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Optimization of study of the Semipalatinsk Test Site lands for the purpose of their transfer into economic turnover

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The monography presents modern data on the present radioecological state of Semipalatinsk Test Site (the STS), characterizing current and foreseeable situation at it. Specific attention was paid to radiation state of conditionally "background" STS lands assessment and assessment of possibility of their use in economic turnover of Kazakhstan. The monography provides the results of works mainly performed by the employees of the Institute of Radiation Safety and Ecology NNC RK in the 2009-2014. The book will be interesting for the specialists working in the area of radiation safety, environmental safety, radioecology, as well as individuals interested in issues of the STS ecological state.

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Introduction

The Semipalatinsk Test Site (STS) is one of the world's largest sites for testing nuclear weapons. Its area is 18,300 km^2 and 456 tests were performed there employing 616 nuclear devices. The tests conducted at STS varied greatly by the test nature (surface, atmospheric tests, tests in tunnels and boreholes, excavation-type tests), type of a nuclear device used (nuclear, thermonuclear) and by energy release (very-low, low, moderate and high yield). Combined with the diverse landscape and geological conditions at the site, these factors stipulated a highly diverse pattern of radioactive contamination. General STS map is given in the Figure 1.

Since the Semipalatinsk Test Site was closed and to the present day, Kazakhstani scientists in cooperation with the international scientific community have gained extensive information regarding the current radiological situation at the site and in the adjacent territories. All significantly contaminated areas have been revealed along with the major routes, pathways and mechanisms of current and potential proliferation of the radioactive substances. Among the most important outcomes of the work was the substantiated understanding that a part of the STS territory remains "clean" and can be released for normal civil use. In terms of radiation safety, current STS borders are obviously excessive and ungrounded.

The decision to run systematic works on gradual transfer of the STS lands for economical turnover is supported by the government of the Republic of Kazakhstan (RK) and the decisions made by the RK Security Council of April 6, 2009 and the Protocol Resolution of the Inter-departmental Commission under the RK Security Council dated May 7, 2009.

According to RK legislative acts, the STS territory as a whole is currently considered as state reserve lands (the RK decree № 172 of February 7, 1996). According to clause 143 'RK Land Code' '…the plots of land where nuclear weapon tests were conducted can only be released for ownership or land use only after all the remediation measures on nuclear weapon tests and the integrated environmental study are completed and supported by a positive Environmental Impact Assessment conclusion…'. Thus, undertaking an integrated environmental study of transferred land is the necessary stage.

The STS territory is rich in minerals, particularly, in coal, gold, nickel, iron and copper. Large STS areas have been in fact used as a farm land for a long time, for example, for cattle grazing. However, further STS development is contained by both the legal status of the test site and its notorious image.

Systematic study of the conventionally 'background' STS territories was initiated in 2008. In 2008 – 2014, an integrated environmental study was conducted on the area of 6,860 km^2 (37% of the total test site territory). The study covered the northern STS part (3,000 km^2) in 2009, the western STS part of 560 km^2 in 2010, in 2011 and 2012 the south-eastern STS parts of 850 km^2 each year, 800 km^2 in 2013, and 800 km^2 in the southern STS part in 2014.

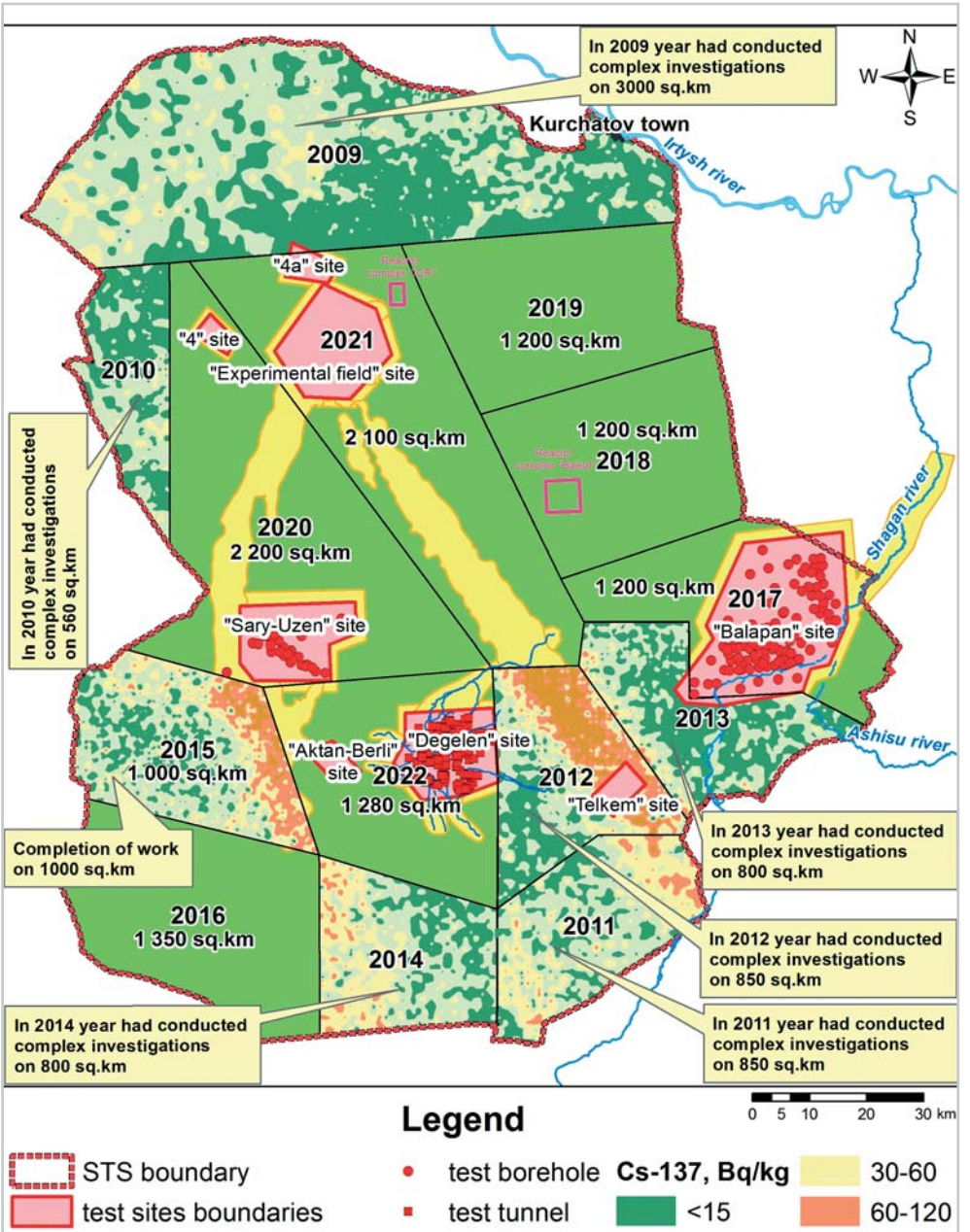


Figure 1. General STS map

Since no adequate and/or reliable information on the scales and nature of radioactive contamination was initially available, the studies were based on a pre-assumption that maximal possible detailed study is to be performed. The methodology included assessment of general characteristics of soil cover and the nature of main radionuclides distribution in soils; hydrogeological condition assessment and assessment of aquatic media contamination nature and dynamics; study of the air basin contamination nature; geobotanical description, theoretical and experimental assessment of vegetation cover contamination levels and nature; fauna assessment and radionuclide content estimates in main wild and domestic animals; assessment on the basis of experimental data of possible radionuclide concentrations for the farm, crop and animal products when produced at the studied territories; based on experimental findings, assessment of dosimetry loads on the population and the personnel in the course of their economic activities at the studied lands employing the scenario "a farmer involved into natural economy".

Sufficient scientific material has been gathered on the conditions of radioactive contamination at STS. The preliminary estimate shows that a number of sites and territories within the STS border have similar nature of their radioactive contamination which allows optimization of methodology for further research.

Chapter 1
GENERAL INFORMATION ON STS CLIMATIC AND LANDSCAPE-GEOGRAPHICAL CONDITIONS

1.1. Climatic conditions

The data from the Internet resource [1] over the 2005–2013 period has been used for climate characteristics of the Semipalatinsk test site.

Geographical location of the site predetermines sharp continental climate and aridness there. Thermal regime is basically determined by the radiation (solar radiation) factors as well as by the effects of atmospheric circulation exhibited in a complex alternation of cold and warm air mass transfer and interaction of masses in various seasonal baric conditions. Continental air temperature conditions are typical and are characterized by strong contrast, significant daily and annual amplitude. Mean monthly air temperatures, their normal maxima and minima are presented in Figure 2.

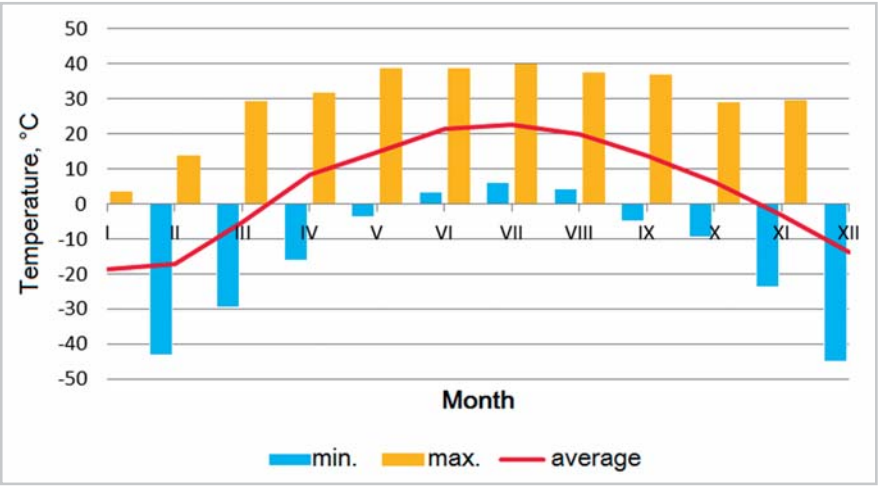


Figure 2. Monthly average air temperatures, maxima and minima

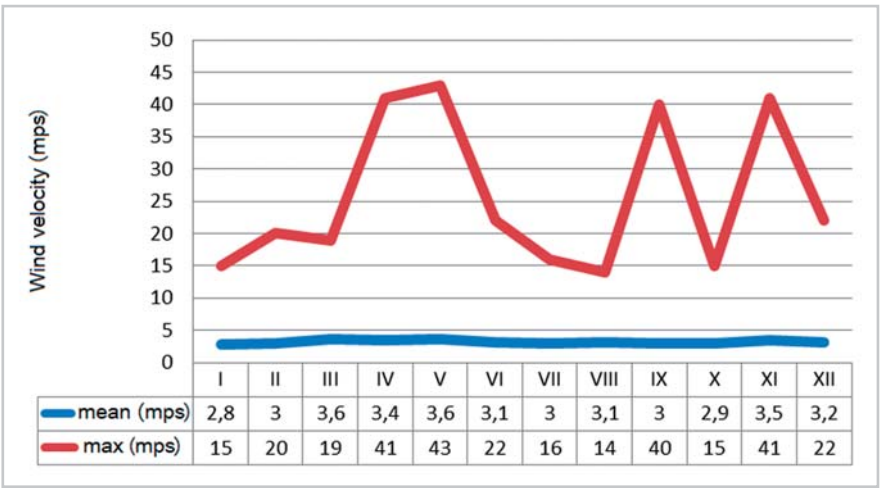
1.1.1. Wind regime

Wind regime is predominantly of continental nature and is basically determined by local barometric-circulation conditions. In the cold season, wind regime is formed under the influence of Siberian anticyclone which brings steady frosty weather to the region. According to the long-term observations, south-eastern (38.4%) and southern winds (16.3%) dominate during the winter season. The winds of opposite direction are observed far less frequently (northwesters – 9.8%, northern – 1.8%, north-eastern – 1.1%, south-western – 3.2%). Winter conditions are characterized by great frequency of anticyclones, therefore, no-wind conditions are observed quite often.

In summer time, the wind regime changes sharply with dominating winds from the north-western (27.4 %), western (16.8 %) and northern (14.9 %) directions, and no-wind conditions are more frequently observed. The wind conditions in spring and autumn are intermediate between those in winter and summer, which is attributed to changes in baric fields of the warm and cold half-year periods. May is characterized by the tendency of dominating south-east to north-west wind directions. In June-July this shift is fully completed.

In October, the summer wind system passes into the winter mode which is conditioned by the start of the seasonal Siberian anticyclone development and sharp attenuation in thermal depression.

Mean wind velocities vary with year seasons (Figure 3). Nature of these variations can be traced in the annual course of average monthly wind velocities.



	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
mean (mps)	2,8	3	3,6	3,4	3,6	3,1	3	3,1	3	2,9	3,5	3,2
max (mps)	15	20	19	41	43	22	16	14	40	15	41	22

Figure 3. Average monthly wind velocity for the period of 2005 through 2013

The annual course of mean values for wind velocity has maxima and minima. The highest average monthly wind velocities can be observed from February to June (3.0–3.6 m/s), the lowest – in July-August and in October (2.9 m/s).

Strong winds are basically observed in spring (April, May) as well as in February and November. Review of the observation data revealed the maximum wind speed of 35–43 m/s. No-wind conditions were observed in 10.0 % cases of the total observations, mostly no-wind conditions occurred in summer – early in autumn (2.0 % of the total observations).

Very strong and long-lasting winds bring dust storms. Their speeds can reach 20–30 m/s and higher. In the conditions typical of arid and semiarid regions, soil particles are picked up by wind from uneven surfaces with poor vegetation; soil surface irregularity and soil cover degradation due to animal grazing, vehicle traffic and human activities intensify dust raised by the wind.

Dust storms most commonly occur in May through July. On the average, dust storms occurred 5 times a year, maximum – 9 times, minimum – once in a year.

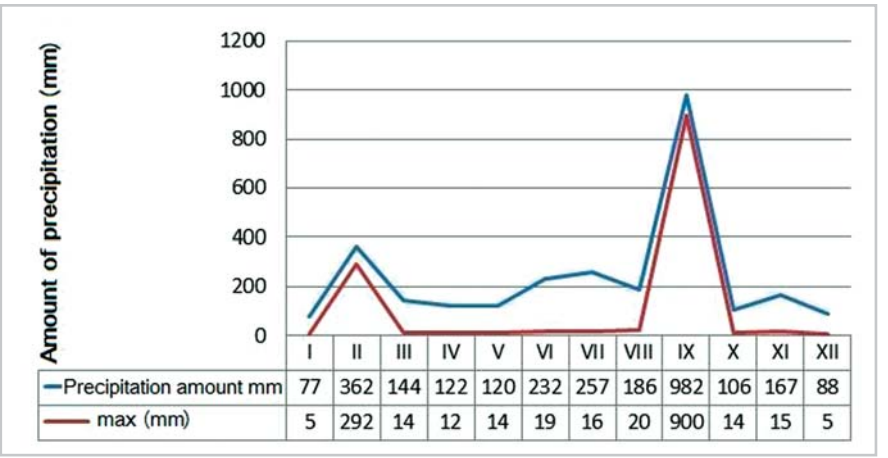
The average wind velocity in dust storms varies from 15 to 20 m/s. A few cases of dust storms have been registered with rather low values of wind velocity (6–8 m/s).

1.1.2. Precipitation

The test site territory lacks precipitation due to Eurasia barometric circulation features: motion of predominantly arctic and middle-latitude moisture-deficient air of continental origin. Aridity of the local climate also grows influenced by the deserts of Central Asia and southern Kazakhstan. Besides, the eastern part of the steppe zone in Kazakhstan is more subjected to anticyclonic impact and, hence, is less humid than the western part.

Local continental conditions determine unstable nature of precipitations; fluctuations from year to year are significant. A feature is characteristic of Kazakhstan that any month of the year may have no precipitation at all or have minute rate, and in some years, a monthly precipitation rate can be significant.

The annual amount of precipitation varies from 77.0 to 362.0 mm. Maximum precipitation took place in 2010 – 900.0 mm/year, minimum – in 2013 (77.0 mm/year). Distribution of precipitation by months is given in Figure 4.



	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Precipitation amount mm	77	362	144	122	120	232	257	186	982	106	167	88
max (mm)	5	292	14	12	14	19	16	20	900	14	15	5

Figure 4. Distribution of precipitation by months over the 2005 through 2013 period

The summer peak is well visible in the precipitation regime. Barometric circulation conditions of the warm half-year period favors a significant precipitation time from May to August with 50 to 60 % of the annual precipitation in storm rains. Significant precipitation is also observed in wintertime as rare abundant snowfalls. However, precipitation in the warm half-year period is combined with high temperatures which diminish its significance as a humidity factor – natural soil moistening is inadequate with significantly increasing evaporability. During the winter season, precipitation remains on the surface for quite a long time because of low temperatures (on the average, 2-3 months). In autumn, compared to summer months, the amount of precipitation is small, but due to a decrease in the air temperature, significant reduction in evaporation there takes place; in falls, precipitation satisfactorily moistens the soil.

1.2. Land cover state

In the soil-geographical respect, the STS territory covers two subzones in the steppe zone, namely, the subzone of dry steppes with a zonal subtype of chestnut soils and that of desert steppes with light-chestnut soils. Light-chestnut soils rimmed by a more humid subzone of chestnut soils in the north, west and south are common in the central and southern part of the STS [2].

By phyto-geographical zoning in the steppe part of the central Kazakh Hummocks, the STS territory is located within dry sheep fescue and feather-grass steppes with chestnut soils and semi-desert feather-grass steppes on light-chestnut soils; it forms a part of the Semipalatinsk and Ekibastuz districts in the East-Kazakhstan sub-province [3].

Thus, over 90% of the STS territory is covered by steppe vegetation on chestnut and light chestnut soils. The remaining part of the territory is fragmentarily occupied by shrub vegetation – desert (on solonetz and saline soils) as well as forests and grasslands (most widespread at the Degelen ground) [4].

Test activities in some areas of the "Experimental Field", "Degelen", "Balapan", "Sary Uzen" technical sites of the STS influenced the local ecosystems; the vegetation was partially destroyed and is still recovering at various stages of restoring associations [5].

The following is a more detailed description of soil and vegetation cover.

1.2.1. Soil cover

Among the zonal soils of the STS territory, the most widespread are underdeveloped soil types. They are formed across worn down tops and bald mountain slopes on thin sedentary-dealluvial rough skeletal deposits. Automorphous, zonal, normal and alkaline soils, often along with automorpous saline soils, are formed across wide arid inter-bald mountain plains. A genetic series of soils from hydromorphic, overmoistened to automorphous, can be observed in valleys of shallow streams and rivers crossing the hummocks. Here, low parts of the valley can be occupied by meadow and even swampy meadow soils. As moving away from the bed, they give way to semi hydromorphic soils which may exhibit to variable degrees the process of salt accumulation. This series generally ends in zonal detritus soils on bald trails.

For the most part, zonal light loamy, rank soils dominate across the denudation plains. They often preserve some alkalinity and salinification. Closed drainless depressions on plains and in hummocks are covered by saline soils. Bottoms of such depressions are fringed with a zone of hydromorphic saline soils combined with semi hydromorphic sodic and saline zonal soils [6].

At the transition territory from the Kazakh Hummocks to the PriIrtyshskaya plain, complexes of zonal alkaline soils with steppe sodic soils are widespread with the latter often playing the dominating role. The morphological profile of chestnut normal soils is closest to the chestnut-type soils. This profile is clearly differentiated into genetic horizons. The depth of humus horizon "A+B" varies between 35-45 cm. Calcareous horizon is located just under the humus horizon. Carbonates are emanated as whitish blurs. Accumulation of gypsum can be found in the parent material [6].

The content of organics in chestnut soils may reach 2.5-3.5%. The upper profile part for normal chestnut soils is carbonate-free. These soils across the profile contain no marked amount of highly soluble salts.

The central and eastern part of STS is occupied by light chestnut soils that are a southern zonal sub-type of the steppe zone. They exhibit a stable formed profile characterized by a shallow depth of humus horizon ('A+B' in varieties of loamy soils does not exceed 35 cm) and distinct division into brownish and grey with layering composition and crumby weak structure of "A" horizon and brownish-light-brown indurated "B" horizon. Firm carbon-bearing and illuvial horizon occurs deeper and passes into the parent rock. Boiling due to hydrochloric acid is observed within the humus horizon. Shallow horizons of light chestnut soils contain about 2-2.5% of humus. The described soils of the site are mostly of light loamy mechanical composition and contain noticeable elevated concentrations of skeletal solids across the profile [6].

Carbonate, alkaline and underdeveloped soil types can also be found among the subtypes of chestnut and light chestnut soils at the site. Carbonate soils are predominantly widespread among the soils of the chestnut subzone.

The main diagnostic sign for the chestnut and light chestnut alkaline soils is the presence of illuvial alkaline horizon standing out sharply in color, density and structure in their morphologic profile. It has darker brown shades in coloration, significant compaction and crumbly and nuciform or nuciform and prism-like structures. Of physicochemical parameters, first of all, a composition of absorbed bases in the alkaline horizon should be singled out. Its absorbing complex contains exchangeable sodium in the amount up to 15% of the sum. Besides that, this horizon increases alkalinity and the content of fine mechanical elements.

Underdeveloped chestnut and light chestnut soils are formed across sloping peaks and slopes of the bald mountains where bedding dense rocks occur close to the surface, and the thickness of skeletonless layer does not exceed 40 cm. They are characterized by a shortened morphological profile, high macadam content in soil material and incomplete set of genetic horizons.

Meadow-chestnut soils are soils of the semi-terrestrial series. They are formed under meadow steppe vegetation in depressed land forms owing to which they are additionally moistened by periodic impact of shallow groundwater or a surface runoff. While developing under more favorable conditions, they are different from the zonal ones in slightly deeper depth of the humus horizon, higher organics content there and consequently, in its darker coloration. These soils rather often exhibit signs of salinification and alkalinity.

Meadow soils at the test site territory are widespread across the low parts in valleys of shallow streams and rivers. Particularly, they are widely presented in the stream floodplains of the Degelen massif [7]. They are actively formed by groundwater occurring at a depth of 1-3 m. Besides, they can be subjected to superficial moistening due to inundation by melt and rainwater. Peculiarity in the meadow soil composition is stipulated by the moisture regime, degree of groundwater mineralization, by features of parent rock. However, formation of the thick humus horizon of high black mold humus is typical of all the meadow soils.

Sodic soils at the test site territory are found in the form of complexes with other soils. They include automorphous, semi-terrestrial and hydromorphic types. Saline soils

profile is clearly differentiated into genetic horizons. The morphologic genetic profile form of saline soils is first of all noticeable due to its two shallow horizons – eluvial and illuvial.

Eluvial (or oversaline) soil horizon is normally colored in lighter, grey tones. It is weakly compacted, depleted with mineral and organic colloids and has a relatively light-weight mechanical composition. The illuvial saline soil horizon is sharply separated from the shallow one. Its coloration is considerably darker. It is strongly compacted, split by vertical cracks and has a prism-like, columnar or nutty structure. Carbon-bearing horizon is located under the saline horizon with bright new formations of carbonates as 'white soft spots'. Parent rock stands out deeper with accumulations of highly soluble salts and gypsum.

Elevated exchange capacity in the sodic horizon up to 20 % and more of the absorbed bases sum should be noted among physicochemical features. Reaction of soil solutions in this horizon rise as high as the alkaline one. Distribution of particle size fractions among the vertical profile shows regularity peculiar to the saline soils – the upper part of the profile is depleted with silt particles, and their number in the illuvial horizon rises sharply. The saline soil profile oftentimes contains increased amounts of highly soluble salts.

Saline soils at the test site territory are common in closed drainless depressions on the denudation plain and the hummocks. Their formation takes place under the influence of mineralized water occurring at a shallow depth and due to salt supply by the runoff from surrounding territories. The common distinctive feature of all the saline soil is the presence in the surface layer of highly soluble salts in the amounts over 1 % [6, 7].

1.2.2. Vegetation cover

Communities of steppe vegetation (Figure 5) are formed on plains, trails and slopes of bald peaks and low-hill terrains. Dry pea shrub-cold vermouth-Volga fescue-feather grass (*Stipa capillata*, *Festuca valesiaca*, *Artemisia frigida*, *Caragana pumila*) steppes on deluvial-proluvial plains and slopes of the hummocks are typical of the STS north-western part. *Stipa kirghisorum*, *Helictotrichon desertorum*-dominated communities are typical in the high hummocks in this part of the test site.

a) b)

Figure 5. Volga fescue-feather grass steppe (a); cold vermouth piedmont steppe of sod grasses (b)

Upland types of desert thinish absinthial-Volga fescue-feather grass (*Stipa sareptana*, *Festuca valesiaca*, *Artemisia gracilescens*) steppes on light chestnut loamy soils are characteristic of sloping clinoplains in the north-eastern and eastern STS part. Absinthial-Volga fescue-sandy needle-grass (*Stipa lessingiana*, *Festuca valesiaca*, *Artemisia sublessingiana*, *A. albida*) steppes on light chestnut crushed stony and rank soils are typical of inter-bald mountain and piedmont plains in the granite low-hill terrain of the central and southwestern part of the site. Hemipsammophite steppe variants marshall-absinthial-Volga fescue-feather grass (*Stipa sareptana*, *Festuca valesiaca*, *Artemisia marschalliana*) with the presence of *Spiraea hypericifolia* on light chestnut slightly loamy and sandy loam soils are given on archaeoaluvial plains in the eastern STS part [4].

Brushwood (Figure 6) found at the STS territory are grouped in certain habitats. Steppe brushwood from *Spiraea hypericifolia*, *Caragana pumila, sometimes Halimodendron halodendron* are confined to inter–bald mountain ravines and steppe downs. Shrub coenosis with the presence of *Spiraea trilobata, Rosa spinosissima, Cotoneaster oliganthus, Lonicera microphylla*, *Pentaphylloides parvifolia, C.melanocarpus, sometimes Berberis sibirica*, *Ribes saxatile*, *Juniperus sibirica* found as their part, are typical of mattress-type laminated granites. *Juniperus sabina* thickets are common on screes across creek valleys. Coenosis from *Caragana pumila*, *Atraphaxis frutescens*, *Convolvulus fruticosus* are widespread on screes and sandy pebble dry washes. Brushwood with the presence of *Rosa majalis*, *R.glabrifolia*, *Padus avium*, *Lonicera tatarica*, *Ribes nigrum*, *Rubus idaeus* are typical in shadowy ravines and under the canopies of birch-aspen holts. Willow thickets consisting of *Salix cinerea*, *S.viminalis*, *S.rosmarinifolia*, *S.triandra* grow in stream floodplains, around springs and man-made reservoirs [4].

a) b)

Figure 6. Caragana-sod-grass steppe on the plain (a), shrub-sod-grass steppe in the high hummocks (b)

Perthophyte steppe variants are widely presented at the STS territory. Granite low-hill terrain, for example, Degelen massif, high and low hummocks form the variety of environmental conditions for perthophyte vegetation (Figure 7, a). Granite low-hill terrain is characterized by well-defined altitude zonal succession of plants. Piedmont plains and trails of low-hill terrain are characterized by Caragano-cold-absinthial-Volga fescue-feather grass (*Stipa capillata*, *Festuca valesiaca*, *Artemisia frigida*, *Caragana pumila*). Crushed stony areas of slopes feature *Ziziphora clinopodioides*, *Thymus ser-*

phyllum, *Veronica incana*, *Festuca valesiaca-dominated* associations. Underdeveloped and incompletely developed soils of slopes in the northern and north-eastern direction form mixed herbs-sedgy-graminous associations (*Helictotrichon desertorum*, *Stipa kirghisorum*, *Festuca valesiaca*, *Carex pediformis*, *Thalictrum foetidium*, *Bupleurum aureum*, *Chamaerhodos erecta*, *Pulsatilla patens*). The graminous-mixed herbs family (*Fragaria viridis*, *Dianthus acicularis*, *Veronica spuria*, *Artemisia latifolia*, *A.rupestris*, *Festuca valesiaca*, *Stipa capillata*, *Agropyron cristatum*) is typical of southern slopes with shrubs (*Spiraea trilobata*, *S.hypericifolia*, *Caragana pumila*, *Lonicera microphylla*). The perthophyte-mixed-herbs-frutescent coenosis are widespread on granite slabs (*Spiraea trilobata*, *Rosa spinosissima*, *Cotoneaster oliganthus*, *Lonicera microphylla*, *Pentaphylloides parvifolia*, *Orostachys spinosa*, *Sedum hybridum*, *Onosma simplicissima*, *Thalictrum simplex*). Perthophyte-mixed-herbs-lichenous aggregations are common on *Parmelia vagans*, *P. cetrata*, *Diploschistes scropsus*, *Orostachys spinosa*, *Euphorbia humilis*, *Patrinia intermedia*, *Onosma simplicissima*, *Silene suffrutescens*, *Hieracium echioides* dominated stony peaks [4].

a) b)

Figure 7. Perthophytes in the high hummocks (a),
fragments of forest vegetation with Pinus sylvestris in the Degelen massif (b)

Fragments of forest vegetation can be found in the particularly favorable conditions: small birch-aspen (*Betula pendula*, *Populus tremula*) shaws with *Populus canescens*, *Crataegus clorocarpa*, *Rosa majalis*, *Padus avium*, *Lonicera tatarica*, *Ribes nigrum*, *Rubus caesius* and rich graminous-mixed herbs (*Angelica sylvestris*, *Sanguisorba officinalis*, *Thalictrum flavum*, *Galium boreale*, *Agrimonia pilosa*, *Calamagrostis epigeios*, *Poa angustifolia*, *Melica transsilvanica*) herbaceous layer are formed in stream valleys and on slopes of shadowy ravines in the granite low-hill terrain (Figure 7, b).

The only habitat of *Pinus sylvestris* (Figure 7, b) has been revealed at Degelen in the high weakly disturbed granite crest. The tree layer is formed by *Pinus sylvestris* and *Betula pendula*. Shadowy crevices in granite slabs are characterized by brackens of *Asplenium* and *Woodsia* kinds. The surfaces of granite slabs have a well-developed moss- lichen layer with dominating Parmelia vagans, P.cetrata, Cladonia sylvatica, and single plants *Pentaphylloides parvifolia*, *Orostachys spinosa*, *Sedum hybridum*, *Veronica incana* border cracks of fine earth [4].

Phragmites australis, *Typha angustifolia*, *T.laxmannii*, *Bolboschoenus planiculmis*, *Carex omskiana-dominated* swampy meadows are characteristic of near-spring meadow grounds, catchment area of Shagan water basin, depressions in dry beds, margins of filtration water bodies at the "Atomic" lake and the man-made lakes. Polyprepotent true meadows of *Calamagrostis epigeios*, *Elytrigia repens*, *Bromopsis inermis*, *and Glycyrrhiza uralensis* are found fragmentarily in river floodplains. Steppe meadows with *Leymus angustus*, *Poa angustifolia*, *Bromopsis inermis*, *Medicago falcata*, *Potentilla bifurca* are typical of inter-bald peak cloughs, slopes of river terraces, piedmont poljes. Halophytic meadow variants are presented as coenosis dominated by *Puccinellia dolicholepis*, *Hordeum brevisubulatum*, *H.bogdanii*, *Aeluropus littoralis*, *Achnatherum splendens*. These are widespread in floodplains and on the terraces above floodplains, lake depressions around the artificial lakes. Grassland vegetation is widely featured in stream floodplains of the Degelen massif (Figure 8, a).

a) b)

Figure 8. Grassland vegetation in a stream floodplain of the Degelen massif (a), saltwort-sorang community in the meadow saline soil (b)

Eremic communities (Figure 8, b), within the steppe area, are formed under specific habitat conditions – in soils of the saline series (solonetz and saline soils). Such habitats are found in saline depressions of plains, places of saline Paleozoic clays, lake depressions as well as on river terraces above the floodplains. Pseudosteppe vegetation is represented by communities formed with hyperxerophilous and haloxerophilous dwarf semishrubs – representatives of *Chenopodiaceae* family and some species of *Artemisia* kind. Eremitic communities are formed by the following dominant species: *Atriplex cana*, *Anabasis salsa*, *Halimione verrucifera*, *Nanophyton erinaceum*, *Halocnemum strobilaceum*, *Kalidium schrenkianum*, *Artemisia schrenkiana*, *A. pauciflora*, *A.nitrosa*.

1.3. Hydrogeologocal conditions

Hydrogeological conditions at the STS territory are typical of the central Kazakhstani hummocks. Poor atmospheric precipitation (170-460 mm per year, long-time average annual – 263 mm, in wet years ~ 382 mm, in dry years ~ 221 mm), even in the absence of solid cover of friable low-permeable deposits (favorable infiltration conditions), forms a

limited amount of natural resources of underground water. Ubiquitously developed fracture underground water in Paleozoic rocks generates significant natural reserves (static, capacitive).

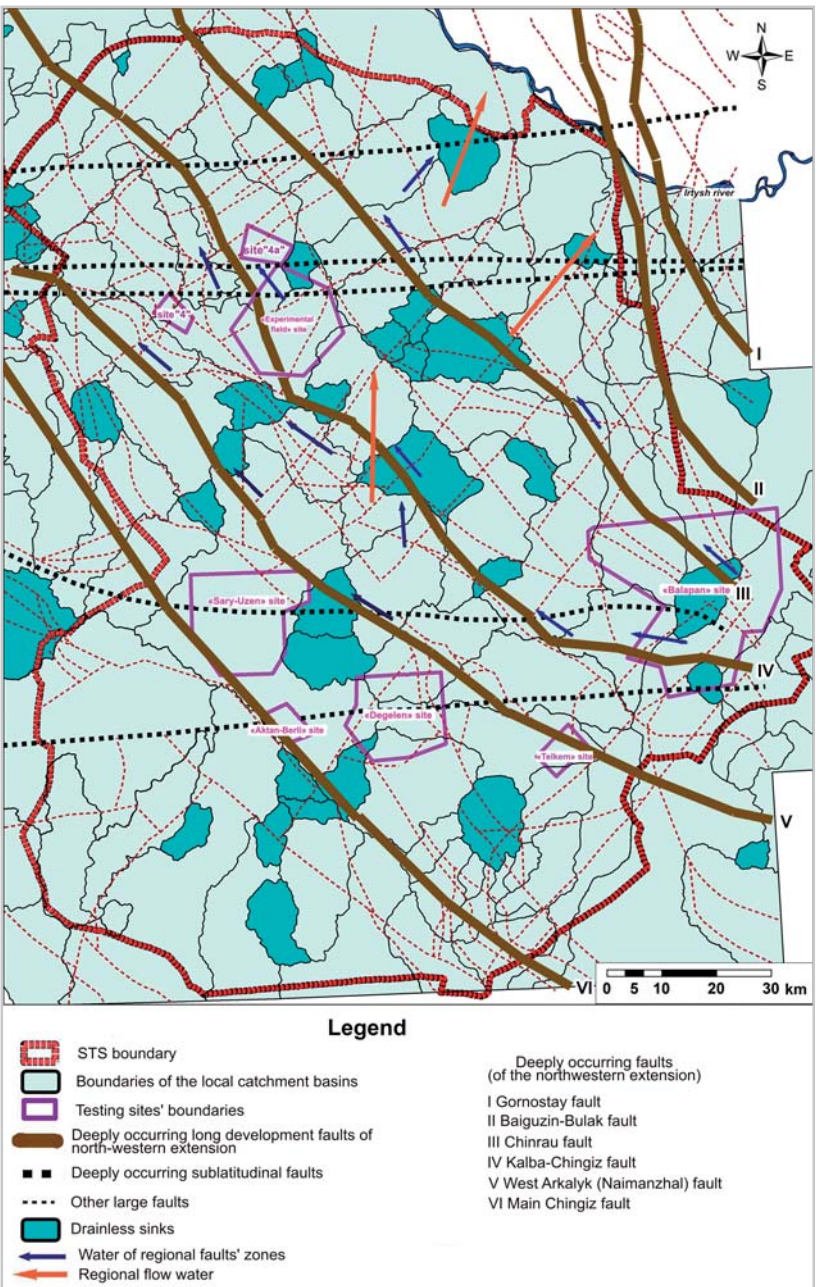


Figure 9. Diagram of local catchment basins and tectonic faults of the STS

The test site territory forms a part of the regional hydrogeological system of the Irtysh River left bank area. The main direction of the underground water is the north-north-eastern one and the area of underground water discharge is the Irtysh River (Figure 9).

As a result of the geological history, the STS territory formed a peculiar geological cross-section determining general geological conditions: unaltered, virtually water-resisting Paleozoic rocks occur at the base, above them – the Paleozoic fractured rocks and disintegrated water-permeable residuum formations overlapped by argillaceous residuum formations and Neogene clays in the topographic lows. Quaternary loamy covering deposits are relatively low water-permeable, thin or none.

The hydrogeological system of the territory involves water-bearing horizons of pore water and the regional complex of fracture water. Groundwater is sporadically distributed and presented as pore water in alluvial deposits in terrace valleys of the permanent and temporary streams as well as pore water in alluvial-proluvial plain deposits. Pore water is non-artesian occurring at depths of down to 10.0 m.

Fracture water is found at the STS ubiquitously and confined to the zone of exogenous basement rock fracturing. There is hydrocarbonate water of low mineralization down to 1.0 g/l dominating in the mountainous terrains. Chloride water of high mineralization up to 70 g/l is frequently observed in spots of drainless depressions. Fracture water, as a rule, is artesian yielding up to 10 l/s. The overall aquifer thickness can be up to 50 m. The occurrence depth of water-bearing structures varies from 10 to 60 m. Values of true fracture water proliferation rate within the test site territory may vary within the interval from 170 to 900 m/year. Transport of underground water at most of the STS territory takes place at quite low hydraulic filtration gradients and low filtration rates. This happens due to low filtration factor values which do not exceed the 1 m/day value. Filtration heterogeneity of the rocks is significant and non-uniform in the area.

Tectonic faults. Tectonic faults include faults that confine the major folded structures. These can be regarded as an adverse factor for engineering structures, which defines deformation, strength and filtration properties of a rock massif.

Zones of fault influence are characterized by increased fracturing, available zones of crushing, brecciating, schistosity and hydrothermal-metamorphic changes in the host rocks. Thickness of the influence zones in the regional faults reaches several hundreds of meters. Planes fall at the inclinations up to 80 degrees. The extent of regional faults varies from few meters to several hundreds of kilometers. Generally, structures of the influence zones are characterized by alternation in compression and extension zones where filtration parameters of the rocks may increase by more than 10 times. The underground water proliferation rate in the influence zones is therefore higher than that in the surrounding rocks. Thus, the zones of regional fault influence form a particular type of fracture water called as fracture-vain water. Figure 9 provides a diagram of tectonic disturbances at the territory of the Semipalatinsk Test Site.

Based on the above, the zones of tectonic fault influence at the STS territory should be considered as the major possible discharge pathways for contaminated underground water from the locations of underground nuclear explosions (UNE) to the underground waters proliferating off the tests site limits.

CHAPTER 2
CURRENT RADIOLOGICAL SITUATION AT THE STS

2.1. "Experimental Field" testing ground

Radioactive contamination of surface soil at the "Experimental Field" testing ground can be spatially categorized as:

- epicentral zones – local circular spots of radioactive contamination, several dozens of meters to several kilometers in diameter depending on the test yield;
- radioactive fallout traces from surface and air nuclear explosions;
- locations of non-nuclear tests (hydronuclear and hydrodynamic experiments) – local spots of radioactive contamination with no particular spatial form;
- radioactive fallout plumes from non-nuclear tests: hydronuclear and hydrodynamic experiments.

2.1.1. Background

The Experimental Field was the first testing ground of the Semipalatinsk Test Site designed for atmospheric (surface and air) nuclear tests and operating in 1949-1962. The testing ground is a plain of 20 km in diameter surrounded from three sides by low mountains. It occupies the area of about 300 km^2 and 64 km in radius. The ground is located 50 km away from Kurchatov city and about 170 km from Semipalatinsk city (Figure 10).

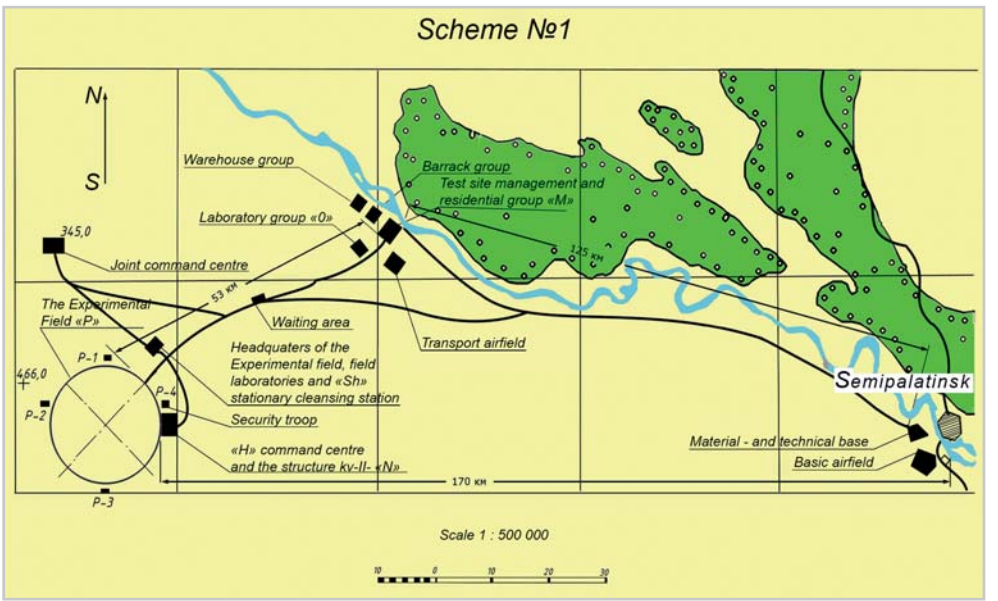


Figure 10. Location of the Experimental Field [8]

The Experimental Field was a large-scale facility with complex constructions designed for full-scale nuclear explosion tests.

The following were arranged to conduct the atomic bomb tests [8, 9]:

– Experimental Field (site "P") of 10 km radius equipped with special facilities for tests, observations and measurements of physical parameters;
– KB-11 site (site "N") located at the boundary of the Experimental Field with buildings and facilities designed for assembling a product before testing, storing minor components of the atomic bombs, instrumentation and equipment.
– headquarters borough ("Sh" site) located 5 km north-east away from the Experimental Field boundary and designed for deploying headquarters of security forces and power supply of the Experimental Field.

Technological "N" site [9]. The technological "N" site was built 10 km away from the center of the Experimental Field in the eastern direction, simultaneously with construction of the Experimental Field. The buildings and facilities of the site are supposed to ensure the charge assembly before testing, storage of the units and components as well as storage of units and equipment. The 12P building is the main extant command post at the Experimental Field. The facility was located 10,800 m eastward from the field center.

Headquarters borough – "Sh" site [9]. The headquarters borough, "Sh" site, was constructed 15 km away from the Experimental Field center in the creek valley between sloping hills; it was designed for deploying a power plant for power supply of the Experimental Field and "Sh" site to accommodate the test staff – test site personnel and attached staff as well as for security forces and construction crew.

Thus, by the August of 1949 the initial facility with a comprehensive test base was arranged allowing both surface and air nuclear ammunition tests to be conducted.

The site for multiple surface and air nuclear explosions. Initially, the entire Experimental Field territory was conventionally termed as 'P site'. It seems that later, when other testing sites within the Experimental Field were arranged, its central part (central site) in a radius of a few kilometers came to be called as P-1 site.

In 1953, intensity of nuclear tests increased with not only ground but also air\atmospheric explosions of various yields performed there, hence, it became necessary to arrange new testing grounds. At that, one can single out two main causes for such a need: firstly, a larger number of different-purpose nuclear weapon devices provided by the industry (for aviation, missile corps and artillery, navy and others) and, secondly, the only available P-1 site at the Experimental Field became insufficient. Besides, a large crater was formed due to the 1953 thermonuclear explosion in August in the center of this site where a tower to place a nuclear charge was arranged, and acute radioactive contamination of the site prevented from further intensive constructions there.

So, construction of new testing sites began: P-2 site for ground explosions; P-3 site for atmospheric explosions of low and moderate yield; P-5 site for high yield atmospheric explosions. At the P-3 and P-5 sites constructed specifically for atmospheric explosions at bombing, target finders were arranged in the form of chalk or white clay crosses for visual identification from the plains. Corner reflectors were also arranged. New underground casemates were built to host the instruments, and for cine- and photo cameras – portable servicing facilities. The territory of constructed testing sites extended

to a distance of 2 km from the site epicenter. P-6 site was constructed in the south-eastern part of the Experimental Field for special tests; no information is available about the tests performed there [10].

Based on the nuclear tests chronology [8], P-7 site construction was completed by 1961 whereupon the tests were conducted there mainly to investigate malfunctions, emergency conditions and situations.

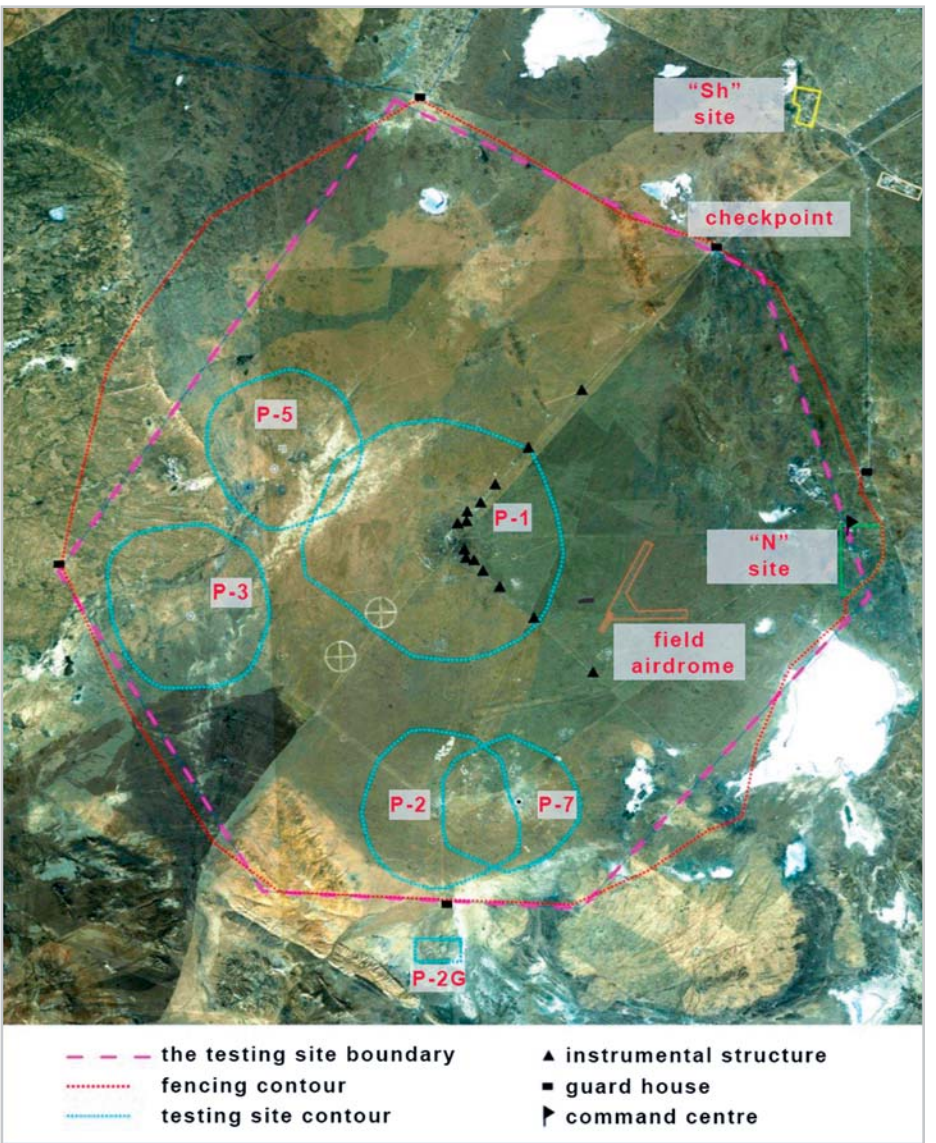


Figure 11. Location of sites at the Experimental Field

Figure 11 presents location of the testing sites at the Experimental Field, the headquarters borough, the command post and other facilities. The space image shows well-visible locations of the nuclear tests, testing sites' contours and some of the structures there (instrument structures, bridges, field aerodrome and others) that were built to study nuclear explosion factors.

