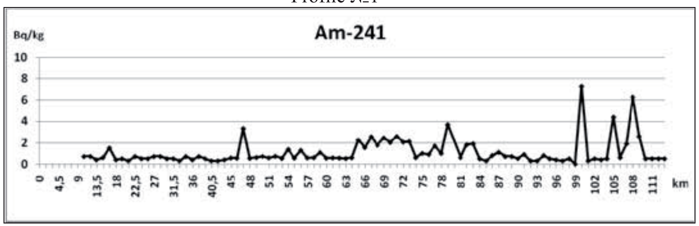

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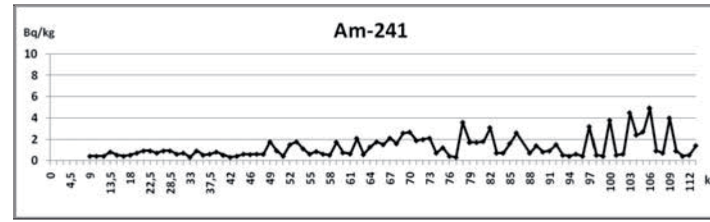

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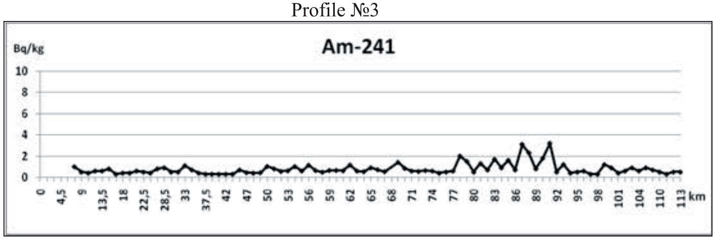

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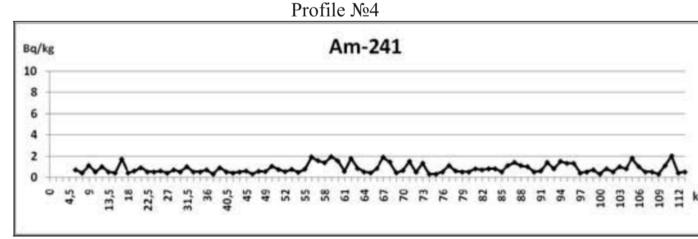

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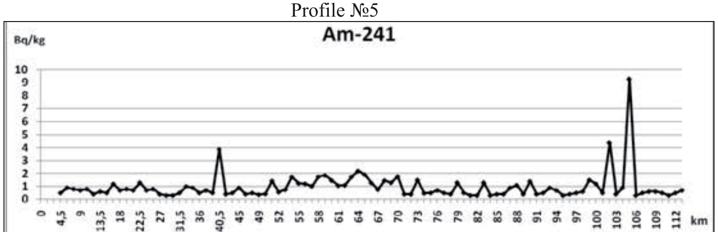

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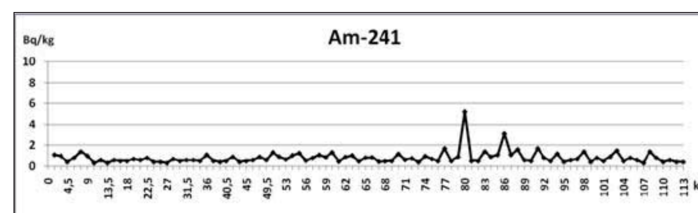

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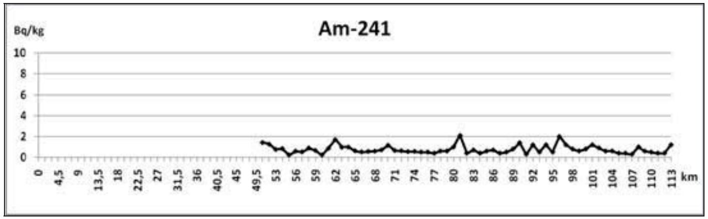

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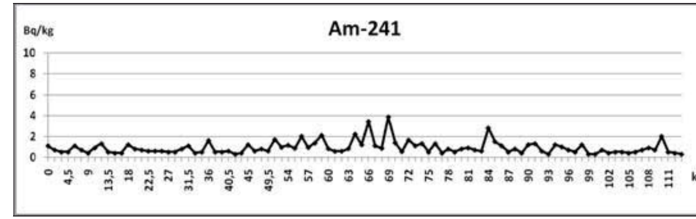