A total of 30 ground explosions have been performed at the Experimental Field (in 5 cases nuclear devices malfunctioned and not exploded) and 86 air tests [10 – 16].

Based on the conditions of the nuclear tests, the following classification has been adopted [8]:

surface explosion – a nuclear test on the earth surface or in a testing tower. This category also includes a 30.10.54 nuclear explosion (aerial bomb) blasted at a low altitude;

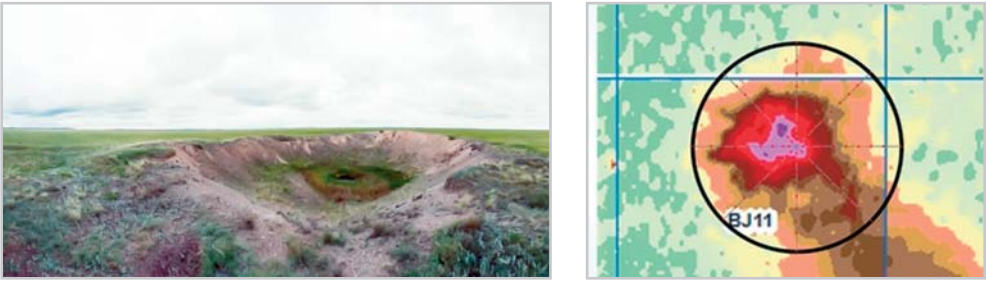
atmospheric explosion – a nuclear test in the atmosphere when the expanding fireball does not contact the earth surface. High altitude and space explosions create subcategories of this class.

Radiation situation in the regions adjacent to the test site was basically affected by 11 ground explosions since the remaining 14 tests were performed to assure maximal deposition of the nuclear explosion products within the test site limits [17].

The formed craters usually reached dozens of meters in diameter with a pronounced soil and slag piles. Some of the ground tests created no craters or other nuclear explosion consequences such as slag or fritted soil. Such pattern is possible in case of testing low yield charges in high towers or if reclamation works were performed with the outburst soil moved back to the crater and the epicentral spot covered with pure soil. The majority of nuclear test ground zeros can be identified, in the first place, by the presence of craters. Other signs for epicentral areas may be target finders on the earth surface in the form of circles and squares with crosses or man-made facilities located around the ground zeros. The main confirmation for an epicenter of a nuclear explosion is the presence of radioactive contamination of the area.

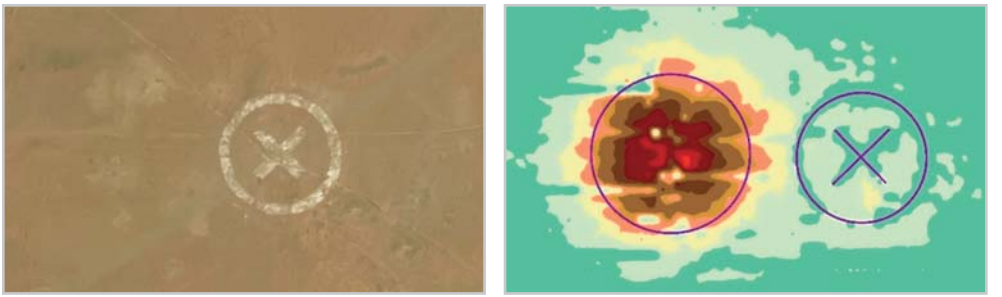
2.1.2. Epicentral areas

Based on the results of areal radiation safety surveying at the "Experimental Field" ground performed in 2012-2014, 24 places of nuclear tests were identified on the surface (presence of craters, Figure 12) or at a low altitude (no significant landscape disturbances, Figure 13).



a) Nuclear test crater b) ^{137}Cs areal distribution in a test venue

Figure 12. Nuclear test at V-1 object



a) Satellite image of a test venue indicative of no crater there

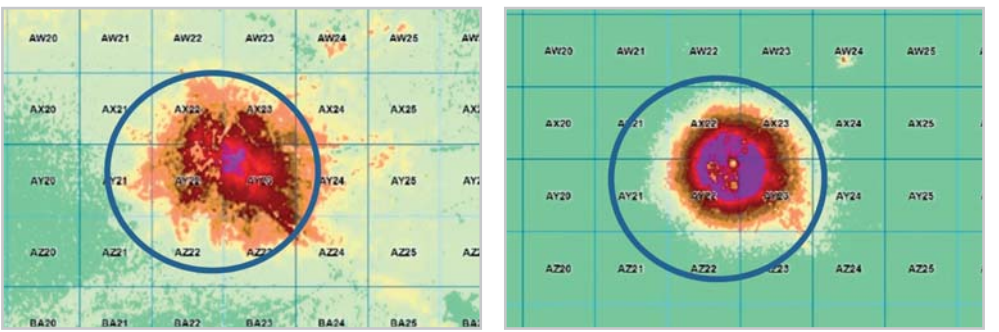
b) ^{152}Eu areal distribution in a test venue

Figure 13. Nuclear test at P-3 site

At P-2 and P-7 technical sites, 13 test epicenters have been revealed; at P-3 and P-5 sites – 8 epicenters, at P-1 site – 2 epicenters; one test was performed outside the limits of the technical sites – at V-1ground the spot is located 2 km to the south of P-3 site.

All the identified locations of nuclear explosions have similar features: spatially, radioactive contamination of the surface soil in a testing ground is round-shape with distinct borders; exponential decrease in specific activity of nuclear explosion products (fission products, activation of construction materials of the charge and environmental elements as well as the nuclear charge material itself) from the explosion epicenter to the boundary of the radioactively contaminated area.

These peculiarities make it possible to group this form of radioactive contamination of the area as "epicentral areas" of nuclear tests. The physical meaning of the notion "epicentral area" in terms of radiological contamination of the area can be described as follows. Epicentral area is an area nearby the ground zero where the presence of radionuclides in the surface soil is conditioned by a complex of physicochemical processes of interacting evaporated radioactive products with the environment in the period of a fireball development, dispersion and outburst of in-situ soil falling out of the explosion crater (if there is any formed) as well as neutron activation of the soil.



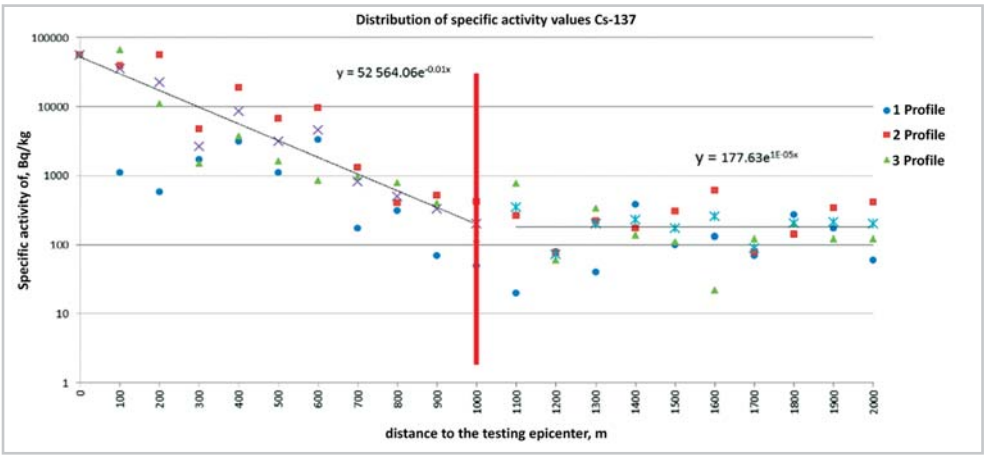
a) b)

Figure 14. Epicentral area at P-1 site:
a) fallout deposition zone (radioactive contamination of the area with ^{137}Cs);
b) induced activity zone (radioactive contamination of the area with ^{152}Eu)

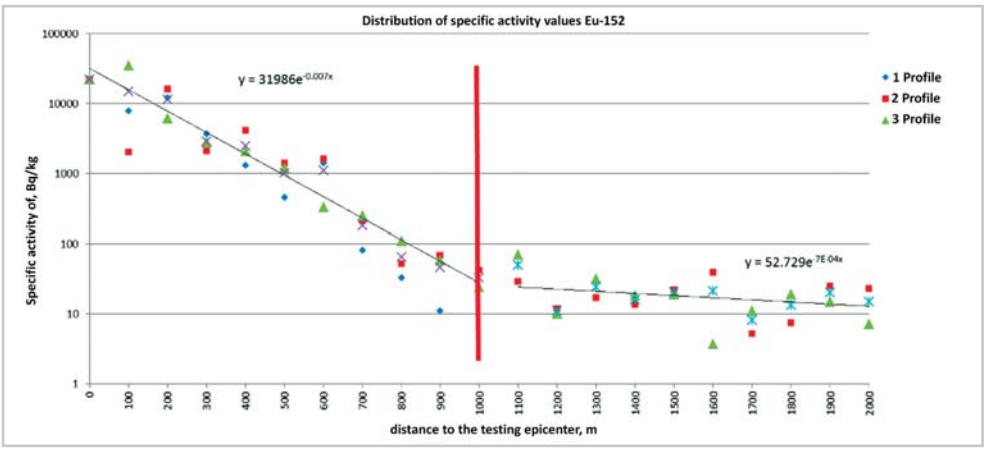
In other words, epicentral areas are the superposition of two regions of radioactively contaminated area – fallout deposition zone from the explosion cloud and a zone of induced activity (Figure 14).

Spatial characteristics of the epicentral areas include their radius, radionuclide penetration depth and activity distribution within the zone; the characteristics are determined by their two main mechanisms – radioactive particles fallout from the explosion plume and neutron activation of the geological substrate.

Simplifying for the first case, the factors determining the radius of the epicentral area and exponential decrease in radionuclides activity from the explosion epicenter to the boundary of the epicentral area are the gravitational settling of particles and Stokes resistance of the medium (Stoke's law) at particles' dispersion during the explosion. Coarser particles bearing high activity fall out closer to the epicenter.



a)



b)

Figure 15. ^{137}Cs and ^{152}Eu radial distributions in the surface soil vs distance from the epicenter. The data are for the 1953 test at P-1 site

In the second case, also in a simplified view, such factors are the full macroscopic interaction cross section of the neutron source interacting with the medium Σ_t, that determines a total free pass for the neutrons $\lambda=1/\Sigma_t$, and a probability to reach the R distance without a collision $\rho(R)=\exp(-\Sigma_t R)$ [18]. It is evident that in interactions with the medium the neutrons lose energy and, as a consequence, the distance they can pass from a source decreases.

Radial distribution of ^{137}Cs (fallout deposition) and ^{152}Eu (neutron activation of the medium) at P-1 site can be referred here as an example (Figure 15).

The studies have been undertaken along the three profiles starting from the explosion epicenter (in the Figure – "Epicenter distance "0" m") and further in three different directions. As it is seen from the Figure, there is an exponential decrease in ^{137}Cs and ^{152}Eu specific activities away from the explosion epicenter (maximum values) towards the 1,000 m mark where the specific activities of these radionuclides reach the plateau of the "background" values (red line denotes the boundary of the epicentral area).

Despite that the two different mechanisms form radioactive contamination of the epicentral area, they produce a net effect with exponential decrease in activity away from the epicentral area, typical for all ground nuclear tests at the 'Experimental Field' ground.

Thus, the "epicentral area" is a round-shaped area/territory where concentrations of the radionuclides formed at explosion reach their maximum values in the central part and exponentially decrease to the periphery.

The key feature of the epicentral area is the function of a certain radionuclide activity reduction with the distance from the ground zero towards the zone characterized by 'background' (for the given territory) levels of the radionuclide concentrations in the surface soil.

Currently, radioactive contamination in the epicentral areas is characterized by the presence of fission products (^{137}Cs, ^{90}Sr), activation products (^{60}Co, Eu, ^{3}H isotopes and others) and nuclear charge material ($^{239+240}$Pu, ^{235}U, ^{241}Am). At that, each test is characterized by its own predominant isotopic composition. Thus, all the test grounds can be conventionally divided into three groups: 1) nuclear test grounds of high energy release with significant quantities of nuclear explosion fission products (^{137}Cs, ^{90}Sr); 2) places of nuclear experiments with low or zero energy release – high concentrations of charge material ($^{239+240}$Pu, ^{241}Am); 3) testing grounds with high neutron fluxes – significant quantities of activation products (^{60}Co, Eu, ^{3}H isotopes and others).

Table 1 below provides typical levels of specific activities in soil for different nuclear testing grounds.

Reverting back to the testing at the P-1 site (Figure 15), – the "1,000 m" mark is the boundary of the epicentral area, i.e. the epicentral area radius is equal to 1,000 m. That is the largest epicentral area at the "Experimental Field".

Sizes of other epicentral areas are far smaller and their radii remain within the range 50 – 250 m.

Speaking of epicentral areas as a whole, one can state that each of the epicenters at the 'Experimental Field' ground has sufficiently distinct and identifiable boundaries of radioactive contamination and certain geometrical dimensions.

Table 1.

Maximum values of radionuclides' specific activities in soil at the 'Experimental Field' testing grounds as of 2014

Radionuclide		Specific activity, Bq/kg		
		places of nuclear tests with high energy release, over 1 kt	places of nuclear experiments with low or zero energy release, less than 1 kt	Testing grounds with high neutron fluxes
Nuclear explosion fission products	^{137}Cs	n*10^{6}	n*10	n*10^{3}
	^{90}Sr	n*10^{5}	n*10	n*10^{3}
Nuclear explosion activation products	^{60}Co	n*10^{2}	n*10	n*10^{3}
	^{152}Eu	n*10^{3}	n*10	n*10^{5}
Nuclear charge material	^{241}Am	n*10^{3}	n*10^{6}	n*10^{3}
	$^{239+240}$Pu	n*10^{4}	n*10^{7}	n*10^{4}

2.1.3. Radioactive fallout traces

The spatially largest radioactive contamination at the "Experimental Field" is represented by the traces of radioactive fallout. About 30% of the testing site surface is contaminated with cesium-137 with concentration in the top 5 cm soil ranging from 150 to n*10^{4} Bq/kg. For comparison, the background ^{137}Cs global fallout in the northern hemisphere from different sources is ~15-30 Bq/kg [19 – 26].

Figure 16 presents a fragment of the 'Experimental Field' illustrating the scale of radioactive contamination with cesium-137.

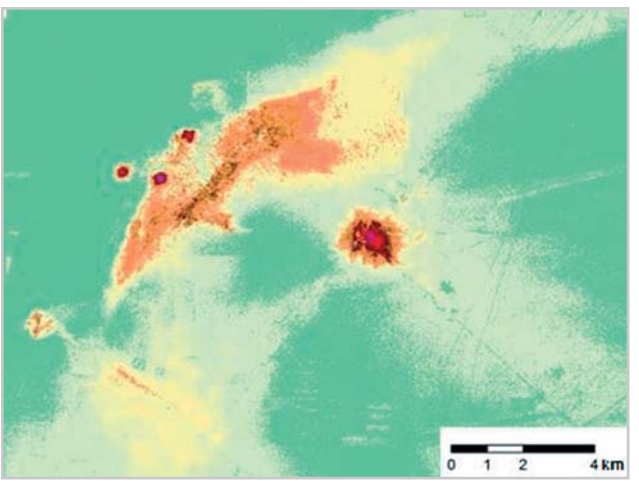


Figure 16. Radioactive contamination with ^{137}Cs

The width of radioactive fallout traces ranges broadly – from hundreds of meters to ~10 km depending on the yields of the performed explosions and meteorological conditions on the test date.

Three traces from the tests performed on 29.08.1949, 24.09.1951 and 12.08.1953 span outside not only the "Experimental Field", but also the STS boundaries. A more detailed description of these traces is presented below in the relevant section.

Formation of the radioactive fallout traces takes place in three main stages. The first stage is the formation of radioactive particles. Fission products of a nuclear charge, non-fissionable components of the nuclear charge and construction materials of the explosive device and the environment, activated by a neutron flux, are evaporated during explosion. In the course of subsequent cooling, each of these substances comes into contact with the components of the environment involved in the explosion (geological substrate) and, due to interactions at high temperatures and nuclear transformations, radioactive particles are formed.

The second stage – formation and lifting of an explosion cloud. At the initial stage of the radioactive cloud lifting vortices are formed and developed. It should be noted without going into details that the cloud formation is quite negligibly influenced by the atmospheric processes. The main role here is played by a shock wave, specifically, the proliferation vectors of the incident and reflected shock waves which actually define the vortices at interaction of the shock wave with the earth surface.

After a radioactive cloud rises up at a certain height, the third stage begins – dispersal of radioactive particles from the radioactive plume. Here meteorological conditions at the time of the test play a key role determining the path of the radioactive plume. Specifically speaking, the air mass motions are characterized by not only a horizontal, but also a vertical component which result in particle diffusion in the cloud towards the plume edges.

Thus, radioactive fallout trace is a terrain subjected to radioactive contamination owing to fallout deposition from the explosion cloud moving as a result of atmospheric processes. The trace shape is a strip with the width depending on the test yield, and the length – on wind intensity and direction at the time of explosion.

The most important conclusion is that only the topsoil is subjected to radioactive contamination formed by the radioactive fallout. Studies at the 'Experimental Field' ground and the entire STS have shown that 90% of artificial radionuclides are bound in the 5 cm topsoil. Any deeper penetration of the radionuclides with activity redistribution is due to secondary processes of both natural and anthropogenic nature.

Figure 17 illustrates typical in-depth distribution of artificial radionuclides in the soil for a fallout trace.

As an example, a trace from the nuclear explosion at the V-1 ground (Figure 12) is taken.

Currently, the major radionuclides in the radioactive fallout traces are ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}$Pu. Their concentrations reach the following values:

^{137}Cs - n*10^{4} Bq/kg;
^{90}Sr - n*10^{4} Bq/kg;
$^{239+240}$Pu - n*10^{3}Bq/kg;
^{241}Am - n*10^{2}Bq/kg.

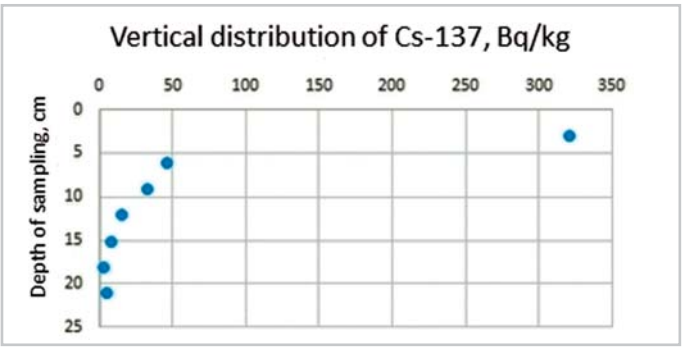


Figure 17. ^{137}Cs vertical distribution in the radioactive fallout trace from the test at the V-1 ground

At that, beyond the 'Experimental Field' ground, the activity of these radionuclides decreases for hundreds and thousands of times.

2.1.4. Sites of the non-nuclear tests (hydronuclear and hydrodynamic experiments)

Describing the contamination at the "Experimental Field" ground, one should note a special form of areal contamination at the grounds of the non-nuclear tests – hydronuclear and hydrodynamic experiments. Contamination there is 100% formed by the isotopes of a nuclear charge (Pu, Am).

According to the nuclear tests classification [27], explosion experiments with nuclear charges where the amount of released energy is comparable to the energy of chemical explosive charges, are categorized as hydronuclear tests. Explosion experiments with nuclear charges with no nuclear energy released are categorized as hydrodynamic tests.

Based on this classification, one can assume that the areal contamination took place at the grounds of non-nuclear tests owing to dispersion of nuclear charge material. Figure 18 presents the areal contamination with ^{241}Am at the P-2M testing ground.

As one can see from Figure 18, P-2M has several spots characterized as the locations of hydronuclear and hydrodynamic experiments. At that, each spot is the origin of different radioactive fallout traces stretching out in various directions (see. p. 2.1.4). This brings us to the conclusion that several non-nuclear tests were performed at each of the locations. Visual examination of the site revealed a high degree of technogenic disturbance on the surface. ^{241}Am specific activity in the soil there exceeds >n*10^4 Bq/kg. At that, due to strong disturbance of the surface at the site, the vertical distribution is different from the typical one: there are areas where radionuclides penetrated the depth down to 0.5 m. Local radioactively contaminated spots in venues of hydronuclear and hydrodynamic experiments are comparatively small in size and do not exceed 100 m longitudinally.

2.1.5. Radioactive fallout traces due to hydronuclear and hydrodynamic tests

Radioactive fallout traces due to hydronuclear and hydrodynamic experiments represent the areas with the shape of a narrow strip with origin at the epicenter and where surface radioactive contamination is formed by deposited radioactive particles (Figure 18).

In total, 16 traces of this kind of radioactive fallout have been identified at the "Experimental Field" ground.

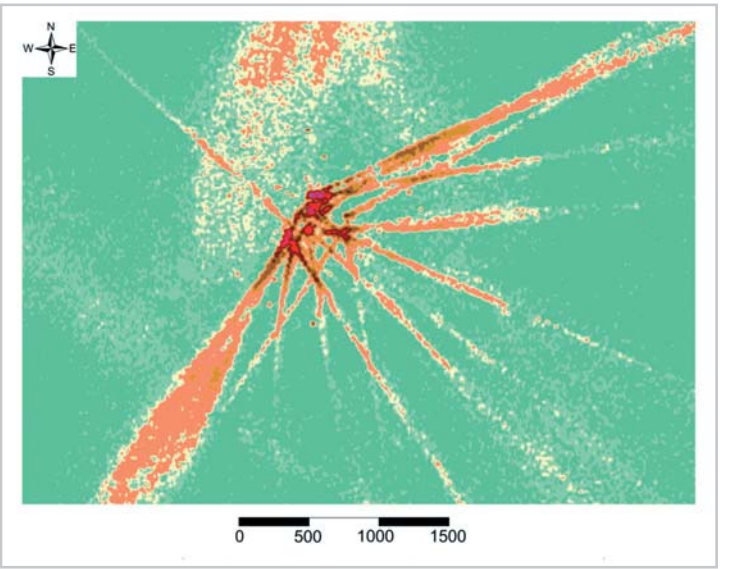
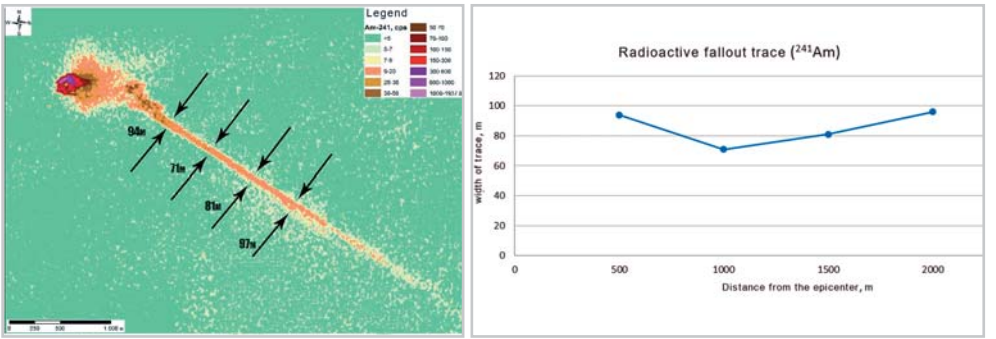


Figure 18. Surface areal contamination with ^{241}Am at the P-2M site

This type of radioactive contamination has several characteristic features which distinguish it from radioactive fallout due to nuclear explosions and from global fallouts.

First, these are the spatial characteristics of radioactive contamination. It is not about the geometrical dimensions of the traces, since it is evident that the fallout after hydronuclear and hydrodynamic experiments are by far smaller than those after "classical" nuclear explosions due to the fact that the yield of hydronuclear and hydrodynamic experiments does not exceed hundreds of kilograms in the TNT equivalent. The span of radioactive fallout due to hydronuclear and hydrodynamic experiments can reach 3-5 km with the width less than 100 m. At that, a characteristic feature is that the width of the trace remains virtually the same at this distance from the origin to the trace end (~80-90 m), i.e. no significant change in the contaminated area width can be observed moving away from the epicenter, unlike the high yield nuclear explosions (Figure 19).

Besides that, the direction of the fallout trace due to hydronuclear and hydrodynamic experiments remains constant across its entire span. Both these facts (constant width and direction) support the idea that the trace formation of this type does not depend on the meteorological conditions at the time of explosion.



a) b)

Figure 19. Radioactive fallout trace (^{241}Am) at the P-3 site

Another distinctive feature of the radioactive fallout traces due to hydronuclear and hydrodynamic experiments is their specific isotope compositions. Radioactive contamination of the area in such places is represented exclusively by the radionuclides in the original nuclear charge. Other radionuclides such as fission and activation products ^{137}Cs, ^{90}Sr, ^{60}Co, ^{152}Eu and others are either absent or their quantities are insignificant and explained by the fallouts from other nuclear tests.

^{241}Am specific activity in soil in the traces can be as high as >n*10^4 Bq/kg.

Since all surface tests of this type were performed at the "Experimental Field" ground, no radioactive fallout traces from these tests have been registered beyond the ground limits.

2.1.6. Man-made objects

There are lots of objects at the STS territory which were constructed there for various purposes. Some of them arose due to human activities prior the military history of the site (winter and summer huts, cemeteries, ruins of ancient settlements, etc.), some – after (mining sites, roads, agricultural facilities, present day winter and summer huts). But most of the man-made objects were constructed during the period of nuclear tests at the STS. The objects are very diverse in scales and purposes. These facilities can be divided into categories (by scale):

- engineering structures (underground and surface bunkers, instrument structures, radiation release channels, targets, trenches, models, dummies and so on);
- craters formed due to nuclear and conventional explosions;
- remediation traces. Large zones of technogenic disturbance of the natural landscape with impact on the topsoil (burial grounds, disposal sites of all kinds of waste, remediation venues, etc.).

According to official data, all nuclear and radiation experiments were conducted at the territories of large-scale infrastructure facilities – testing sites. Testing sites were generally equipped with complexes of engineering structures to provide preparation for and

perform the nuclear tests. The tests resulted in formation of the areas of anthropogenic impact.

Based on the experience gained at the "Experimental Field" testing ground in 2012-2014, significant attention was further paid to the analysis and field interpretation of the man-made objects at sites and adjacent territories. This approach demonstrated great efficiency in searching for sources of surface radioactive contamination and potential hidden radiation sources.

Engineering structures. Analyzing the obtained information, it was found that the engineering structures (Figure 20) in the form of gauge buildings, caponiers, bunkers (surface and underground), cable channels and others pose no radiation hazard. Typically, radiation background at such sites corresponds to the surrounding one, and materials of the structures themselves contain no radioactive material. The exception can be the structures located in close proximity to ground zeros of nuclear explosions where they could have been exposed to the effects of neutron activation products – ^{125}Eu, ^{154}Eu and ^{60}Co. It is worth noting that in such places, apart from these radionuclides, due to their proximity to the epicenters, there are also some fission products and transuranic elements that form general radiation pattern in the epicenter.

Figure 20. Strong 4-storeyed reinforced concrete instrument structure of "goose" stiffening rib. Located at the P-1 technical site. Armored hood in a permanent fire position (PFP) is to the right

Craters. At the territory of the "Experimental Field" testing ground, besides nuclear testing, experiments with chemical explosives were also performed. The number of such explosive tests there, according to some sources, could reach 175, of which 44 were performed with conventional explosive of more than 10 tons. These tests were performed in the late 1970's, i.e. performed there after the nuclear experiments at the site [28, 29]. The works performed at the "Experimental Field" territory verified and confirmed this information: a lot of craters were discovered with the radiation parameters corresponding to natural background levels and slag (ground fritted into glass – the major visual sign for a nuclear explosion conducted) is not present at all. It should be noted, however, that in some cases there were some effects of chemical explosion overlapping with the

pre-existing radiation situation: some craters are located in the epicentral areas of the nuclear technical sites where the levels of contamination with technogenic radionuclides are sufficiently high. Nevertheless, in some craters the radiation parameters have the background values. This is because a later in time (as it is also confirmed by literature data) chemical explosion with soil outburst covered surface radionuclide contamination from the previous nuclear explosion with a layer of "clean" soil. It is not improbable that some of these tests could have been used for the purpose of remediation in the region of heavily contaminated epicenters. Therefore, this type of sites while investigating the STS territory are to be studied quite carefully: craters left after nuclear explosions – to be inspected for radial and vertical radionuclides distribution, water is to be analyzed for tritium; deeper soil layers are to be inspected in the craters from conventional explosions. Over the years of research, no craters containing technogenic radionuclide have been identified outside the testing sites, so the attention is to be paid to the test site territories (Figure 21).

a) b)

Figure 21. Crater left after a surface nuclear explosion at the P-5 testing site (a); crater after a chemical explosion at the K-1 site (b)

Remediation traces and areal man-made alterations. Modern studies at the "Experimental Field" ground and analysis of the satellite images identified the areas where heavy machinery was previously used and the radiation background did not blend into the general picture of the area contamination. Visually, this kind of spots, generally, represent longitudinal strips of removed soil, parallel lines of backfilled trenches, filling traces of clean soil in pits or just earth depressions. Besides, not all of these sites were located at the territory of the "Experimental Field" with some located in the adjacent areas which may be indicative of potentially hazardous sites beyond the testing site limits. For example, at the unknown "P-2M" site, contamination in a pit was detected at the depth of 2.5 m under the layer of clean soil. This site is located 2 km to the south of the "Experimental Field". A trench-type burial has been discovered in the rectangular perimeter. Radioactively contaminated materials have been detected under the layer of dumped soil 10 cm deep. The site is located beyond the administrative boundary to the north-east of the testing site. Remediation traces and displaced soil were revealed at the territory of IK-1 engineering facility at the "Experimental Field" in the longitudinal

earth pile, where significant amount of contaminated soil is discovered across the whole pile depth. At the IK-2 in the region of the P-1 technical site, radiation contamination has been detected that does not fit in with the general nature of the area contamination. Perhaps, this is due to an individual test conducted there. Taking into account presence of these sites, it is worth paying individual attention to these places of areal technogenic alterations because they may hide significant amounts of radioactively contaminated materials (Figure 22). Their detection requires a thorough analysis of satellite images and further field interpretation.

Figure 22. To the left– Mortuary M-3. The area is fenced with barbed wire, at the center – dumped trenches, at the surface– material outcrop into the daylight surface. To the right – a pit at the P-2M site with traces of earth dumped. At a depth of 2.5 meters radiation parameters rise by 3-4 orders of magnitude

2.2. Traces of radioactive fallout beyond the "Experimental Field" Site

In spite of a significant number of nuclear tests performed at the "Experimental Field" (116 tests), only three radioactive fallout traces currently span beyond its limits: those are the traces from the test performed on 29.08.1949 – a so-called "eastern trace", the 24.09.1951 test – a "southern trace", and the test on 12.08.1953 (the first thermonuclear test) – a "south-eastern trace".

At that, two traces (the "southern" and the "southeastern") have been identified afield as a result of aerial-gamma spectrometric surveying carried out in 1990-1991 (Figure 23) and integrated radioecological investigations at the STS territory performed by the Institute of Radiation Safety and Ecology NNC RK since 2009.

The third trace ("eastern") was identified during the radioecological investigation at the territories adjacent to the STS in vicinity of Mostik, Cheryomushki, Bodene, Dolon populated localities. At that, this trace or even its fragments can hardly be recognized at the STS territory, which can most likely be explained by adverse meteorological conditions at the testing date (strong gusting wind, rain [30]).

Main characteristics of the radioactive fallout traces are: radionuclide composition, activity levels of the radionuclides within the traces, traces widths and lengths.

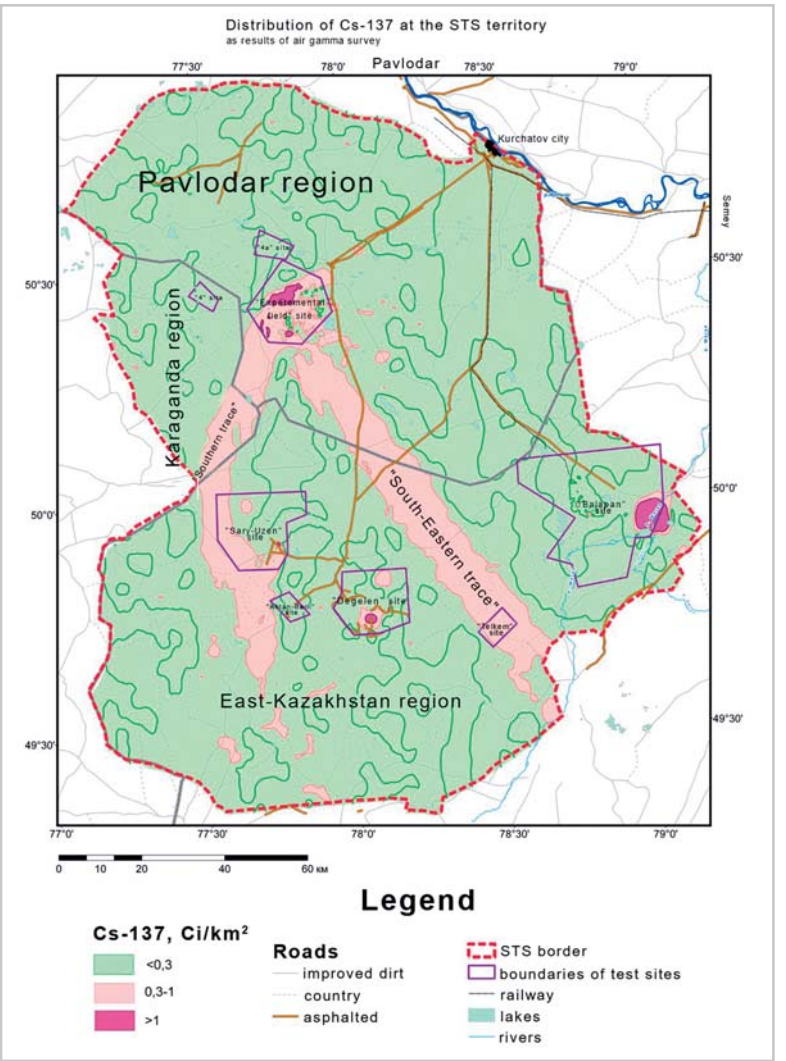


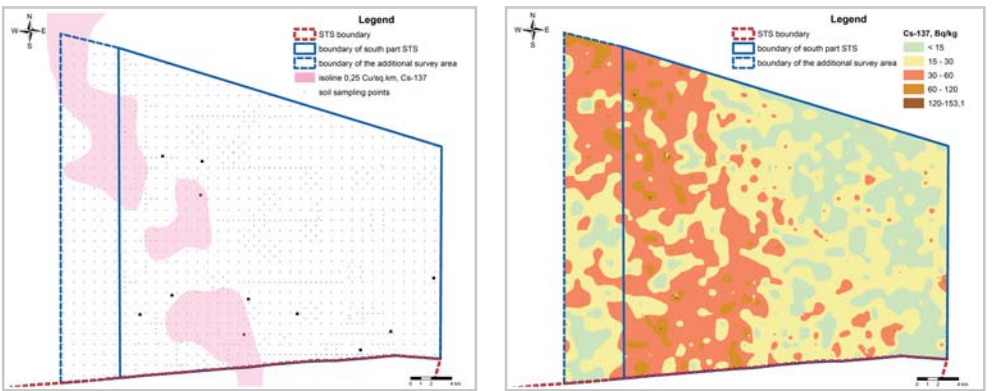
Figure 23. Radioactive fallout plumes (^{137}Cs) at the STS

Radionuclide composition of contaminated soils and subsoils in the trace zones basically includes the fission products ^{137}Cs and ^{90}Sr as well as nuclear charge material ^{241}Am, $^{239+240}$Pu, and ^{241}Pu. There are practically no activation products Eu and ^{60}Co remained due to their comparatively short half-life (^{152}Eu – ~13.5 years, ^{154}Eu – ~8.6 years, ^{155}Eu – ~4.7 years, ^{60}Co – ~5.3 years).

Specific activity of the radionuclides in the soil depends significantly on a test type: the type of fissile material, design and technical features of a nuclear charge, its yield. The determining factors in characterization of the radioactive fallout traces are the isotopic ratios – each trace is characterized by individual values of ^{90}Sr/^{137}Cs and $^{239+240}$Pu/^{241}Am isotopic ratios which eventually determine the trace individual features.

The widths of all the three traces is approximately the same and equal to 10-14 km. Each trace spans over a hundred kilometers, and all of them go beyond the STS limits. However, the actual lengths of the radioactive fallout traces have not yet been measured.

The "southern" radioactive fallout trace. The "southern" radioactive fallout trace was formed due to a nuclear explosion on 24.09.1951. The initial trace direction is south-western in vicinity of "Sary-Uzen" testing ground, and then it turns towards the south (Figure 23). According to the aerial-gamma surveying, closer to the STS border the trace splits into several radioactive "spots" including those outside the STS in the region of Kainar village [31]. However, according to the data from the integrated radioecological surveying in the southern part of the STS, radioactive contamination there is in the form of a quite distinct trace (Figure 24).



a) b)

Figure 24. Fragment of the "southern" trace based on: a) aero-gamma surveying in 1990-1991; b) integrated radioecological surveying in 2012-2013

Mean values of the technogenic radionuclides specific activity in the soil within the trace are:

^{90}Sr – ~30 Bq/kg;
^{137}Cs – ~45 Bq/kg;
^{241}Am – ~0.5 Bq/kg;
$^{239+240}$Pu – ~20 Bq/kg.

The ^{90}Sr/^{137}Cs ratio is 0.7; $^{239+240}$Pu/^{241}Am – 13.3.

It should be noted that the mean values above describe the "southern" trace near the STS border, i.e. at a distance of about 100 км from the epicenter. Approaching to the "Experimental Field" ground, the radionuclide specific activities in soil increase, but the isotopic ratios remain unchanged (with a certain rate of precision).

The "southeastern" radioactive fallout trace. The "southeastern" radioactive fallout trace was formed after the 12.08.1953 thermonuclear explosion. The trace goes beyond the STS limits and passes close to Sarzhal village (Figure 25).

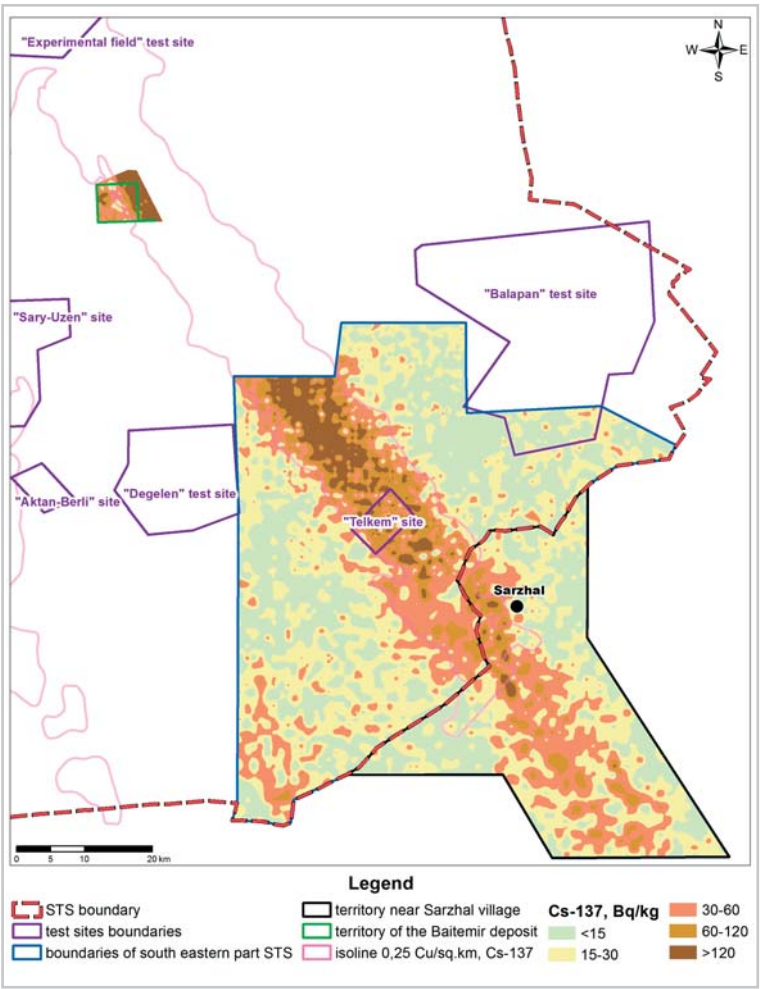


Figure 25. "South-eastern" radioactive fallout trace

Mean values of technogenic radionuclide specific activity in soil within the trace are:

^{90}Sr – ~450 Bq/kg;
^{137}Cs – ~150 Bq/kg;
^{241}Am – ~2.5 Bq/kg;
$^{239+240}$Pu – ~30 Bq/kg.

The ^{90}Sr/^{137}Cs ratio is 3.0; $^{239+240}$Pu/^{241}Am – 12.0.

Mean values of the technogenic radionuclide specific activities in soil are also provided for the trace near the STS border at a distance of ~100 km from the epicenter.

The "eastern" radioactive fallout trace. The "eastern" radioactive fallout trace was formed as a result of the first nuclear test in USSR performed on 29.08.1949, (Figure 26).

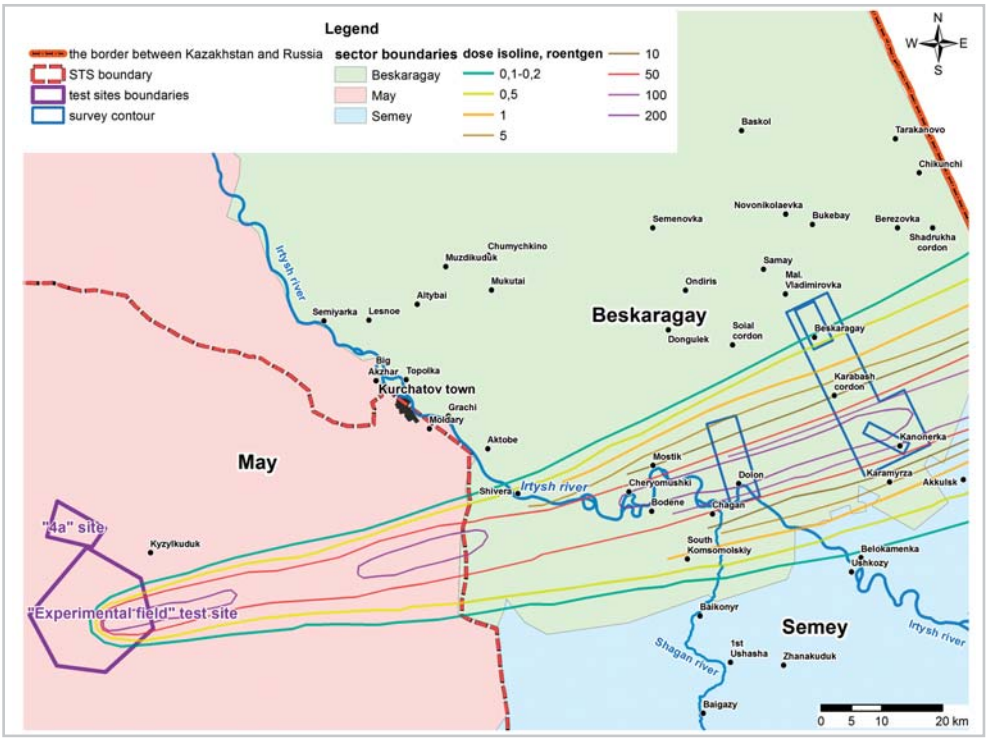


Figure 26. Radioactive fallout traces from the 1949 test

As it was mentioned above, the aerial gamma surveying could hardly reveal the trace within the STS. At that, the trace was well recognized at the distances 100-120 km from the "Experimental Field" site within the complex radioecological surveying of the STS adjacent territories (Bodene, Cheremushki, Mostik, Dolon, and Kanonerka inhabited localities). It should be noted, that no comprehensive large scale investigation has yet been undertaken for the "eastern" trace within the STS limits. By the present time, only some disembodied data on specific activities of the artificial radionuclides in soil are available there. These data are insufficient for reconstruction of a reliable pattern due to radioactive fallouts contamination.

However, in spite of the insufficiency of the radiological data of the "eastern" trace within the STS (mean and maximum specific activities of the radionuclides in soil), the isotopic ratio values obtained for the trace outside the STS can be used as a reference.

Therefore, near Dolon village, the $^{90}Sr/^{137}Cs$ ratio is 0.4; $^{239+240}Pu/^{241}Am$ – 28.0.

Most probably, these ratios are somehow the same for the entire eastern trace span.

2.3. “Degelen” site

2.3.1. General information

“Degelen” test site is located within the homonymous mountain massif in the southern part of Semipalatinsk Test Site, and it was designed for testing in tunnels (Figure 28). The area of the test site is approximately 350 sq. km. One of the main reasons to arrange a site for underground nuclear tests was signing the Partial Test Ban Treaty in 1963.

“Degelen” site was used for the low yield nuclear tests (up to several dozens of kilotons), and for related research in materials sciences, radiation stability of materials, radiation interaction with matter, and development of the methods for registration of nuclear explosion parameters. Nuclear devices were arranged in horizontal tunnels which extended the scope and range of related research allowing channeling the ionizing radiation to physical and biological objects.

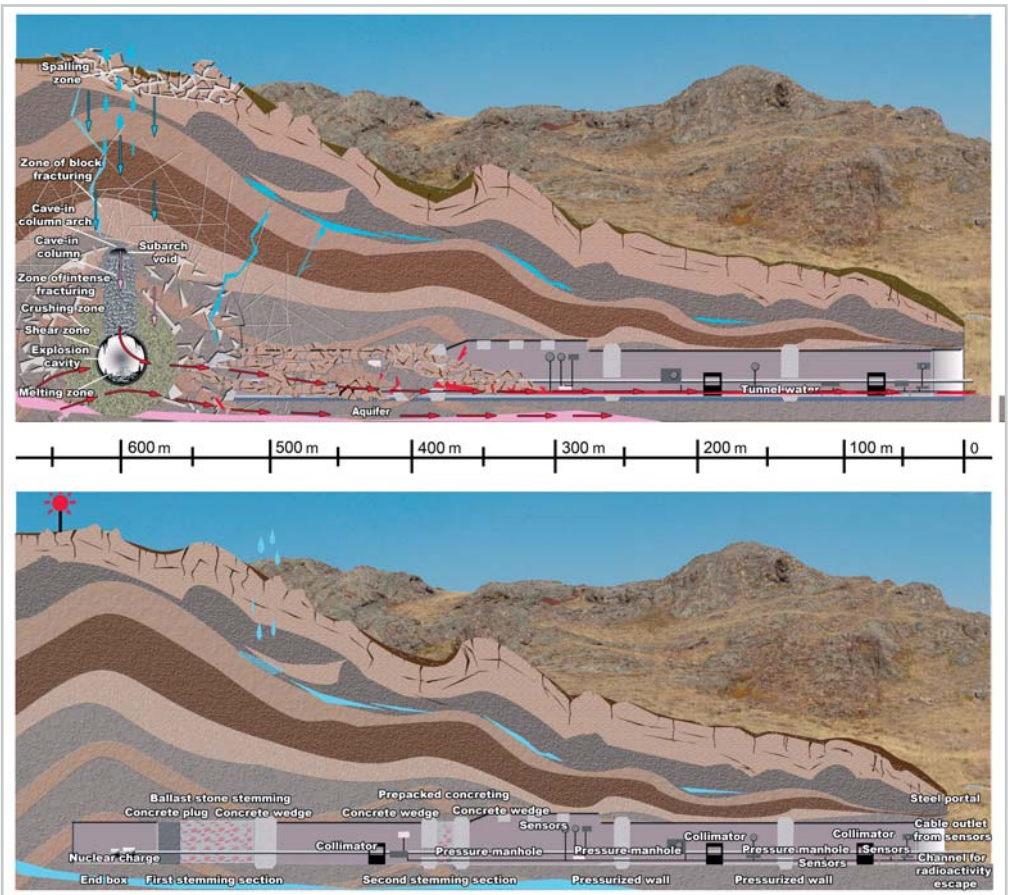


Figure 27. Cross-cut of the tunnel before (a) and after (b) the test

The horizontal mines (tunnels, drifts) drilled for underground nuclear tests had cross sections of 9-50 m^2 [8] to allow normal operation of the excavating equipment, transporting nuclear charges and equipment units, installation of this equipment and arranging cable communications. Length of tunnels was selected to assure required depression of the end boxes where nuclear charges were installed and varied from 140 to 1,600 m. Excavations were performed in dry drained rocks; during intensive precipitations they could be watered due to infiltration by fractures. To drain the water from the excavations, the tunnels and the drifts were drilled with the slope of 0.004 towards the entry. Physical and chemical properties of the rocks made it possible to make the tunnels without supports or props. Only entry parts of the tunnels, chamber excavations and high excavations, as well as excavation sites with tectonic disturbances were supported. Schematic tunnel profile is shown at the Figure 27.

Industrial sites were arranged at peri-portal area of each tunnel; the following objects were located there: locomotive barn, compressor shed, an overpass for car dump, power supply substation, materials and equipment warehouse, surface railways. At some distance an explosive active storage was located. Upon completion of the driven workings the site was transformed into a site for testing equipment. For that the following was arranged: a nuclear charge unloading and assembling site, material and equipment storage site, measuring complexes installation site, a site for charge explosion automation systems, overpass for unloading tamping material, lightning discharger, and a guard post were additionally constructed. The control station with explosion control and measuring equipment control automation was located 1-5 km from the tunnel, depending on the expected explosion yield and the landscape.

The first nuclear explosion with the yield of 1 kt was performed in the granite massif of the tunnel V-1 of Semipalatinsk Test Site on the 11th of October, 1961. The main objective was to determine the possibilities for measuring the technical characteristics of underground nuclear explosions and to study physical phenomena for further development of the measurement techniques and remote detection of nuclear explosions.

During 11.10.1961 – 04.10.1989, 209 tests (including 2 so-called “peaceful” tests) have been carried out in 181 tunnels [8]. The total area of the test site is 331 sq. km. Arrangement of the tunnels at the “Degelen” site is presented at the Figure 28.

Underground nuclear explosions in the tunnels performed in 1969 – 1989 and related activities caused considerable impact on the Degelen mountain massif. Huge energy release resulted in significant changes in the interiors including embedding the explosion chambers in glass, destruction of mine domes, formation of disintegration zones in the rocks, contamination of fracture waters with radionuclides. Sites of dislocated rocks have been formed at the surface. Emissions of nuclear decay products into atmosphere and to the daily surface took place at some tunnels as the result of the tests. These products created spots of local radioactive contamination.

After the gas migration stage of the underground nuclear explosion (UNE) is completed, the radionuclides proliferation with ground waters becomes the main transport mechanism for proliferation of the radionuclides from the epicentral UNE zones. According to modern concepts, the radionuclides are currently washed out of the solidified radioactive rock melt and brought to the daily surface. Contaminated ground waters reach the temporary and permanent streamflow and proliferate outside the mountain massif.

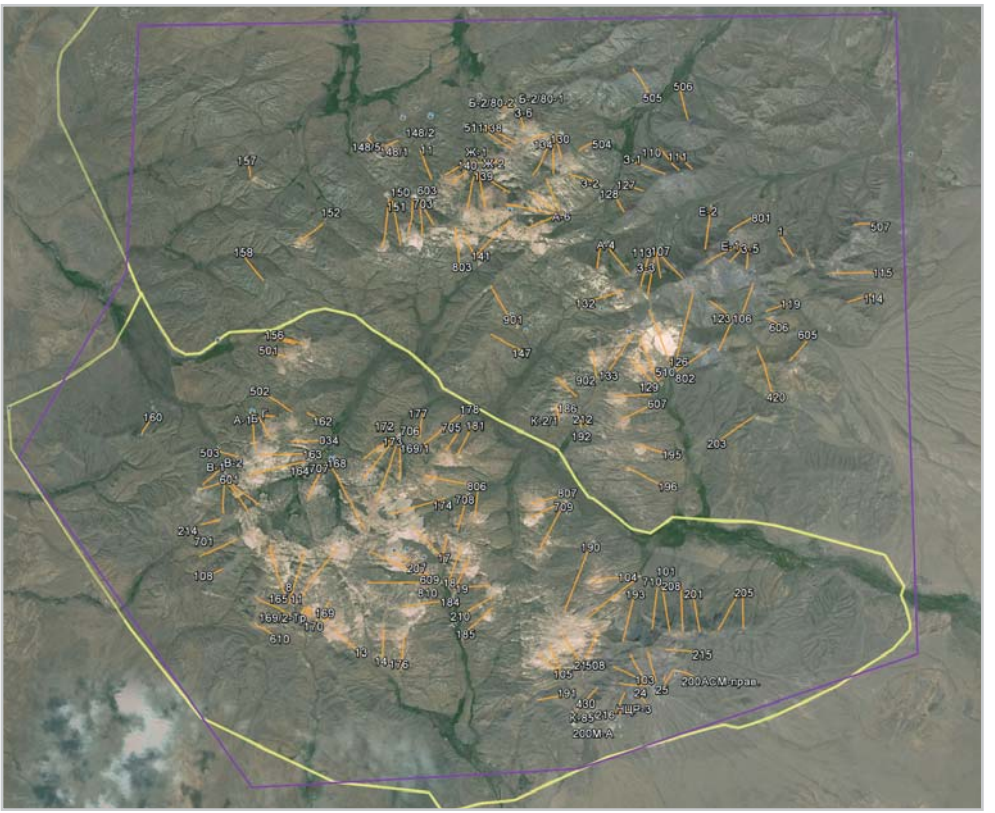


Figure 28. Entries to the tunnels at "Degelen" site

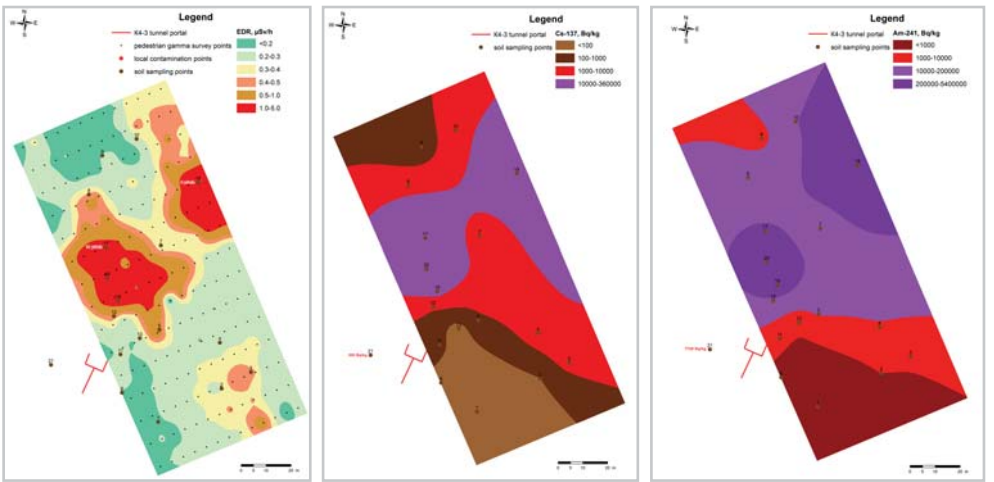
2.3.2. Peri-portal sites of "Degelen" site

Peri-portal sites are the areas of about one hectare next to the tunnel entries. These sites have significant anthropogenic disturbance, resulted both from testing and unauthorized economic activities after closing the STS. All the equipment as well as the excavated dump rocks was arranged at the peri-portal sites. After the test, some remaining equipment (beam holes, technological metal structures, air ducts, rail ways, and etc.) was left at the peri-portal sites (Figure 29). Many of the tunnels were reopened after the tests to study the consequences, as well as for reusing them in other tests. At that the backfill material with artificial radionuclides was extracted from the tunnel and stored in piles at the peri-portal sites.

Currently, the majority of the peri-portal sites have radioactive contamination formed mainly by the following contributing factors (or their combination):

1. Emission of radioactive fission products from the tunnels during nuclear tests. According to available sources [8, 32], emission of radioactive fission products could happen at incomplete camouflet tests, and in emergency situations. Over the years of operation, total 80 incomplete camouflet tests have been carried out in 69 tunnels with 6 emergency situations in the tunnels A-6, A-8, 11, 204, 810 and 608 (Figure 30).

Figure 29. Examples of peri-portal sites



a) b) c)

Figure 30. Schematic maps of EDR distribution (a), ^{137}Cs (b) and ^{241}Am (c) at the territory of peri-portal site of the Zh-Z tunnel

2. Opening the tunnels after tests. According to available information [33], some of the tunnels were opened to inspect the results of experiments. There were also several tunnels reused for testing. In these cases the tunnels were opened with extraction of backfill material, which contained significant concentrations of radionuclides resulted from the performed nuclear test. This material was stored in piles at the peri-portal sites (Figure 31). For the purpose of radiation safety, the piles with radioactive materials, as well as other areas of the peri-portal site contaminated during the tunnel opening could be embanked or covered with a layer of clean soil. As a consequence, these areas can still hide the radioactive contamination at some depth under a layer of clean soil at the peri-portal sites of some tunnels. This understanding was indirectly supported by several studies which revealed significant concentrations of artificial radionuclides in vegetation while the concentrations of these radionuclides in the top soil were very low.

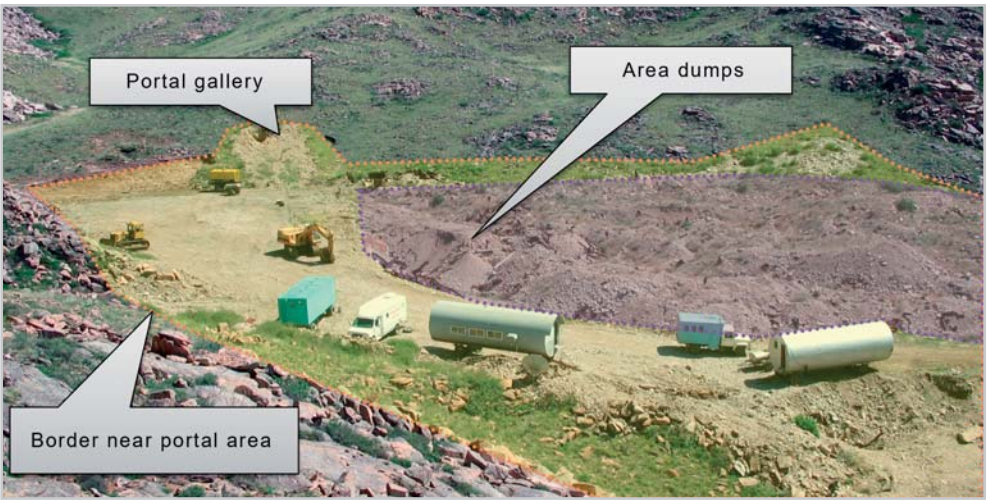


Figure 31. Examples of location of piles of ground extracted from the tunnel

Figure 32. Results of unauthorized activities

3. Opening the tunnels as the result of unauthorized activities after closing the test site. As it was noticed above, the remnant technological equipment was left at many tunnels' peri-portal sites attracting scavengers. At some of the tunnels, there was revealed radioactive contamination due to unauthorized access into the tunnels as well as unauthorized activities at the peri-portal sites such as cable firing or disassembling of metal structures (Figure 32). Contamination, formed this way, has a strongly pronounced local character, and in most cases the contaminated areas are about several dozens of square meters. At the present time all the tunnel cavities opened without authorization, have been re-sealed [34, 35]. To prevent further unauthorized opening and any other unauthorized activities, "Degelen" test site is currently guarded by state military forces.

4. Radioactivity transport with water. Within the test site, several tunnels with either permanent or temporary brooks were found. These streamflows provoke takeout of radionuclides from the tunnels to the daily surface. The radionuclides transported out of the tunnels settle down in bottom sediments and form radioactive contamination along the streamflows. For some streamflows there were found the sites with increased

concentrations of artificial radionuclides $^{239+240}$Pu, ^{90}Sr, and ^{137}Cs with concentrations of up to $1 \cdot 10^4$ Bq/kg, 10^5 Bq/kg, and 10^6 Bq/kg, respectively. More detailed information on distribution of radioactive contamination with water is given in the i.2.3.3 below.

The character and rates of radioactive contamination at the peri-portal sites vary greatly. So, the EDR varies from <0.1 to 140 μSv/h; b-particles flux density – from <10 to $1.3 \cdot 10^4$ part/(min·cm^2), a-particles flux density – from <1.0 to 900 part/(min·cm^2). Concentrations of artificial radionuclides in soil at several peri-portal sites can be as high as $1 \cdot 10^9$ Bq/kg, $1 \cdot 10^8$ Bq/kg, $1 \cdot 10^5$ Bq/kg and $1 \cdot 10^6$ Bq/kg for $^{239+240}$Pu, ^{241}Am, ^{90}Sr and ^{137}Cs, respectively. Examples of radioactive contamination distribution are given on the schematic maps (Figure 30).

To assess current radioecological conditions at the peri-portal sites, the sites were classified based on artificial radionuclides concentrations (according to the state regulatory docs). The sites with radionuclides concentrations below those specified for the limited use materials (LUM) were categorized as clean peri-portal sites. The sites with contamination level exceeding the LUM threshold, but below the level of radioactive wastes (RAW), were categorized as conditionally contaminated ones. The sites with contamination levels exceeding RAW levels were categorized as contaminated sites. According to this classification, there are 42 moderately contaminated peri-portal sites, 58 conditionally contaminated, and 81 contaminated peri-portal sites. Based on the results of this classification, almost at a half of the peri-portal sites (45 %) the ground is contaminated with artificial radionuclides to the RAW levels. At that, the area and levels of contamination of these sites can differ by several orders of magnitude. The most contaminated areas at many of the tunnels are limited by the territory of the peri-portal sites and do not exceed several hundred sq. meters, except for the tunnels where emergency situations occurred or the tunnels with streamflows, where radioactive contamination spread over several hundred meters. The radionuclide analysis shows that depending on, first of all, the character of the test, the radioactive contamination was mainly formed by the combination of the following radionuclides: ^{241}Am-$^{239+240}$Pu and ^{137}Cs-^{90}Sr (radionuclides release in gas-particulate matter phase from tunnel during the test). Peri-portal sites of the tunnels №№Zh-1, Zh-2, Zh-3 and Zh-4 are the most contaminated ones.

After termination of the STS operation, within the frame of the program for liquidation of nuclear weapons testing infrastructure, in 1996-1999 the works were aimed at closing of the 180 tunnel entries. Depending on the tasks, the following methods were used for closing the tunnel portals: construction of a concrete plug, drilling with inner explosion, drilling with external explosion or with pressure charge. After that, landfilling works were carried to restore the natural landscape (Figure 33).

To reduce the threat of nuclear wastes proliferation, additional works were carried out in 2005-2010 to strengthen physical security in over 50 tunnels. Such additional protection of the engineering structures involved filling up the tunnel cavities with sealing material, excluding the possibilities for unauthorized extraction of nuclear wastes.

Rehabilitation of the most contaminated peri-portal sites was initiated in 2006 within the state Program “Provision of Radiation Safety at the Territory of the Republic of Kazakhstan” and other programs [34]. Figure 34 below shows the results of such works on the example of the tunnel № 511 peri-portal site.

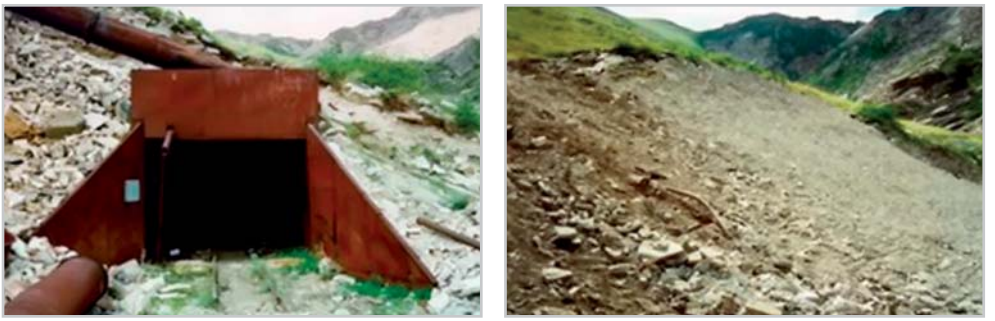
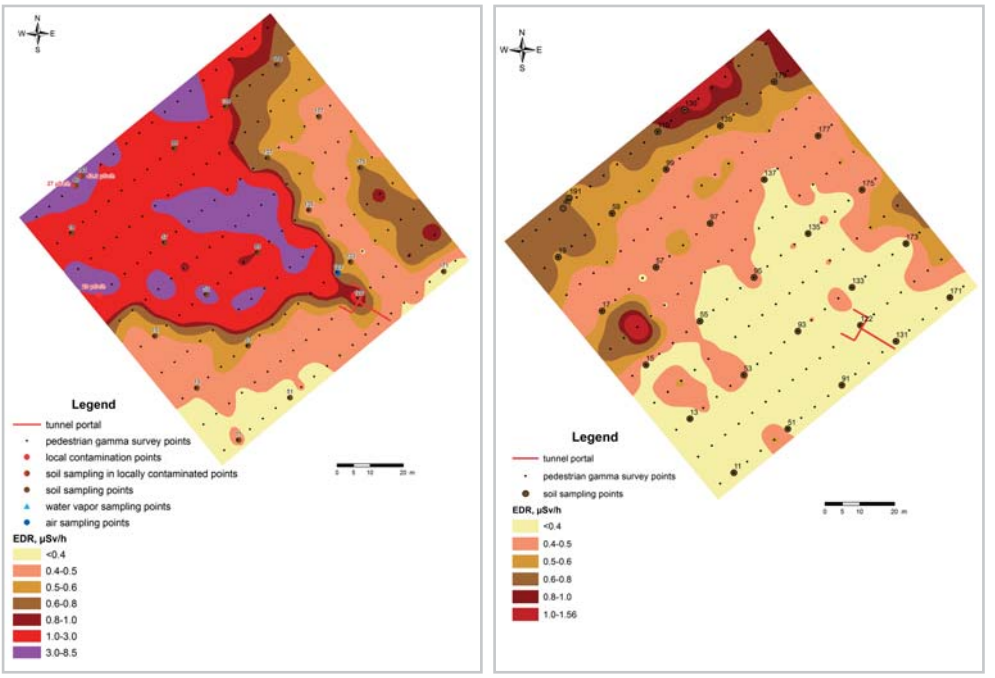


Figure 33. Entry to the tunnel №022 before and after closing



a) b)

Figure 34. EDR distribution maps for the tunnel 511 peri-portal site during preliminary (a) and final (b) survey

These works allowed for significant improvement of the radioecological situation at these peri-portal sites [33, 35, 36]. Nevertheless, contamination at the peri-portal sites of many tunnels is still significantly exceeding the regulatory levels set for radioactive wastes, and pose radiation hazard both on population and personnel.

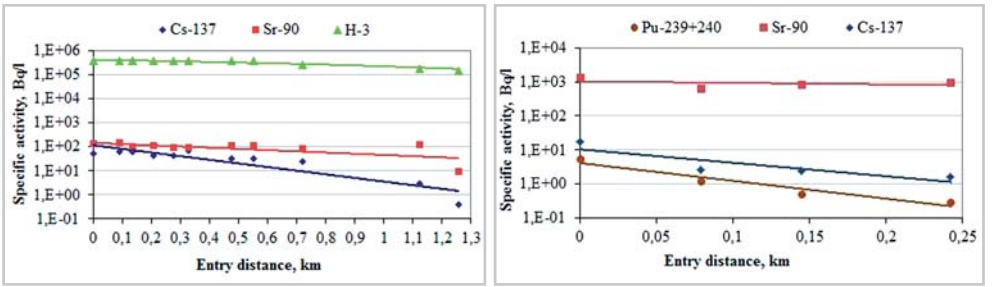
2.3.3. The peri-portal sites of the tunnels with streamflows

Together with the peri-portal sites of the tunnels with emergencies, the most contaminated areas at the "Degelen" site are the peri-portal sites with streamflows (Figure 35).

Figure 35. A streamflow typical for the "Degelen" site with meadow vegetation

Years of monitoring show that proliferation of radionuclides with water from the nuclear explosion cavities continues. Total number of the tunnels with water seepage at the "Degelen" site varies from 8 to 12 from year to year depending on weather conditions (precipitations significantly influence the situation). Assessment of the annual release of the radionuclides with the streamflows was performed in 1999 – 2003. In 2003, the radionuclides release rates were as follows: ^{137}Cs ~ 2 Ci, ^{90}Sr ~ 5 Ci, ^{3}H ~ 3.5 kCi. The streamflows were found then in 9 tunnels. Maximal radionuclides specific activities in water of the streamflows from the different tunnels are as follows: ^{137}Cs – 820 Bq/l (tunnel 504), ^{90}Sr – 2,100 Bq/l (tunnel 177), $^{239+240}$Pu – 6.4 Bq/l (tunnel 503), ^{241}Am – 2.6 Bq/l (tunnel 177) and ^{3}H – 9.9×10^{5}Bq/l (tunnel 160). At that, average maximal specific activity values for these radionuclides are 158, 698, 1.7, 2.6, and 2.9×10^{5} Bq/l, respectively.

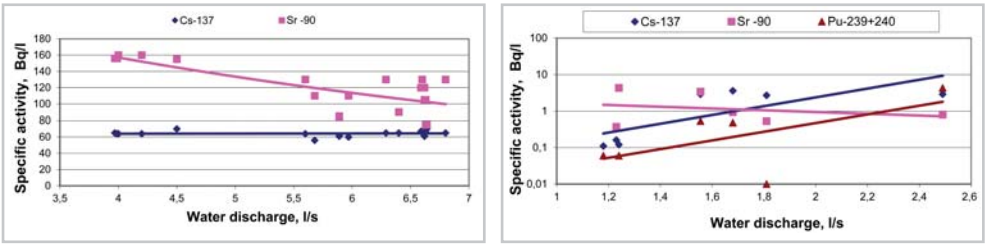
$^{239+240}$Pu and ^{137}Cs demonstrate the lowest proliferation abilities: their pass with water along the creek channels does not usually exceed several hundreds of meters from the source. The ^{90}Sr proliferation with water ranges from several hundred meters to several kilometers (Figure 36).



Tunnel № 176 Tunnel № 177

Figure 36. Radionuclides distribution in surface water of the studied ecosystems at different distances to the tunnel portals

Tritium keeps proliferating with water for many kilometers: at the distance of 7 km to Degelen, tritium concentration in ground water exceeds 67 kBq/l. Monitoring of the radionuclides proliferation with water from several tunnels at the "Degelen" site revealed some dependence of the radionuclides concentration in the streamflow water at the daily surface on the flow rate. Still the dependencies for different tunnels are quite contradictory, that can result from various hydrogeological peculiarities of the studied tunnels (Figure 37).



Tunnel № 176 Tunnel № 177

Figure 37. Radionuclide concentrations in water from the tunnels as a function of water discharge.

At the banks and the bottomlands of the water discharge brooks, spots with the following radionuclide concentrations were found: $^{39+240}$Pu in soil – up to n×10^4 Bq/kg, ^{90}Sr – n×10^4 to n×10^5 Bq/kg, ^{137}Cs – n×10^4 to n×10^6 Bq/kg. The main peculiarity is the significant concentration of artificial radionuclides along the banks of the streamflows and in the bottom sediments. Maximal radioactive contamination can usually be found near the tunnel portals next to the streamflow outlet. The areal contamination decreases at larger distances from the tunnel outlets (Figure 38) [37 – 40].

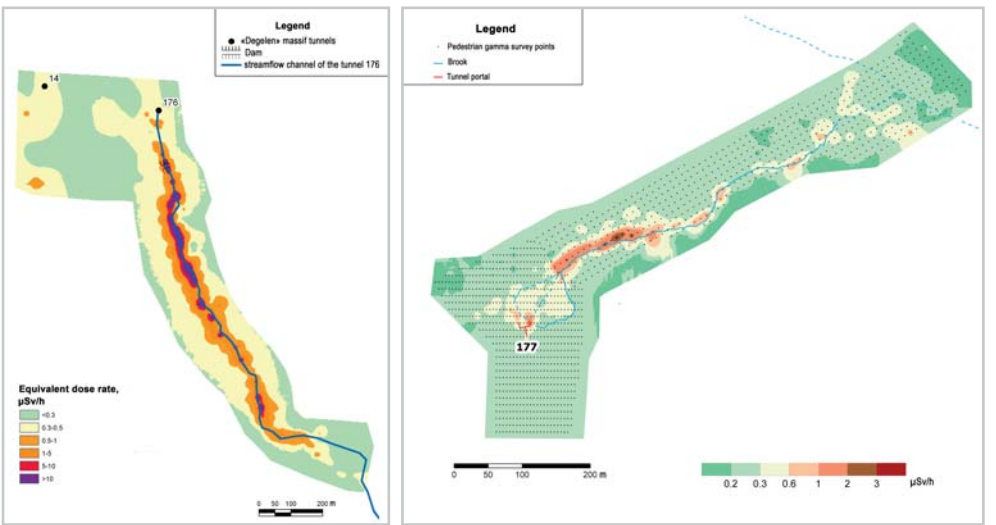


Figure 38. Schematic EDR distribution maps
for the peri-portal areas of the tunnels with water outflows

The gradient proliferation of the radionuclides in soils is pre-determined by the geomorphological conditions, while the range depends on initial concentration in the tunnel water, slopes and the stream flows. The widths of the radionuclides traces depend on the widths of the water flow and topography. As a rule, the channel width of such brooks does not exceed 1 m, and the bottom-land widths vary from several meters to several dozens of meters.

Vertical distribution of radionuclides at the peri-portal sites of the tunnels with streamflows complies in general with the pattern typical for the STS territory [41], i.e. the concentration decreases with depth. However, some peculiarities can be found depending on the water source location: in central channels of the streamflows, high radionuclide concentrations were found at the depth of up to 1 m at the level of parent rocks occurrence, while there is no signs for anthropogenic disturbance of the soil cover (Figure 39).

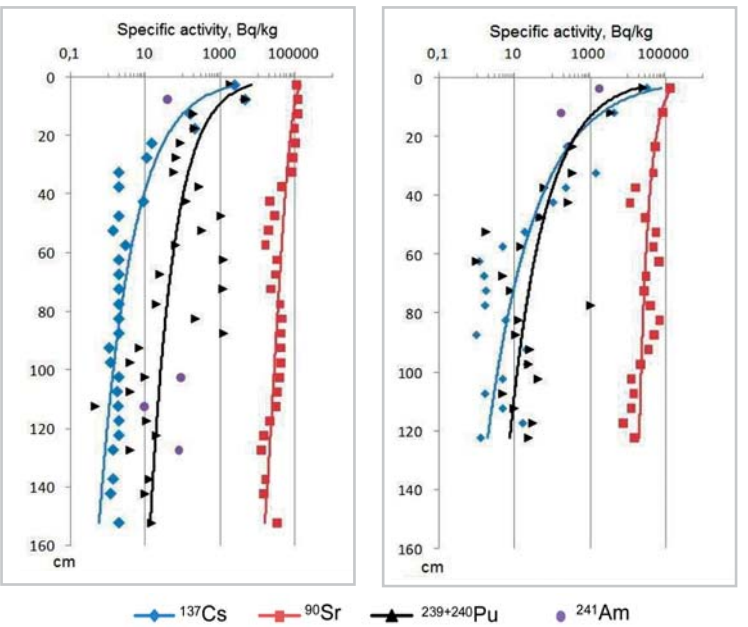


Figure 39. Vertical distribution of radionuclides in soils of the tunnel № 177 streamflow

The highest specific activities are usually found in vegetation along the tunnel streamflow banks. For ^{137}Cs, this value can reach approximately $n\times10^4$, for ^{90}Sr – $n\times10^4$, and for $^{239+240}$Pu – $n\times10^1$. Specific activity of ^{241}Am found in the plants has the value at the level of detection limit – 2-4 Bq/kg. Away from the tunnels, specific activity of these radionuclides in vegetation falls. The ^{3}H radionuclide is a part of the hydrodynamical system at the Degelen massif. Its presence in vegetation is therefore caused not only by presence of the constant surface streamflow, but also by the near-surface ground waters. The depth of the ground waters in the brook valleys and interhummocky lowlands is low; ^{3}H can therefore be found in vegetation of the plains and interhummocky lowlands within the "Degelen" site (Figure 40).

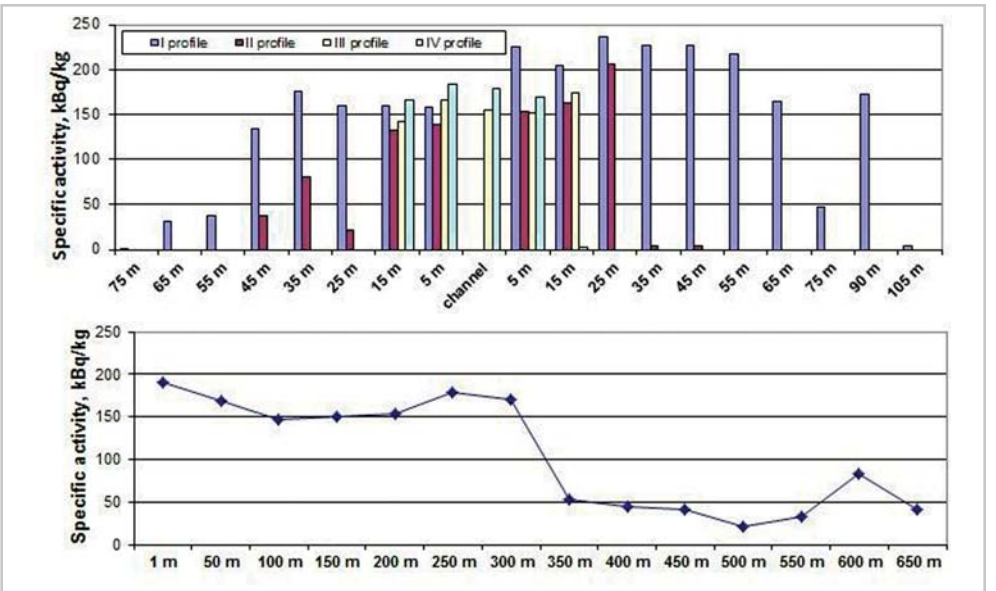


Figure 40. Distribution of ^{3}H in free water of plants along the tunnel № 177 streamflow sections and along its channel

Specific activity of tritium in free water of plants tends to equilibrium with specific activity of the radionuclide in the source (water) and its mean value is $n \times 10^{5}$ Bq/kg [42, 43].

Atmospheric air studies there revealed no quantitative concentrations of such artificial radionuclides as ^{137}Cs, ^{90}Sr, ^{241}Am or $^{239+240}Pu$. ^{3}H concentration in the atmospheric air, sometimes reaching 1,000 Bq/m^3, was detected. This value does not exceed, but is close to the limit of mean annual volumetric activity in air for population, which is 1,900 Bq/m^3. At that, ^{3}H concentration in atmospheric air is proportional to ^{3}H concentration in water source, soil air, plants and it can also depend on productivity of the soil cover at significant concentrations of ^{3}H in plants (Figure 41).

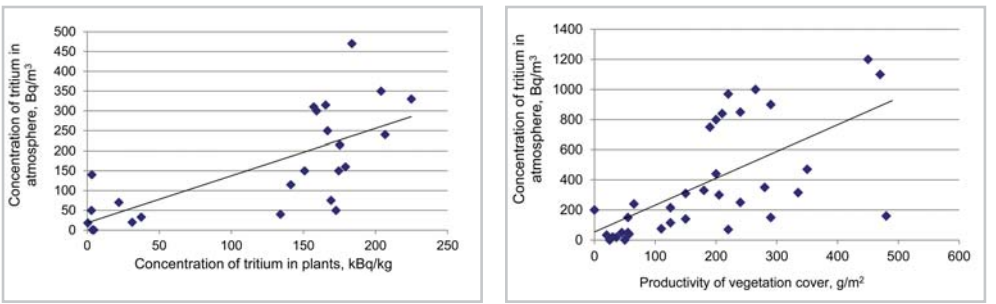


Figure 41. Dependence of ^{3}H concentration in atmospheric air on ^{3}H concentration in plants and productivity of vegetation cover contaminated with ^{3}H

Maximum concentrations of ^{3}H in air can be observed near the open water objects (streamflows, dams, springs), contaminated with ^{3}H (Figure 42).

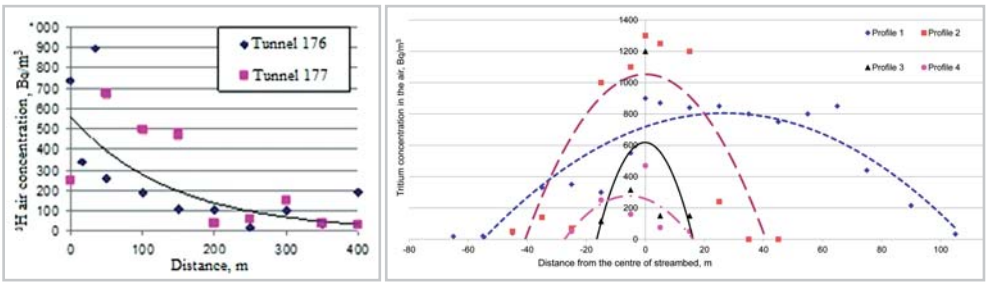


Figure 42. Change in ^{3}H concentration in atmospheric air along and across the channels of the surface streamflows

Radionuclides were found in some local fauna species at the peri-portal areas of the tunnels with streamflows. So, in bodies of sand lizard *(Lacertaagilis Linn.),* entrapped in vicinity of the tunnel № 176, concentration of ^{137}Cs artificial radionuclide ranged within 340-610 Bq/kg, while for same sand lizards entrapped at the bank of the central channel of Uzynbulak creek, the content of ^{137}Cs artificial radionuclide ranged within 10-50 Bq/kg (Figure 43).

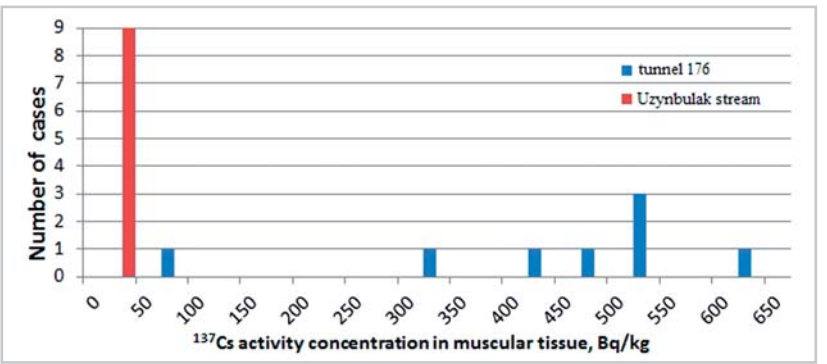


Figure 43. ^{137}Cs concentration occurrence frequency in bodies of sand lizards inhabiting radioactively-contaminated banks of the streamflow from the tunnel 176 and in the valley of Uzynbulak stream

In general, in spite of the continuous delivery of the radionuclides to the daily surface with water, the environmental samples taken at the peri-portal areas with water seepage do not demonstrate extremely high radionuclide concentrations. In present days, the ratio between the maximal specific activity values for radionuclides in water to the specific activities of radionuclides in soil at the peri-portal areas does not exceed the following values: $^{90}Sr - n\times10^{-3}$, $^{137}Cs - n\times10^{-5}$, $^{241}Am - n\times10^{-4}$ and $^{239+240}Pu - n\times10^{-6}$ (Figure 44).

Development of radiological situation at the territory of "Degelen" massif is still in progress. Over the years, some seepage stopped, and other appeared with related redistribution of the radionuclides sources for the local ecosystems and the environmental components.

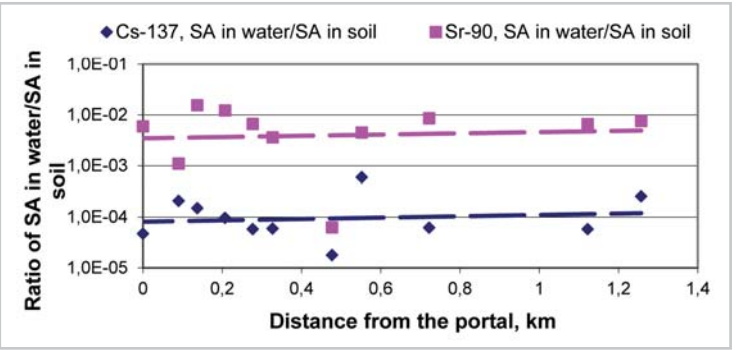


Figure 44. The ratio between ^{137}Cs and ^{90}Sr specific activities in water of the tunnel № 176 streamflow and specific activity of these radionuclides in soil

2.3.4. The zone of brooks running beyond the "Degelen" site limits

It was recently believed that radioactive contamination of the environment at the "Degelen" site is associated with the streamflow channels of the tunnels and brooks hydrologically associated with them. Recent studies demonstrated that radionuclides proliferate beyond the site limits. The main migration pathways here are the creeks Uzynbulak, Baitles, Toktakushyk, Karabulak and several unnamed brooks – as a rule, seasonal streamflows that depend on precipitations and stay dry most of the summer. One can therefore assume that the largest contributor to the radiological contamination beyond the "Degelen" site limits is provided by the ground waters; according to the hydrogeological maps, such waters mainly appear at the depth of 2-5 m, along the dry channels of the major brooks. It was proved that the main contaminating agent here is ^{3}H, whose concentration in ground and surface water reach several dozens of kBq/kg. Figures 45, 46 demonstrate spatial distribution of ^{3}H in air basin and vegetation cover at the boundary of "Degelen" site and within the impact zone of the main creeks, running beyond its boundaries [44].

The maps above demonstrate that the zones of ^{3}H proliferation beyond the "Degelen" site in most cases are territorially associated with the zones of the main creeks, with their origin at the territory of the mountain massif and running far beyond its limits. These are Uzynbulak, Baitles, Toktakushyk creeks, left tributary of Bezymyanny and Aktybay creeks, Karabulak creek, and little water discharge at the eastern boundary of the site; those are actually the main sources for ^{3}H delivery to the environmental objects at this territory. At that, main contamination of air basin and vegetation cover of the territory with ^{3}H is associated with the channels of the creeks Uzynbulak, Baitles and Toktakushyk.

Concentration of ^{3}H in soil air ranges between <0.2 and 50 Bq/m^3 exceeding the background level at this territory for 1.5 to 250 times. In the area of Karabulak creek, ^{3}H concentration is not so significant; however, even at the distance of approximately 9 km to the site boundary, detectable volumetric activities of ^{3}H were revealed in soil air. At that, ^{3}H concentration in air of Bezymyanny creek is approximately 0.2 Bq/m^3, which is the background concentration of ^{3}H for this territory [45].

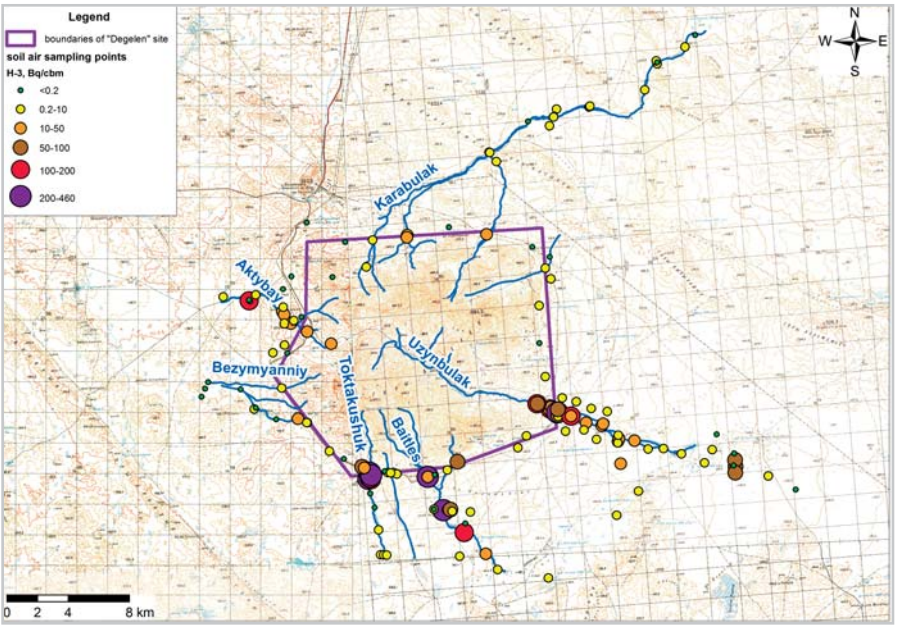


Figure 45. Schematic map of ^{3}H distribution in air
(according to ^{3}H volumetric activity data for soil air)

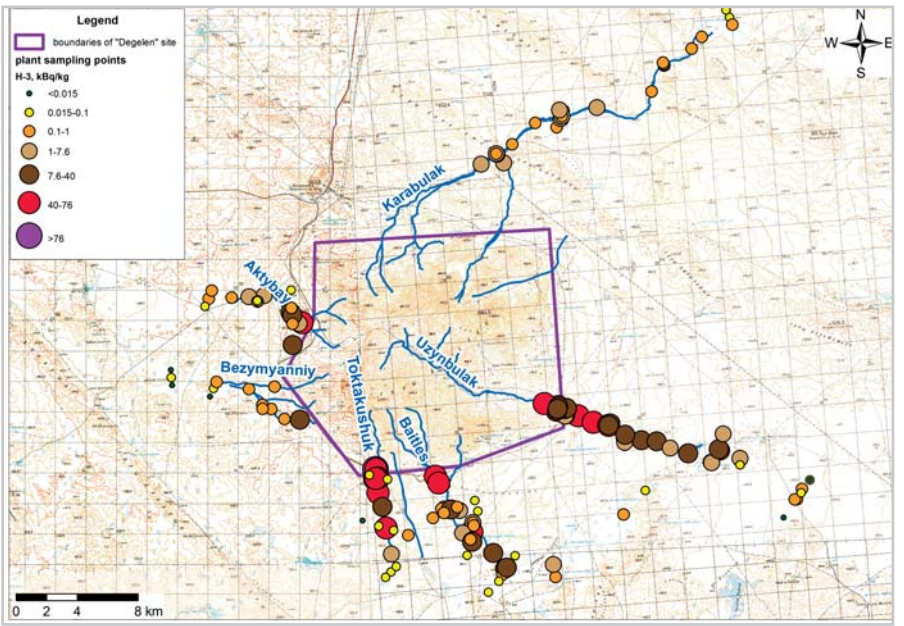
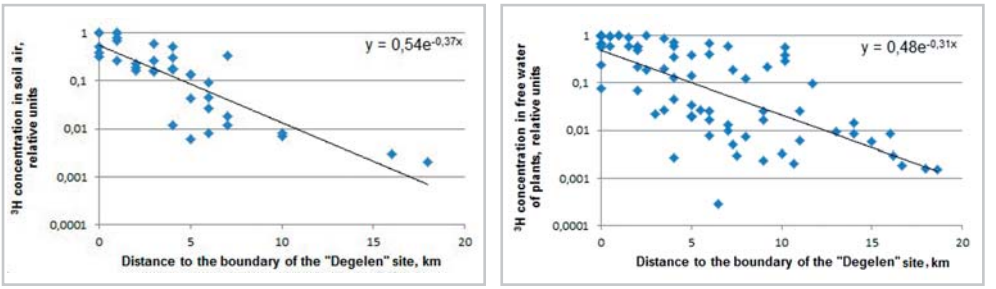


Figure 46. Schematic map of ^{3}H distribution in vegetation cover
(according to the data on ^{3}H specific activity in free water of plants)

^{3}H content in free water of investigated plants varies from n×10^1 Bq/kg to 85 kBq/kg frequently exceeding the intervention level for water, which is 7.6 kBq/kg according to normative documents (Appendix 2 of the HS SERPRS) [46].

In general, volumetric and specific activity of ^{3}H in soil air and free water of plants along the channels obeys the expotential law – at larger distances to the site boundary, ^{3}H concentration decreases (Figure 47).

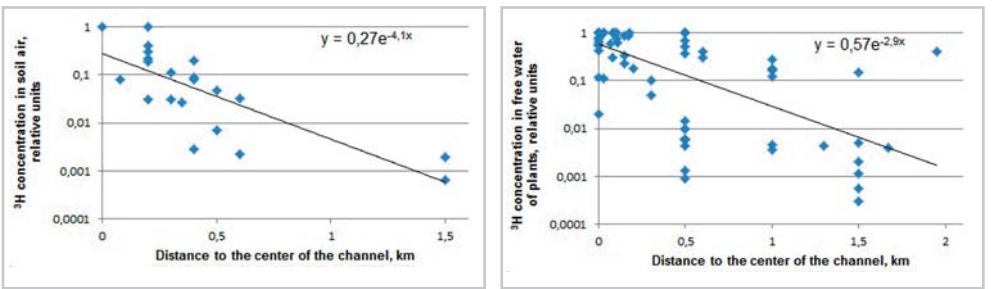


a) b)

Figure 47. Character of ^{3}H distribution in air (a) and vegetation cover (b) as a function of distance to the "Degelen" site

Increased ^{3}H concentrations proliferated to quite large distances from the "Degelen" site. The zone with maximal ^{3}H content in air is located within 5 km to the site; farther at the distance of 10 km to the boundary, ^{3}H content decreases and falls below 1 Bq/m^3. High specific activity values of ^{3}H in free water of plants in the channels can be found at much larger distances to the boundary – up to 10 km. Minimal concentrations of ^{3}H in both cases were noticed in terminal discharge zones of each of the creeks and comprised 0.1-0.2 Bq/m^3 in soil air and dozens of Bq/kg in free water of plants.