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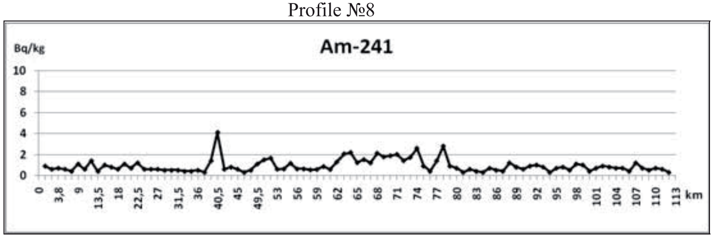

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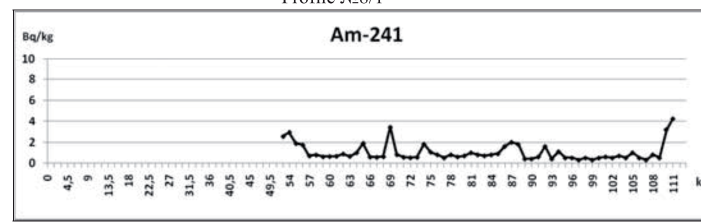

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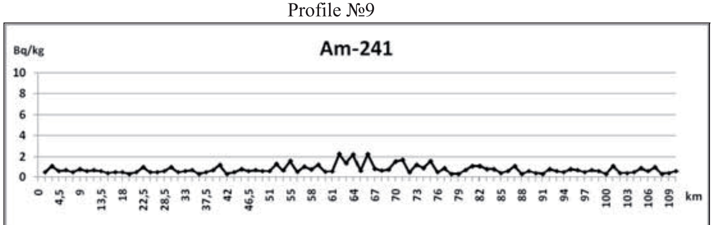

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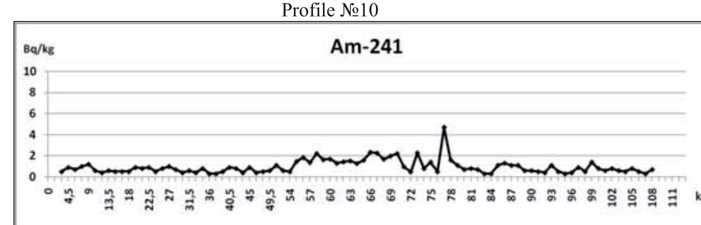

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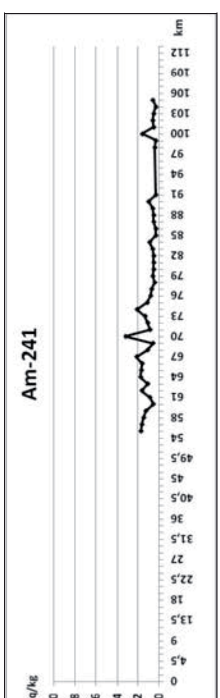

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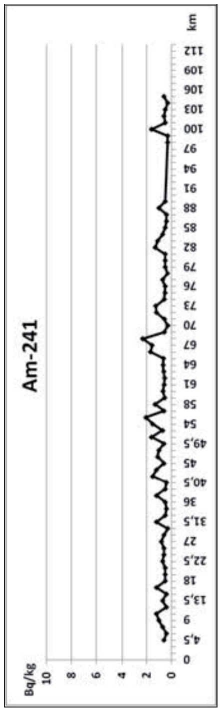

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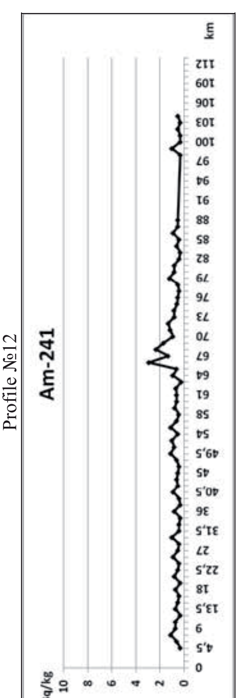

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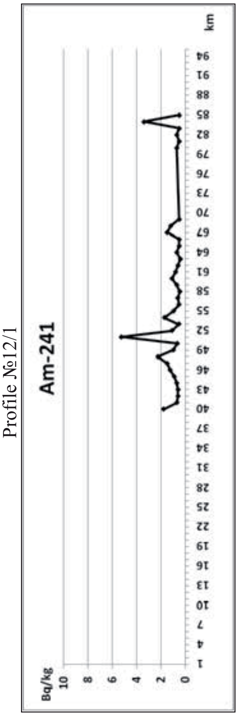