^{3}H concentration in soil air decreases at larger sideward distances to the creek channels, and can also be described by the exponential law. ^{3}H distribution in vegetation cover has more complicated character (Figure 48).



a) b)

Figure 48. ^{3}H distribution in air (a) and vegetation cover (b) as a function of sideward distance to the channels of the main creeks

While ^{3}H concentration in free water of plants decreases further from the channels, in some individual cases the situation is different – the minimal values can be found

closer to the channels. Such an ambiguous distribution of ^{3}H in vegetation cover can result from species composition of plants at the studied territory. While the hydrophytes mainly grow in the channel using surface and near-surface water, phreatophytes growing at some distance can use ground and so-called pore waters for their needs. When ^{3}H concentrations are different in these sources, respective values of ^{3}H specific activity are found in free water of plants. Another factor explaining the situation can be the character of ground water distribution which is not entirely same as the channels of the surface streamflows. In this case, relatively high ^{3}H concentrations can be noticed in plants at significant distances to the channel centers (up to 2 km in our case), that speaks of the width of ground water stream contaminated with ^{3}H.

So, the contamination of the creek zones beyond the boundary of the "Degelen" site is due to the ^{3}H radionuclide, which concentration in free water of plants, as well as in surface and ground water reaches several dozens of kBq/kg; and several dozens of Bq/m^3 in air.

2.4. "Balapan" site

2.4.1. General information

"Balapan" was one of the testing sites of Semipalatinsk Test Site used for underground testing of nuclear weapons. The site is located in the eastern part of the STS. Total area of the site is approximately 780 sq. km. In geographical respect, the "Balapan" site is located in the eastern part of the STS. The site landscape is mostly a plain. The only surface streamflow of the site is the left tributary of Irtysh river – low water Shagan river running from west to east along the southern boundary of the site.

Nuclear weapons at the "Balapan" site were tested in boreholes. Total 119 boreholes were drilled. From 1965 to 1989, 106 of them were used to perform 105 tests; 167 nuclear devices were exploded at that, 13 boreholes remained unused [8, 9]. The explosions yield mainly remained within the range from 20 to 150 kt. Schematically, the locations of the boreholes are shown at the Figure 49.

A borehole is a vertical cylindrical mine drilled with a drill rig in rocks of the earth crust, having large depth to diameter ratio. At the test site, mainly the boreholes of the maximum depth 650 m and maximal diameter 1.4 m were drilled [9]. Depth of the borehole casing with pipes ranged as a rule within 50-200 m. Casing pipes were arranged to overlap each aquifer. To assure reliable waterproof insulation, the annular space was filled up with cement. Underlying bed was overlapped with pipes of smaller diameter. Depending on purpose of the experiment, the number of cables ranged from several dozens to several hundreds [8].

A borehole was drilled to preset depth, and then a charge was placed in. To prevent radioactive products from emission into atmosphere, a plugging complex consisting of several plugs and backfilled space between them was arranged. Near the point of nuclear charge, the borehole was filled up with iron ore concentrate [9]. A running string was filled up with cement mortar except for several experiments where it was used as a sample port.

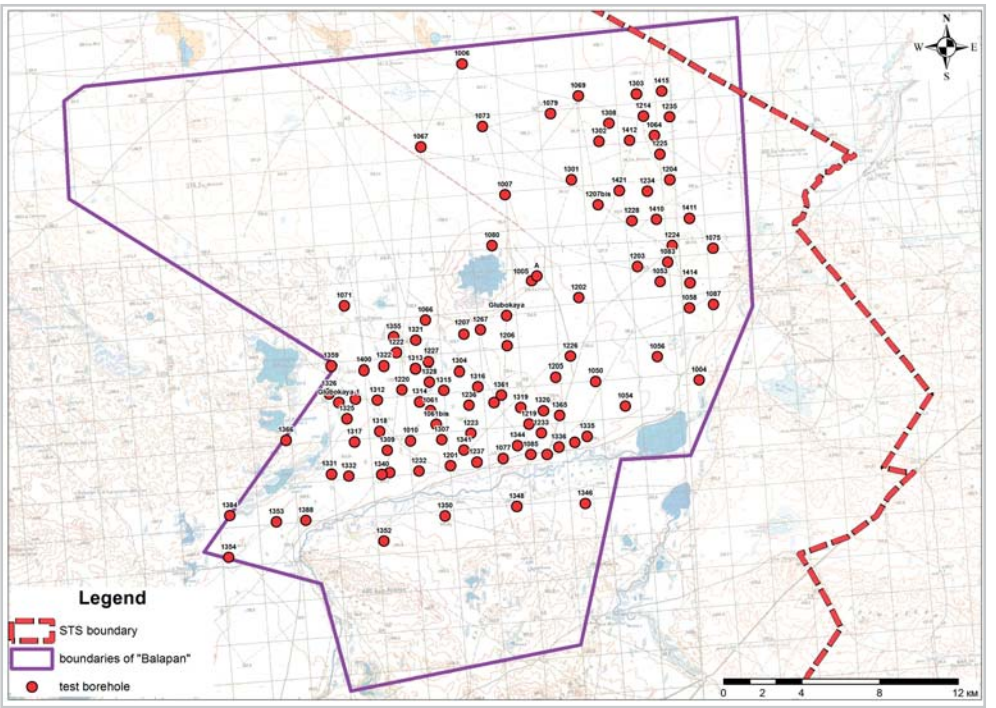


Figure 49. Boreholes locations at the "Balapan" site

A typical borehole is shown at the Figure 50 [8].

Unlike atmospheric tests, radioactive contamination resulted from underground explosions in boreholes is incomparably small. Most of radioactive products remain "buried" underground. At the nuclear explosions with internal action in rocks with significant amounts of silicon, melted rock covering the cavity walls consists of relatively insoluble vitreous mass embedding most of the fission products. Such vitreous material captures 60 to 85 % of all fission products. At the dome collapse, a part of the radioactive fission products remaining in the cavity in gaseous form penetrates into the destructed rock. Quite significant amounts of ^{90}Sr and other isotopes left by gaseous and volatile elements are deposited at significant distances from the highly radioactive zone and get distributed within the destruction rock zone.

In spite of protective measures taken during the underground tests, radioactive emissions into atmosphere did happen. Radiation events in USSR resulted from nuclear tests were divided into normal and emergency radiation situations [8].

According to the character of the actual observed radiation situation, all the underground explosions performed at Semipalatinsk Test Site were divided into four categories as follows [47]:

1. Explosion with ground outburst (EGO) – underground explosion with external effects, accompanied by destruction and relocation of rocks in epicentral zone and emission of radioactive products into atmosphere in form of particulate matter and gases. As the result of explosion an outburst crater appears.

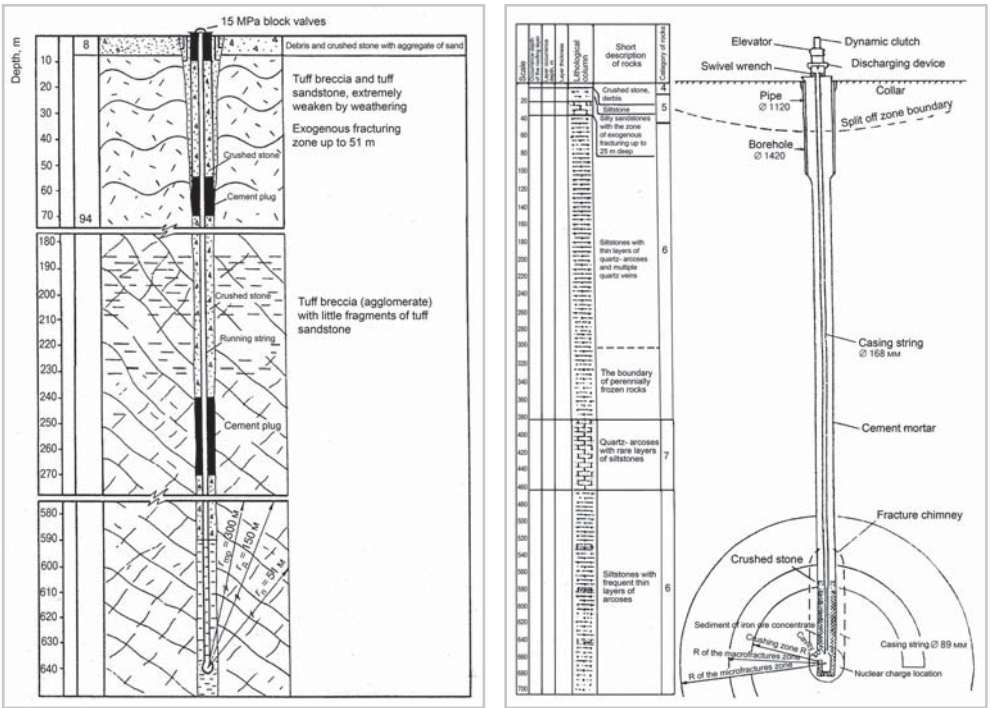


Figure 50. Schematic structure of the boreholes and the plugs at STS.
Zones of mechanical impact from an explosion

2. Total camouflet explosion (TCE). All the radioactive products remained inside the explosion cavity in such explosions.

3. Incomplete camouflet explosion, with insignificant emission of radioactive noble gases into the atmosphere (ICE -RNG).

4. Incomplete camouflet explosion with emergency radiation situation (ICE-ERS). Such explosion is accompanied by early pressured emission of radioactive products in gaseous and vaporous form into atmosphere due to accidental disturbance of normal testing procedure and (or) unexpected consequences that could result or resulted in radiation exposure of personnel above a predetermined level or in material damage. ICE-ERS explosions could cause significant emergency exposure of the personnel and, due to significant dilution of the explosion cloud on its way outside the test site, very insignificant exposure of population of the territory, adjacent to the test site (below the permissible dose limits).

50% of all the underground tests performed at Semipalatinsk Test Site including those performed at the "Degelen" and "Sary-Uzen" sites can be categorized as total camouflet explosions, ~46% – as incomplete camouflet explosions with insignificant emissions of noble gases (NRG) into the atmosphere of epicentral explosion zones in ventilation discharge mode, and 4% – as explosions with pressure discharge of radioactive explosion products (REP) to the surface [8]. Table 2 provides data on the tests with emergency situations, performed at the "Balapan" site.

Table 2.

Underground nuclear explosions with emergency radiation situations

Borehole number	Date of testing	Primary radiation effect, residual ground contamination
1007	10.02.72	T_o ~ 1 min.: dynamic release of gaseous and vaporous products, containing hard-melting, semi-volatile, easily volatile radionuclides and RNG through the warfare borehole; ignition of the mixture occurred, flame body reached ~ 70 m height (at the 21st minute) and it was observable for 24 hours. Exposure dose rate afield at the distance of 1 km to the borehole on the route of explosion products drift comprised ~ 14 R (over 6 hours of the dosimeters exposure). At the present time there is almost no areal contamination within the epicenter area.*
1204	10.12.72	T_o ~ 1 min.: in the course of lowering rock dome, outbreak of explosion products including primary aerosols occurred. EDR level in the epicentral area comprised $1.1 \cdot 10^4$ R/h after an hour of explosion. Health protection zone has been secured in the epicentral area.
1069	04.11.73	T_o ~ 30 s: dynamic outbreak of gaseous and vaporous products from the borehole ("cannon effect") with no primary aerosols involved. EDR level 1 km away from the ground zero reached ~ 500 R/h. Currently, there is practically no residual areal contamination in the ground zero area.*
1301	16.04.74	T_o ~ 1.5 min.: dynamic outbreak of inflammable gaseous and vaporous products in the epicentral area. EDR level in the RNG escape spot was over 10 R/h. There is currently no residual areal contamination at the site.*
Note: * data on residual areal contamination is apparently provided as of the test site closure in 1991		

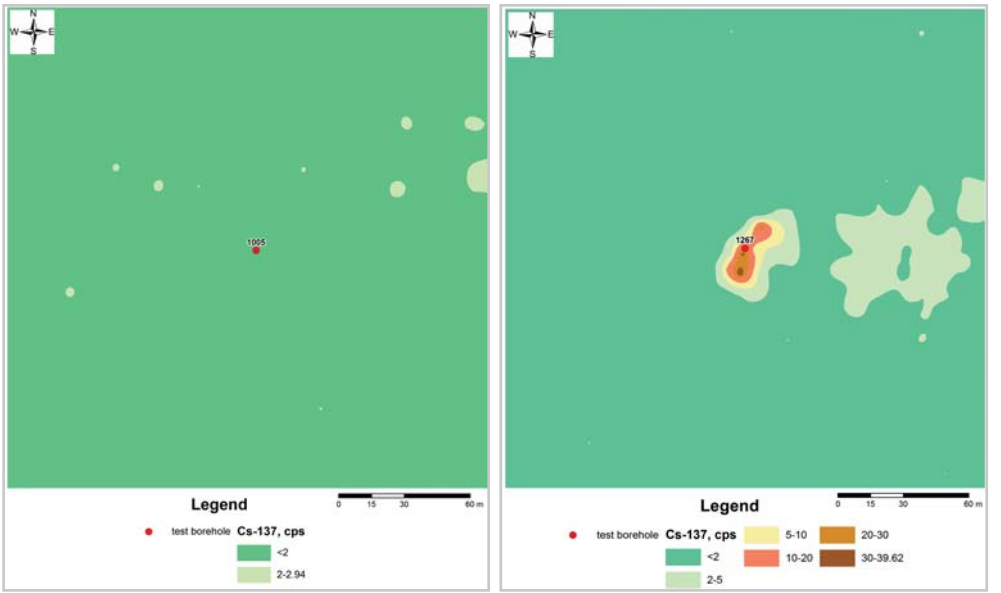
In spite of "almost no" residual contamination declared in the table in the area of the three boreholes, in fact, this statement is not correct which will be discussed below.

Furthermore, radiation effects from underground tests in boreholes could result only in contamination of insignificant part of the area near the well-mouth sites, as well as in radioactive contamination of the earth crust in places with emissions of noble radioactive gases.

2.4.2. Surface contamination

Boreholes with normal radiation situation. The boreholes with normal radiation situation keep all the radioactive products within the explosion cavity, or the explosion was accompanied by minor emission of radioactive noble gases into atmosphere [47]. No contamination of the well-mouth area of such boreholes should therefore be expected [8].

Based on the performed investigations, the well-mouth territories of most of the boreholes with standard radiation situation (86 boreholes out of 100) can be classified as territories with background concentrations of radionuclides in soil (Figure 51, a), or the background values can be insignificantly exceeded [48]. Increased contents of radionuclides in such boreholes are mainly attributed to the borehole heads and present in the form of local spots (Figure 51, b). Away from the wellheads, radiation parameters decrease sharply, and at the distance of approximately 50-100 meters they correspond to the background values.



a) b)

Figure 51. Distribution of ^{137}Cs radionuclide at the well-mouth area of the boreholes 1005 (a) and 1267 (b)

At that, for 14 boreholes where the radiation effect was classified as a normal one, contamination of the soil cover is present due to, most probably, emission of radioactive gases. At the well-mouth territories of 7 boreholes specific activities of radionuclides in soil correspond to the class of "restricted materials", while in other 7 boreholes (№№ 1050, 1053, 1054, 1069, 1071, 1077, 1080, 1204, 1209, and 1267) the levels of soil cover contamination correspond to radioactive wastes.

Maximal radioactive contamination levels were found at the well-mouth site of the borehole 1080. The ^{137}Cs radionuclide concentration there can be compared with values, registered in the boreholes with emergency radiation situations. Figure 52 below presents the ^{137}Cs radionuclide distribution in vicinity of the borehole 1080.

The Figure demonstrates the main trace of the radioactive emissions up to 300 meters long. Maximal width of the trace spot is 100 meters. The processes during an UNE result in contamination of the day surface, mainly with the radionuclides ^{137}Cs and ^{90}Sr, predecessors of which are the RNG ^{137}Xe and ^{89}Kr. Presence of $^{239+240}$Pu radionuclide in soil of contaminated well-mouth sites demonstrates the fact that together with RNG, other fission products were also released.

Boreholes with emergency radiological situations. According to the official data, no residual contamination of the area was found in three of four boreholes (№№1007, 1069, and 1301) with emergency radiological situation (Table 2) where unexpected emission of radionuclides into atmosphere took place [8]. The radiological studies there however revealed some significantly contaminated spots. The radiation parameters according to measured alpha- and beta- particles flux density comprised from 0 to 2 part/(min*cm^2),

and 10 to 490 part/(min*cm^2), respectively; EDR at the ground surface – from 0.1 to 9.1 μSv/h. Maximal EDR values were registered at the well-mouth sites of the borehole №1069 [49]. Radioactive contamination is concentrated at both the boreholes' well-mouths and beyond their sites (the boreholes №№ 1007, 1069 and 1301) in the form of elongated spots from radioactive fallouts. Distribution of ^{137}Cs radionuclides at the boreholes № 1069 and № 1301 is shown at the Figure (Figure 53, a, b). The traces from radioactive fallouts have typical dimensions with the width of 100-200 meters in the widest part, the length from 250 to 2,000 meters for various boreholes.

Radioactive contamination has mainly been formed at the well-mouth sites right after nuclear test. But there is also another mechanism of radioactive contamination – unauthorized activities associated with extraction of casing pipes, cables, as well as due to hydrological studies that involved pumping of ground water out of the hydrogeological boreholes. At the present time, casing pipes have been cut off and the filling material extracted from all the boreholes [48]. At that, both positive change of the radiological situation because of backfilling with clean ground of the locally contaminated sites near the well mouths and negative change of the radiological situation due to taking out of the contaminated rock to the daily surface could take place.

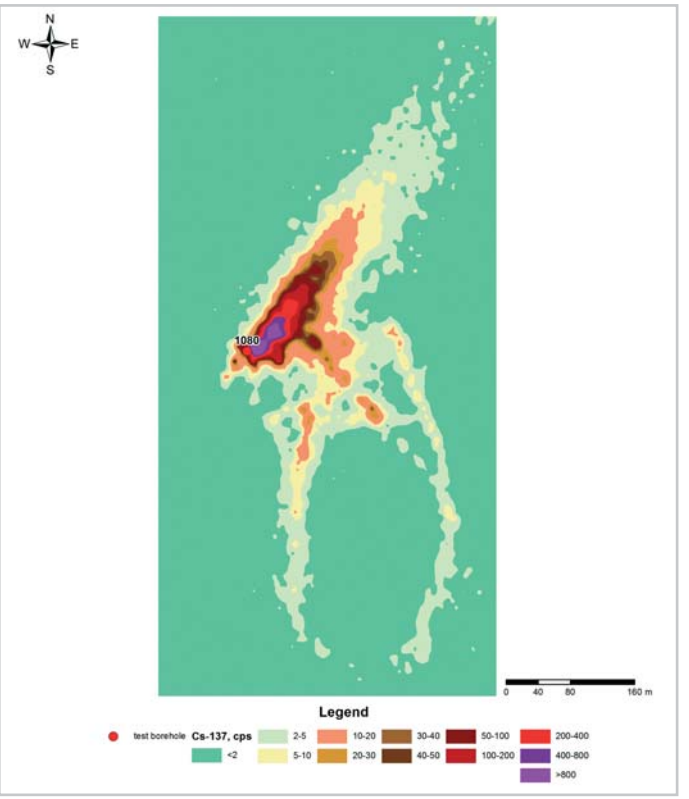
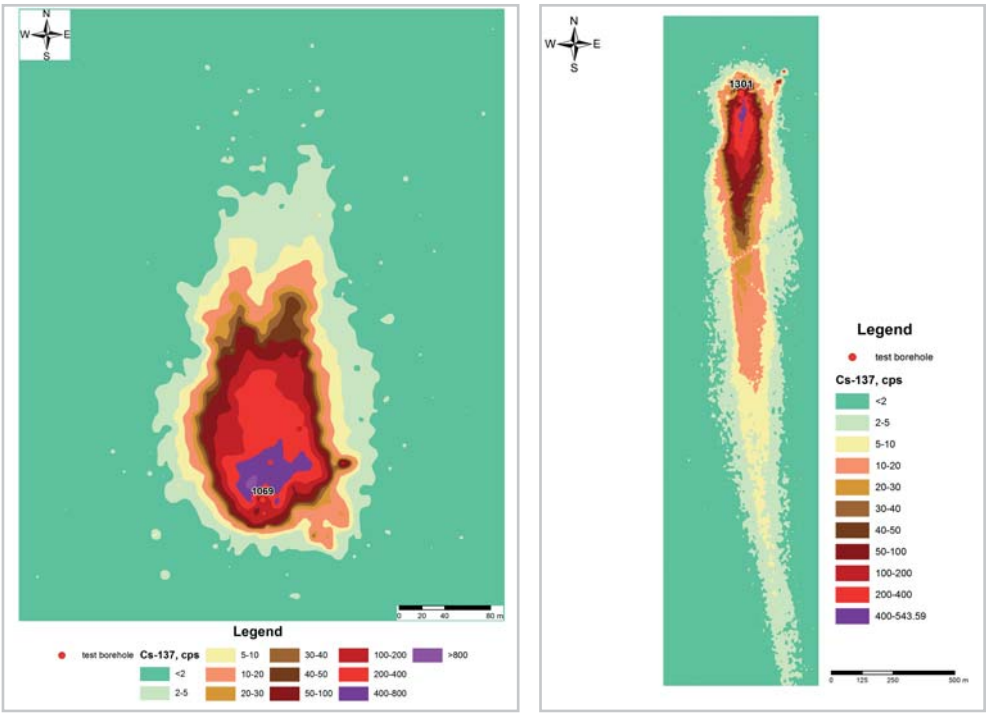


Figure 52. Distribution of ^{137}Cs radionuclide at the well-mouth area in vicinity of the borehole 1080



a) b)

Figure 53. Distribution of ^{137}Cs radionuclide areal activity at the borehole 1069 (a) and the borehole 1301 (b)

2.4.3. Character of air basin contamination with tritium in venues of underground nuclear tests

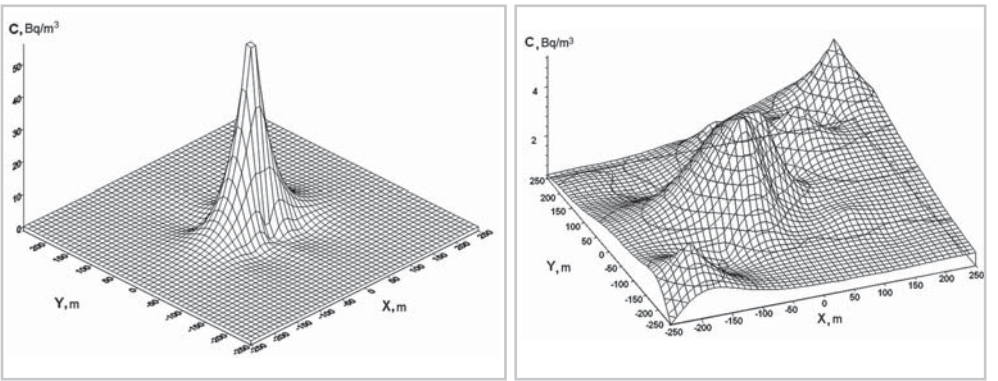
At the present time, tritium (^{3}H) is the main radionuclide posing hazard on air environment at UNE locations at the "Balapan" site. After the tests most of the dose forming radionuclides, such as ^{90}Sr, ^{137}Cs, $^{239+240}Pu$ remained buried underground, while tritium can penetrate through the rock mass and proliferate to the atmosphere thanks to its physical, chemical and proliferation properties.

Studies of ^{3}H tritium content in air environment at the "Balapan" site have been performed near the well mouths of the warfare boreholes. Tritium has been revealed both in the atmospheric and soil air in form of tritiated water (HTO) and in form of gaseous compounds ($H_{gas.}$).

Volumetric activity of ^{3}H in HTO and H_{gas} in atmospheric air comprised from 0.5 to 70 Bq/m^3 and 0.7 to 180 Bq/m^3, respectively; in soil air – from 0.05 to 300 Bq/m^3, and 0.1 to 220 Bq/m^3, respectively.

To study spatial distribution of ^{3}H in air environment at the warfare boreholes, more detailed studies covering the whole well mouth areas were carried out. Obtained data was processed using Kriging method with further reconstruction of 3D-pictures allowing visualizing the ^{3}H distribution character in air [50].

Figure 54 shows the ^{3}H distribution on example of two boreholes: №1010 (Figure 54, a) and №1361 (Figure 54, b).



a) b)

Figure 54. Character of tritium distribution in air at the well-mouth area of the boreholes №1010 (a) and №1361 (b)

Spatial distribution of ^{3}H in atmospheric air with respect to the well mouth of the boreholes was not determined since at larger distances to the boreholes the ^{3}H volumetric activity decreases sharply, in many cases, below the detection threshold of < 0.05 Bq/m^{3}.

Spatial distribution of ^{3}H in soil air at various well-mouth sites differs from borehole to borehole. In some cases, only one point of ^{3}H release to the surface was registered and the radius of ^{3}H distribution over the borehole remaining within several dozens of meters, like in the case of the borehole №1010 (Figure 54, a).

In other cases spatial distribution of ^{3}H has a heterogeneous character – several points of ^{3}H release to the surface can be found; the radius of ^{3}H distribution in air can therefore reach several hundred meters and cover almost the whole well-mouth area, as at the territory around the borehole №1361 (Figure 54, b).

In general, the studies showed that at the distances of 500 m and more to the well mouth, the ^{3}H volumetric activities in soil air of the well-mouth areas do not exceed the background values for this territory (0.05 – 0.1 Bq/m^{3}).

Volumetric activities of ^{3}H in air at the warfare boreholes vary within the wide range – from 0.5 to 220 Bq/m^{3}, but the mean values do not exceed 5 - 10 Bq/m^{3} [51]. These values do not exceed regulatory volumetric activities for ^{3}H in inhaled air (1,900 Bq/m^{3}) [46].

The studies also show that, in spite of insignificant ^{3}H concentrations in air near the warfare boreholes, the problem of air contamination with tritium still exists at this territory. This fact should be considered for agricultural or any other activities performed at each of the individual grounds within the “Balapan” site.

At distances from the nearest warfare borehole less than 500 m, additional studies of the ^{3}H content in atmosphere and soil air are required. At distances over 500 m to the well mouth sites, the study of ^{3}H concentrations in air can be of simple estimative character.

One should note that these recommendations provide just some general guidance for the studies. In each exact case, the study should be supported with real data obtained for the ^{3}H concentrations in environmental objects of the studied territory.

2.5. "Sary-Uzen" site

according to archive materials [52], 24 underground tests were performed at the "Sary-Uzen" site in the period from 1965 to 1980. According to available data, in most cases the explosion yield did not exceed 20 kt at the depths ranging from 50 to 430 m. The area of the highest man-induced impact from the underground nuclear explosions is located in the center of the northwestern part of the site. Location of the boreholes is shown at the Figure 55.

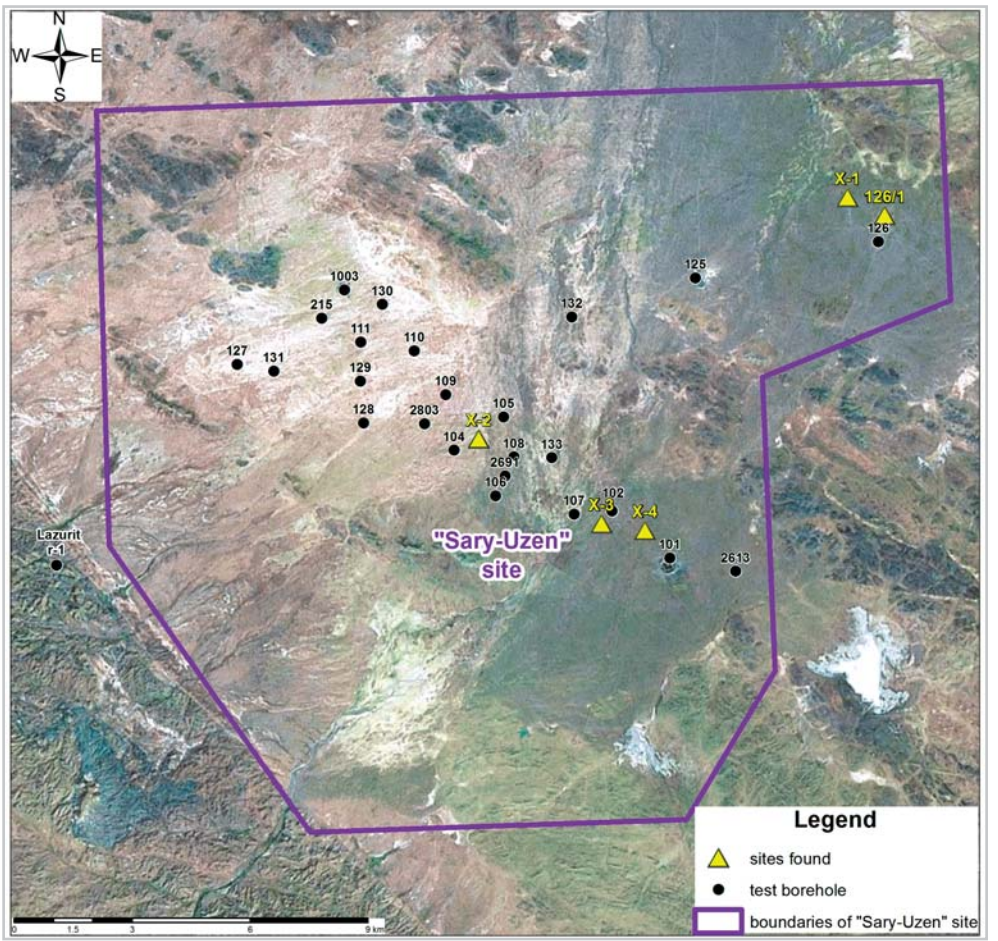


Figure 55. Satellite image of the "Sary-Uzen" site. Location of the "warfare" boreholes at the site

All the "warfare" boreholes can be conditionally classified into four groups by radioactive contamination of the soil cover at the well-mouth areas (Table 3).

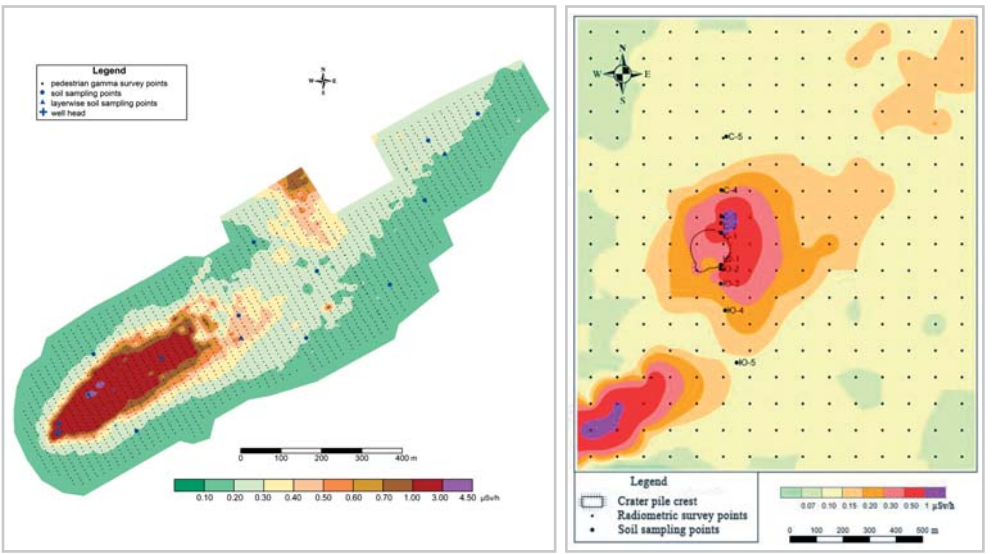
Table 3.

Radiation parameters at the well-mouth areas of the "warfare" boreholes with maximal concentrations of radionuclides in soil samples.

Number of boreholes	γ, μSv/h	β, part/min*cm²	^{241}Am, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
Heavily contaminated						
3	1 - 5.21	100 - 210	**2,070 – 40,600**	2,000 – **32,200**	3,370 – 4,000	180 – **6,800**
Moderately contaminated						
5	0.15 – 5.0	0.1 - 185	6.0 - 925	220 – **20,430**	20 – 11,530	**70 – 1,900**
Weakly contaminated						
6	0.1 - 0.26	0.1 – 150	72 - 320	50 – 3,560	40 – 4,800	180 - 600
Relatively clean						
14	0.1 - 0.25	0.1 - 160	-	7 - 550	8 – 3,100	3 - 90
		MSSA, Bq/kg	**1,000**	**10,000**	**100,000**	**1,000**
Note: "-" - no data						

The first group – heavily contaminated boreholes. This group includes three boreholes. Concentrations of radionuclides exceed the minimal significant specific activity (MSSA) from 2 to 40 times. These boreholes are absolutely different in terms of the tests performed there and the character of radionuclides distribution at the well-mouth areas.

Radioactive contamination at the well-mouth area of the first borehole №215 has resulted from the emergency situation during the UNE. EDR distribution is schematically shown at the Figure 56, a.



a) b)

Figure 56. EDR distribution: a) borehole №215; b) borehole №1003

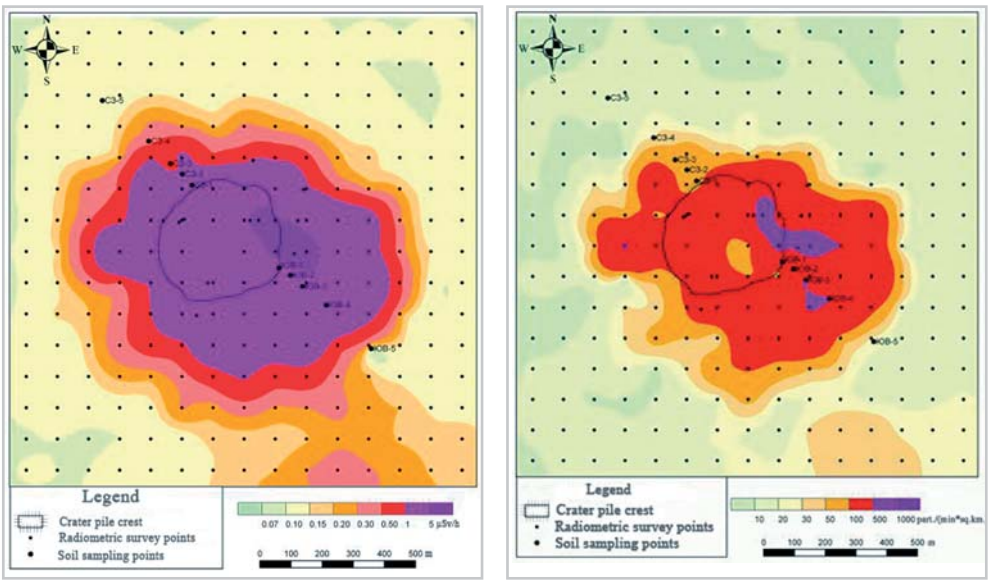
Excavation explosion in the borehole №1003 led to destruction and relocation of rocks in the epicentral zone, and release of radioactive products in form of particulate matter and gases to the atmosphere. The outburst crater with contaminated rocks was formed there. Areal distribution of the radiometric parameters is shown at the Figure 56, b.

The third borehole of this group has a complicated engineering structure. According to all indications, there was no UNE performed at all.

The second group – moderately contaminated boreholes. This category includes 5 boreholes with emergency situations and radioactivity release to the surface. Concentrations of radionuclides there exceed MSSA from 1.5 to 2 times.

The borehole 101 located in the western part of the "Sary-Uzen" site is the most thoroughly investigated one of this group. As a result of the explosion, a 350-400 m crater with the pile height of ~10-15 m was formed around the borehole №101.

Radioecological pattern is shown on a map below (Figure 57, a, b).

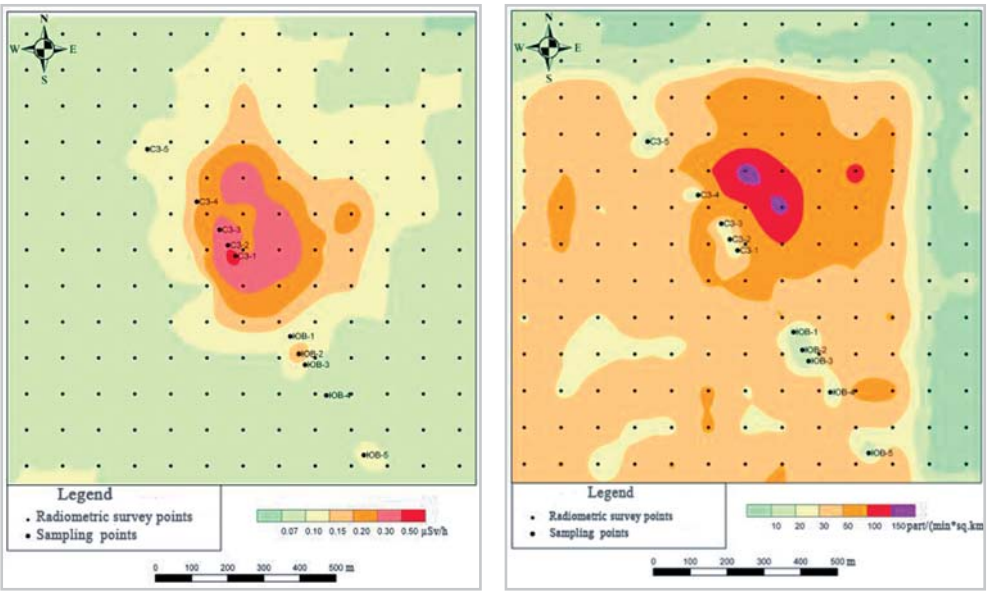


a) b)

Figure 57. The borehole №101. EDR (a) and beta flux density (b) distribution maps

The third group – Weakly contaminated areas. The group includes 6 boreholes, where radionuclide concentrations do not exceed the MSSA levels, but are relatively high. The most noticeable representative of this group is the borehole №125, in the northeastern part of the "Sary-Uzen" testing site. At the present time, there is a crater 250-300 m in diameter near the wellhead (the pile height is 10-15 m). Results of radioecological survey are shown at the schematic map (Figure 58, a, b).

Maximal EDR value is 0.5 μSv/h. Within the radius of about 500 meters to the well mouths, the background of 30 to 50 beta particles/(min*cm^2) is registered.



a) b)

Figure 58. The borehole №125. EDR (a) and beta flux density (b) distribution maps

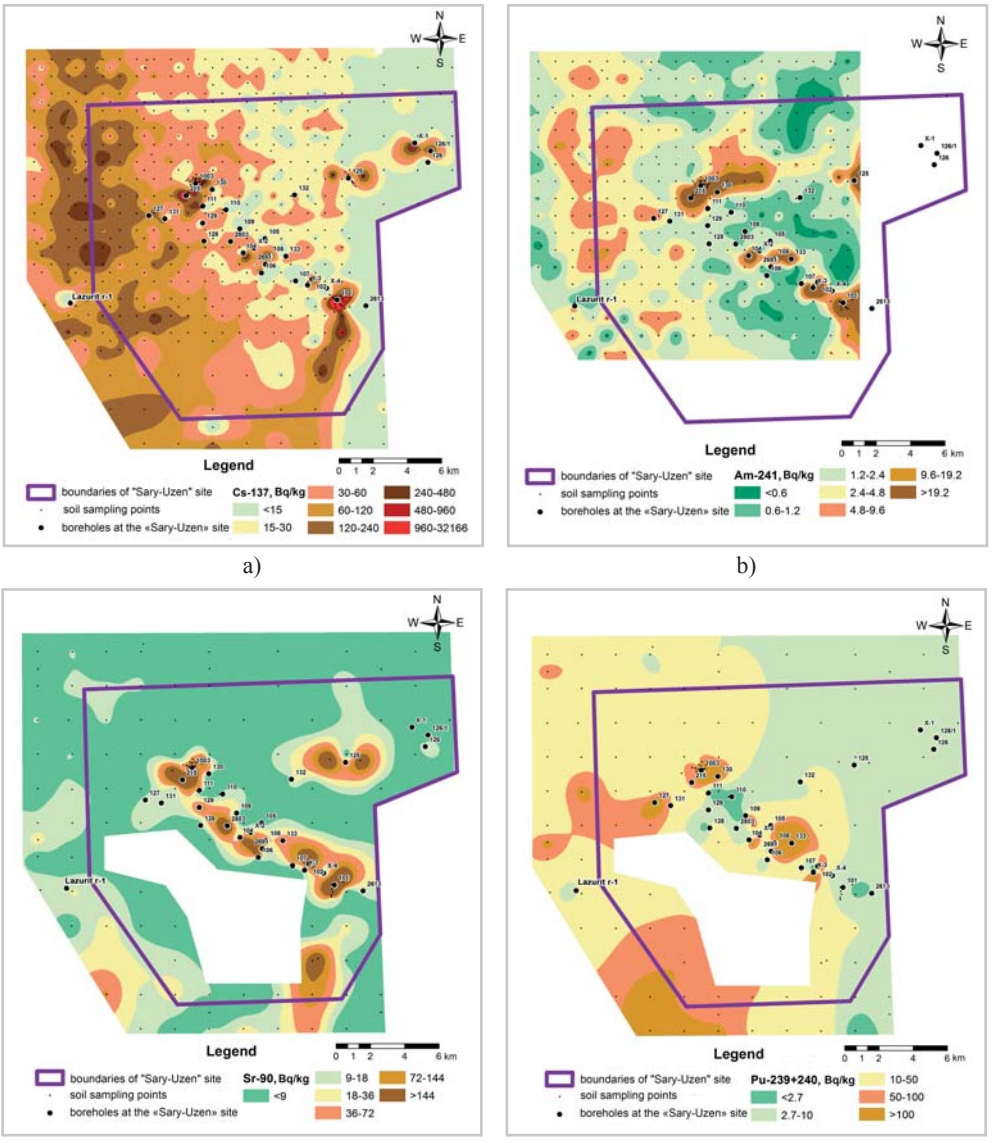
The fourth group – Relatively clean boreholes. This category includes 14 boreholes where radioactive contamination is insignificant, and such sites can be categorized as "clean" ones.

General pattern of the site contamination is shown at the maps of ^{137}Cs, ^{241}Am, ^{90}Sr, ^{239,240}Pu radionuclides distribution (Figure 59) [53].

Areal activity of ^{137}Cs radionuclide in 45% of the studied points exceeds the value of global fallout background (GFB) equal to ~65 mCi/km^2 (15 Bq/kg); in the remaining cases it is either at or below the background level. Areal activity of ^{90}Sr in 30% of the surveyed points exceeds the GFB value of ~39 mCi/km^2 (9 Bq/kg). Almost in all samples, the $^{239+240}$Pu specific activity exceeds GFB of ~12 mCi/km^2 (3 Bq/kg). The highest exceeding is for 52 times [46, Appendix 4].

Ground water. The following types of groundwater can be found at the "Sary-Uzen" site: fracture water – distributed everywhere within the exogenous fracturing zone of Palaeozoic rocks; fraction-vein waters, associated with tectonic faults zones; sporadically distributed pore waters in quarterly alluvial-proluvial and alluvial deposits. Occurrence depths of the groundwater vary from 2.0 to 32.0 m below the day surface. Ground water flows in the northern and the northeastern directions.

The main transport agents of UNEs' radioactive products at the "Sary-Uzen" site are fracture and fracture-vein ground water. High concentrations of ^{137}Cs and ^{90}Sr in ground water were found only in immediate proximity to the "warfare" boreholes. In most cases, within the first hundreds of meters from the "warfare" boreholes well mouths the, ^{137}Cs and ^{90}Sr concentrations decrease down to the values below 1.0 Bq/kg. Concentration of ^{3}H in the samples of groundwater varies within the interval 0.007 to 500 kBq/kg.



a) b)

c) d)

Figure 59. Distribution of radionuclides over "Sary-Uzen" site a) ^{137}Cs; b) ^{241}Am; c) ^{90}Sr; d) $^{229+240}$Pu

2.6. "Aktan Berli" site

Over 89 hydronuclear experiments of various types were performed in 1958 – 1989 in the USSR [54]. 40 of 68 surface tests were carried out at P-2G site [55], the remaining 28 experiments were performed in other parts of the STS (not specified in open sources), including the "Aktan-Berli" site [32, 56]. Information about locations of these 28 ex-

periments (sites coordinates or their location plans) is not available. It is known that hydronuclear tests at the "Aktan-Berli" site were performed underground in boreholes at the depth of 5-30 meters. The locations of these tests were identified first of all based on the consequences of artificial activities (mainly, ground removal) within specified boundaries of the site.

The "Aktan-Berli" site is located in the southern part of the test site to the west from the "Degelen" and to the south-east from the "Sary-Uzen" site (Figure 60). Flat, sometimes a little hilly territory of the site is located on spurs of Arkalyk mountains. Landscape depressions are occupied by salt marshes and lakes, filled up depending on a season.

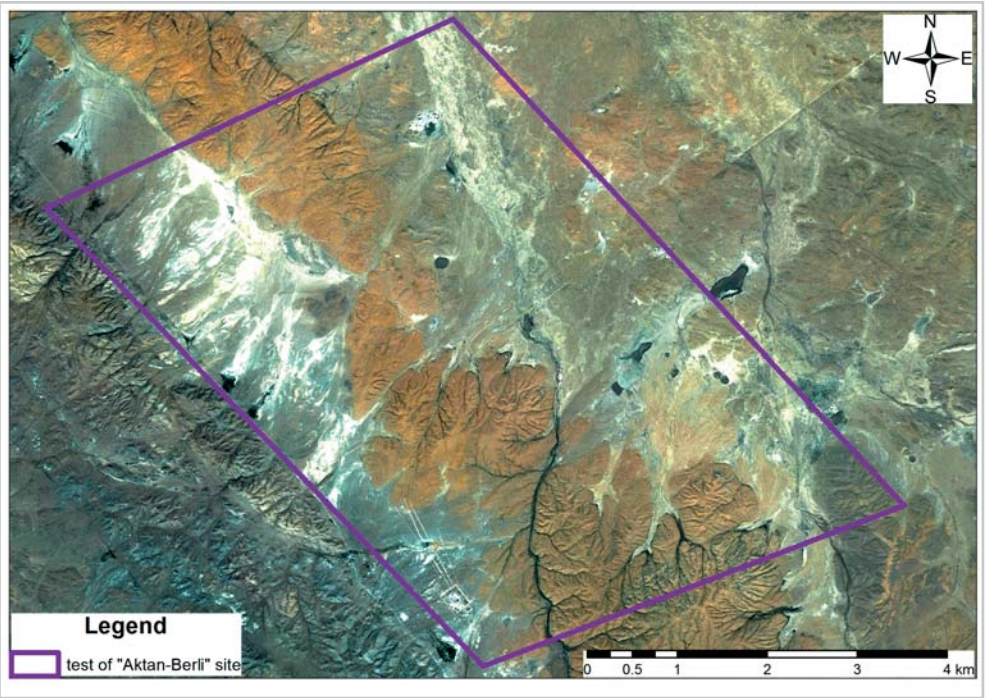


Figure 60. Satellite image of the "Aktan-Berli" site

Figure 60 provides a satellite image of the site area, where the roads leading to two sites, located in the southern ("S" site) and the southwestern ("SE" site) parts of the site (at the figure they are shown as roads marked with red dotted line) are clearly seen. A rectangular object is denoted within the "southern" site and marked with red at the map.

Based on the satellite images interpretation, it can be assumed that several objects with related infrastructure were constructed in the southern part of the "Aktan-Berli" site. Probably, these objects were used for model experiments. Figure 61 provides an overview of the "southern" part.

Radiation situation at the objects. In 1999-2004, works have been carried out at the "Aktan-Berli" site to remediate two areas after the hydronuclear tests [57].

Figure 61. "Southern" part of the site

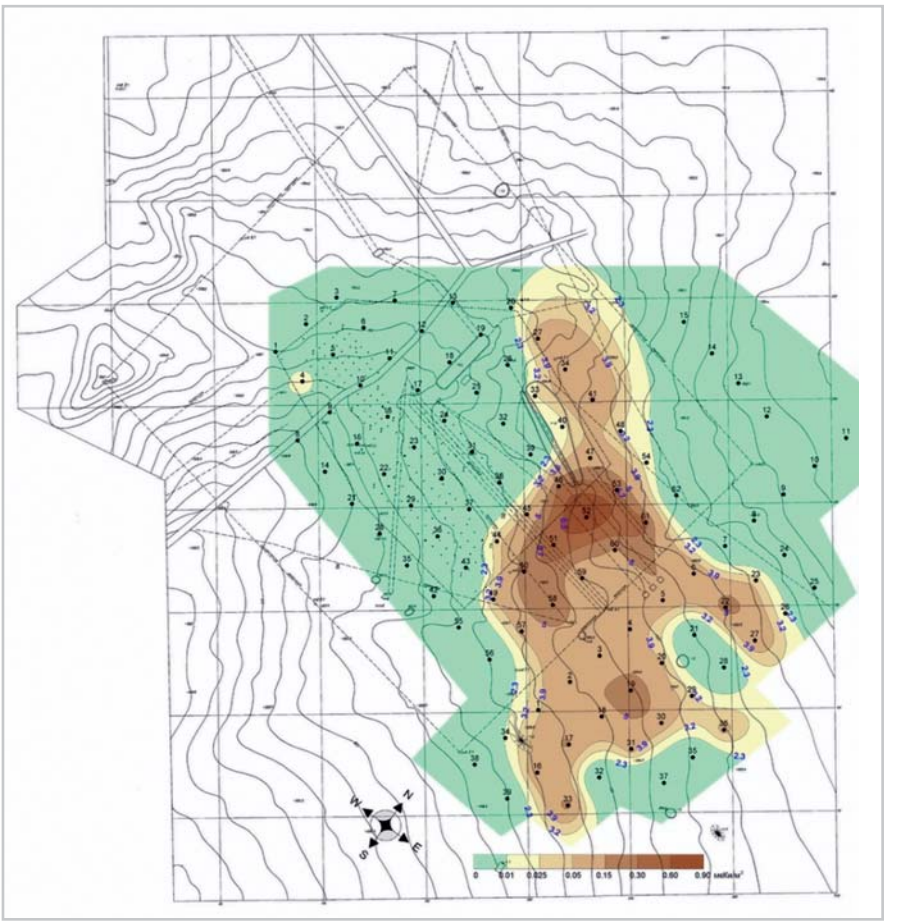


Figure 62. Distribution of ^{241}Am radionuclide areal activity at the territory of the "southern" site

158 experimental boreholes were found at the territory of the "southern" site during a preliminary survey. Maximal radioactive contamination (>30 μR/h) was detected in the boreholes at the depth of approximately 5 meters. Upon completion of the studies, a protective shelter covered with soil was constructed of reinforced concrete slabs.

Performed works have led to decrease of surface contamination at the "southern" site [57]. Radiological survey data obtained after the completion of the works are given at the map of ^{241}Am activity distribution (Figure 62).

28 boreholes were found at the territory of the "southeastern" part of the site [57]. Surface contamination levels ranged within 0.19-0.28 μR/hour. Specific activity of ^{137}Cs and ^{90}Sr in soil samples was at the level of global fallout. $^{239+240}$Pu contents exceeded the background values by an order of magnitude. No presence of ^{241}Am, ^{152}Eu, and ^{154}Eu radionuclides has been detected. Maximal radiation contamination levels were found in the boreholes at the depth of more than 20 meters [57].

Remediation at the site included construction of a dome of reinforced concrete over the testing boreholes with further covering with soil. EDR distribution at the site after remediation is shown at the Figure 63.

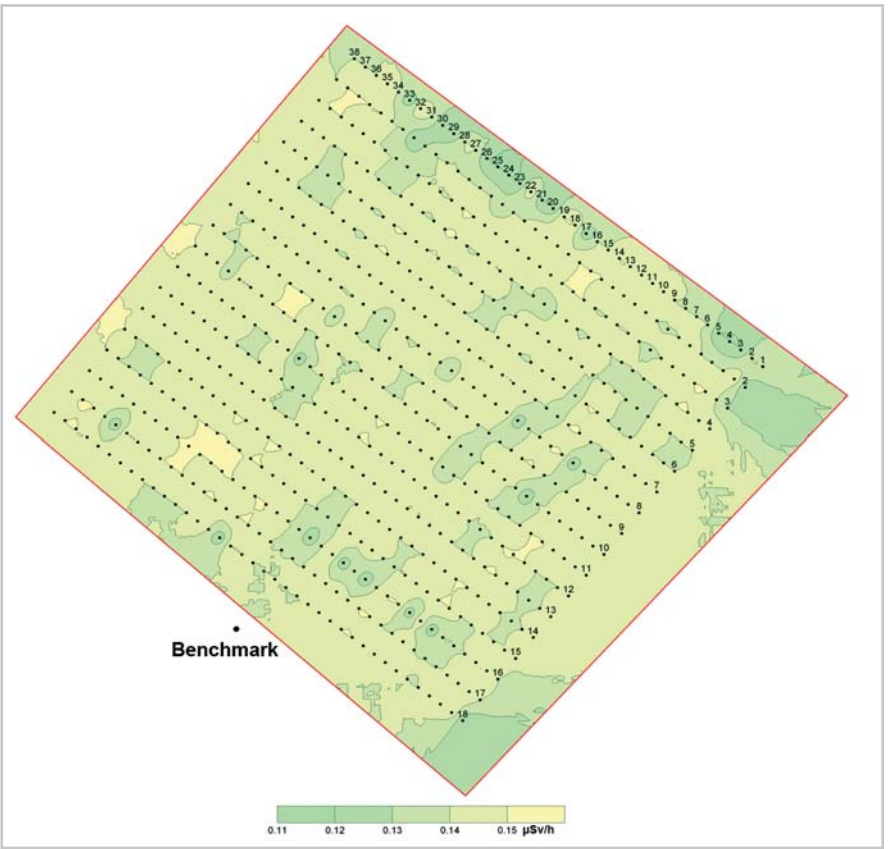


Figure 63. EDR distribution at the "southeastern" site

Within the investigated territory, the EDR values varied within the interval 0.12-0.14 μSv/h, which corresponds to the background levels typical for this area.

The radiological situation at two locations of the model experiments at the "Aktan-Berli" site after remediation can be considered as normal. Radiological survey beyond the indicated lands has not been performed remaining the present radiation situation unknown. Based on the obtained data on radiation parameters distribution at the studied sites, it can be assumed that the sites with increased radiation parameters could hardly be found at the remaining territory of the "Aktan-Berli" site. Taking into account the conditions of the experiment, when surveying the site, special attention should be paid to radionuclides content in ground waters. Radiological surveying of the territory will be carried out within the frame of the complex radioecological survey of the STS in 2021.

2.7. Sites "4" and "4a"

In 1953-1957 the sites "4" and "4A" were used as testing grounds for testing warfare radioactive agents (WRA). Warfare radioactive agents are liquid or powder-like radioactive compounds, made either of radiochemical wastes, or by irradiating specially collected substances with neutron fluxes in a nuclear reactor. Their specific activity varied between deciles and several Curie per liter [58].

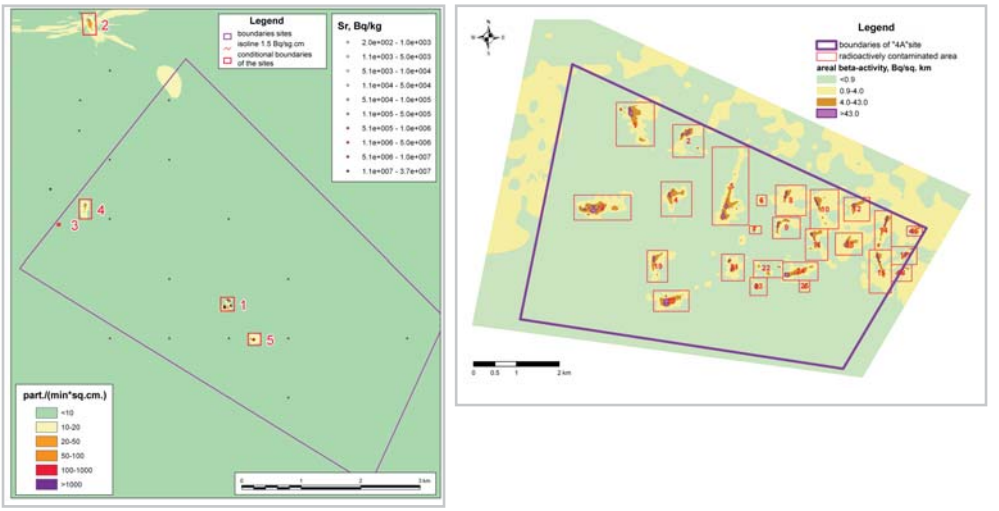
The tests included WRA dispersion by blowing up individual shells, bombing sites with mortar shells, release of bombs or dispersion of WRA from planes. WRA were delivered to the STS in lead containers. After that they were placed into special reservoirs (shells of aircraft bombs) and blew. When plains were used, the bombs were filled up with liquid WRA and dropped on the targets.

In the late 1950-s the unpromising tests of this kind were stopped in the USSR: the tests lead to contamination of military equipment and personnel exposure, but demonstrated low damage effectiveness.

"4A" site is located to the north and the site "4" – 7-km to the west from the "Experimental Field" (Figure 1). Various artificial objects can be found at the test site: trenches, fortifications, craters, numerous and diverse metal fragments remained from the tested weapons (Figure 64). In most cases, the found metal fragments had very high level of surface contamination and probably were used as carriers of the tested WRA.

Figure 64. Entry to one of the bunkers and a fragment of a metal ware

By the present time a variety of radiological surveys have been carried out at the territory of these sites, the largest of those are: air gamma-survey of 1956; air gamma-spectrometric survey in 1990-1991; pedestrian alpha-, beta-, gamma–survey in 2004 [59], beta-, gamma- surveying and laboratory studies of soil and vegetation samples collected at the most contaminated sites in 2006 and 2011 [33, 60]. It should be noticed, that air gamma-spectrometric surveys carried out in different times did not reveal radioactive contamination in this part of the test site [61]. Only modern investigations performed by the IRSE NNC RK allowed to reconstruct the radiological pattern and distributions within the testing sites "4" and "4A": soil contamination is mainly formed by the artificial beta-emitting radionuclide ^{90}Sr. The studies showed that the radioactive contamination is heterogeneous and is formed by local contamination spots around the detonation epicenters of WRA munition, as well as in form of small (up to several hundreds of meters) traces from radioactive fallouts (Figure 65).



a) b)

Figure 65. Distribution of β-particles flux density at the territory of the sites "4" (a) and "4A" (b)

At the identified local contamination sites, whose area varied from 0.01 to 0.53 km^2, radiological situation was additionally studied. The radiation parameters at the surveyed territories ranged as follows: b-particles flux density varied within <10 to >1•104 part/ (min•cm^2), EDR values at the surface reached 122 μSv/h. Distributions of the β-particles flux density at the territory of the "4" and "4A" sites are shown at the Figure 65.

Along with radiometric and dosimetry parameter measurements, laboratory studies were performed to study radionuclides composition of the contamination. It was revealed that ^{137}Cs specific activity varies within <1 to $3 \cdot 10^5$ Bq/kg, ^{90}Sr – from <2 to $5.8 \cdot 10^8$ Bq/kg, ^{239,240}Pu – from 1 to $1.6 \cdot 10^4$ Bq/kg. Artificial radionuclides ^{241}Am, ^{60}Co, ^{154}Eu, ^{155}Eu and ^{152}Eu were also found in the taken samples. Their specific activities range as follows: ^{241}Am – <0.3–5,900 Bq/kg; ^{60}Co – 0.58–190 Bq/kg; ^{154}Eu – 6.6–3,600 Bq/kg; ^{155}Eu –

27–1,400 Bq/kg; ^{152}Eu – 8.5–130 Bq/kg. The analyses identified ^{90}Sr radionuclide as the main contaminating agent in the soil (Figure 66). It should be noted however that plutonium isotopes could also significantly contribute to the radiation hazard. Radioactive contamination of the sites is not uniform, and specific activities differ by several orders of magnitude at different locations. Analysis of the isotopic ratios allows concluding that the radioactively contaminated spots were formed as the result of different and independent from each other WRA tests.

Figure 66. ^{90}Sr specific activity distribution at the "4A" site

The investigations revealed that the "4A" site is the most contaminated by artificial radionuclides and the most contaminated ground in it is the area №5 (Figure 66).

To obtain reliable information on possible impact of the radioactive contamination at "4" and "4A" sites on adjacent territories, special studies at the most contaminated area №5 were performed. Among the outcomes are the diagrams of surface contamination with β-emitting radionuclides (Figure 67).

Studying the possibilities for radioactive contamination remediation at these sites, some assessment regarding the contamination soil volume with ^{90}Sr contents above the level set for radioactive wastes. Areas of the contaminated spots, with contamination level above that for radioactive waste, ranges from 0.1 to 3.2 ha. Total area of such spots is over 23 ha. ^{90}Sr vertical distribution was assessed for the soil samples taken layerwise to the depth of 50 cm. It has been verified that the depth of soil contamination with ^{90}Sr with specific activity of $5 \cdot 10^4$ Bq/kg does not exceed 40 cm. The amount of RAW to be found at WRA sites was therefore assessed to be ~100,000 m^3.

Since there is the radiological hazard at the sites "4" and "4A", the territory of the sites was bordered with physical protection trench and warning radiation hazard signs to prevent cattle from access to the sites and to prevent local population from unauthorized access (Figure 68).

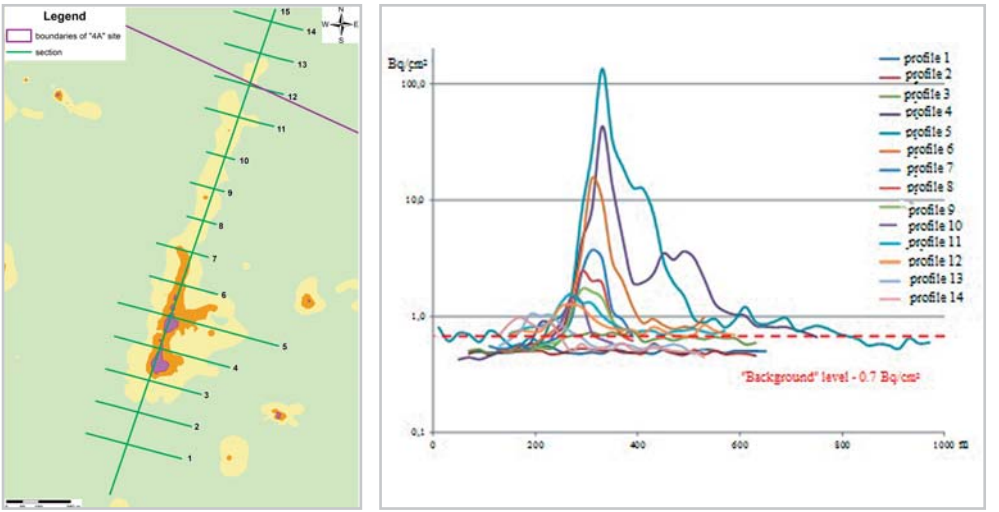


Figure 67. Sampling profiles and the distribution of surface contamination with β-emitting radionuclides along the profiles

Figure 68. Physical barriers and warning signs

2.8. Objects of excavational explosions

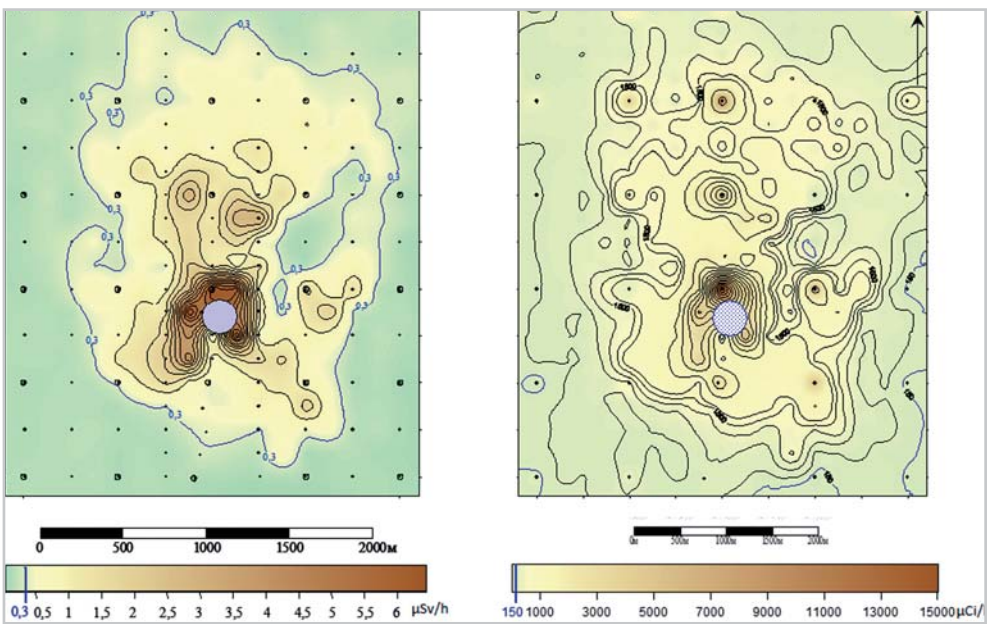
2.8.1. "Atomic" lake

In 1965, the first excavation explosion with ground outburst in the USSR was carried out in the borehole №1004 at the "Balapan" site of Semipalatinsk Test Site. That was the first pilot experiment for civil purposes to assess the possibility of using nuclear explosions for creating water reservoirs in arid regions of the USSR, particularly, in Kazakhstan. Yield of that explosion was 130 kt, the depth of nuclear charge installation – 178 m. The diameter of a crater resulted was – 408 m. As the result of the excavation explosion, approximately 6 mln cubic meters of soil was taken out. This soil has formed a 20-25 m high dump around the crater and closed the channel of Shagan river [62].

This explosion has resulted in joining Shagan and Aschisu rivers forming a 100 m deep water reservoir that was further called as the "Atomic" lake.

In total the following amounts of long-living radionuclides were generated: $^{239+240}$Pu – 8.5 Ci; ^{137}Cs – 800 Ci; ^{60}Co – 80 Ci; ^{152}Eu – 120 Ci; ^{90}Sr – 400 Ci; ^{3}H – $4 \cdot 10^5$ Ci. At that, approximately 30 – 40% of the radionuclides remained within the ground pile area [63]. Radiological studies performed in early 2000s at the "Atomic" lake and vicinity covered 20 sq. km registered the maximal values of radiation parameters at the western bank: EDR – 6.56 μSv/h; alpha- and beta- particles flux density – 4.4 part/(min·cm^2) and 60 part/(min·cm^2). At the present time, the maximal concentrations of artificial radionuclides is soils of the "Atomic" lake are: ^{241}Am – 4,000 Bq/kg, $^{239+240}$Pu – 17,000 Bq/kg, ^{238}Pu – 7,500 Bq/kg, ^{137}Cs – 22,000 Bq/kg, ^{90}Sr – 10,000 Bq/kg, ^{152}Eu – 16,000 Bq/kg, ^{154}Eu – 6,000 Bq/kg.

So, a territory where EDR value exceeds 0.3 μSv/h (Figure 69, a) was outlined based on the performed radiometry. A map with the boundary of the ^{137}Cs radioactive contamination is shown at the Figure (Figure 69, b).

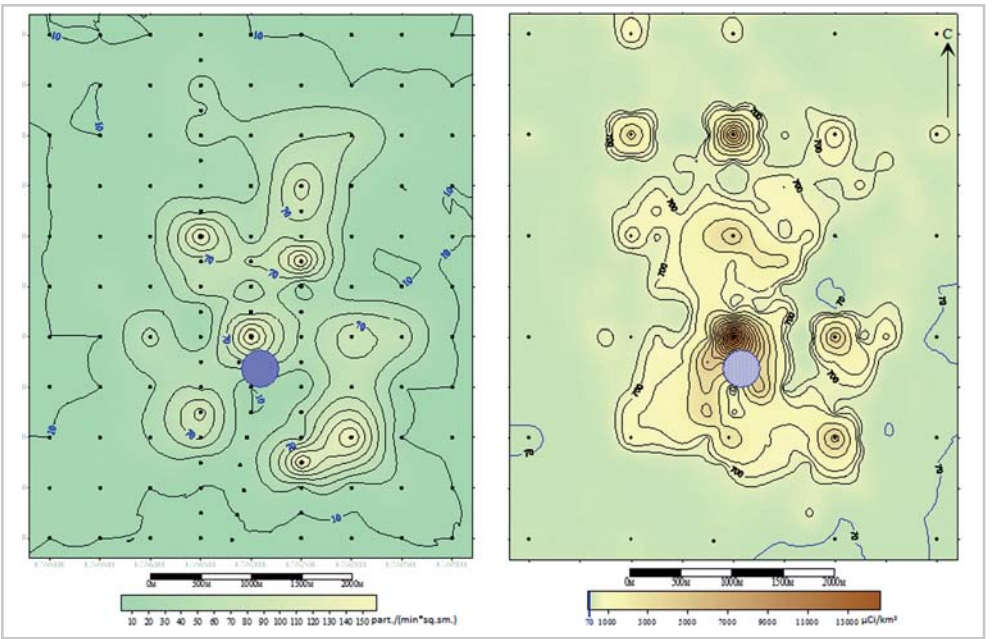


a) b)

Figure 69. Exposure dose rate distribution and radioactive contamination with ^{137}Cs

Density distribution of surface contamination with beta-emitting radionuclides and a schematic map of ^{90}Sr contamination are shown at the Figure 70 [64].

The main zone of soils contamination lies in direct proximity to the crater of the "Atomic" lake and has areal character. Total contamination area is limited within the distance of 1–2 km to the crater crest. The level of contamination with artificial radionuclides in this area significantly exceeds the global fallouts background.



a) b)

Figure 70. β-particle surface contamination density distribution and ^{90}Sr contamination

In 2009 – 2012 the level of "Atomic" lake water contamination with artificial radionuclides was assessed. To do this, water was sampled in 9 points of the "Atomic" lake and in the outer reservoir (Figure 71).

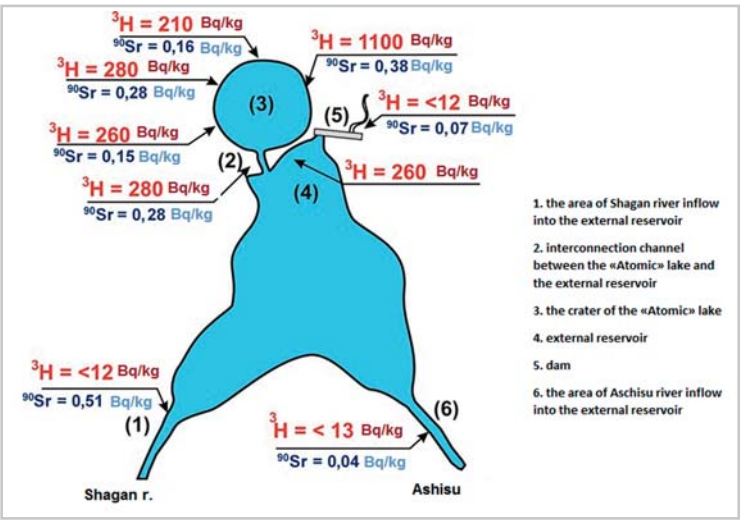


Figure 71. Water sampling locations at the "Atomic" lake and at the outer water storage reservoir

Upon the performed studies, the ^{90}Sr concentrations in water of the "Atomic" lake and the water reservoir were found at the level of 0.04 to 0.51 Bq/kg. ^{3}H concentration lies within the interval from the detection threshold of <12 Bq/kg in the area of Shagan and Aschisu rivers inflow, to maximal registered value 1,100 Bq/kg in the eastern part of the "Atomic" lake crater. Specific activity of ^{137}Cs in water does not exceed detection limits of the measurement equipment (0.01 Bq/kg). Maximal concentration of the $^{239+240}Pu$ radionuclide is 0.005 Bq/kg. No data on water contamination with artificial radionuclides ^{241}Am and $^{152,154}Eu$ is available.

However, according to the 2001 – 2002 data, ^{90}Sr concentration in water at various sites of the "Atomic" lake crater varied from 3 to 15 Bq/kg, while its maximal value was found in the central part of the lake at the depth of 30 meters. ^{137}Cs specific activity reaches 3.5 Bq/kg in the center of the crater at the depth of 10 m. At that, $^{239+240}Pu$ was found virtually everywhere at the levels of up to 0.006 Bq/kg [65].

Most probably, such significant changes in concentrations of the artificial radionuclides in water result from instability of water regime, i.e. variation of water level and discharge of the "Atomic" lake and the outer reservoir, that in its turn can directly influence the radionuclides washout from the pile and bottom sediments of the "Atomic" lake, serving as a permanent and long-term storage of radionuclides.

Artificial radionuclides in air were registered within the distances less than 1,000 m from the crater at the levels of several hundred μBq/m3, and do not pose radiation hazard for people.

Therefore, the main hazardous place for people can only be the zone of soil dump around the "Atomic" lake, with the radius of 3 – 4 km, which should be considered as a serious potential source of secondary contamination of environmental objects (water, vegetation, air). From here, artificial radionuclides can further be transferred with water, or washed out with precipitations both to the surrounding area and into the channel of Shagan river with further transfer of the radionuclides with the surface streamflows.

During the radioecological studies of the objects of this type, special attention is to be paid to the content of artificial radionuclides in water. Their concentration can sharply vary and directly depend on hydrological regime.

2.8.2. "Telkem-1, 2"

In the southeastern part of Semipalatinsk Test Site, two underground explosions with ground outburst were performed: a single underground explosion with the yield of 0.24 kt – "Telkem-1" (21.10.1968) and a group explosion (consisting of three charges with the yields of 0.24 kt each put in one line) – "Telkem-2" (12.11.1968). The crater resulted from this group explosion was filled up with water (Figure 72).

The experiments were held to develop technologies for constructing the channels for transportation of water from arctic regions of the country into Volga river basin and the Caspian sea. Important data for planning works on the construction of Pechora- Kama channel were obtained in these experiments. The radioecological studies at "Telkem-1" and "Telkem-2" revealed presence of radionuclides almost in all environmental components – soil, vegetation, and water. Maximum values of the radionuclides specific activities are given in the Table 4. Specific activities of some individual radionuclides

correspond to the level of "emergency ecological situation" set by the state Decree of RK №653 of 31st of July, 2007 "About approval of criteria for assessment of ecological state of territories".

Figure 72. "Telkem-2" object panoramic view from the dump, (note the pipe posts in the lake)

Table 4.

Radionuclide contents in the environment

Radionuclide	Telkem – 1			Telkem – 2		
	ground	plants	water	ground	plants	water
^{137}Cs	1.4×10^{4}	260	0.3	6.0×10^{3}	305	0.2
^{241}Am	2.2×10^{4}	380	-	1.7×10^{4}	210	-
^{90}Sr	5.8×10^{3}	760	177	4.2×10^{3}	1.3×10^{3}	136
$^{239+240}Pu$	2.5×10^{4}	2.2×10^{3}	0.3	1.5×10^{5}	1.2×10^{3}	0.2
^{3}H			60			20

The highest specific activities of the radionuclides in soil were found on the crests and slopes of the dumps. Contamination of the territory resulted from these tests is quite local – the radionuclide contents decrease significantly at larger distances to the epicenters of explosions (Figure 73) [65].

Due to peculiarities of the dump formation during the explosions, high specific activities of the radionuclides in soil profiles are observed almost along all the profiles at the crests and the slopes of the craters' dumps [66]. In the vertical profile at the bottomland, the highest values are observed in the top layers of soil at the depth of 0-6 cm. Going down along the profile, sharp decrease in radionuclide specific activity was noticed, i.e. classical character of the radionuclides distribution in soil was observed (Figure 74).

Land cover of the "Telkem-1" and "Telkem-2" objects is mainly represented by steppe species of plants – feather grass (*Stipa sareptana),* sheep fescue (*Festuca valesiaca*), wormwood (*Artemisia gracileccens*). Maximal specific activity values of the radionuclides in the plants growing at the crest and the piles of the craters are given in the table 4 [67]. In some individual cases the ^{90}Sr concentrations exceed the permissible levels of radionuclide concentrations set by the Ministry of Agriculture of the Republic

of Kazakhstan [68] for 52 times (at the "Telkem-1"). Concentration of ^{137}Cs exceeds the regulatory norms for 4 times (at the "Telkem-2"). Quite high specific activities of ^{241}Am and $^{239+240}Pu$ were found in vegetation. High concentrations of radionuclides in plants are, as a rule, associated with the crests and the slopes of the dumps of the man-made water reservoirs.

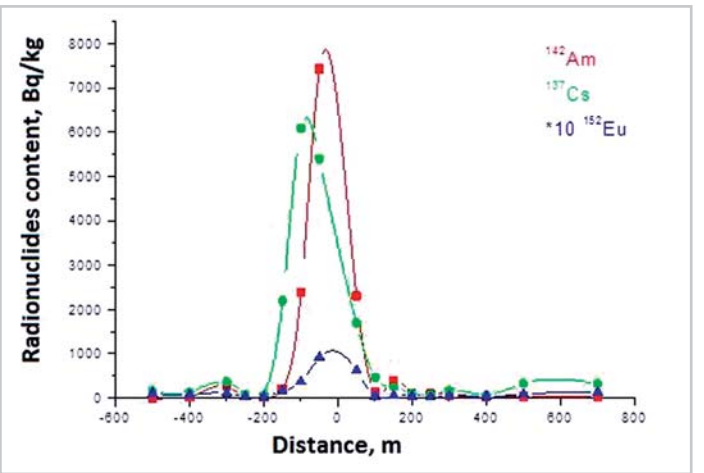


Figure 73. Radionuclide distribution as a function of distance to the crater dumps of the "Telkem–2" object

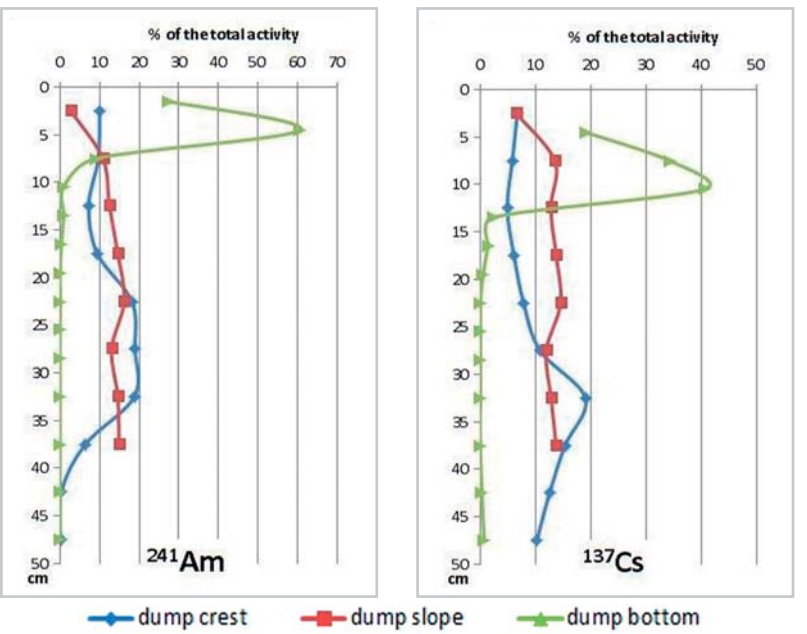


Figure 74. Distribution of radionuclides in the dumps and the bottomland soil at the "Telkem–2" object

Although the craters there were formed by nuclear explosions, no abnormal concentrations of radionuclides were found in water of the craters (Table 4).

Detectable values of tritium were found in the atmospheric air of the objects "Telkem-1", "Telkem-2". Tritium was also detected in soil air. Volumetric activity of gaseous tritium varies within the wide range from 0.1 to 1.6 Bq/m^3; at that, its permissible content in air is 1,900 Bq/m^3.

Therefore, the radionuclides at the objects of excavation explosions "Telkem-1" and "Telkem-2" are localized around the craters (lakes) created by these nuclear explosions. Total area of the territories recommended for rehabilitation at the "Telkem-1" and "Telkem-2" lands are 6.2×10^4 m^2, and 1.6×10^5 m^2, respectively [65]. In general, any activities (agricultural, recreational) are not recommended at this territory due to the present activities of the radionuclides in soil and vegetation. Still, the radiological situation at these objects is stable and does not require special measures to restrict the impact of these objects on the adjacent territories. To limit the access of population and farm animals to these objects by installing physical barriers with informative signs would be quite enough there.

2.9. Shagan river

Low-water Shagan river with its tributary Aschisu river is the longest surface streamflow at the territory of Semipalatinsk Test Site and its main waterway. It runs along the eastern STS boundary and is the left-bank tributary of Irtysh river. The river basin covers the area over 10,000 km^2, the main channel length is 275 km, and the span of the left tributary, Aschisu river, is 115 km (Figure 75).

The Shagan river valley has been contaminated due to nuclear tests at the STS. Radioactive contamination of the environment is mainly concentrated near the "Atomic" lake, where an excavation explosion was performed in the borehole №1004. The contamination is also resulted from the underground nuclear tests in "warfare" boreholes of the "Balapan" site. Surface tests performed at the "Experimental Field" site and global fallouts have insignificantly contributed to the contamination.

According to the performed studies, ground contamination with ^{137}Cs, ^{90}Sr and $^{239+240}$Pu only significantly exceeds the background from global fallouts within the "Atomic" lake area. Specific activity of ^{137}Cs ranges widely from 1 to 500 Bq/kg, ^{241}Am concentration varies from 1 to 50 Bq/kg. Measurements of the ^{152}Eu, ^{154}Eu, ^{60}Co activation products have shown the quantitative values only in proximity to the "Atomic" lake where they do not exceed 270 Bq/kg. Specific activity of $^{239+240}$Pu can be as high as 400 Bq/kg.

Concentrations of artificial radionuclides in the coastline ground and bottom sediments along the river channel also have their maximal values near the "Atomic" lake crater: ^{137}Cs – up to 500 Bq/kg, ^{241}Am – up to 20 Bq/kg, ^{152}Eu, ^{154}Eu, ^{60}Co do not exceed 70 Bq/kg.

Specific activity of ^{90}Sr in water of Shagan and Aschisu rivers before flowing into the "Atomic" lake ranges within 0.01–0.03 Bq/kg. Concentration of ^{137}Cs and $^{239+240}$Pu along the Shagan river channel is below the detection limits of the equipment used (0.01 and 0.001 Bq/kg, respectively). Concentration of ^{90}Sr in Shagan river at the point where it runs out from the "Atomic" lake is approximately 0.07 Bq/kg. At that, according to

previous studies, ^{90}Sr artificial radionuclide was detected at the distance of 6 km to the "Atomic" lake. This fact shows that the source of its origin is not associated with inflow of contaminated surface waters. In this case either wash out of radionuclides from bottom sediments, bank soil or inflow of contaminated groundwater takes place.

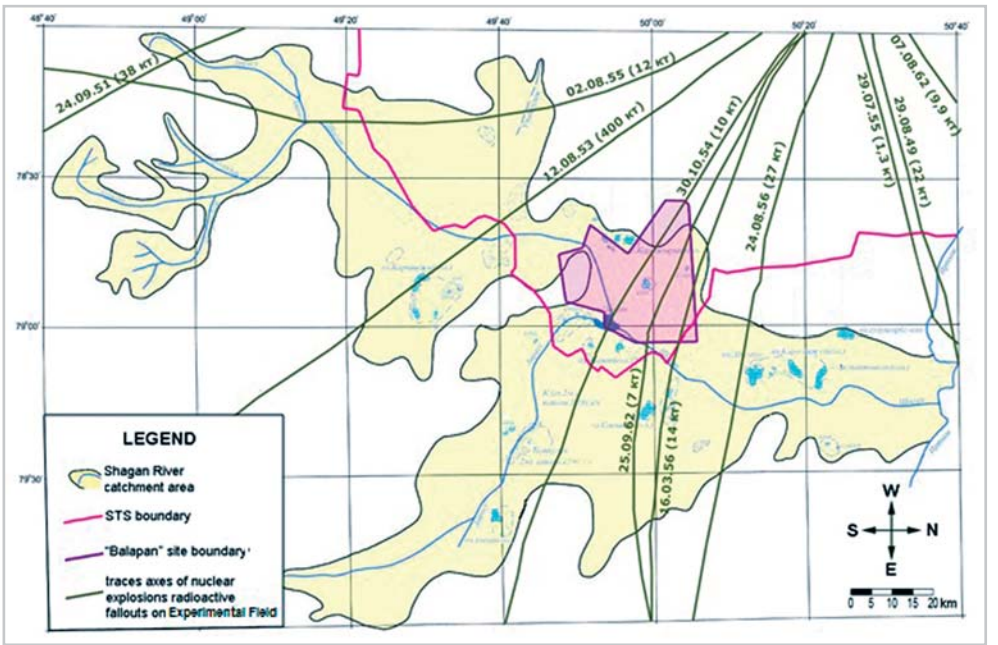


Figure 75. Water catchment area of Shagan river and local atmospheric fallout traces from surface tests at the "Experimental Field

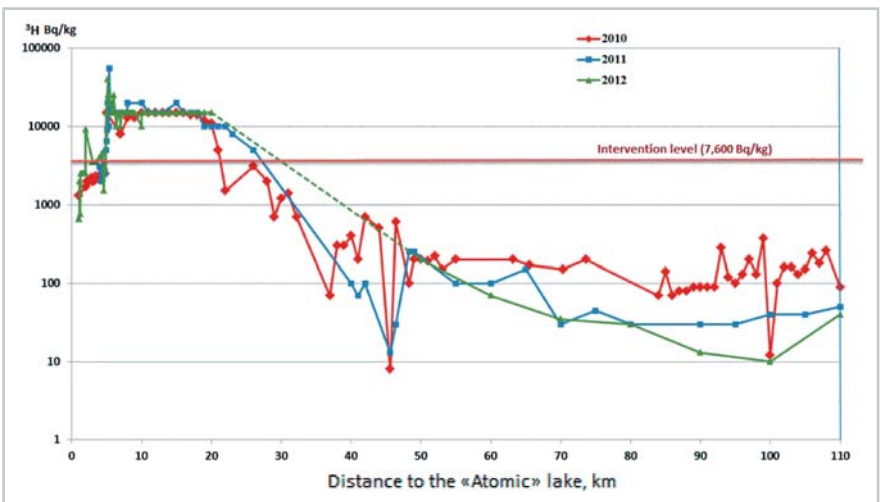


Figure 76. Contamination of Shagan river water with tritium

Studies performed in 2006 – 2009 verified high concentrations of ^{3}H in water of Shagan river at the distances up to 5 km downstream the "Atomic" lake (Figure 76).

The discharge of groundwater contaminated with 3H into the surface streamflow of Shagan river has been verified and confirmed at this area. Specific activity of 3H in water of this river section can be as high as 680 kBq/kg (Figure 77).

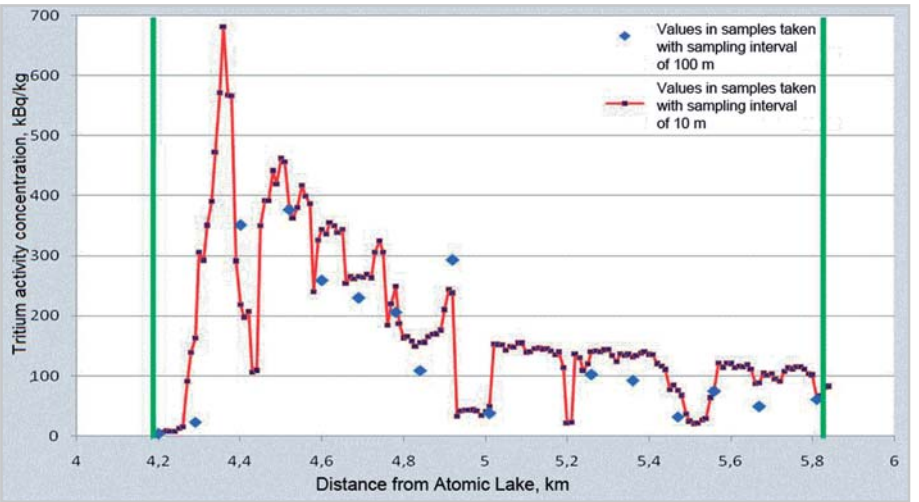


Figure 77. Tritium specific activity values in the channel of Shagan river at the distance 4 – 6 km from the "Atomic" lake

The 2010 studies revealed for the first time the quantitative ^{3}H concentrations along the whole river up to its inflow into Irtysh river where tritium specific activity comprised 400 Bq/kg.

This area also serves as the ^{3}H secondary contamination source for plants, cattle breeding products, and air. So, ^{3}H was detected in all samples of plants taken at the banks of Shagan river; at that, its maximal concentration ($65 \cdot 10^{3}$ Bq/kg) was detected in reed. The ^{3}H content in milk samples taken at the winterings located on the banks of Shagan river, does not exceed the regulatory levels.

According to the performed assessments, intake of ^{3}H with inhaled air is the critical route of entry into human organism for this radionuclide. Therefore the coastline territory of Shagan river can be divided into three zones according to the level of expected annual effective dose from intake of ^{3}H radionuclide with inhaled air as follows:

– the zone with relatively satisfactory radiation situation (<0.3 mSv/year);
– the restricted for population zone (<0.3–1 mSv/year);
– the zone with hazardous radiological situation (>1 mSv/year).

Therefore, the restricted for population zone ends only at the distance of 40 km to the "Atomic" lake along the river channel bordering there the zone with relatively satisfactory radiological situation where ^{3}H concentration in air is < 140 Bq/m^{3}. It should be noticed that the restricted for population zone and the zone with hazardous radiological

situation are comparatively narrow being just several dozens of meters wide: at the distances more than 50 m from the channel, ^{3}H concentrations in air impose no hazard on humans along the whole Shagan river range.

2.10. "Burials"

Like in any human activity, wastes were generated during operation of Semipalatinsk Test Site in 1947-1991. These are not only residues of nuclear activities directly related to nuclear explosions, but also residues of various preparatory activities, as well as residues from research performed there after the tests. The residues were mainly represented by laboratory chemical glassware, various reservoirs, fragments of equipment, construction materials and alike. Such residues were stored in specially allotted places because in most cases these were the highly active toxic wastes. However, there is no official information available nowadays about the venues where these wastes were disposed. This complicates the search for such places.

So, during the complex areal radioecological surveys of the STS territories, the IRSE specialists have revealed four burials. These burials were marked as "Burial" objects.

These objects are the areas initially "fenced" with barbed wire. Nowadays, however, only fragments remained there – some concrete posts and fragments of the barbed wire.

Indications for artificial activities can be noticed within the perimeter: trenches, earth-embankments, and etc. (Figure 78).

Figure 78. A view on a "burial" object

As the rule, "burials" represent orthogonal sites with edges of 100-200 m, i.e. such objects are quite large, and during the areal surveying of the territory these objects can be identified by field methods and can further be studied employing a special scheme.

There is also another type of the "burials": these objects have no fencing and are small in size. Such objects represent ditches (pits, craters) of ~3-5 m in diameter, where laboratory wastes (glassware, materials and etc.) were disposed. This type of "burials" presents some definite difficulties in searching, identification and subsequent surveying.

At the territory of all "burial" objects, various materials were found disposed: chemical glassware, construction materials, animal remnants, metal containers, fragments of plastic boxes, and etc. (Figure 79).


Figure 79. Items disposed at the "burial" objects

Almost all the objects pose a radiation hazard. Concentrations of artificial radionuclides in soil can reach the following values:

^{137}Cs - 20,000 Bq/kg;
^{90}Sr - 10,000 Bq/kg;
$^{239+240}$Pu - 1,000 Bq/kg;
^{241}Am - 100 Bq/kg.

At that, radioactively contaminated spots at the surface of "burials" are small, mostly, 1-2 m in diameter. It should be noticed however, that the main part of radioactivity is buried, and the depth of the burials can vary as well.

Search for the "burial" type objects is a difficult task since standard surveying of the territory with uniform grid or employing the radial grid method does not assure their detection.

Therefore, for the purpose of search and identification of the "burial" objects, taking into account their small dimensions (5-200 m) comparing with the scale of the surveyed territories (1,000-2,000 sq. km), the following operations are to be performed:

1. In-house decoding of high-resolution satellite and aerial images (up to 2-5 m). Identification of potential objects with characteristic features.

2. Verification of decoding results afield. Description of the objects, revealing the indications for "burials" (fragments of fencing, trenches, bulks, laboratory "trash", and etc.).

3. Detailed radiological survey of the "burial" with sampling.

CHAPTER 3
DEVELOPMENT OF THE TECHNIQUE FOR INVESTIGATION OF VARIOUS ENVIRONMENTS OF THE FORMER STS

3.1. Soil cover

3.1.1. Study of spatial parameters of surface contamination due to radioactive fallouts from nuclear tests

The main objective to study spatial parameters of surface contamination due to radioactive fallouts and migration of radionuclides with water from the nuclear tests venues is to identify the boundaries of radioactively contaminated areas using optimal schemes of radioecological surveying of territories.

At the present time, 4 main types of surface radioactive contamination can be found beyond the "Experimental Field", "Degelen", "Balapan", "Sary-Uzen" and other technical sites:

– Radioactive fallout traces spanning outside the testing sites limits for more than 100 km.
– Radioactive fallout traces from nuclear tests of low and moderate yield, up to 20-30 km off the testing grounds. Contamination of this type also includes radioactive fallouts resulted from excavation explosions (the "Atomic" lake, boreholes at the "Sary-Uzen" site), as well as tests with emergency situations (emergency emissions) at the "Degelen" and "Balapan" sites.
– Radioactive contamination of the streamflow channels resulted from proliferation of artificial radionuclides from the nuclear tests venues beyond the technical sites – brooks of Degelen massif, Shagan river.
– Radioactive "spots" of several square kilometers, located at significant distances to the testing venues (50-60 km) and beyond the main radioactive fallout traces. This type of contamination was revealed in complex investigations performed by the Institute of Radiation Safety and Ecology since the 2008 [69, 70].

Obviously, each type of the surface radioactive contamination needs individual research approach. At that, the balance should be kept between the scope and deepness of radioecological studies and economic efficiency of the method used. In other words, optimal tools and methods sufficient for characterizing whatever type of the radioactive contamination taking into account further aim to transfer the lands for civil use, i.e. taking into account radiation safety of the population should be specified.

It should be noted, that quite many works worldwide have been dedicated to theoretical approaches in radioecology. So, the theoretical basis of radioecological monitoring described by Yu.A.Izrael in [71] provide general approaches for dealing with environmental contamination resulted from nuclear fuel cycle operations and global fallout from

nuclear tests. Handling the Chernobyl accident consequences, a variety of techniques and recommendations was developed for surveying and assessment of environmental radioactive contamination [72 –76]. However, significant differences in radiological situation at Chernobyl NPP and the STS, difference in climatic zones and several other peculiarities make use of these techniques and recommendations impossible without adjusting to local (STS) conditions. For this purpose, they should be significantly amended using large amount of experimental data.

Let us now consider the peculiarities of surface radioactive contamination at the STS in the light of empirical data obtained by the Institute of Radiation Safety and Ecology for more than 20-year period of radioecological research at the STS [69, 70, 77-79].