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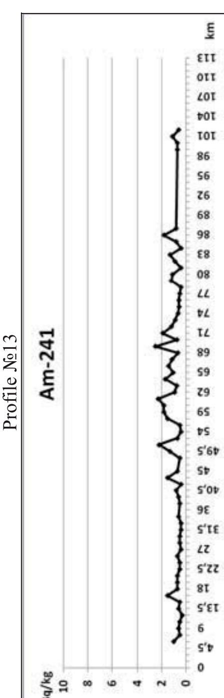

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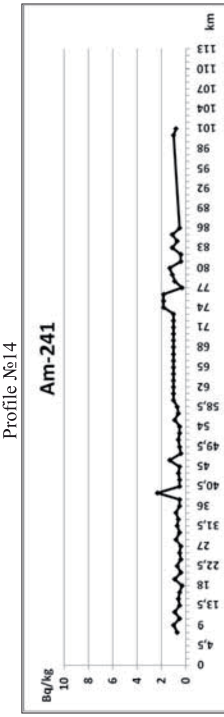

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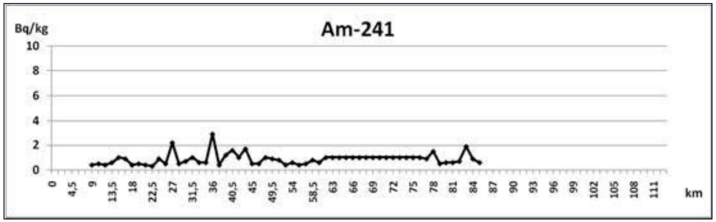

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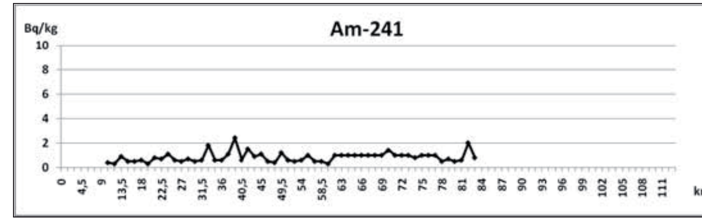

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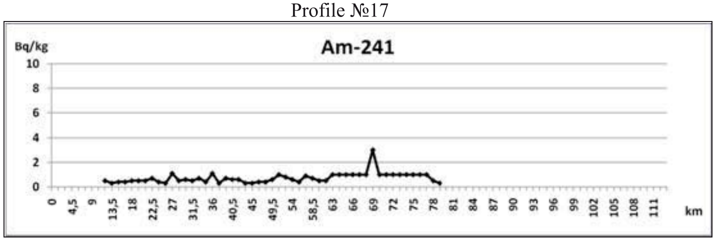

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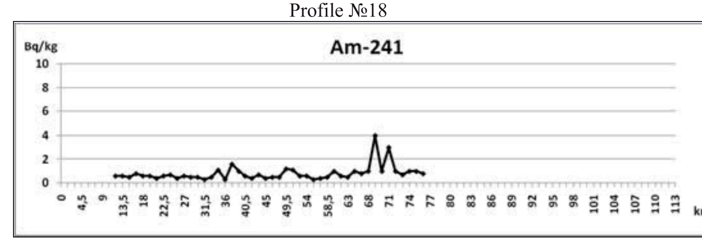

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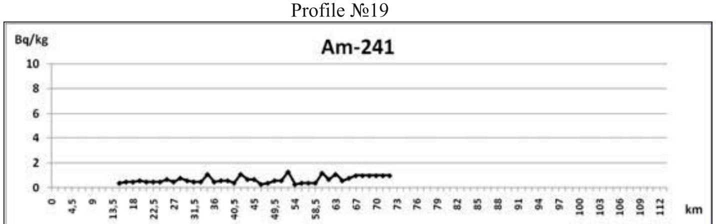

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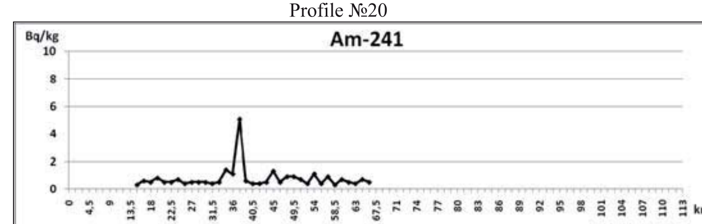