3.1.1.1. Radioactive fallout traces outside the STS boundary

The largest radioactively contaminated sites of the STS at the present time (beyond the technical sites "Experimental Field", "Balapan", "Degelen" and others) have been formed by three plumes of radioactive clouds: the trace of the test made on 29.08.1949 – the "eastern trace", the plume from the test on 24.09.1951 – the "southern trace", and the plume from the test on 12.08.1953 (the first thermonuclear test) – the "southeastern trace".

There was performed the areal radioecological surveying over the regular 1x1 km grid with sampling of the top soil layer (0-5cm) in the grid nodes with further laboratory analyses of samples. Equivalent dose rate (EDR) and beta particles flux rate were measured in sampling points at ground level and 1 m above the ground.

Let us consider as an example the "southeastern" radioactive fallout trace. Figure 80 shows areal distribution of ^{137}Cs in the "southeastern" part of the STS and beyond its boundaries.

The Figure 80 is based on the survey covered the territory of ~3,500 sq. km. The figure clearly shows the trace of radioactive contamination, expanded off the "Experimental Field" in the southeastern direction and overran the STS territory for more than 40 km; the trace width of 10-14 km remains almost unchanged along the whole surveyed range.

Although the radioactive fallout trace has been identified, the issue of representability level of the soil sampling over the 1x1 km grid remains open. The question is whether such sampling interval is enough to reliably outline the trace boundaries, or the 1x1 grid is excessive, providing that the trace width varies from 10 to 14 km.

Let us consider the ^{137}Cs specific activity distribution in soil along 2 sampling profiles, crossing the radioactive fallout trace (Figure 80). Gamma-spectrometry of soil samples provide us with the diagrams of ^{137}Cs and ^{241}Am specific activity distribution along the sampling profiles (Figure 81).

Distribution of the artificial radionuclides shows that the trace area is quite pronounced. Increased activity values of ^{137}Cs and ^{241}Am can be observed at the distances 4-6 km on either side from the trace axis. The width of this area is 10-13 km.

In general, the number of samples in the trace area can be reduced up to 4 times, i.e. 2x2 km grid can be used for sampling. A wider sampling grid can lead to distortion of the reconstructed areal contamination pattern. For example, ^{137}Cs specific activity in samples

collected with 3 km interval at the first profile (i.e. via 3x3 km grid) can reach minimal values (at the distance of 1 and 4 km to the west (left) from the trace axis).

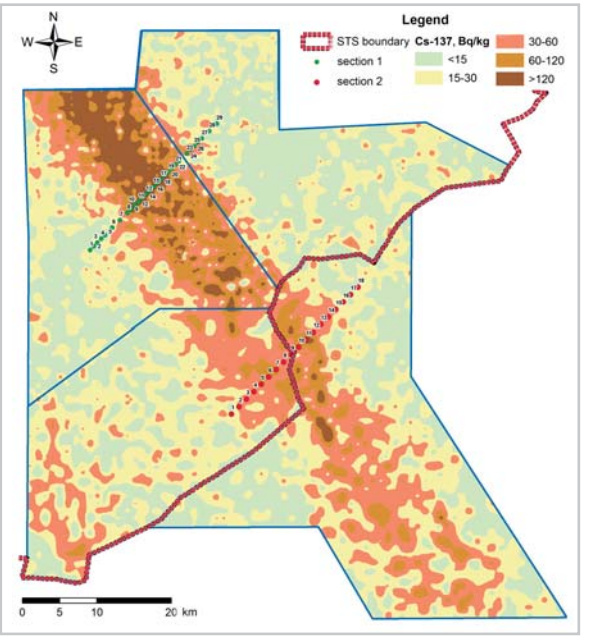
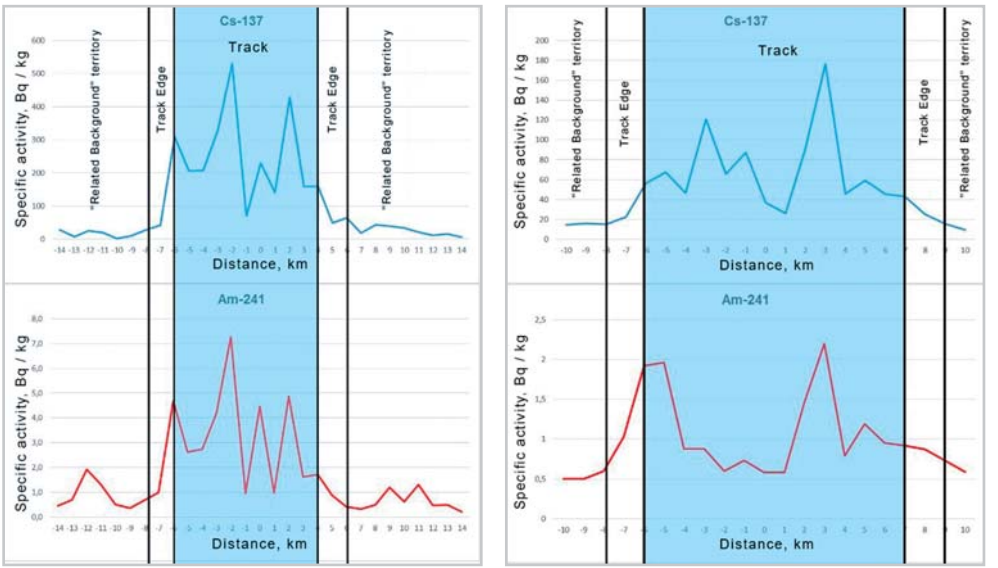


Figure 80. Areal distribution of ^{137}Cs in the "Southeastern" part of the STS in vicinity of Sarzhal village



a) 1st profile b) 2nd profile

Figure 81. Distribution of ^{137}Cs and ^{241}Am specific activity along the sampling profiles

Speaking about the boundary area between the "trace" and the "conditionally background territory", the experimental data show that this territory has very uncertain borders. Although sampling by 1x1 grid did allow outlining the trace, but the activity peaks of this area ("trace boundary" at the figure) show that cesium specific activity decreases for 2-6 times in the direction of the "conditionally background" territory at the distance of just 1 km. At that, activity continues decreasing further, although less intensively. Therefore, within the boundary zone between the "trace" and the "conditionally background territory" the 1x1 km grid is not sufficient. For more precise outlining of the trace boundary the grid should be decreased to 500x500 m or even 250x250 m.

3.1.1.2. Radioactive fallout traces from moderate- and low-yield tests

Unlike large-scale traces from radioactive fallouts resulted from high-yield nuclear tests extended for several hundred kilometers from testing grounds, the plumes from low and moderate yield tests rarely overrun the testing sites. Such situations however took place with small radioactive fallout traces propagating off the test site, for instance at the "Experimental Field".

This fact should be considered when considering the territories adjacent to the STS technical sites.

Radioactive fallouts resulted from the excavation nuclear explosions (the "Atomic" lake, boreholes at the "Sary-Uzen" site), as well as the tests with emergency radiation situation (emergency emissions) at the "Degelen" and the "Balapan" sites can also be categorized as radioactive contamination of this kind.

Figure 82 provides typical characteristics of small traces from radioactive fallouts.

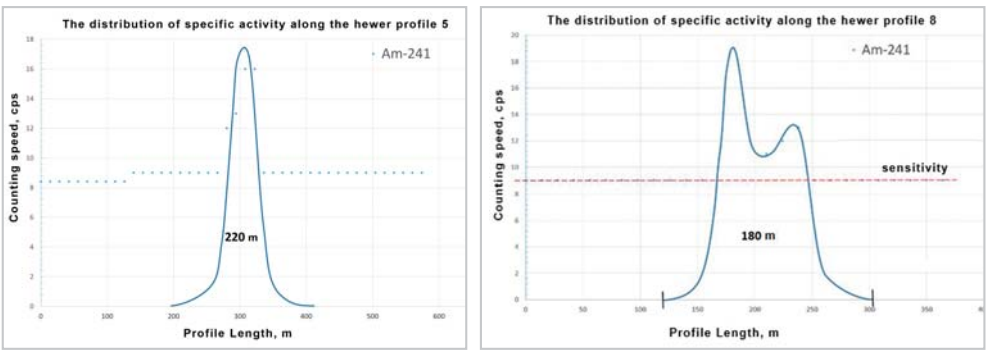


Figure 82. Width of the radioactive fallout traces formed due to low-yield nuclear tests

As one can see at the figure, the widths of the radioactive fallout traces from the low-yield nuclear tests rarely exceed 1 km, and the 1x1 km sampling grid is too big to assure reliable identification of such traces. To avoid this, the survey grid density should be increased at the boundaries of the technical sites, as shown at the Figure 83.

The sampling scheme provided ensures detection of radioactive fallout traces with the width of 100 m and higher. After that, a closer look at the identified area should be made, i.e. its boundaries should be outlined.

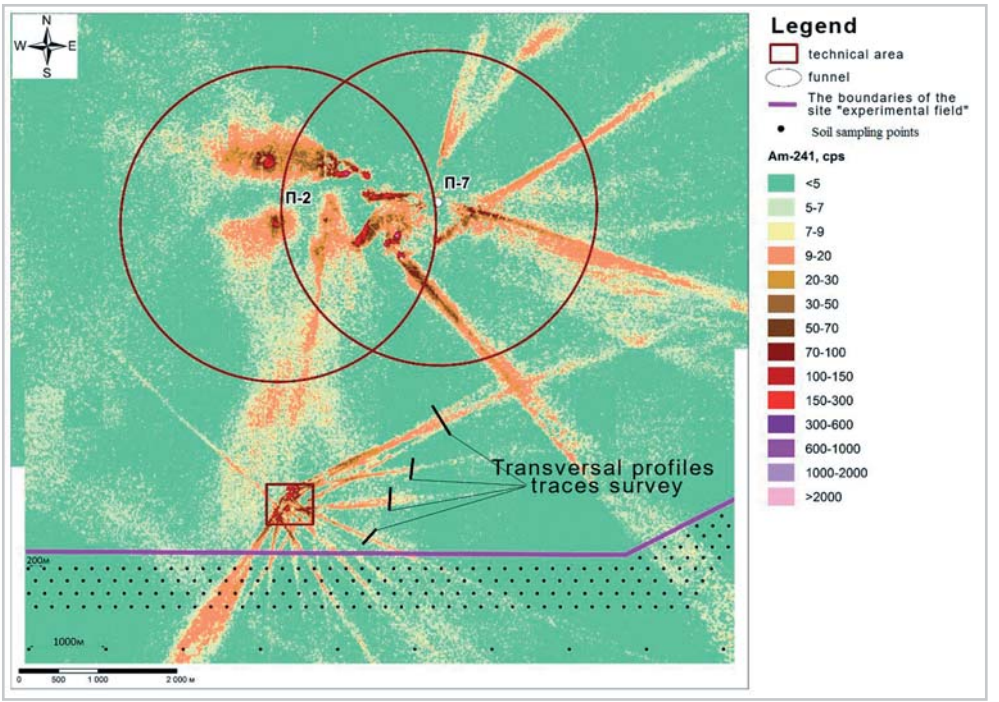


Figure 83. Scheme of sampling near the technical sites

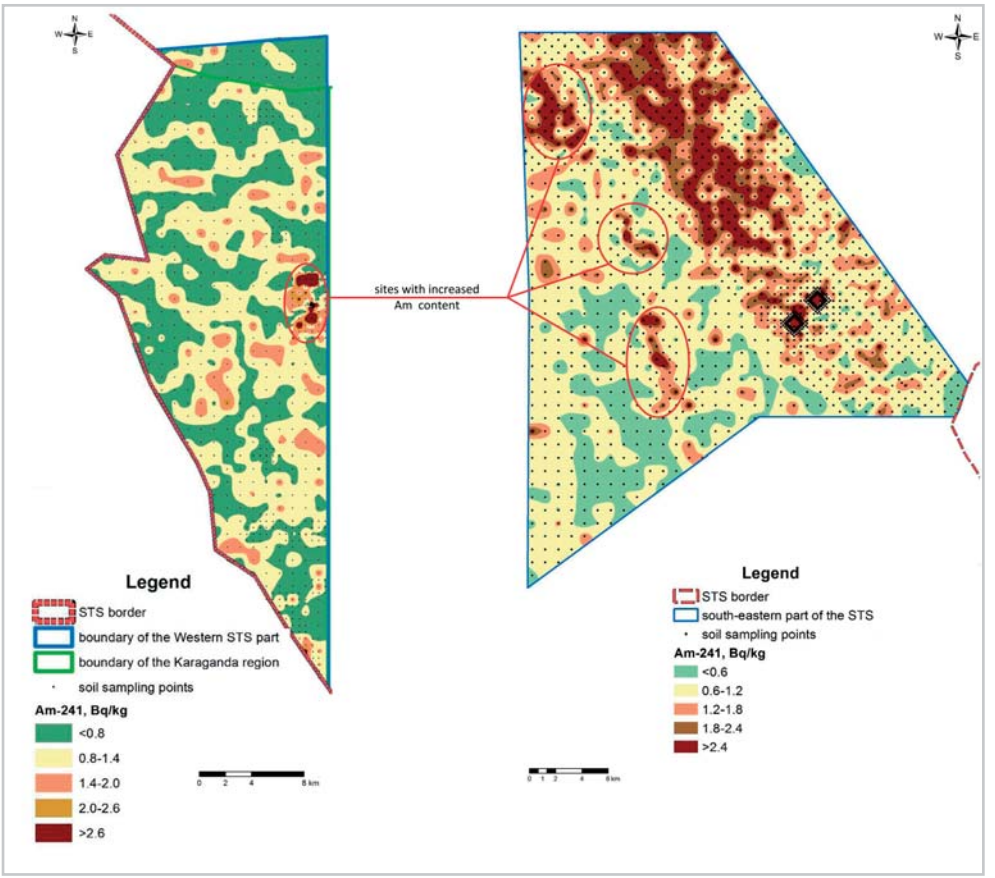
Beyond the technical sites, there are virtually no radioactive fallout traces with the width less than 100 m.

3.1.1.3. Radioactive "spots" beyond the main traces of radioactive fallouts

The hardest to detect type of areal radioactive contamination is small radioactive "spots" located beyond the main traces of radioactive fallouts and at significant distances to the STS technical sites. Figure 84 provides examples of such "spots", revealed in the "western" and the "southeastern" parts of the STS.

As the experience shows, such "spots" are 1-3 km wide and 1-8 km long. The 1x1 km survey grid is quite suitable for revealing the radioactive "spots" with the area of several square kilometers, which is comparable with the scales of cattle grazing and haymaking lands. In other words, when characterizing the territories for their transfer into economic turnover, this survey scheme assures detection of radioactively contaminated sites, comparable with farmlands in size.

It should be noted, that the activity levels at radioactive "spots" are not high remaining between the levels of the "conditionally-background" territories and the radioactive fallout traces. For example, the mean specific activities of artificial radionuclides for the traces in the southeastern part are: ^{137}Cs – 30 Bq/kg; ^{90}Sr – 15 Bq/kg; ^{241}Am – 2.6 Bq/kg; $^{239+240}$Pu – 20 Bq/kg. These values are 10 times lower than the mean values of artificial radionuclides specific activity at the "southeastern" radioactive fallout trace and for more than a thousand times lower than the activity at the technical sites of the STS.



a) "Western" part of the STS b) "Southeastern" part of the STS

Figure 84. Sites with increased specific activities of ^{241}Am in soil

The Figure 85 shows the scale of agricultural activities in the area of Beskaragai village upon the results of survey of the territories adjacent to the test site.

It is obvious that there are even smaller radioactively contaminated sites with smaller than 1 sq. km areas at the STS; those can hardly be revealed when surveying the territory by 1x1 km grid. It should still be understood, that taking into account the typical cattle grazing ranges (20-30 sq. km depending on animal species), the contribution from a 0.5 sq. km radioactive "spot" to the exposure dose would be neutralized by the huge difference in the area. Moreover, cattle pasturing differs from keeping in confinement, i.e. animals walk almost all the time when pastured, i.e. the animals stay within the impact zone of a "spot" for some limited period of time.

Hence, radioecological survey of territories via 1x1 km grid, under conditions of small radioactive "spots", is quite feasible.

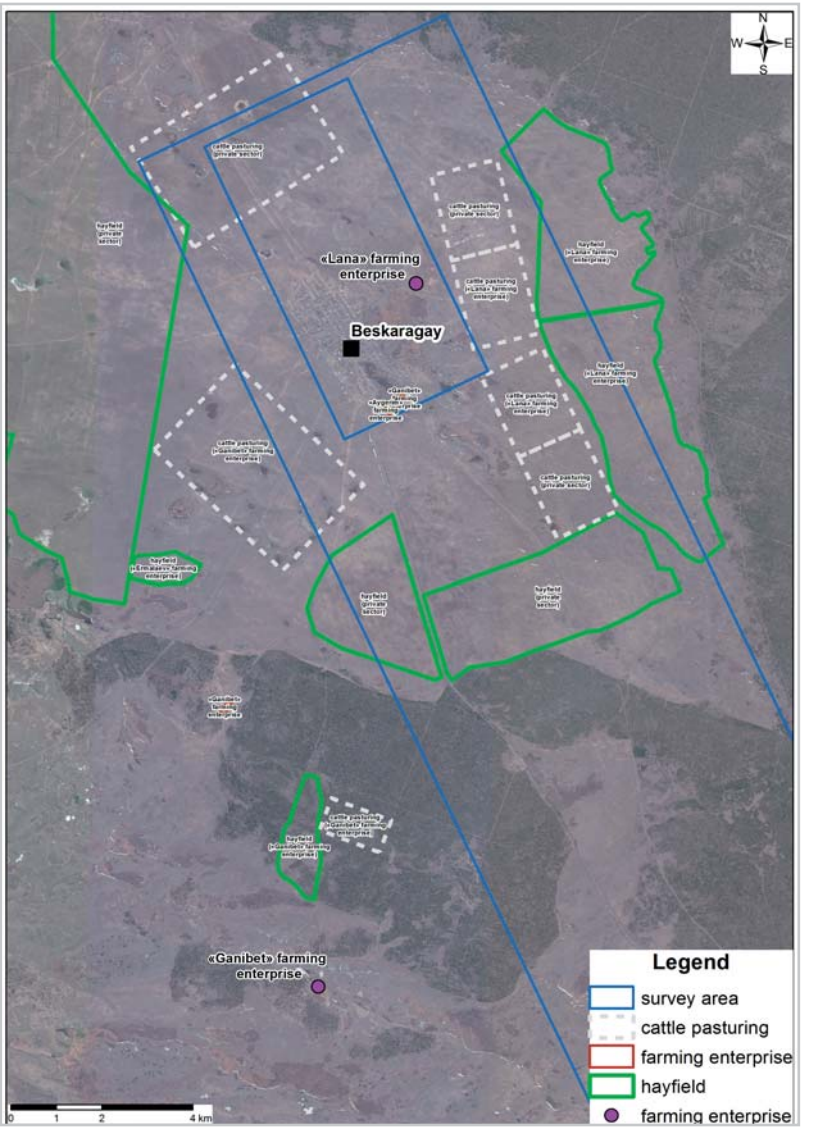


Figure 85. Cattle pasturing and haymaking ranges within Beskaragai village area

3.1.1.4. Radioactive contamination of the streamflow channels due to artificial radionuclides proliferation from the nuclear test venues

Radioactive contamination of the streamflow channels due to the artificial radionuclide proliferation from the nuclear test sites is a bit different from the areal contamination described above. Nevertheless, this type of contamination can be detected beyond the "Degelen" technical site, in places considered for potential transfer of the lands into economic turnover [80].

Figure 86 demonstrates radioactive contamination of the channel of the brook running out of the tunnel 176, and flowing into the Baitles creek, running out of the "Degelen" site.

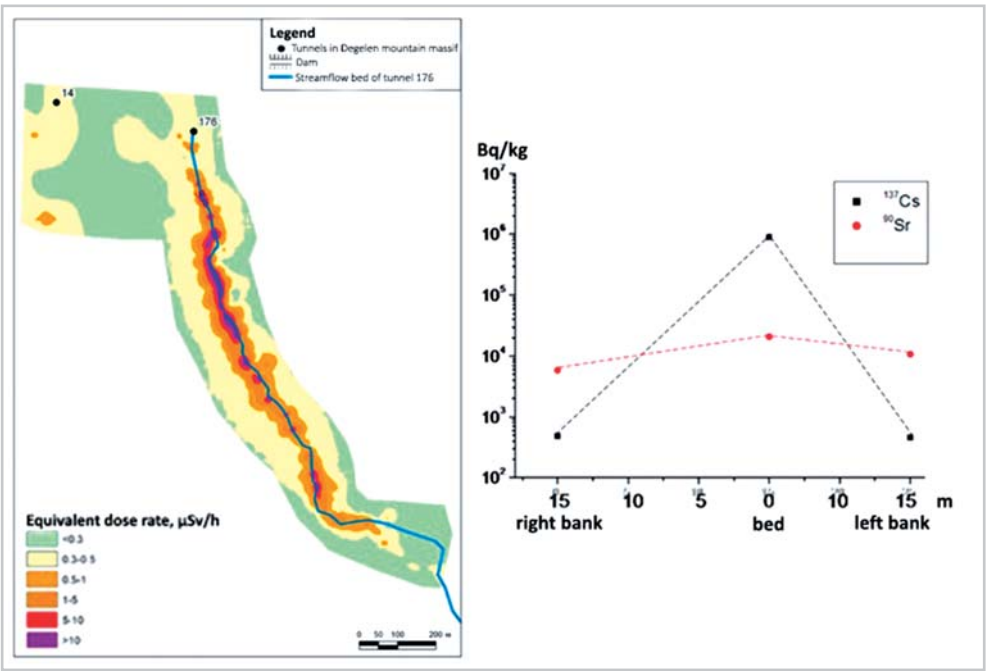


Figure 86. Radioactive contamination of the channel of the brook running out of the tunnel 176

It is obvious that the scale of contamination of the brook channel differs from contamination formed due to radioactive fallouts. Radioactive contamination spreads for several dozens of meters from the brook channel. At that, the closest zone to the brook channel is the most attractive for both cattle grazing and haymaking because of the soil quality and water regime there.

Therefore, radioactive contamination of brook channels as well as outlining the boundaries of radioactive contamination are to be studied individually virtually for each brook. It is not feasible to speak about any regular survey grid like 20x20 m or 50x50 m, but several cross-sections with intervals of 5-10 m between the sampling points can be used. Generally speaking, as a conclusion to the description of various approaches to spatial radioactive contamination investigations, such studies are performed in iterations via step-by-step process.

At the first stage, a preliminary surveying of the territory with a regular grid should be performed. The experience shows that the grid is 1x1 km. This grid allows for getting primary information about spatial characteristics of radioactive contamination (if any could be detected) at the surveyed territory.

Hereafter, based on obtained results of the preliminary surveying, additional studies are to be carried out to clarify the boundaries of the radioactive contamination based on an individual plan.

As the final result, the territories are characterized in terms of their possible transfer into economic turnover, i.e. taking into account the radiation safety for population living and working at such the STS lands.

3.1.2. Radionuclide concentrations in soils and their ratios for conditionally "background" territories of the STS

Possible surface contamination of the "background" territories resulted from operation of the former Semipalatinsk Test Site (STS) can be caused by surface, atmospheric, excavation and emergency tests.

Contamination of the territories adjacent to the test sites with artificial radionuclides results from the following main factors:

1. Residues of fissile material.
2. Fission fragments.
3. Activation of environmental nuclei with prompt neutrons.

Nuclear fission of uranium and plutonium results in formation of a complex mixture of over 200 radionuclides found in the middle of the periodic table. These are mostly represented by the radionuclides with the mass numbers of 95÷103 and 130÷144. Formation of the two ranges of the mass numbers comes from peculiarity of the fission products yield distribution by their mass numbers with two peaks on the curve. Table 5 provides the fission product yields within this range of mass-numbers for the explosion yield of 1Mt as well as their half-lives and absolute activities (Bq/Mt).

Table 5.

The main fission products, their yields in fission reactions, half-lives, as well as absolute activities for a 1 Mt nuclear explosion

Radionuclide	T½	η, %	A (Bq)
^{89}Sr	50.5 days	2.56	$5.9 \cdot 10^{17}$
^{90}Sr	28.6 years	3.50	$3.9 \cdot 10^{15}$
^{95}Zr	64.0 days	5.07	$9.2 \cdot 10^{17}$
^{103}Ru	39.4 days	5.20	$1.5 \cdot 10^{18}$
^{106}Ru	368 days	2.44	$7.8 \cdot 10^{16}$
^{131}J	8.04 days	2.90	$4.2 \cdot 10^{18}$
^{136}Cs	13.2 days	0.036	$3.2 \cdot 10^{16}$
^{137}Cs	30.2 years	5.57	$5.9 \cdot 10^{15}$
^{140}Ba	12.8 days	5.18	$4.7 \cdot 10^{18}$
^{141}Ce	32.8 days	4.58	$1.6 \cdot 10^{18}$
^{144}Ce	284 days	4.69	$1.9 \cdot 10^{17}$

52 years have passed since the atmospheric tests have been stopped. Therefore, radionuclides with the half-life of less than one year have almost completely decayed. Of course, some more long-living radionuclides like ^{151}Sm and ^{99}Tc also exist, however their absolute amounts are small. Their contribution to the environmental contamination is assessed as 8% for ^{151}Sm and 1.6% for ^{99}Tc of the ^{137}Cs activity. Of all the above mentioned radionuclides, current areal radioactive contamination is therefore formed by ^{90}Sr and ^{137}Cs. The predecessors of these radioisotopes are short-living isotopes decaying into ^{90}Sr and ^{137}Cs in 30 minutes. Below are given the typical radioactive decay chains for these radionuclides:

$$Br^{90} \xrightarrow[\beta^-,1.6\ sec]{} Kr^{90} \xrightarrow[\beta^-,\gamma,33\ sec]{} Rb^{90} \xrightarrow[\beta^-,\gamma,2.91\ min]{} Sr^{90} \xrightarrow[\beta^-,28\ years]{} Y^{90} \xrightarrow[\beta^-,\gamma,64,3\ h]{} Zr^{90}(stab)$$

$$J^{137} \xrightarrow[\beta^-,\gamma,24.4\ sec]{} Xe^{137} \xrightarrow[\beta^-,\gamma,3.8\ min]{} Cs^{137} \xrightarrow[\beta^-,30\ years]{} Ba^{137}(stab)$$

The bulk of the remaining fissile materials (plutonium and uranium isotopes) similarly remained in vicinity of the explosion epicenter, however fine dispersed particles can travel larger distances and contribute to global fallouts. Plutonium isotopes are also always accompanied with ^{241}Am. ^{241}Am is the product of ^{241}Pu decay, whose concentration in the weapon-grade Pu exceeds ^{239}Pu activity for an order of magnitude. With its quite short half-life (14 years), ^{241}Pu quickly decays into ^{241}Am ($T_{1/2}$ = 432 years).

After closing the STS, its territory becomes involved in civil and commercial activities. This stipulated for immediate and intensive studies of the test site contamination. At the present time, approximately 6,000 km^2 of the test site have been surveyed in details. The contents of the main natural (^{40}K, ^{226}Ra, ^{232}Th) and artificial (^{137}Cs, ^{90}Sr, $^{239+240}$Pu, ^{241}Am) radionuclides were analyzed in more than 7,300 soil samples. Such studies are quite expensive – about $20 million USD was spent for these works. At that, the most expensive part of the research is radiochemical analysis for $^{239+240}$Pu and ^{90}Sr.

Since by the origin, $^{239+240}$Pu is allied with ^{241}Am, and ^{90}Sr is allied with ^{137}Cs, an assumption was made that $^{239+240}$Pu/^{241}Am and ^{90}Sr/^{137}Cs ratios can only vary within a small interval. In this case, concentrations of $^{239+240}$Pu and ^{90}Sr can be determined using relatively cheap gamma-spectrometric analysis. Further studies could, therefore, be aimed at generalization of the accumulated data and optimization of the assessment methods used in estimations of the contamination levels at the STS territory.

Objects of research. Until the 2012 the "northern" (3,000 km^2), the "western" (560 km^2) and the "southeastern" (850 km^2) parts of the test site were studied in details [69, 77, 79]. Geographical location of these territories is given at the Figure 87.

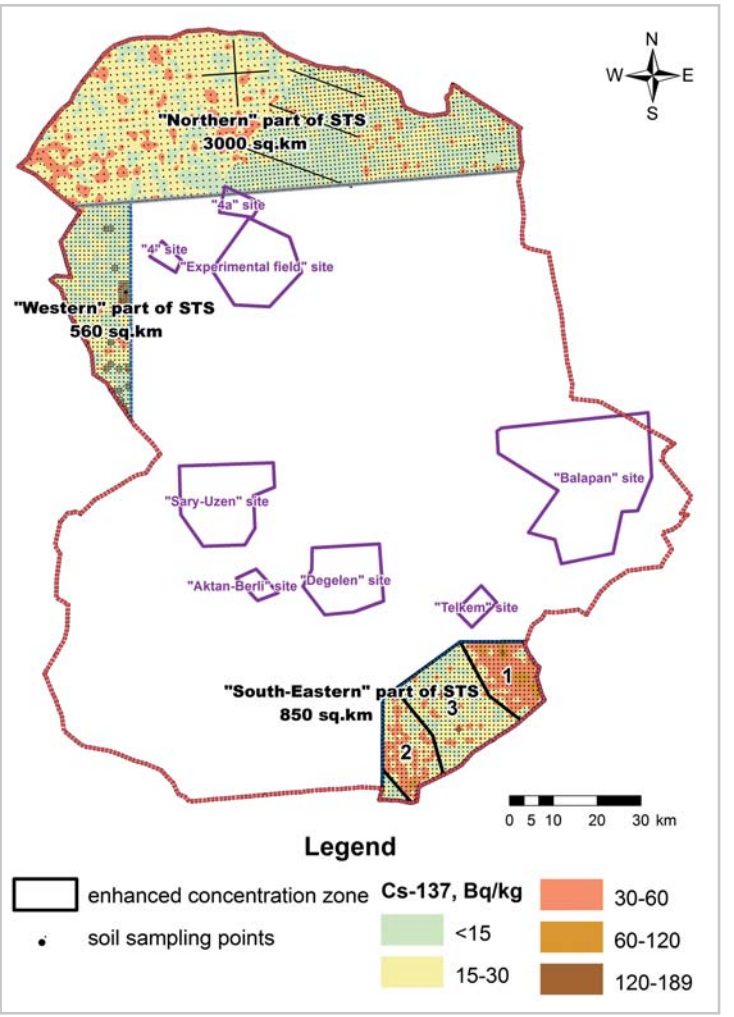


Figure 87. Surveyed territories

3.1.2.1. Average concentrations of artificial radionuclides in soil of the studied territories

No nuclear test of any kind was ever performed immediately at the surveyed STS territories, and contamination there could only result from local and global fallouts. These lands are located within geographically diverse parts of the test site, and at significant distance to the "Experimental Field" which is the main source of radioactive contamination. In the investigations there the same equipment and methodology, the same personnel were used that allowed considering the chance for accidental error as minimal.

During analysis of the areal radionuclide distribution in the "northern" and the "western" parts of the test site, no differences in contamination structure was revealed. Sur-

veying the "southeastern" part of the territory, 3 zones with different structures and levels of radioactive contamination, presumably formed by different sources, were found. Outlining the zones, attention was paid to the areas with increased specific activity values of the radionuclides and their relation to possible passage over of the radioactive plumes from hydronuclear and thermonuclear tests. In terms of radionuclides distribution, two zones (1 and 2) with increased specific activities registered in soil and the zone with relatively low values (3) were marked. Zone 1 is the area related to the trace from the thermonuclear radioactive fallouts of 12.08.53. In further calculations of the basic parameters, only the data on the zone 3 was used [69, 77, 79].

The survey data was analyzed employing the methods of mathematical statistics, and average concentrations of the basic artificial radionuclides were determined at the studied lands. The calculations were performed as follows:

– calculation of statistical parameters: volume of distribution (data amount), arithmetical mean, root-mean-square deviation, variation coefficient, and etc.;
– determination of stray values (abnormally high values) and exception of them from the data massif.

Normalized deviation was used to identify the stray values – the measurement value index with respect to the whole data set [81]. After withdrawal of the stray values, the first stage calculations were repeated.

Calculated ^{137}Cs and ^{241}Am mean specific activities, as well as mean ^{90}Sr/^{137}Cs and $^{239+240}$Pu/^{241}Am ratios for the investigated territories are given in the Table 6 below.

Table 6.

Parameters of contamination with artificial radionuclides at the studied territories

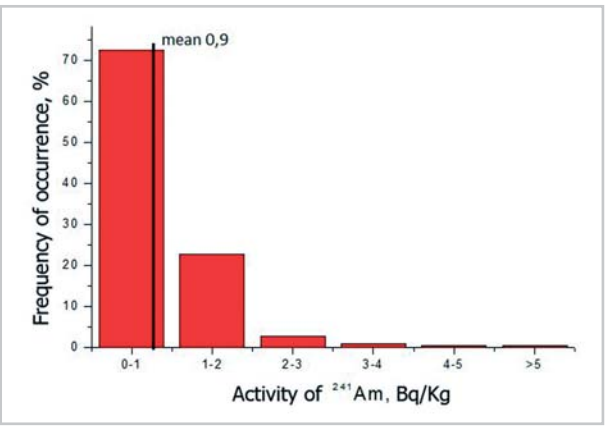
Territory		^{137}Cs, Bq/kg	^{241}Am, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
"Northern" part of the STS		17.2	0.8	0.5*^{137}Cs	5.1*^{241}Am
"Western" part of the STS		16.7	0.9	0.25*^{137}Cs	5.4*^{241}Am
"Southeastern" part of the STS-1	zone 3	19.0	0.7	0.18*^{137}Cs	5.1*^{241}Am
	zone 1	43.9	0.8	0.43*^{137}Cs	17.9*^{241}Am
	zone 2	30.2	0.8	0.14*^{137}Cs	7.0*^{241}Am

Analysis shows that some of the STS lands ("Northern", "Western", "Southeastern" – zone 3) can be characterized by virtually the same parameters (mean concentrations of ^{137}Cs, ^{241}Am); at that, these are exactly the territories not immediately suffered from the impact of the test site. That is, no nuclear test has ever been performed at these territories, and the studies did not reveal any trace from radioactive clouds. It can therefore be assumed that a part of the territory can be categorized as the "background territory of the test site", and that the "background" territories are characterized by the same set of radiological parameters. To make up such a set of radiological parameters, all the available and collected data were compiled for a large data massif used in further analyses on the selected territories.

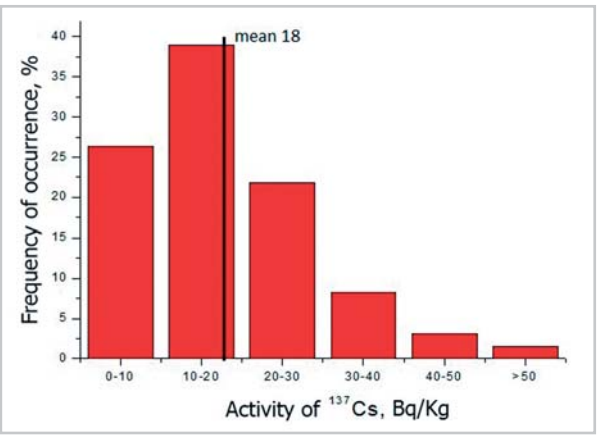
3.1.2.2. Calculation of the basic parameters of radioactive contamination for the "background" territories

Average specific activity of ^{241}Am and ^{137}Cs. When calculating the mean specific activity values for ^{241}Am and ^{137}Cs, data from over 3,500 sample analyses were used. Approximately two thirds of the individual ^{241}Am measurements at the surveyed territories were below the detection thresholds of the technique. To preserve this part of the data for further processing, the detection limit was set as the numerical value of specific activity, and therefore, the mean specific activity of ^{241}Am should be considered as an upper-bound estimate.

Distribution of ^{241}Am and ^{137}Cs specific activities in soil of the "background" territories by frequency of occurrence is shown at the Figure 88.



a)



b)

Figure 88. Distribution of specific activity occurrence in soil of the "background" territories a) ^{241}Am b) ^{137}Cs

Maximal frequency of ^{241}Am concentration occurrence was found in the samples with specific activity less than 1 Bq/kg, with the average of 0.9 Bq/kg. Maximum occurrence frequency for ^{137}Cs belongs to the samples with specific activity ranging from 10 to 20 Bq/kg, with the average of 18 Bq/kg.

Mean ^{90}Sr/^{137}Cs ratio. In calculation of the ^{90}Sr/^{137}Cs ratio, only numerical results of ^{90}Sr and ^{137}Cs measurements were used. Therefore, results from 150 samples were subjected to statistical processing. Distribution of the ^{90}Sr to ^{137}Cs specific activities ratio in soil of the "background" territories by their occurrence frequency is shown at the Figure 89.

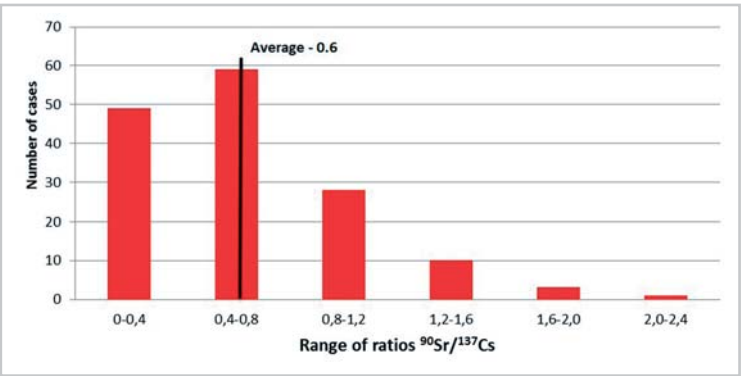


Figure 89. Distribution of the ^{90}Sr to ^{137}Cs specific activity ratios in soil of the "background" territories

Obtained distribution is consistent with the logarithmic-normal law, as one can see from the "tailing" directed towards the high values. 91% of the selection lies within the range of values from 0 to 1.2. The distribution maximum belongs to the range 0.4-0.8, where the initial ^{90}Sr/^{137}Cs ratio values for plutonium and uranium charges also lie.

The mean geometrical value is used at lognormal distribution for calculations of the average values. However, there is some definite ratio between the mean values: $h < g < \mu$ (harmonic mean is always lower than the geometrical mean that is in its turn always lower than the arithmetical mean). The difference between the geometrical mean and the arithmetical mean is usually insignificant; at that the ^{90}Sr/^{137}Cs ratio for the background territories did not become an exception: the inequality $g < \mu$ is numerically equal to $0.5 < 0.6$. Therefore, the ^{90}Sr to ^{137}Cs specific activity ratio equal to 0.6 can be used for the data characterization [81].

Mean $^{239+240}$Pu/^{241}Am ratio. When calculating the $^{239+240}$Pu/^{241}Am ratio, over 360 readings were statistically processed. The distribution of $^{239+240}$Pu/^{241}Am specific activity ratios for soil at the "background" territories by frequency of occurrence is shown at the Figure 90.

The obtained distribution obeys the lognormal law, what can be seen from the "tail" towards the high values. Approximately 90% of the whole data set is concentrated within the range from 0 to 9. The distribution maximum lies within the range of 3 – 6.

The $^{239+240}$Pu/^{241}Am specific activity ratio equal to 5.2 can be used for the abovementioned method.

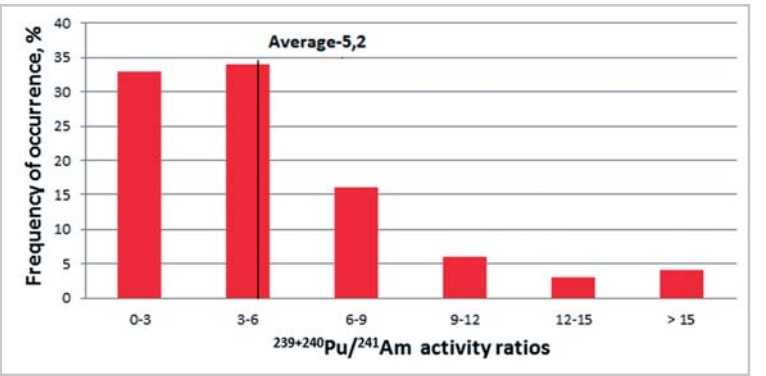


Figure 90. Distribution of 239+240Pu to 241Am specific activities in soil of the "background" territories

3.1.2.3. Comparative assessment of radiological parameters at the "background" lands of the STS and other territories

Since no nuclear tests of any kind have been performed directly at the surveyed territories of the former STS and no traces from the radioactive plumes are registered there, global fallouts could serve as the only source of radioactive contamination there. Literary sources provide enough data on specific activity of ^{137}Cs, ^{90}Sr and $^{239+240}$Pu in global fallouts. According to the publicly available data, the ^{137}Cs, ^{90}Sr and $^{239+240}$Pu concentrations due to global fallouts in the northern hemisphere are: ^{137}Cs – 4 - 29 Bq/kg, ^{90}Sr – 1-19 Bq/kg, $^{239+240}$Pu – 0.02 – 5.0 Bq/kg [19 – 26, 82].

No similar data was found for ^{241}Am specific activity, probably since it is hard to detect this radionuclide at low levels.

To compare the data obtained at surveying of the "background" territories with the global fallout background, global fallout density was theoretically assessed for the northern hemisphere.

^{241}Am is the product of ^{241}Pu decay. Presence of plutonium isotopes in the atmosphere is determined by one basic factor – surface and atmospheric nuclear tests. Of course, Chernobyl accident has also contributed to the situation, however the value of this contribution can be assessed as less than 10%. Table 7 provides activities of $^{239+240}$Pu, ^{241}Pu, ^{137}Cs and ^{90}Sr, injected into the atmosphere as the result of surface and atmospheric nuclear tests [82].

Table 7.

Activities of radionuclides, injected into the atmosphere

Radionuclide	Activity, Bq
$^{239+240}$Pu	$(11 – 15)*10^{14}$
^{241}Pu	$(140 – 360)*10^{14}$
^{137}Cs	$9.6*10^{17}$
^{90}Sr	$6.0*10^{17}$

To assess the density of global fallouts let us use the following source data and assumptions:

– most of the fallouts (~75 %) due to nuclear tests occur in the northern hemisphere;
– area of the Earth surface – 510 Tm^2;
– approximately 75 % of all the fallouts occur in the northern hemisphere;
– its assumed that radionuclides are distributed uniformly over the globe surface;
– depth of the radionuclides distribution in the lithosphere is – 0.05 m;
– density of the soil is 1,500 kg/m^3.

Theoretically assessed densities of global fallouts, taking into account decay by the 2012, are presented in the Table 8.

Table 8.

Theoretically assessed $^{239+240}$Pu, ^{241}Am, ^{137}Cs and ^{90}Sr concentrations, due to global fallouts in the northern hemisphere

Radionuclide	$^{239+240}$Pu	^{241}Am*	^{137}Cs	^{90}Sr
Concentration, Bq/kg	0.34 – 0.59	0.2 – 0.4	15.2	9.4
*Values of ^{241}Am concentration were calculated on the basis of its accumulation at ^{241}Pu decay.				

Obtained specific activities of $^{239+240}$Pu, ^{137}Cs and ^{90}Sr agree well with the published data for global fallouts and calculated mean specific activity values for these radionuclides at the studied territories. An exception is ^{241}Am, since its estimated specific activity is for 2-3 times lower than the mean specific activity of ^{241}Am at the investigated territories. Possibly, this is due to the fact that some amount of ^{241}Am has already been generated in a nuclear charge at the moment of its explosion. In fact, theoretically obtained concentrations range should be extended, since the radionuclides migrate in natural landscapes and their redistribution takes place with a course of time.

Certainly, obtained results are approximate and can only be used for rough comparisons.

Therefore, the proximity between the concentrations of artificial radionuclides at the researched territories and concentrations of artificial radionuclides, typical for global fallouts, verifies the original conclusion that global fallouts are the only source of radioactive contamination at the surveyed territories. This fact allows characterizing these lands as the "background" lands globally.

3.1.2.4. Development of the method of $^{239+240}$Pu and ^{90}Sr mean specific activities assessment upon the results of ^{241}Am, ^{137}Cs analysis

After analyzing the integrated data, mean specific activity values of ^{137}Cs and ^{241}Am in soil of the background lands were determined as the basic parameters of radioactive contamination at the background territories (Table 9). The range of acceptable variations in specific activities was determined as 10 %, given that 10 % is a standard error in gamma-spectrometry.

Table 9.

Basic parameters characterizing the background territories of the STS

Basic parameters for the background territories	
^{137}Cs, Bq/kg	16 – 20 (18)
^{241}Am, Bq/kg	<0.8 – 1.0 (0.9)

At these parameters, $^{239+240}$Pu specific activity at the background territories correlates with ^{241}Am specific activity, and ^{90}Sr specific activity correlates with that of ^{137}Cs. Therefore, $^{239+240}$Pu and ^{90}Sr specific activities can be assessed based on ^{241}Am and ^{137}Cs analyses, and the related method has been developed under the name "the Basic Parameters Method" (BPM). In other words, the method is described in the Table 10 below.

Table 10.

The Basic Parameters Method

If:		Then:	
^{137}Cs, Bq/kg	**^{241}Am, Bq/kg**	**$^{239+240}$Pu, Bq/kg**	**^{90}Sr, Bq/kg**
16 – 20	<0.8 – 1.0	5.2 * ^{241}Am	0.6*^{137}Cs

At this stage it should be noted that mean specific activity of ^{241}Am is the upper estimate. Therefore, the lower limit for ^{241}Am concentration range can be shifted towards the lower ^{241}Am specific activity. In other words, the basic parameters method can most probably be used also at ^{241}Am specific activities below 0.8 Bq/kg.

3.1.2.5. Application of the Method of Basic Parameters

In 2012, the complex ecological surveying of the "Southeastern" part 2 (SEP-2) was completed. Upon the results of the survey, maps of ^{137}Cs and ^{241}Am specific activities distribution (Figure 91) were developed. These maps show that the studied territory includes 2 contamination zones. Zones 1 and 2 were visually marked and categorized as the conditionally "contaminated" zone and the conditionally "clean" territory, respectively.

For each zone, mean specific activities of ^{137}Cs and ^{241}Am were calculated. Average specific activity of ^{137}Cs and ^{241}Am in the 1st contamination zone is 111 and 1.6 Bq/kg, while in the zone 2 – 21.6 and 1.1 Bq/kg, respectively.

Mean specific activity values for the zone 1 significantly exceed previously selected basic parameters, and specific activities of $^{239+240}$Pu and ^{90}Sr can not be calculated using the proposed method.

Since this exceedance for the zone 2 was insignificant, an attempt was made to apply the basic parameters method for assessing $^{239+240}$Pu and ^{90}Sr concentrations. Assessed values are given in the Table 11 compared with actual data obtained during survey.