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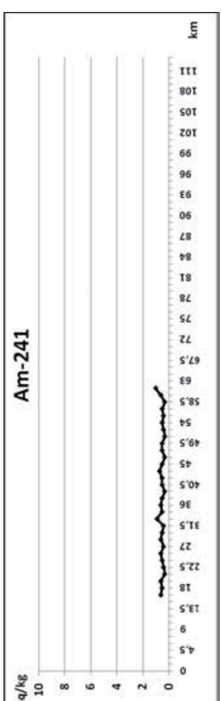
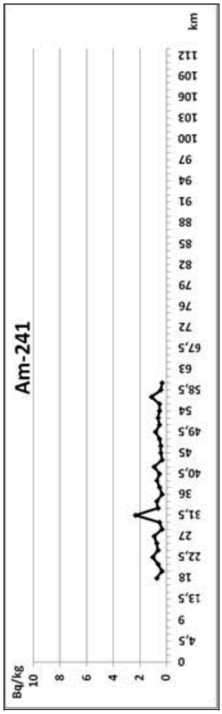
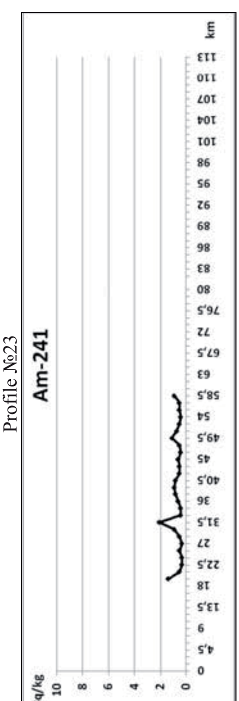


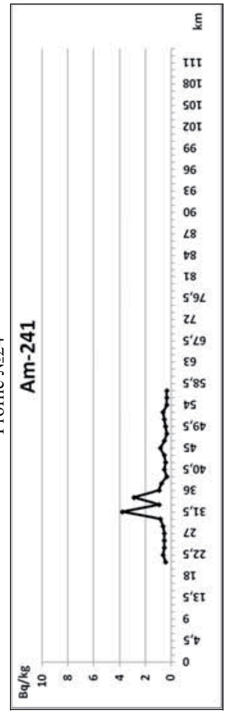
Profile №22



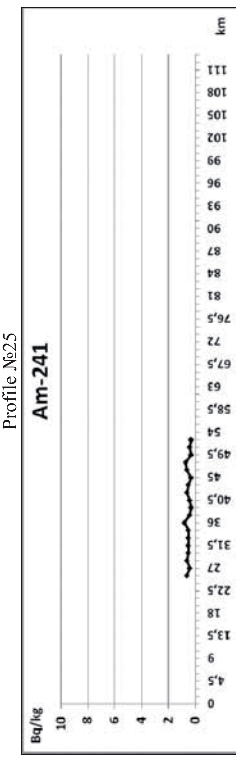
Profile №23



Profile №24



Profile №25



Annex D

Table D.1

Vertex points' coordinates of the zones at the northern territories recommended for economic use

Point No.	geographical coordinates					
	Longitude east			Latitude north		
	°	'	"	°	'	"
"Northern" part of STS territory for use with no restriction						
1	77	14	12	50	34	25
2	77	10	43	50	36	20
3	77	6	58	50	38	32
4	77	3	51	50	39	34
5	77	4	43	50	39	59
6	77	5	46	50	40	35
7	77	6	18	50	41	13
8	77	7	0	50	42	3
9	77	7	23	50	42	24
10	77	7	57	50	42	53
11	77	8	42	50	43	33
12	77	9	10	50	44	0
13	77	10	12	50	44	45
14	77	10	35	50	45	2
15	77	11	8	50	45	27
16	77	11	43	50	45	52
17	77	12	41	50	46	30
18	77	13	52	50	47	3
19	77	14	20	50	47	19
20	77	15	2	50	48	12
21	77	15	20	50	48	33
22	77	15	52	50	49	2
23	77	16	15	50	49	22
24	77	16	44	50	49	44
25	77	17	7	50	50	6
26	77	17	38	50	50	25
27	77	18	17	50	50	57

Point No.	geographical coordinates					
	Longitude east			Latitude north		
	°	'	"	°	'	"
28	77	18	53	50	51	22
29	77	19	42	50	51	60
30	77	20	59	50	53	1
31	77	21	34	50	53	19
32	77	22	26	50	53	44
33	77	23	19	50	54	7
34	77	24	15	50	54	20
35	77	25	12	50	54	31
36	77	26	13	50	54	45
37	77	27	56	50	54	53
38	77	28	16	50	54	53
39	77	29	1	50	54	57
40	77	30	42	50	54	55
41	77	31	5	50	54	55
42	77	32	59	50	54	51
43	77	34	2	50	54	47
44	77	34	36	50	54	55
45	77	35	39	50	55	8
46	77	36	27	50	55	19
47	77	37	28	50	55	33
48	77	38	24	50	55	34
49	77	39	24	50	55	34
50	77	40	28	50	55	36
51	77	41	41	50	55	39
52	77	42	54	50	55	28
53	77	44	2	50	55	16
54	77	45	43	50	55	3
55	77	46	49	50	55	6
56	77	47	39	50	55	11
57	77	48	23	50	55	6
58	77	50	7	50	54	57
59	77	51	15	50	54	52
60	77	52	2	50	54	48
61	77	52	55	50	54	14
62	77	53	28	50	53	54
63	77	54	31	50	53	20
64	77	55	34	50	52	44
65	77	57	3	50	52	16
66	77	57	34	50	52	7

Point No.	geographical coordinates					
	Longitude east			Latitude north		
	°	'	"	°	'	"
67	77	58	52	50	51	43
68	77	59	46	50	51	25
69	78	0	41	50	51	11
70	78	1	30	50	50	58
71	78	2	14	50	50	45
72	78	3	24	50	50	35
73	78	4	51	50	50	24
74	78	6	25	50	50	13
75	78	7	12	50	50	14
76	78	7	41	50	50	14
77	78	8	6	50	50	9
78	78	8	55	50	49	58
79	78	9	39	50	49	49
80	78	9	50	50	49	49
81	78	10	16	50	49	50
82	78	10	29	50	49	48
83	78	11	21	50	49	43
84	78	12	53	50	49	6
85	78	14	10	50	48	45
86	78	15	11	50	48	23
87	78	15	36	50	48	16
88	78	16	14	50	47	56
89	78	17	29	50	47	21
90	78	18	11	50	47	1
91	78	18	25	50	46	23
92	78	18	40	50	45	53
93	78	18	58	50	45	10
94	78	20	0	50	44	51
95	78	20	58	50	44	33
96	78	21	49	50	44	16
97	78	22	59	50	44	6
98	78	23	50	50	43	58
99	78	24	52	50	43	59
10	78	25	33	50	44	1
101	78	26	6	50	44	3
102	78	27	29	50	44	11
103	78	27	28	50	44	32
104	78	27	28	50	45	8

Point No.	geographical coordinates					
	Longitude east			Latitude north		
	°	'	"	°	'	"
105	78	27	29	50	45	34
106	78	27	9	50	46	8
107	78	27	43	50	46	25
108	78	28	26	50	46	45
109	78	28	10	50	46	59
110	78	28	38	50	47	37
111	78	29	34	50	47	17
112	78	29	58	50	47	3
113	78	30	14	50	46	50
114	78	41	20	50	41	53
115	78	40	59	50	41	38
116	78	41	2	50	38	36
117	78	41	21	50	37	40
118	78	40	47	50	36	16
scheduled control zone						
P 1	77	40	58,6	50	35	9,8
P 2	77	44	57,8	50	38	41,9
P 3	77	50	23,2	50	35	25,0
P 6	77	46	31,4	50	35	19,4
P 5	77	43	41,3	50	36	14,3
P 4	77	43	16,0	50	35	13,4
P 1	77	40	58,6	50	35	9,8

Table D.2

Vertex points' coordinates of the zones not recommended for economic use

Point No	geographical coordinates					
	longitude east			latitude north		
	°	'	"	°	'	"
"4a"ground territory (WRA)						
P 4	77	43	16,0	50	35	13,4
P 5	77	43	41,3	50	36	14,3
P 6	77	46	31,4	50	35	19,4
"Disposal" site territory						
M 7	78	18	47,4	50	42	35,0
M 8	78	19	12,8	50	42	34,4
M 9	78	19	11,8	50	42	18,4
M 10	78	18	46,3	50	42	19,0

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