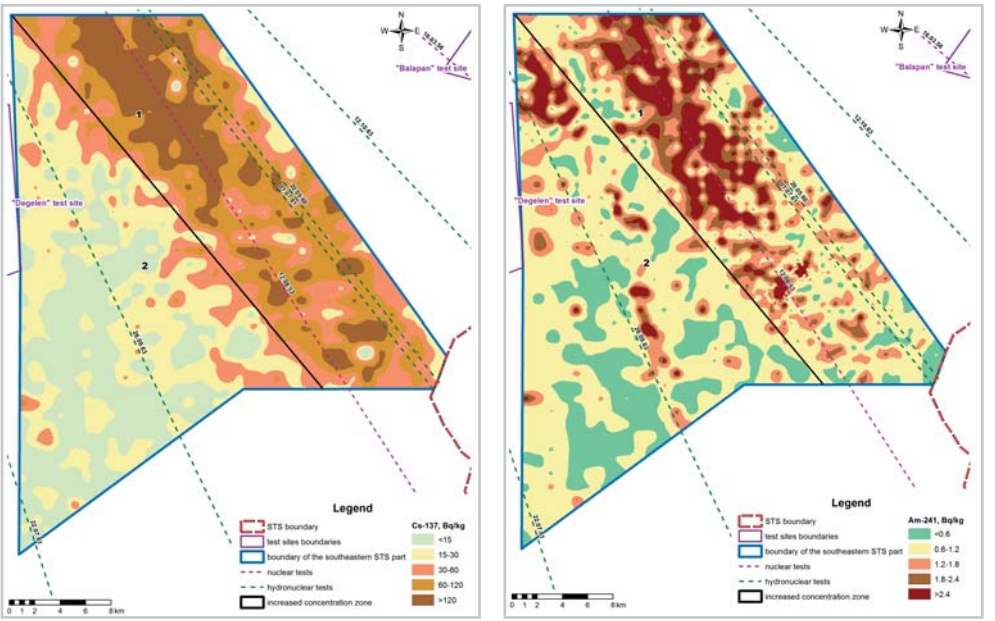


Figure 91. Specific activity of ^{137}Cs and ^{241}Am in soil samples taken at SEP-2

Table 11.

Activity assessments for plutonium isotopes using BPM and actual surveying data.

^{137}Cs	^{241}Am	$^{239+240}$Pu, Bq/kg		^{90}Sr, Bq/kg	
		Assessed	Actual	Assessed	Actual
22	1.1	5.70	23.0	13.0	47.3
Deviation, %		75		- 72	

It became obvious that even at slightly higher average specific activities of ^{137}Cs and ^{241}Am than the BPM condition, the reliability of such an assessment remains very low.

To assure that the ^{137}Cs and ^{241}Am mean specific activities in the zone 2 satisfy the BPM condition, the right boundary of the zone 2 was shifted for 0.5 km parallel to contamination axis towards to more clean territories. It was done in several iterations until the mean specific activities of ^{137}Cs and ^{241}Am in the zone 2 satisfied the BPM condition (Figure 92).

Table 12 provides average specific activities of ^{137}Cs and ^{241}Am in soils of SEP-2 (zone 2) after shifting the boundary.

Table 12.

Average specific activities of ^{137}Cs and ^{241}Am in soils of SEP-2, zone 2.

Zone	^{137}Cs, Bq/kg	^{241}Am, Bq/kg
SEP-2, zone 2	18.3	1
BPM.	16 - 20	0.8 – 1.0

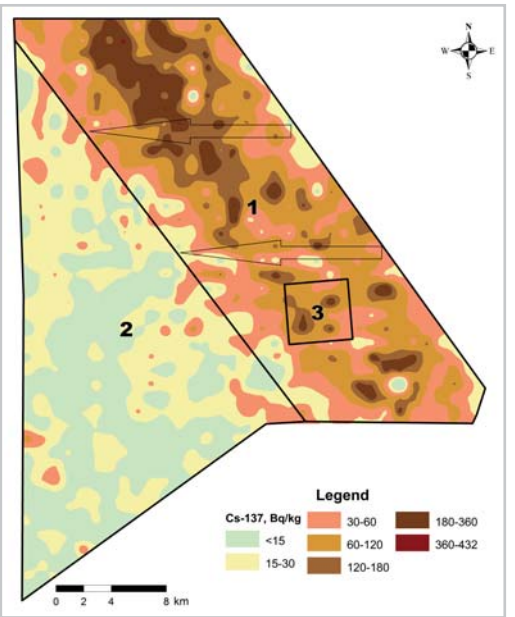


Figure 92. Zoning the background territory using the basic parameters method

After that, the $^{239+240}$Pu and ^{90}Sr mean specific activities were calculated again with the optimized boundaries. Table 13 reports outcomes of the BPM application for assessing the Pu activities in the "southeastern" part–2 of the STS, zone 2.

Table 13.

Assessed activities of plutonium isotopes using the method of basic parameters for the "southeastern" part of the STS – 2, zone 2.

^{137}Cs	^{241}Am	$^{239+240}$Pu, Bq/kg		^{90}Sr, Bq/kg	
		Assessed	Actual	Assessed	Actual
18.3	1.0	5.20	5.35	11.0	14.4
Difference, %		2.8		- 24	

It has therefore been shown not only a possibility of the BPM application for assessing the $^{239+240}$Pu and ^{90}Sr activities, but also the method application for identification of the boundaries for the background lands. The accuracy of the $^{239+240}$Pu and ^{90}Sr activity assessment using the BPM is high allowing to optimize complex ecological investigations, and avoid extremely expensive radiochemical analyses for $^{239+240}$Pu and ^{90}Sr, using them only for verification of the obtained data.

Based on the above, it can be concluded that it is reasonable to introduce the notion of background STS territories with the following parameters: mean concentration of ^{137}Cs – 18 Bq/kg, mean concentration of ^{241}Am – <0.9 Bq/kg, mean $^{239+240}$Pu/^{241}Am ratio – 5.2, mean ^{90}Sr/^{137}Cs ratio – 0.6.

Studying the background territories and assessing the $^{239+240}$Pu and ^{90}Sr activities, one can use average $^{239+240}$Pu/^{241}Am and ^{90}Sr/^{137}Cs ratios equal to 5.2 and 0.6, respectively. The obtained data can therefore be used for optimizing complex investigations reducing the extremely expensive radiochemical analyses for $^{239+240}$Pu and ^{90}Sr, limiting them only by verification of the obtained data.

3.1.3. Vertical distribution of artificial radionuclides at the conditionally "background" lands of the STS

It is known that soil is the main environmental component contaminated due to nuclear tests. The soil accumulates and preserves all the substances – contaminants of an ecosystem, including artificial radionuclides. Quite extensive data on surface contamination of the STS soil have been accumulated. Previous studies at radioactively contaminated parts of the technical sites show that the behavior of radionuclides in non-disturbed soil can depend on peculiarities of the performed tests and the landscape peculiarities of these soils [37, 83]. However, investigations of vertical distribution of radionuclides in soils were performed at the nuclear test grounds only. At the same time, the majority of the STS territory is actually a "conditionally" clean territory that could be released for economic activities. As a part of the assessment for possibility of their transfer into economic turnover, a large-scale areal survey of the surface radionuclide distribution in soils has been performed. However, the data on surface distribution of the radionuclides in soil cannot provide complete radioecological characteristics lacking the information on their vertical distribution in soils and due to impossibility of obtaining the vertical distribution data using the same density grid as for surface distribution; so, it is reasonable to obtain some generalized parameters, characterizing the vertical distribution. Weak differentiation of the soil cover characteristics at the most of the STS territory and uniform character of radioactive contamination at these sites (as the result of passage of radioactive clouds and global fallouts) prove the possibility of getting such parameters.

3.1.3.1. Brief characteristic of the soil cover at the Semipalatinsk Test Site

The Semipalatinsk Test Site is located in the eastern part of Central- Kazakh low hill land. Denudation plains, low-hill terrain, inter-bald peak plains, shor-deflation cavities, valleys of small brooks and creeks are very common for this area.

In soil-geographical respect, the test site territory covers two subzones of the steppe zone: the dry steppe subzone with zonal subtype of brown soils, and a subzone of desertified steppes on light brown soils. Brown soils are widely spread in the western and the northwestern parts of the test site, light brown soils occupy central, eastern and southern lands. Nonuniformity of the soil cover within the subzones is caused by moistening and the landscape of the area, as well as composition of the mother rocks. The most widely spread types of soil among zonal brown and light brown subtypes at the territory researched are underdeveloped, normal and alkalinized soils.

Underdeveloped brown and light brown soils are formed along the flat peaks and slopes of bald peaks, in places where dense mother rocks occur close to the surface at the low-density eluvial-deluvial rough formations, while the density of the stone-free layer

does not exceed 40 cm. These are the most widely spread types in these subzones. These soils typically have shorten morphological profiles; the soil mass is rubbly, and often there is an incomplete set of genetic horizons. The humus horizon of underdeveloped soils usually has a high content of organic matter (up to 4-5%), however since the density of humus horizon is very low (up to 5-10 cm); the volume of humus per area unit is not high. The same can be noticed for concentrations of nutrient elements. Underdeveloped soils are well flushed from easy-soluble salts and have low alkalinity. In the subzone of brown soils they have a brown (bright-brown) color in profile and significantly higher humus concentration comparing with similar soils of the subzone of light brown soils distinguished by the grey-brown color of the profile caused by the lack of moistening. Comparing with their analogues, underdeveloped light brown soils contain less organic matter and other nutrient elements, such as nitrogen, potassium, and phosphor.

Normal brown soils at these lands have moderate humus content, i.e. 3.5-5.0% (humus concentrations at the territory of the Semipalatinsk Test Site exceed the generally accepted values for all types and subtypes of soils for 20-30% since limited access to these lands over a large period of nuclear tests). The thickness of humus horisons ($A+B_1$) ranges within 15 to 40 cm. Within this region, mainly light clay loams are distributed, less frequently – clay loam varieties. Normal brown soils are weakly salted with easily-soluble salts, the reaction of water suspensions ranges from neutral at the surface to alkaline at the bottom of the profile. Soils are represented by normal as well as underdeveloped type soils. They are characterized by highly channery profile. They occupy the lower parts of even slopes of bald peaks, elevated watersheds and clinoplains.

Light brown normal soils contain up to 4% of organic matter that can also be considered as an overestimated value, caused by special conditions of using these lands. Like brown soils, these are spread over low gradient slopes of the bald peaks, watershed and flat plains. However, under conditions of intensively broken landscape, there are not many sites where such soils can occur since the light brown soils are more rarely met at this territory than underdeveloped, carbonate, alkalinized soils. Light brown soils have much lower content of humus and other nutrient elements (nitrogen, potassium and phosphor) than normal brown soils. In their mechanical composition, the soils are mainly represented by clay loams. They are flushed from easily soluble salts. The reaction ability of the water solutions ranges from weak alkaline to strong alkaline one. Carbonates appear in the lower part of humid horizon; as the rule, they are "B_{1}" or "BC". The soils are of light brown channery type, as well as the rest of soils in the low hill area.

Among the brown and light brown soils, alkalinized soils can be found. They are spread everywhere as little spots or as a part of the complex with other soils. Most frequently, they are formed along the valleys of small rivers, lakes and inter-hummocky lowlands, slopes and bald peaks on heavy, slightly saline mother rocks. The main specific feature of brown and light brown alkalinized soils is presence of illuvial alkalinized layer pronounced in the color, density and structure within their structure. It has more brown tones of color, and also can be characterized by significant solidification and lumpy-nut or nut-prism like structure. In respect of physical and chemical properties, specifying these soils, first of all the composition of absorbed grounds in alkalinized layer should be mentioned. Its absorbing complex contains up to 15% exchangeable sodium from the

total amount, which results in intensified alkalinity. In respect of humus and carbonates content, the described soils do not differ from the normal type soils of this subzone.

Meadow-brown soils are formed in conditions of intensive moistening, both due the landscape roughness and, therefore, moisture redistribution at the soil surface, as well as under impact of closely occurring ground water. They are frequently met in form of small spots in depressions of hummocky landscape, in valleys of small brooks and creeks. Developing in conditions of intensive humidification, meadow-brown soils differ from those of zonal type automorphous soils by higher humus content (up to 6-7%) with better developed vegetation; they belong to the semi-hydromorphic range. In morphological structure of the profile, clays and clay loams dominate; that partly results in high salinity and alkalinity of the soils. Such soils are well enough supplied with mobile forms of nitrogen and potassium and weakly – with mobile phosphor. Among them, meadow-brown non-saline or simple and meadow-brown salt soils can be noted.

Meadow-brown non-saline soils have no signs of salinization, alkalization, solodization, or occurrence of carbonates within the humus horizon. Humus content is high; in respect of mechanical composition, the soils are represented by loams and heavy loams.

Meadow-brown salt marsh soils are formed on weakly mineralized and salted ground waters, occurring at the depth of 4-6 m. The vegetation cover includes representatives of both wormwood-feather grass-sheep fescue associations, and meadow herbs. The soils of this kind are distinguished by lower density of humus horizons, closely occurring water-soluble salts (within 30-80 cm depth), that allows to classify them as salt marshes.

Mountain-brown soils of the studied territory occupy the slopes of low hills, high watersheds and they can be met in both subzones in small spots. They are developed under diverse physical and geographical conditions – their conditions are specified by the character of parent rocks, slope degree, exposition and location in the mountain system. These soils are very similar to the underdeveloped type. The soil cover is mainly represented by dry steppe cultures, with spiraea and pea shrubs. In terms of mechanical composition, the soils are formed by heavy clay loam with high (up to 50%) content of gritty-channery bulk. In profile, the mountain brown soils significantly differ from other soils with brighter color of loamy ground. Humus content varies within a wide range of 2-3 to 8-10%, depending on location of the site. This area is well supplied with nutrient elements. General alkalinity of soils and pH value are low. The soils are flushed and free from easily soluble salts and carbonates.

Salt marshes are mostly distributed within the zone of desertified steppes. They occupy small areas, such as low terraces of small rivers and creeks, lake-shor terraces, interhummock lowlands, and valleys. Salt marshes are formed on deposits of heavy mechanical composition with closely occurring mineralized water. The salt content in the surface layer reaches 1% and more. As a rule, the profiles of salt marshes are weakly differentiated by genetic horizons, however, in respect of humus and other nutrient elements content, they differ significantly depending on location, and therefore on the process of salt accumulation. The vegetation of salt marshes is represented by halophytes, often widely spaced, up to total absence.

3.1.3.2. The radionuclides vertical distribution in soils of the background STS territories

Based on characteristics of the STS soil cover, for further analysis of radionuclides distribution character within the soil profile, the soils were grouped based on typical, subtype and generic features, specified by conditions of water regime. No grouping details were considered, since the diagnostic features result from definite types of moistening. At the allocated sites of conditionally "background" STS territory, 47 research sites with soil profiles (Figure 93) and layer wise soil sampling on them for radionuclide analyses were arranged in 0-3, 3-6, 6-9, 9-12, 12-15, 15-18, 18-21, 21-24, 21-27, 27-30 30-35, 35-40, 45-50 cm intervals. In some individual cases, the intervals on underdeveloped soils were as follows: 0-2, 2-5, 5-10, 10-15 cm. The sites were arranged taking into account soil contours and covered all the main types, subtypes and kinds of soil at the STS territory.

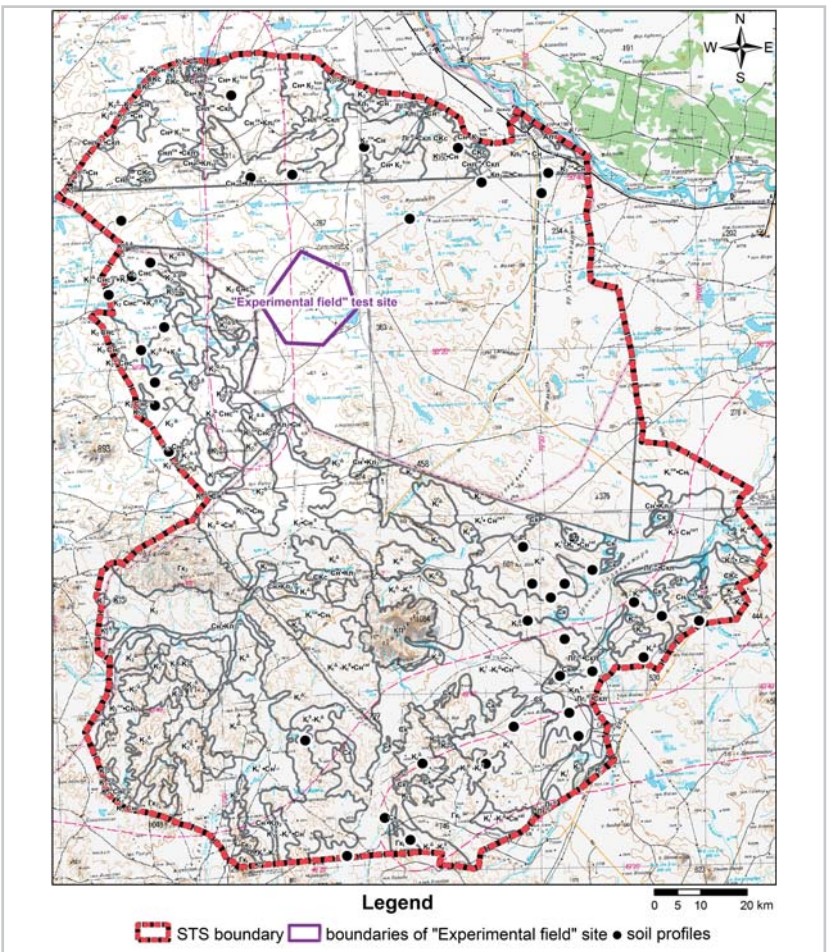


Figure 93. Soil profiles at various studied sites of the STS

The sites have covered all the main types, subtypes and kinds of brown soils, since brown is the type of soils dominating at the whole test site territory. The main subtypes of brown soils were determined. These are the subtypes of light brown soils with their variations as follows – underdeveloped, normal and alkalinized soils. The subtype of brown soils has the following varieties: underdeveloped normal and alkalinized soils. These two subtypes of brown soils are the most widely spread types at the test site. There were also less frequently occurring mountain-brown and meadow-brown soils with non-saline and saline soils found. Individually, the saline type of soil was emphasized.

These studies were mainly aimed at revealing the peculiarities of radionuclides vertical distribution in soils, not at radiological assessment of soil. Therefore, the data provided hereinafter are expressed not in terms of specific activity in soil layer, but as a percentage of the total specific activity within the vertical soil profile.

Peculiarities of the radionuclides vertical distribution in the light brown soils

Light brown is the most popular soil type at the STS territory. As the result of field works, three kinds of soils were found within this type: underdeveloped, alkalinized and normal.

Light brown underdeveloped soils. Results of radionuclide analyses of layer wise soil samples shows that the studied radionuclides are mainly found within the top 0-3 cm layer (Figure 94).

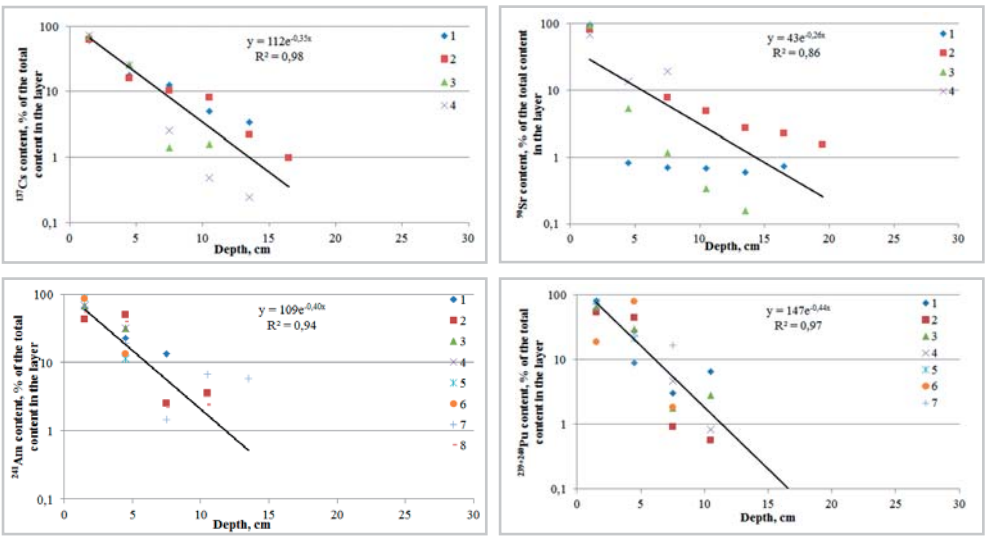


Figure 94. Vertical distribution of radionuclides in light brown underdeveloped soils

For ^{137}Cs and ^{241}Am, the percentage of the radionuclides within the 0-3 cm layer is approximately 66 %, for ^{90}Sr and $^{239+240}$Pu – 84 % and 63 %, respectively. The percentage of radionuclides within the 0-10 cm layer is approximately as follows: ^{137}Cs- 94 %, ^{90}Sr and ^{241}Am – 96 % and $^{239+240}$Pu – approximately 98 %. Such a low activity of ^{90}Sr is quite untypical, since it is characterized, as a rule, by increased migration capabilities in soil due to good solubility [84].

The most mobile radionuclide in the vertical profile of this soil type is ^{90}Sr, while the least mobile radionuclide here is $^{239+240}$Pu.

In general, detectable activities can be observed up to the depth of 15-17 cm.

Light brown normal soils. The character of ^{137}Cs vertical distribution in light brown normal soils is similar to that in light brown underdeveloped soils (Figure 95). So, provided that its top 0-3 cm layer contains approximately 66%, the 0-10 cm contains approximately 95% of ^{137}Cs. The situation with distribution of ^{241}Am and $^{239+240}$Pu is similar.

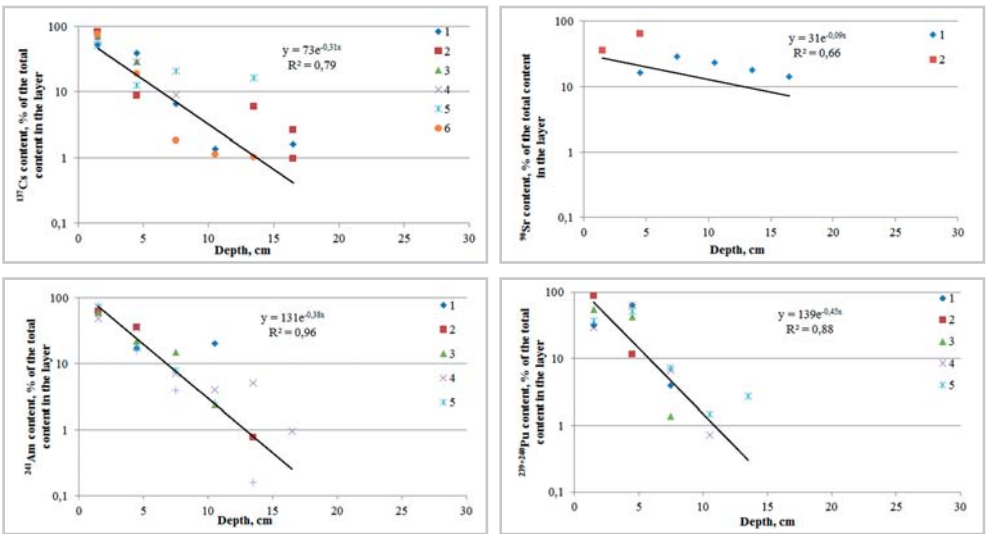


Figure 95. Vertical distribution of radionuclides in light brown normal soils

For this kind of soils a classical distribution of ^{90}Sr can be observed. The exponential line describing this process demonstrates gradual decreasing of specific activity. This can be due to the fact that ^{90}Sr, poorly bond in soil, gets easily transferred into gravity moisture and then proliferates down mainly within soluble salts and organic compounds [84]. Also, a non-typical situation for $^{239+240}$Pu was observed when in the second 3-5 cm layer its specific activity was higher than in the first layer of 0-3 cm (3 cases out of 5). It can be assumed that this character of ^{90}Sr and $^{239+240}$Pu distribution is associated with possible artificial soil disturbance, however the character of ^{241}Am and ^{137}Cs distribution in the same soil profiles, as well as field description of soil profiles eliminates this possibility.

In general, comparing the character of ^{241}Am and $^{239+240}$Pu distributions between the top layers of light brown normal soils and light brown underdeveloped soils, the percentage of these radionuclides within the 0-10 cm layer of both soil subtypes almost match one another. In particular, for normal soils, approximately 94% of ^{241}Am and 99% of $^{239+240}$Pu was registered. The approximate concentration of ^{90}Sr within the 0-10 cm layer is 74%.

The exponential functions of the radionuclides distribution in light brown normal soils are pretty close for ^{241}Am and $^{239+240}$Pu.

Light brown alkalinized soils. The character of ^{137}Cs radionuclide vertical distribution in light brown alkalinized soils differs from the character of its distribution in previous two subtypes of light brown soils; although the percentages in 0-3 and 0-10 cm layers are pretty close to one another – 63 and 93 %, respectively (Figure 96). With more intensive transfer of ^{241}Am from the top 0-3 cm layer, where its concentration is approximately 59 %, the concentration of ^{241}Am within the 0-10 cm layer is almost at the same level as in two previous subtypes of light brown soils, that is approximately 94 %.

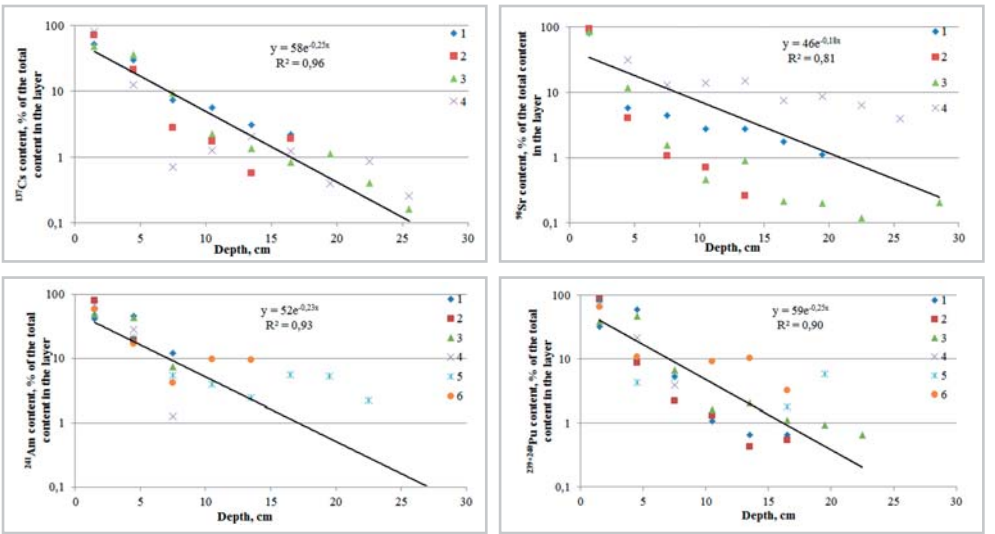


Figure 96. Vertical distribution of radionuclides in light brown alkalinized soils

$^{239+240}Pu$ from the light brown alkalinized soils is much better transferred into lower layers, than in the previous soils, since within the 0-10 cm layer the lowest concentration was registered comparing the abovementioned soil types; for those it is 93 %. This is in spite of increased transfer of $^{239+240}Pu$ in light brown normal soils into the second layer. Total ^{90}Sr content in light brown alkalinized soils within the 0-10 cm layer is close to that for light brown normal soils – that is 78 %.

Exponential functions, describing the radionuclides distribution in light brown alkalinized soils are pretty close for all the radionuclides found for this kind of soils. The functions tend for a less sharp decrease in specific activity at larger depths.

It should also be noticed that only in light brown alkalinized soils a negligible amount of radionuclides can be registered within the 20-25 cm layer, while in normal and underdeveloped soils, the radionuclides specific activity can be detected only up to the layer of 15-17 cm.

Light brown soils. Considering the light brown soils as a whole, not dividing them by class, the mean concentration of radionuclides within the 0-3 cm layer is approximately 63 %, 75 %, 63 % and 59 % for ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}Pu$, respectively (Figure 97). In spite of the lowest concentrations of $^{239+240}Pu$ in the 0-3 cm layer, the total for the 0-10 cm layer demonstrates the highest concentration of this radionuclide comparing with other radionuclides, which is 96 %. The same peculiarity can be observed for $^{239+240}Pu$ when

dividing soils into the subtypes. The approximate content of ^{137}Cs, ^{90}Sr and ^{241}Am radionuclides within the 0-10 cm layer is 95, 90 and 93 %, respectively.

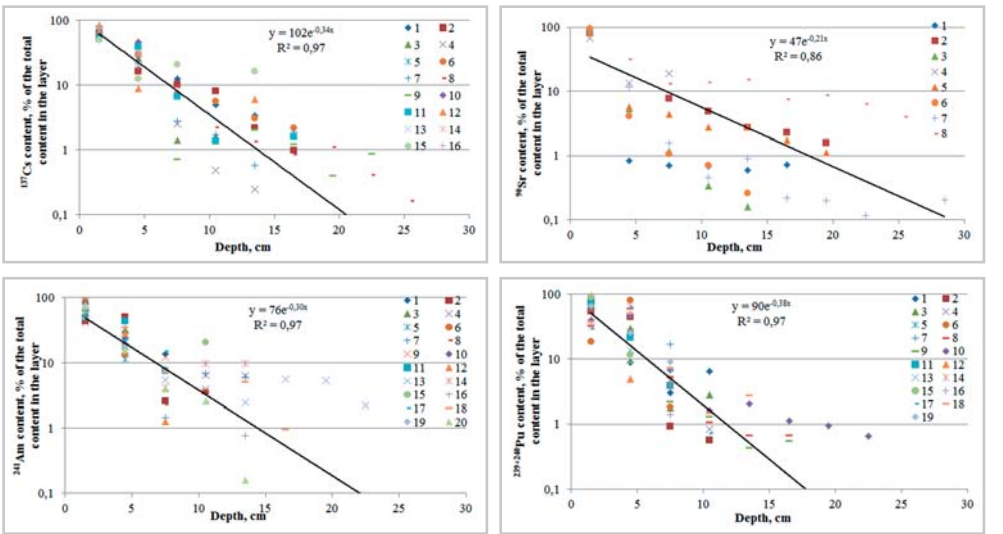


Figure 97. Vertical distribution of radionuclides in light brown soils

Variability in the radionuclide concentrations in various soil layers speaks of the fact that the character of ^{90}Sr distribution in this soil subtype can be more affected by the much larger number of factors; although the exponential functions of the radionuclides distribution lines in the subtype of brown soils for this radionuclide have the closest values for the kinds of soil of this subtype (Figure 94 – Figure 96).

The exponential functions of ^{137}Cs and $^{239+240}$Pu distribution in light brown soils are also very close to each other; although when considering the radionuclides distribution in kinds of light brown soils, a similarity was registered in the ^{241}Am and $^{239+240}$Pu distributions (in normal and alkalinized soils).

Peculiarities of the radionuclides vertical distribution in the subtype of brown soils

One more quite frequently occurring subtype of the brown soils (as a type) at the STS territory is the subtype of brown soil itself. As the result of the field works, three kinds of brown soils were specified for this type as follows: underdeveloped, normal and alkalinized (like for the light brown soils).

Brown underdeveloped soils. For the ^{137}Cs, ^{241}Am and $^{239+240}$Pu radionuclides, obvious maximal concentrations were registered within the top 0-3 cm layer: 76, 81 and 68 %, respectively. The exponential line describing the ^{90}Sr distribution demonstrates the high mobility of this radionuclide comparing with other ones, which was quite predictable. Therefore, within the 0-3 cm layer, its percentage is much lower – approximately 38 % (Figure 98).

Exponential functions characterizing the ^{137}Cs and $^{239+240}$Pu distributions in underdeveloped brown soils hardly differ from each other. At that, these functions for ^{137}Cs are quite similar to the functions describing their distribution in the light brown underde-

veloped soils (Figure 94). The burial zone for the studied radionuclides was limited by 17-20 cm, for ^{241}Am – 100 % of the detectable specific activity was concentrated at the depth of 5 cm since the original ^{241}Am specific activity in the top 0-3 cm layer lies within ~ 1.5 Bq/kg in all profiles. The percentage of ^{137}Cs, $^{239+240}$Pu and ^{90}Sr in 0-10 cm layer was approximately 97, 96 and 82 %, respectively.

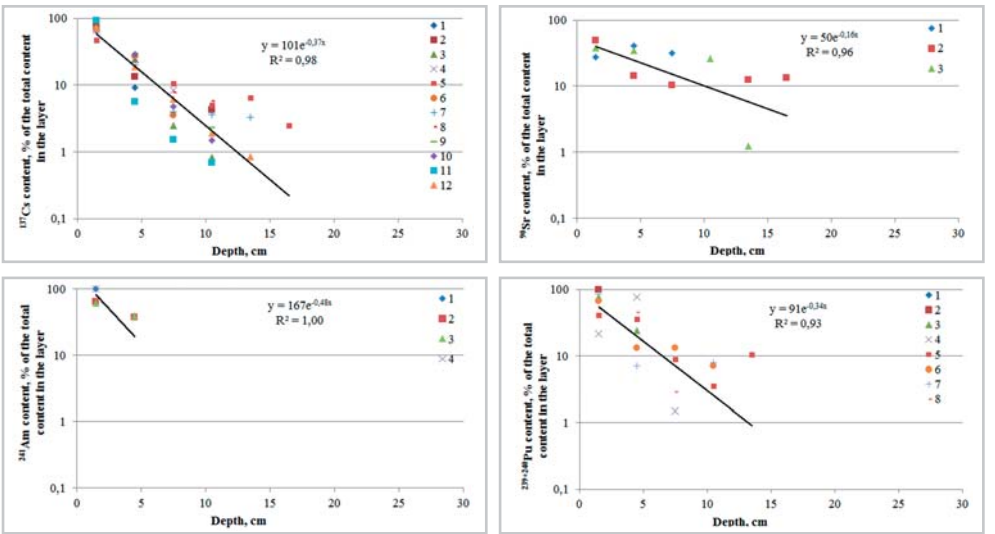


Figure 98. Vertical distribution of the radionuclides in underdeveloped brown soils

Normal brown soils. The character of the ^{137}Cs and $^{239+240}$Pu radionuclides distribution in normal brown soils is similar to that of brown underdeveloped soils (Figure 99). Moreover, the ^{137}Cs content in 0-3 cm layer is almost the same as in the soils of the previous type, which is 75.7 %. For ^{241}Am and $^{239+240}$Pu, this value comprises approximately 69 and 77 %, respectively. Unfortunately, due to low specific activity of the radionuclides in soils of points selected for this soil type, the character of ^{90}Sr distribution has not been revealed.

Normal brown soils. The character of the ^{137}Cs and $^{239+240}$Pu radionuclides distribution in normal brown soils is similar to that of brown underdeveloped soils (Figure 99). Moreover, the ^{137}Cs content in 0-3 cm layer is almost the same as in the soils of the previous type, which is 75.7 %. For ^{241}Am and $^{239+240}$Pu, this value comprises approximately 69 and 77 %, respectively. Unfortunately, due to low specific activity of the radionuclides in soils of points selected for this soil type, the character of ^{90}Sr distribution has not been revealed.

In spite of some in the radionuclides redistribution between the upper layers of the brown underdeveloped soils, the bulk 0-10 cm layer demonstrates quite close values of the total radionuclide contents: for the ^{137}Cs, $^{239+240}$Pu and ^{241}Am values these are approximately equal to 97, 99 and 95 %, respectively.

Exponential functions that characterize the ^{137}Cs and ^{241}Am distributions within the normal brown soils subtype are pretty close to each other.

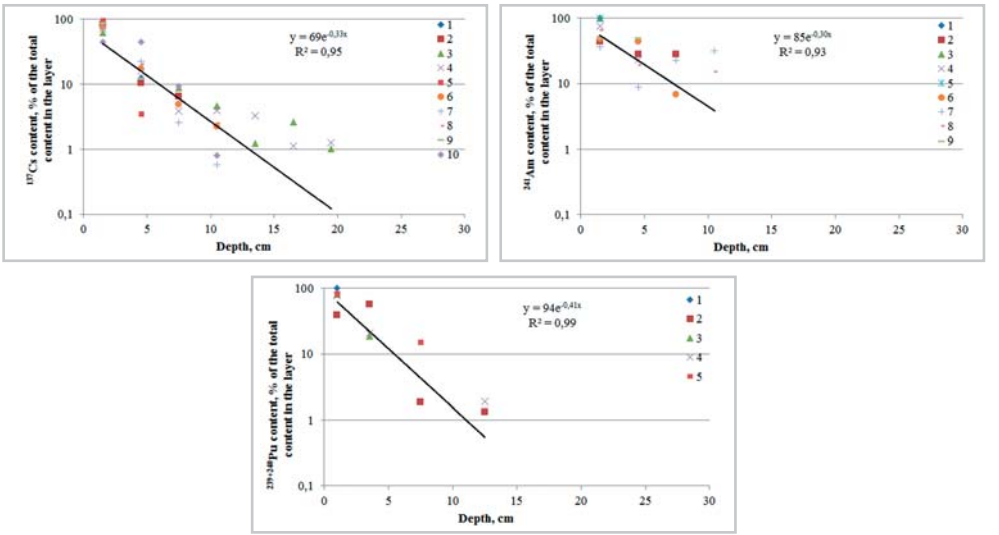


Figure 99. Vertical distribution of the radionuclides in the normal brown soils

Brown alkalinized soils. The character of the radionuclides distribution in the vertical profile of the brown alkalinized soils is quite similar to that in the brown soil types (Figure 100). The 0-10 cm layer contains up to 97% of ^{137}Cs radionuclide. Like in the brown underdeveloped soils, 100% of ^{241}Am was detected in the 0-6 cm layer. 100% of $^{239+240}$Pu was detected within the upper 10 cm. Like in the previous case, due to low activity, the ^{90}Sr distribution was not determined.

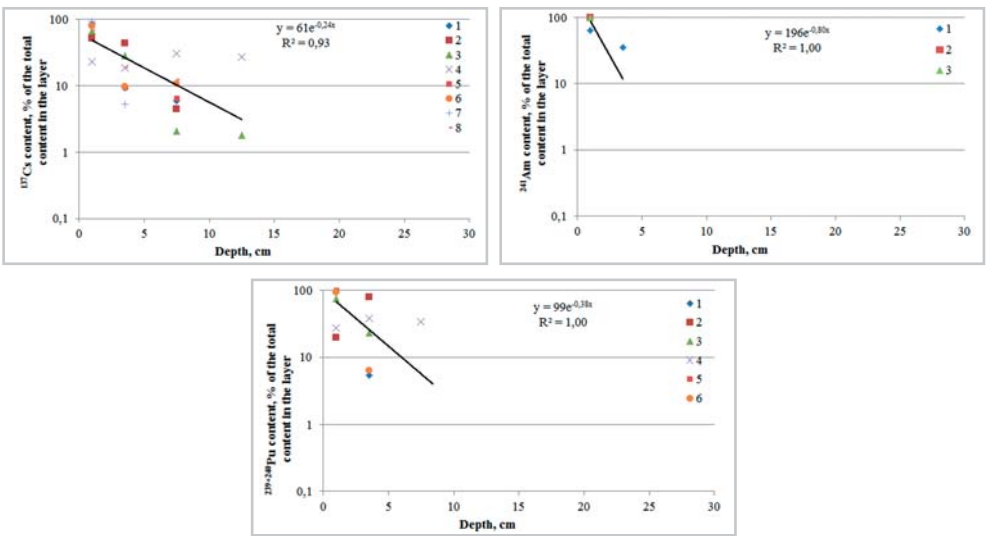


Figure 100. Vertical distribution of the radionuclides in the brown alkalinized soils

Brown soils (subtype). Considering the subtype of brown soils irrespective of their kinds, vertical distribution of radionuclides can be compared with their distribution in the light brown soils (Figure 101). Although the radionuclides contents within the top 0-3, 3-6, and 6-9 cm layers vary, their content proportions in the brown soils are very close to each other: 97 % for ^{137}Cs, 82 % for ^{90}Sr, 97 % for ^{241}Am, and approximately 98 % for $^{239+240}$Pu.

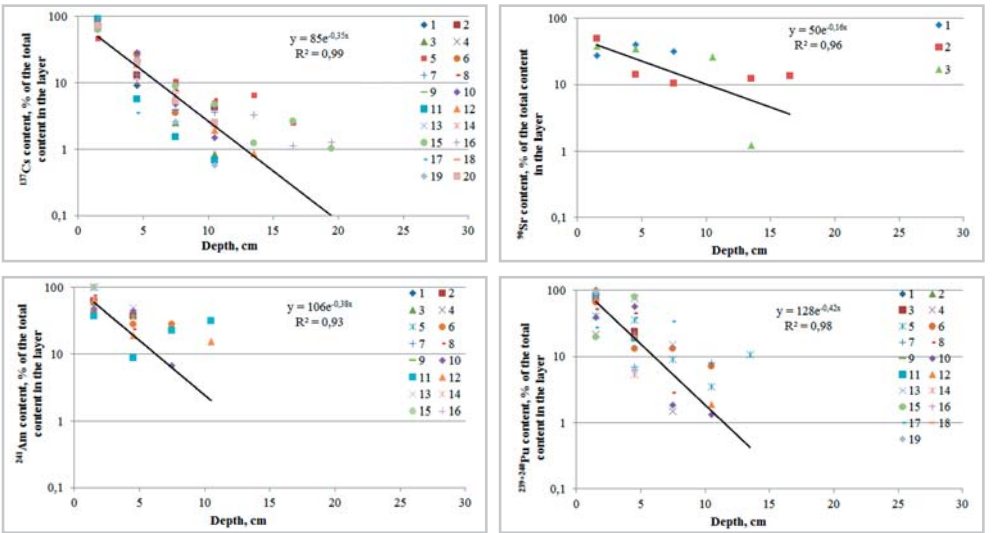


Figure 101. Vertical distribution of the radionuclides in the brown soils

In general, the data obtained for vertical distribution of radionuclides in soil profiles of the brown soil subtype shows that the ^{137}Cs, ^{241}Am and $^{239+240}$Pu distributions in all three soil kinds of the same subtype vary insignificantly (Figure 101). Small difference in the distribution was also registered for the light brown soils. In the case of ^{90}Sr, some difference in the distribution was noticed in various types of the light brown and the brown soils. However, considering the distribution at the subtype level, the ^{90}Sr radionuclide concentrations within the 0-10 cm layer are very close to each other.

The data (Figure 101) shows that, like for the light brown soils, the most mobile radionuclide in the vertical soil profile is ^{90}Sr, and the least mobile radionuclide in this subtype is $^{239+240}$Pu.

Peculiarities of the radionuclides vertical distribution in the meadow-brown soils

Unlike the light brown and the brown soil subtypes, the meadow-brown soils are not much widely spread over the STS territory and can be met in vicinity of the "Degelen" massif within the Shagan river valley. The field works there revealed two kinds of the meadow-brown soils – non-saline and salt marshes.

Meadow-brown non-saline soils. For this kind of soils, only 3 soil profiles were made. The deepest proliferation of ^{137}Cs was registered in these soils. Quantitative amounts can be registered within the upper 20-25 cm layer, while the same for $^{239+240}$Pu is approximately 20 cm (Figure 102). No numerical values for ^{241}Am were registered. In general, the 0-3 cm layer still contains approximately 60 % of ^{137}Cs, 55 % of ^{90}Sr and approxi-

mately 82 % of $^{239+240}$Pu; within the 0-10 cm layer, the percentage of these radionuclides is approximately 83, 81 and 93 %, respectively.

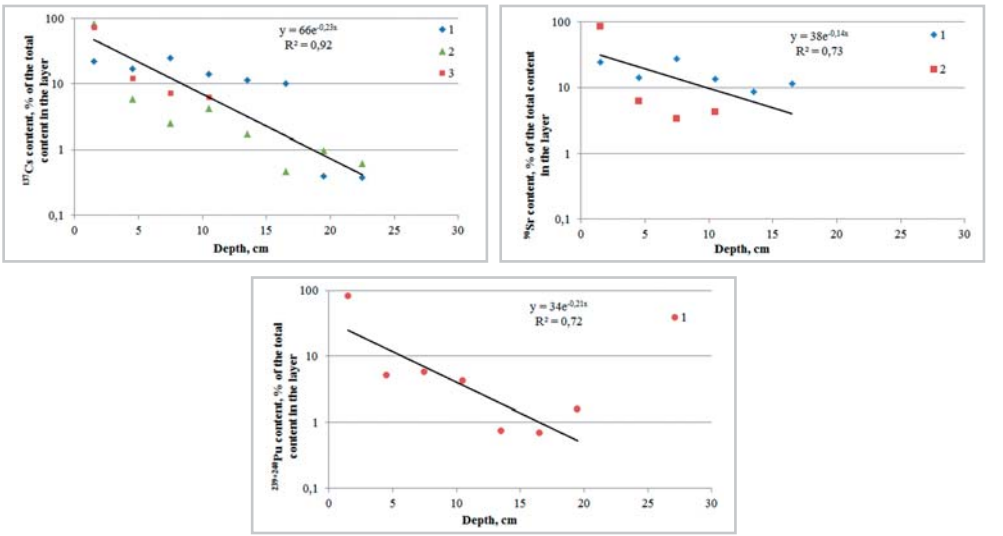


Figure 102. Vertical distribution of the radionuclides in the meadow-brown non-saline soils

Meadow-brown salt marshes. For this type of soils, only the data on ^{137}Cs, ^{90}Sr and ^{241}Am vertical distributions in soil profile was obtained (Figure 103). In general, comparing it with the previous soil kind of this subtype, one can see that the character of distribution is almost identical in both cases. The ^{137}Cs concentrations in 0-3 and 0-10 cm layers are also close (approximately 51 % and 95 %, respectively). For ^{90}Sr, these values are approximately 43 % and 71 %, for ^{241}Am – 70 % and 100%, respectively.

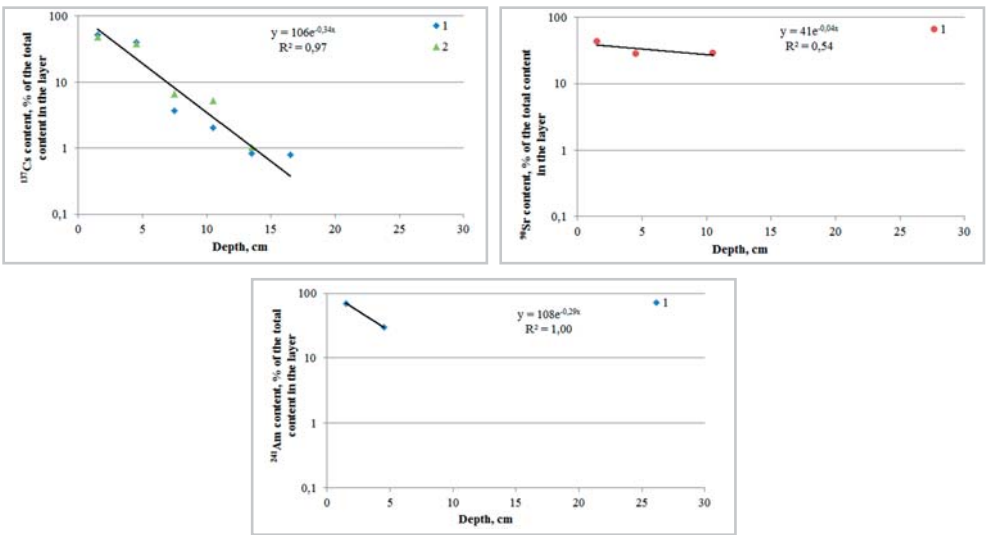


Figure 103. Vertical distribution of the radionuclides in the meadow-brown salt marsh soils

The line, describing the ^{90}Sr distribution is smoother compared to the lines for the ^{137}Cs and ^{241}Am vertical distributions (Figure 103). The character of ^{241}Am distribution does not differ from the character of its distribution in the previous soil subtypes. Due to low specific activities of ^{241}Am, it was not possible to reveal the distribution pattern below the 10 cm depth.

Meadow-brown soils. Considering the meadow-brown soils in general, it should be noted that a large amount of radionuclides in soils of this type is transferred from upper 0-3, 3-6 cm-thick layers into the lower layers, in particular, into those occurring below the 10 cm depth; the radionuclides (in particular, ^{137}Cs) can however be determined within the 20-25 cm layer (Figure 104).

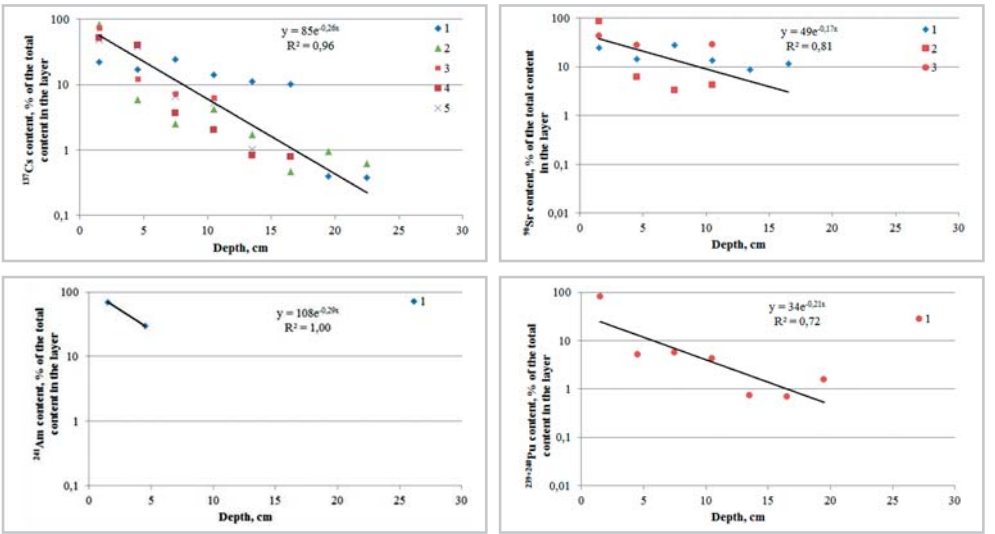


Figure 104. Vertical distribution of the radionuclides in the meadow-brown soils

Exponential functions for the ^{137}Cs and ^{90}Sr distribution in the meadow-brown soils confirm the radionuclides higher mobility comparing with the previous soil subtypes (Figure 104). This can be because the meadow-brown soils belong to a semi-terrestrial range and are formed by meadow-steppe vegetation in depressed landscapes. As the result, they get additionally moistened due to periodical impact of shallow occurring ground waters or surface drainage, and the factor of additional moistening plays significant part in transporting radionuclides within the soil profile at the STS territory [37, 83].

Peculiarities of the radionuclides vertical distribution in the rock-chestnut soils

Only the ^{137}Cs specific activity was registered for this soil subtype (Figure 105). At that, the observed distribution of this radionuclide is typical for the STS. The approximate concentrations registered within the 0-3 cm and 0-10 cm soil layers are 76 % and 92 %, respectively.

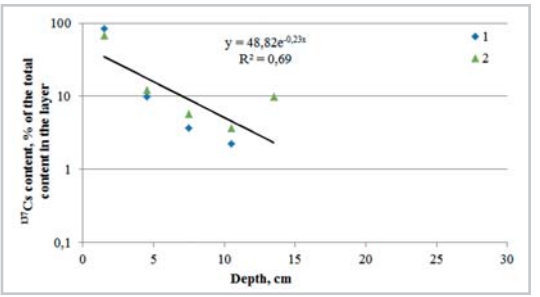


Figure 105. Vertical distribution of the radionuclides in the rock-chestnut soils

Peculiarities of the radionuclides vertical distribution in the salt marshes

Salt marsh is also not a widely spread type of soil for the STS territory. Soil of this type can be found in isolated drainless depressions of denuded plains and low hill lands. The character of ^{137}Cs and $^{239+240}$Pu distribution is in general similar to its distribution in other soil subtypes mentioned above (Figure 106).

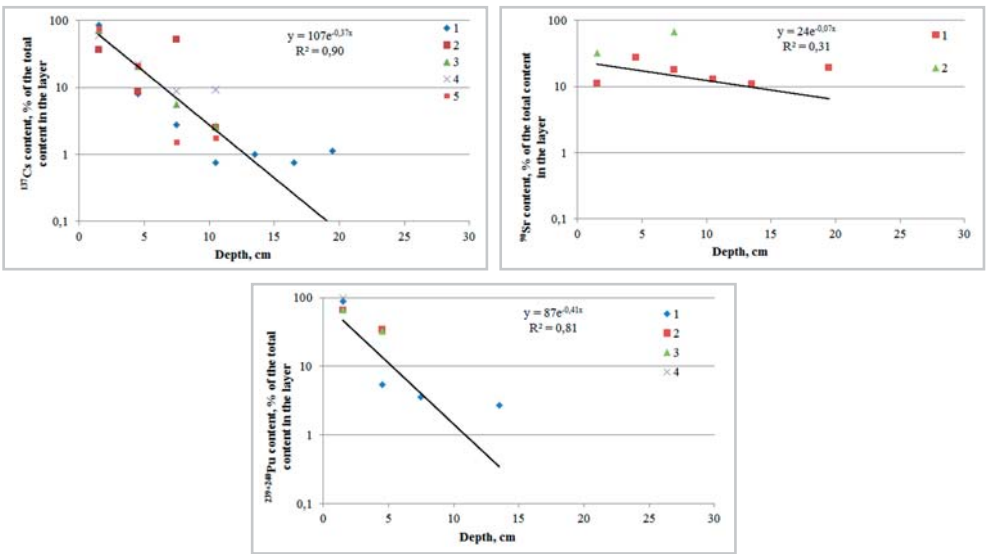


Figure 106. Vertical distribution of the radionuclides in the salt marshes

The 0-3 cm layer contains about 66 % of ^{137}Cs and 80 % of $^{239+240}$Pu, at that the content of these radionuclides in 0-10 cm layer is 96 and 99 %, respectively. In the case of ^{90}Sr, its significant part is kept in the 6-9 cm layer. Like in the case of the light brown normal soils, a classical distribution pattern can be observed for ^{90}Sr. The exponential curve demonstrates the gradual decrease in specific activity. This can be due to both chemical properties of ^{90}Sr, and peculiarities of the salt marshes associated with additional moistening. In general, the 0-10 cm layer contains approximately 78 % of ^{90}Sr.

Peculiarities of the radionuclides vertical distribution in the chestnut soils

The obtained results describe the radionuclides distribution in the chestnut soil subtypes and show that at the non-percolate water regime the artificial radionuclides remaining after nuclear tests and radioactive decay products are mainly accumulated in the surface soil layers and weakly migrate deep into the soil profile. This fact is supported by current and previous investigations by the authors [37]. Only additional moistening of soils due to the slope runoff or ground waters in soils of intrazonal and azonal type can change the character of the radionuclides distribution in the soil profile [83]. Formed in the conditions of constrained hydrothermal regime and high shortage of moisture received only from atmospheric precipitations, zonal chestnut and light chestnut soils are mostly characterized by a shallow wetting from the surface.

Taking into account the light differentiation in the radionuclides distribution which can also result from the measurement errors, methodology errors at the field works and omitted factors (previous mixing up of the soil layers by burrowers or farm animals, for instance), it can be stated that to assess the radionuclides distribution in vertical soil profile, one just needs to classify the soil cover type. In particular, soils of the STS territory are represented by chestnut type, and to predict possible content of the radionuclides in soil profile at a specific STS site one can use the generalized data on the radionuclides in the subtypes of light chestnut, chestnut, meadow-chestnut and rock-chestnut soils (Figure 107, Table 14). Comprehensive data on the radionuclides vertical distribution in soil are available. While for ^{137}Cs and $^{239+240}$Pu the data obtained for salt marshes can be included, for ^{90}Sr these data should be separated. Moreover, the salt marshes are not usually used by farmers, and the main animal breeding activities take place in the STS at chestnut and light chestnut soils due to their prevalence.

The radionuclides distribution character in chestnut soils is shown at the Figure 107 and the Table 14.

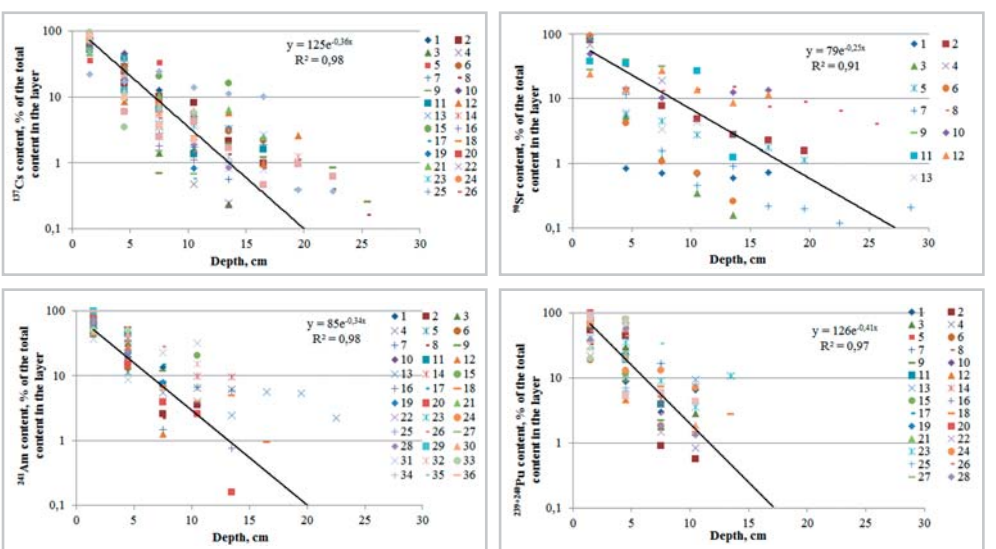


Figure 107. Vertical distribution of the radionuclides in the chestnut soils

One can see that the exponential lines describe quite well the character of ^{137}Cs, ^{241}Am and $^{239+240}$Pu radionuclides distribution to the depth of 10 cm. This can be explained by the fact that moistening is the main factor, affecting migration of radionuclides in the soil profile. Because of the arid conditions at the STS territory, the mean depth of moistening from precipitations ranges from 7 to 10 cm (if there is no additional moistening from the streamflows or runoffs in inter-hummocky lowlands). At the depth of more than 10 cm, presence of moisture does not serve as the basic factor, impacting the distribution of radionuclides in soil stratum.

The ^{137}Cs radionuclide in clay loams is not exchange-coupled with the clay minerals matrix [85]. Its migration is driven by relocation of these minerals. The top layer of chestnut soils dominating at the STS (0-7 cm – 0-10 cm) is quite crumbly due to presence of high amounts of fragmentary material of various sizes. Soil particles intersperse due to gravity. Below this depth, more solid structures occur, and ^{137}Cs, ^{241}Am and $^{239+240}$Pu do not transfer into those structures, since these radionuclides either travel with colloidal mineral particles (^{137}Cs), or like in case of Pu, their behavior is mainly determined by hydrolysis. As it was mentioned above, presence of moisture can be sufficient for hydrolysis only in the top soil layers.

As the rule, due to low specific activities of radionuclides in the top soil layer at the "background" STS territories, quantitative amounts can be registered above the depth of 10-15 cm, where the radionuclides specific activities are below the lower detection limits of the equipment and methods. This also explains the uncertainty in the data on radionuclides distribution in soil below the 10-15 cm depth.

More evident proliferation of the radionuclide ^{90}Sr to the deeper levels, as it was mentioned above, can be explained by its prevailing presence in soluble forms.

In general, considering the radionuclides distribution functions in various soil subtypes, one can note similarity of the functions for ^{90}Sr, and the function obtained for the chestnut soil types can be used for other subtypes. The functions of other radionuclides obtained on the basis of data generalization for the chestnut soil type can also be used irrespective of subtypes for the most of the STS territory. An exception is the meadow-chestnut soils around the Degelen massif. For them the specific function obtained for this soil subtype is recommended.

Table 14.

Vertical distribution functions for the radionuclides in the chestnut soils.

Radionuclide	soil subtype			chestnut	salt marsh
	light chestnut	chestnut	meadow-chestnut		
^{137}Cs	$y = 102.5e^{-0.34x}$	$y = 84.6e^{-0.35x}$	$y = 84.8e^{-0.26x}$	$y = 124.7e^{-0.36x}$	$y = 106.6e^{-0.37x}$
^{90}Sr	$y = 46.9e^{-0.21x}$	$y = 50.6e^{-0.16x}$	$y = 48.6e^{-0.17x}$	$y = 78.8e^{-0.25x}$	$y = 24.1e^{-0.07x}$
^{241}Am	$y = 76.4e^{-0.30x}$	$y = 105.8e^{-0.38x}$	$y = 107.9e^{-0.29x}$	$y = 85.4e^{-0.34x}$	-
$^{239+240}$Pu	$y = 89.9e^{-0.38x}$	$y = 128.3e^{-0.42x}$	$y = 34.1e^{-0.21x}$	$y = 125.8e^{-0.41x}$	$y = 86.6e^{-0.41x}$

Comparing the functions based on the data generalization for chestnut soils with that for the salt marshes (Table 14), one can note the similarity for the ^{137}Cs and $^{239+240}$Pu functions, while for ^{90}Sr these functions significantly differ. Therefore, to determine the

character of radionuclide distribution in salt marshes, it is recommended to use exactly the functions obtained for this type of soils.

This data can be used to assess possible distribution of radionuclides within the vertical soil layer at the conditionally background STS territories in general. When small territories of the STS are assessed, the information about distribution of radionuclides in soils obtained for individual soil subtypes can be used. As it was mentioned above, there are differences in the distribution functions at the level of soil subtypes mainly within the 0-10 cm layer. Comprehensive data is available on specific activities of the radionuclides exactly within the 0-10 cm soil layer with new data introduced after each field study at the STS territory. Therefore, when converting the radionuclide specific activities in 0-10 cm soil for the root 0-20 cm layer and further, these variations would not produce any effect.

3.1.4. Artificial radionuclide distributions in granulometric fractions of soil at the conditionally "background" STS territories

Atmospheric fallouts of radioactive substances form on the earth surface form some specific character of their distribution among the structural components of soil depending on the dispersion level and the speciation of the radionuclides (presence forms). Peculiarities of the radionuclide interaction with the soil components determine the radionuclide migration ability and the rate of their proliferation into other parts of the environment.

Analysis of literary data shows that many authors notice the highest concentrations of the radionuclides in fine soil fractions. In the zones of local fallouts from nuclear explosions, researches from the USA and Kazakhstan have revealed in different times that Pu contents in fine soil fractions increase at larger distances to the explosion epicenters. So, at the trace area from the "Trinity" explosion in New Mexico (USA) at the distance of 1 to 45 km, the percentage of Pu activity in the fraction <53 μm raised from 0.8% to 73% [86]. At the distance of more than 100 km to the epicenter of the thermonuclear explosion of 1953 (Sarzhal village, Semipalatinsk Test Site, Kazakhstan) the content of $^{239+240}$Pu in <100 μm soil fraction reached 95% of its total specific activity [87].

Enrichment of fine soil fractions (<100 μm) with the radionuclides was also detected in places contaminated after the NPP accidents (Chernobyl, Ukraine; Fukushima, Japan) [88 – 90]. At that the large-grain fraction of >500 μm is also enriched with the radionuclides from Chernobyl fallouts. The authors in [88] think that the reason for this fact is sorption of highly-active particulate matter of smaller dispersion class with large soil particles and aggregates or small residues of vegetation and organic matter.

The radionuclide accumulation facts in fine soil fractions were also confirmed in the impact zones of industrial objects and research laboratories (Krasnoyarsk mining and chemical combine in Russia, Los Alamos National Laboratory in the USA) [91, 92].

Various nuclear tests at the Semipalatinsk Test Site (Kazakhstan) delivered the explosion products into the atmosphere in the form of highly active polydisperse particles. Previous quite sporadic studies performed for the long-living artificial radionuclides such as ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}$Pu were mainly focused on their distributions among

the granulometric soil fractions at the testing grounds with quite high radioactive contamination and had quite an episodic character.

Understanding the radionuclide distribution in granulometric soil fractions is essential for risk assessment of air basin contamination, inhalational hazards imposed by various radiation-hazardous objects, secondary wind transfer of the radioactive substances, especially of transuranium radionuclides, entering the organism mainly via inhalational pathways. The works were performed to reveal the peculiarities in redistribution of the main dose-forming radionuclides at the Semipalatinsk Test Site in soil fractions with various dispersion levels at some of its conditionally "background" territories.

Objects of research. We studied the conditionally "background" lands of the *"northern", "western", "southeastern" and the "southern"* parts of the STS. Geographic location of the territories, the map of the ^{137}Cs specific activity areal distribution in soil cover as well as the soil sampling points are shown at the Figure 108.

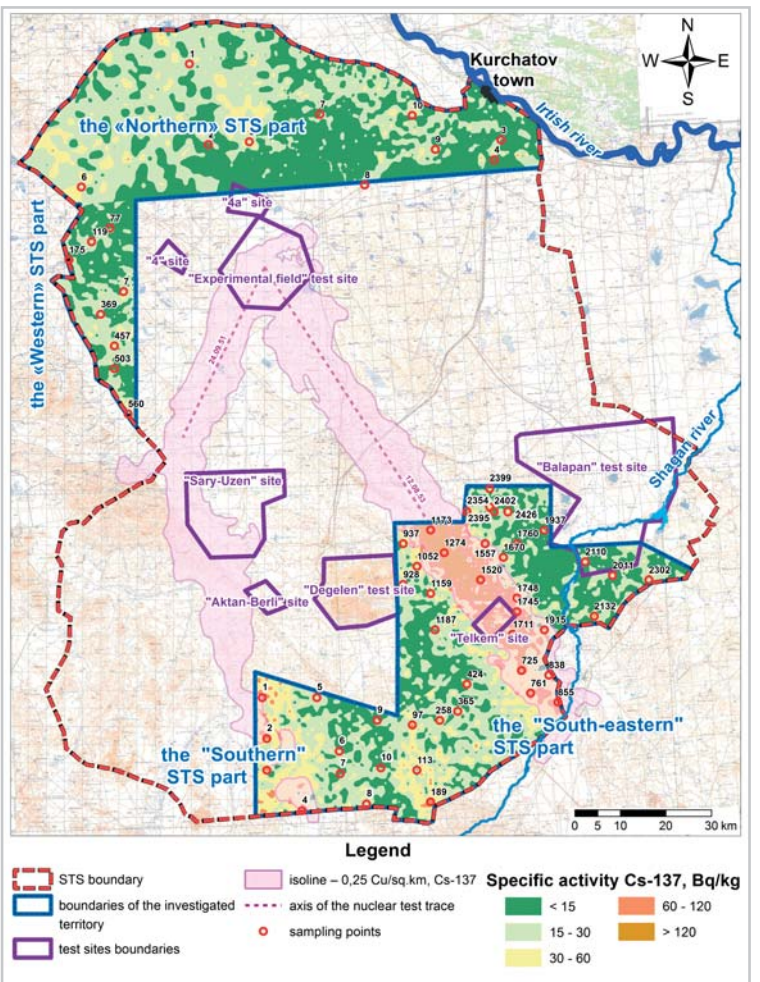


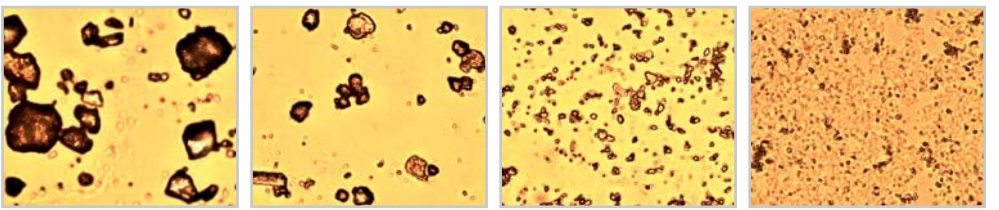
Figure 108. Arrangement of sampling points at the conditionally "background" STS territories

Sampling. The samples of the top 5-cm soil layer were taken either using the "envelope" method or by the point sampling. Sampling area was 600-800 cm^2. Mean weight of a sample was 3 kg. In each point, geographical coordinates (latitude and longitude) were determined using a GPS–navigator (Garmin), and exposure dose rate (EDR) and β-particles flux density was measured using MC-AT 6130 dosimeter-radiometer by "Atomtech".

Preparation of samples for analysis. Soil samples were dried in a drying cabinet at the temperature below 60 °C. Large stones and vegetative inclusions were then removed from the dried samples; the samples were then sieved via a 1 mm sieve.

Soil fractioning. The following two methods were sequentially used at determination of the granulometric composition: "wet" sieving and sedimentation. "Wet" sieving allowed to obtain 1,000-500, 500-250, 250-100, 100-63 and 63-40 μm fractions, the sedimentation method allowed to get 40-8 μm, 8-5 μm, 5-1 μm and <1μm fractions.

Granulometric soil fractions separated by sedimentation were studied employing an optical microscope to determine the particle sizes and fineness of the fraction. Size of the particles was determined using the micron-scale mesh. Figure 109 provides fragments of microphotographs of the studied fraction samples.



a) fraction 40-8 μm b) fraction 8-5 μm c) fraction 5-1 μm d) fraction <1 μm

Figure 109. Various dust fractions, magnified * 400

Radionuclide analysis. Radionuclide contents were studied in each of the segregated fractions. Concentrations of ^{137}Cs and ^{241}Am were determined using gamma-spectrometric method, while ^{90}Sr and $^{239+240}Pu$ were radiochemically determined employing the standard techniques [93 – 95].

3.1.4.2. Results and discussion

Granulometric composition of studied soils. The fine grained soil (a fraction of less than 1,000 μm) was of the particular interest in the studies of the radionuclide distribution in granulometric soil fractions, while the stony fraction (10,000-1,000 μm) was removed from further investigations. The mass fraction (ω, %) of each granulometric fraction in the fine grained soil was determined as a part of the total weight of a dry sample.

Outcomes from the granulometric analysis of soils at the studied territories are presented in the Table 15 below.

Table 15.

Granulometric fraction distribution in soils of the "northern" and the "western" lands of the STS, %.

Fraction, μm	"Northern" territory (n=10)			"Western" territory (n=8)			"Southeastern" territory (n=30)			"Southern" territory (n=10)		
	min.	max.	average	min.	max.	average	min.	max.	average	min.	max.	average
1,000-500	40.6	63.7	**52.5**	41.4	70.5	**53.9**	14	39.2	**25.4**	28.8	55.9	**40.3**
500-250	4.2	13.6	**9.6**	7.91	13.3	**11**	10.2	24.9	**17.3**			
250-100	6.5	15.4	**9.7**	5.3	12.5	**8.5**	9.3	22	**16.1**	23.1	44.9	**32.5**
100-63	13.8	31.3	**22.3**	11.5	24.4	**17.7**	4.2	21.2	**11.3**			
63-40							3.4	14.8	**9.3**			
40-8							5.4	16.1	**10.6**	4.3	12.5	**7.8**
8-5							3.1	11.6	**7**	2.7	8.13	**5.6**
5-1							4.3	9.4	**6.4**	3.5	9.2	**6.4**
<1							0.5	3.7	**2.1**	1.5	3.5	2.4

According to the granulometric analysis, sandy fraction dominates in the soils at the studied territories comprising about 70 % of the total mass of the soil. The remaining part of the soil is represented by dust and slit fractions. Weight percentage of the silt fraction (<1 μm) is low and varies within 0.5-3.5 %.

Concentration of artificial radionuclides in soil. Concentration of the ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}$Pu radionuclides in the source soils was analyzed both by analytical and calculation methods. Specific activity of radionuclides was calculated based on the radioisotopes content in each soil fraction considering their weight and employing the following formula:

$$\overline{A}_{sp}^{f} = \frac{\sum_{n=1}^{i} A_{sp_i}^{f} \times m_i^{f}}{m^{s}},$$

where $\overline{A}_{sp}^{s}$ – pecific activity of a radionuclide in soil, Bq/kg;

$A_{sp_i}^{f}$ – specific activity of a radionuclide in the *i*-th granulometric fraction, Bq/kg;

m_i^{f} – weight of the *i*-th granulometric fraction, kg;

m^{s} – weight of the analytical soil sample, kg.

Average repeatability of the results of analytical and calculated specific activities in soil comprised 80 %. The calculated radionuclide specific activities in source soil were used to assess the radionuclide distribution in the granulometric soil fractions.

Table 16 below contains the radionuclide average specific activities in soils of the studied territories.

Table 16.

Average specific activity values of the radionuclides ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}$Pu in studied soils, Bq/kg.

Radionuclide	Territory					
	Conditionally "background" territory				Traces	
	"Northern" (n=10)	"Western" (n=8)	"Southeastern" (n=17)	"Southern" (n=6)	Trace of the thermo-nuclear explosion on 12.08.1953 (n=12)	Trace of the surface explosion on 24.09.1951 (n=4)
^{137}Cs	25	31	43	42	190	115
^{90}Sr	31	5.9	45	5.6	720	20
^{241}Am	1.7	1.3	2.0	<3	2.4	<3
$^{239+240}$Pu	8.6	8.6	15	13	48	39

Radionuclide distribution in the soil granulometric fractions. A unitless parameter – enrichment factor (E_f) determined as a ratio between the radionuclide specific activity in the granulometric fraction ($A_{sp.}^{fr.}$) and the specific activity of the same radionuclide in the source soil ($\overline{A}_{sp}^{S}$): $E_f = A_{sp.}^{fr.} / \overline{A}_{sp}^{S}$ was used in the quantitative assessments of the artificial radionuclide ^{137}Cs, ^{241}Am, $^{239+240}$Pu and ^{90}Sr distributions in the granulometric soil fractions. This parameter serves as an indicator of the enrichment or depletion rate in the granulometric fractions with respect to the average radionuclide content in soil. So, $E_f>1$ means the increased radionuclide concentration in this fraction, while $E_f<1$ means that the isotope concentration in the fraction is diluted.

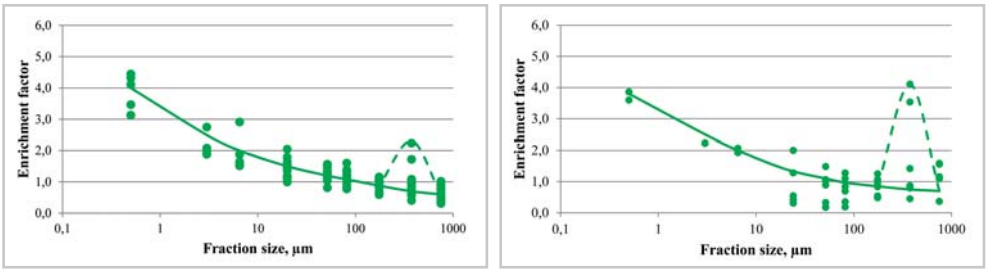
Radionuclide distributions in the granulometric fractions of soil at the conditionally "background" sites

Distribution of artificial radionuclides among the granulometric soil fractions at the conditionally "background" lands is more evidently presented on the figures 110 – 113.

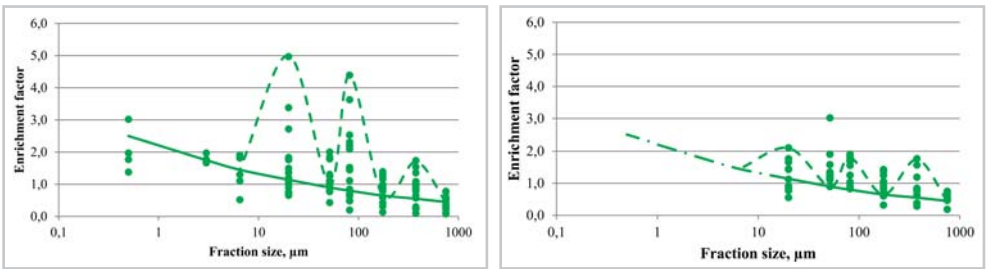
The radionuclide distributions in the granulometric soil fractions at all conditionally "background" territories demonstrate increased concentrations in the fine soil fractions. Some increase in the Ef concentration in specific soil fractions has been revealed at all the studied territories confirming that enrichment with artificial radionuclides takes place. Increased Ef values can be found in the following fractions: 500-250, 100-63, 40-8 and 40-5 μm. The 500-250 μm fraction was noticed at all the conditionally "background" territories, the fractions 100-63 μm and 40-8 μm were found only at the "southeastern" territory, while the 40-5 μm fraction was found at the "southern" territory.

Distribution of the radionuclides among the granulometric fractions of soils at the traces of nuclear explosion fallouts

The studied territories were affected to different extent by the tests performed on 29.08.1949 (the first nuclear explosion), 24.09.1951 and 12.08.1953 (thermonuclear explosion) at the "Experimental Field". Radioactive fallout traces created by two explosions are located at the "southern" (24.09.1951) and "southeastern" (12.08.1953) territories [11, 77, 96]. The diagrams of radionuclide distribution in the granulometric soil fractions in the traces are presented on the figures 114 – 115.

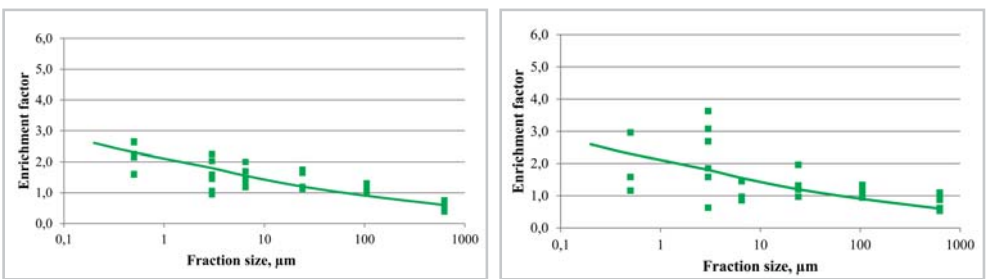


a) ^{137}Cs b) ^{90}Sr

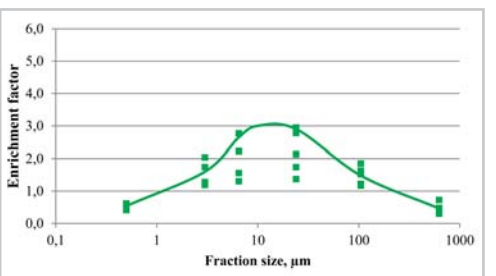


c) $^{239+240}$Pu d) ^{241}Am

Figure 110. Distribution of artificial radionuclides in the granulometric soil fractions at the "southeastern" part of the STS

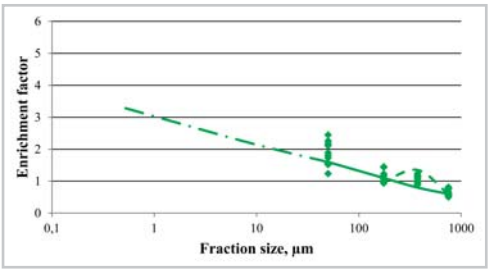


a) ^{137}Cs b) ^{90}Sr

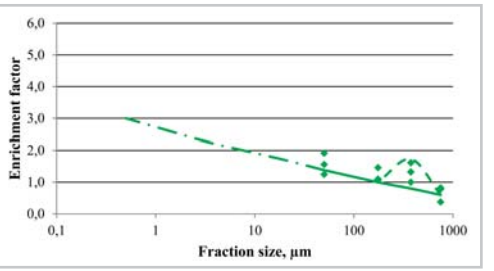


c) $^{239+240}$Pu

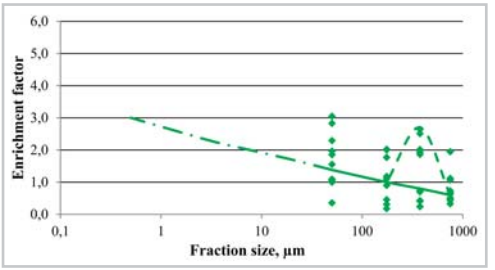
Figure 111. Distribution of artificial radionuclides in the granulometric soil fractions at the "southern" part of the STS



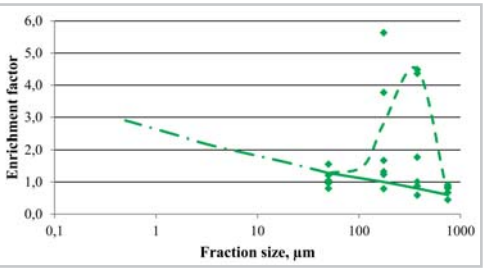
a) ^{137}Cs



b) ^{90}Sr

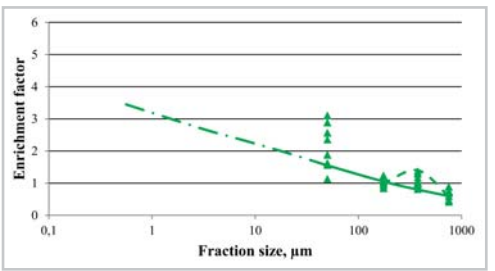


c) $^{239+240}Pu$

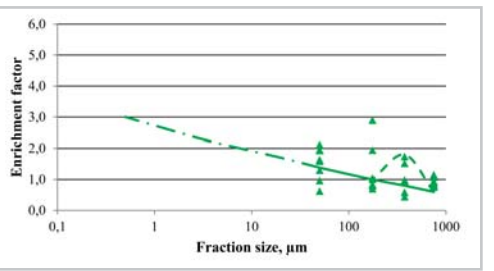


d) ^{241}Am

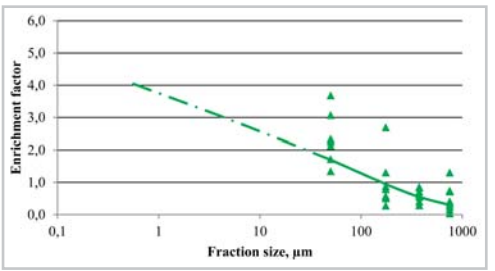
Figure 112. Distribution of artificial radionuclides in granulometric soil fractions at the "northern" part of the STS



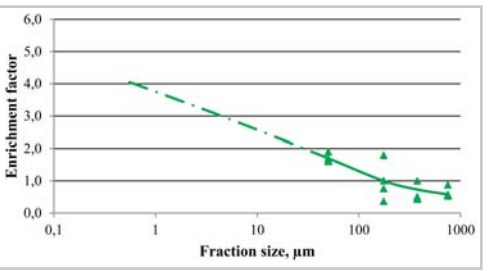
a) ^{137}Cs



b) ^{90}Sr

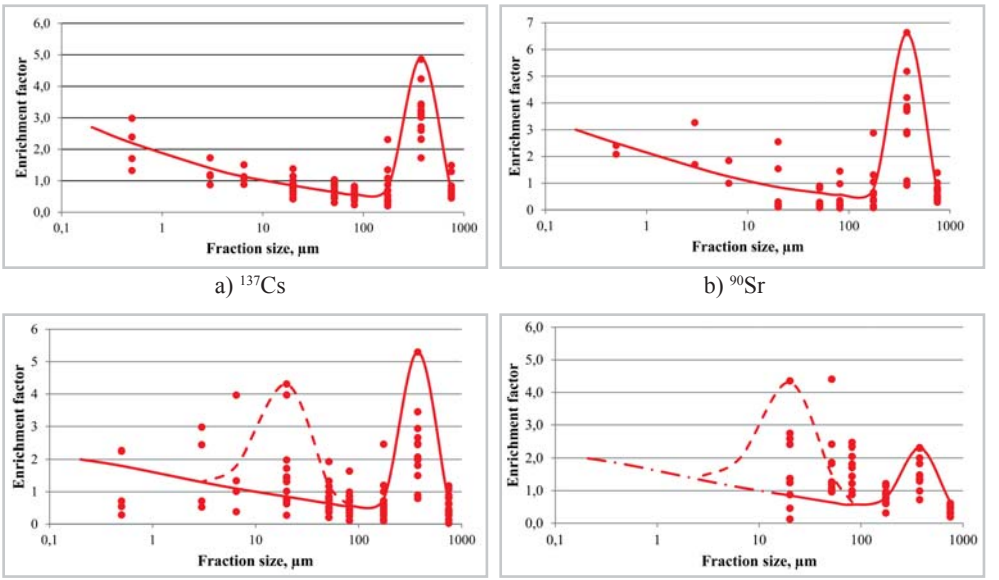


c) $^{239+240}Pu$



d) ^{241}Am

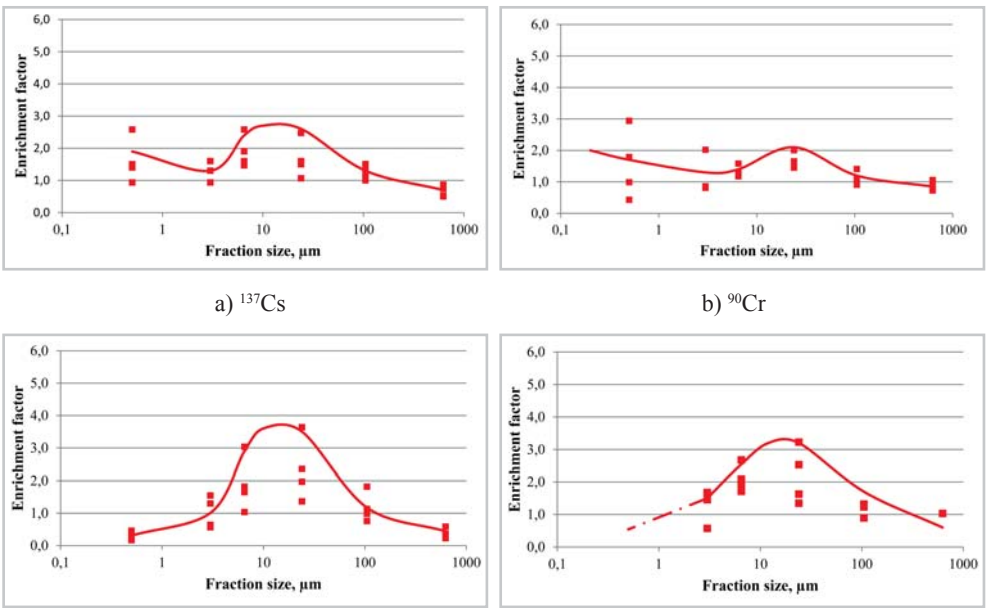
Figure 113. Distribution of artificial radionuclides in the granulometric soil fractions at the "western" part of the STS



a) ^{137}Cs b) ^{90}Sr

c) $^{239+240}$Pu d) ^{241}Am

Figure 114. Distribution of artificial radionuclides in the granulometric soil fractions at the trace from the thermonuclear explosion performed in 1953



a) ^{137}Cs b) ^{90}Cr

c) $^{239+240}$Pu d) ^{241}Am

Figure 115. Distribution of artificial radionuclides in granulometric soil fractions at the plume of the 1951 surface test

Some soil fractions in the traces have been enriched with the radionuclides to the greater extent. So, at the studied part of the thermonuclear explosion trace (70-100 km to the epicenter), significant concentrations of all the measured radionuclides were found in the fractions 500-250 μm; $^{239+240}$Pu and ^{241}Am were also found in the fraction 40-8 μm (Figure 109). The "enriched" fraction in the trace from the surface test on 24.09.1951 belongs to the fraction 40 – 5 μm.

Besides grouping in the "enriched" fraction, the radionuclides tend to concentrate in smaller fractions. This tendency is most clearly seen in the trace from the thermonuclear test (Figure 110).

The radioactive fallouts are formed at nuclear explosions due to generation of radioactive particles (activity carriers) as a result of physicochemical, nuclear-physical processes occurring in the fireball. Therefore, presence of soil fractions enriched with artificial radionuclides is most probably stipulated by presence of the radioactive particles from the abovementioned surface nuclear explosions. Alpha-autoradiography of several 500-250 μm soil fraction samples taken at the trace of the thermonuclear explosion on 12.08.1953 was performed by our colleagues from the SE "The Laboratory for Microparticle Analysis" (Moscow, Russia) and showed that single alpha-tracks on the exposed detectors were left by individual particles. Figure 116 shows typical area with tracks at the surface of one of the detectors.

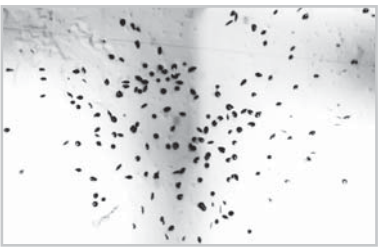


Figure 116. A fragment of a detector, exposed over the 500-250 μm fraction of soil sample taken at the trace from the 1953 thermonuclear explosion

As it was mentioned above, besides presence of some "enriched fractions" (radioactive particles), the distribution of radioisotopes in the granulometric soil fractions is also characterized by increase in their concentration in smaller soil particles. Such a tendency is typical for the "background" territories; it was although verified that such pattern can take place at the radioactive fallout traces. Continuously repeating processes of sorption and transfer back to the solution (desorption) in soil lead to transfer, dispersion or concentration of the radionuclides. Since sorption-desorption processes in soil occur in a heterogeneous system, an increase of radionuclides concentration is proportional to the specific surface of the particles, i.e., the smaller the fraction is, the higher is the concentration of the radionuclides on it.

Accumulation of the artificial radionuclides activity in fine soil fractions can occur not only due to their "sorption-desorption redistribution", but also due to fallout of the fine-grain radiation carriers formed at surface and atmospheric nuclear explosions. Ac-

cording to some experimental data, sizes of such particles usually lie within the range 0.01 to 40 μm.

Comparative analysis of the radionuclides distribution in the granulometric fractions shows that the sizes of "enriched fractions" in the traces from surface tests align with sizes of fractions with increased Ef values at the adjacent conditionally "background" lands (Figure 117).

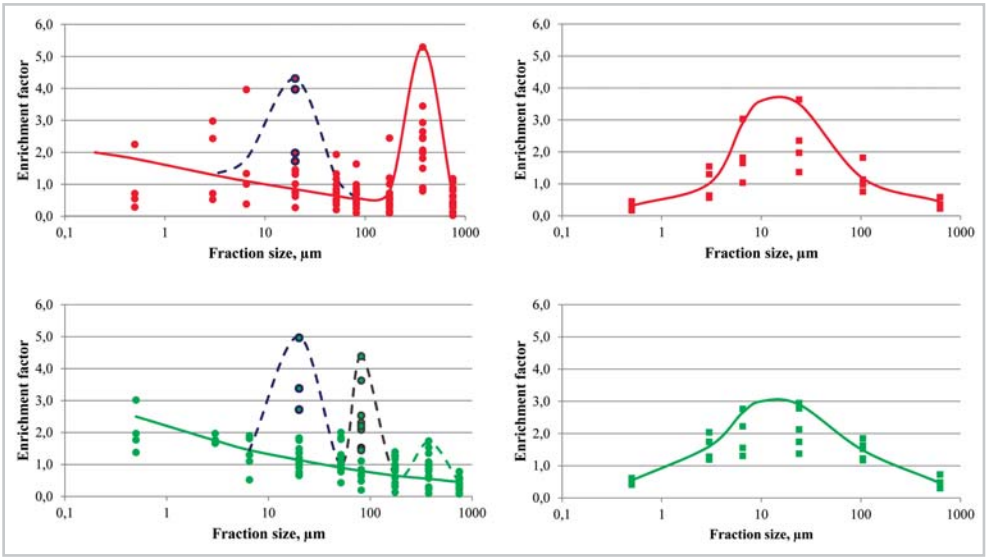


Figure 117. $^{239+240}$Pu distribution in the granulometric fractions of soil at the trace from the 12.08.1953 thermonuclear explosion (1) and at the adjacent southeastern territory (2), on the trace from the 24.09.1951 surface explosion (3) and at the adjacent southern territory (4)

Figure 117 shows that at the trace from the thermonuclear test, two specific (enriched) fractions of 500-250 and 40-8 μm can be found. The fraction 500-250 μm can be found everywhere both at the trace and at the adjacent "background" southeastern territory. At that, the fraction 40-8 μm was found only at the southeastern boundary of the trace (pp. 1557, 1748, 1670, and 1915) and in some points at the southeastern territory (pp. 2110, 2011, 2302). In these points, two enriched fractions 500-250 μm and 40-8 μm are present at the same time.

Together with this, soils of the conditionally "background" southeastern territory contain a 100-63 μm fraction significantly enriched with plutonium that was not found in the thermonuclear trace (p. 97, 113, 189, 1187, 424, 2132, 1760). This fact can serve as an evidence for one more unidentified source of radioactive contamination at the southeastern STS territory, besides the thermonuclear explosion.

The boundary between the "southeastern" and the "southern" parts of the STS is quite conditional; still, only one "enriched fraction" (40-5 μm) existing both at the trace of the 1951 surface test, and in the conditionally "background" areas was found at the southern territory (Figure 117). Based on the above, the studied "southern" part has most probably suffered only from just one thermonuclear explosion on the 24.09.1951.

The above-mentioned facts allow assuming, that the radionuclides distribution in the granulometric soil fractions can serve as an additional diagnosing sign for the origin of soil contamination.

In the majority of the considered cases therefore the soil fractions enriched/depleted with radionuclides were found. The enrichment/depletion rates lie in the range of 0.1 to 5.0. The average Ef values of the most enriched fractions, typical for some territories, are given below (Table 17).

Table 17.

Average enrichment factors for different fractions.

Territory	Fraction, μm	Radionuclide			
		^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
"Southeastern" (n=6)	<1	3.9	3.6	2.1	3.3
"Southern" (n=6)	<1	2.1	1.9	0.5	-
Trace from the thermonuclear explosion, 12.08.1953(n=13)	500-250	3.0	3.3	2.6	1.5
Trace from the surface explosion, 24.09.1951 (n=4)	40-8	1.7	1.5	2.3	2.2

It should be noticed, that no fractions "abnormally" enriched with the radionuclides was found. The maximal registered E_f value did not exceed 5.0. Based on the statistical data massif (n=58) used in these studies, it is unlikely to expect extremely high enrichment with radionuclides of the granulometric soil fractions including those posing radiological hazard if inhaled (<10 μm). However, E_f values can vary within a small range depending on changes in the fraction weight of the granulometric fractions in soil, i.e. decrease in the fraction weight can result in even higher enrichment or vice versa.

Available information about the E_f value in the granulometric fractions allows to provide an alternative calculation method for determining artificial radionuclides content in air. Besides E_f values, the average annual concentration values for the artificial radionuclides in soil and average dust contents (easy to determine) are also needed for calculation purposes. The following formula was used for assessing the radionuclides activity in air:

$$C_{air} = C_{soil} \cdot K_o \cdot \rho_{sus} \cdot 10^{-9},$$

where: C_{air} – volumetric activity of radionuclides in air, Bq/m^3;
C_{soil} – average specific activity of radionuclides in soil, Bq/kg;
K_o – enrichment factor of soil granulometric fraction;
r – average annual dust content in air, μg/m^3;
10^{-9} – kg into μg conversion factor.

The enrichment factor of the fractions <10 μm plays the most important role in the assessments of the radionuclides content in air since it is considered as potentially inhalation-hazardous.

The following recommendations can be given for further studies of the radionuclides distribution in granulometric fractions of the STS soils. The decision on the need in further detailed study of the radionuclides distribution in the granulometric fractions should be made based on the character of the radioactive contamination of the area:

1) if no traces of radioactive fallouts were left after nuclear tests and/or there is no local contamination revealed, one can expect the highest concentration of the radionuclides in fine soil fractions. In this situation just some verification investigations are enough therefore limiting the number of extracted fractions to the necessary minimum;

2) if there are indications for radioactive contaminations and/or local contaminations revealed, a detailed study is reasonable since specific "enriched"fraction can possibly be found in soil.

3.1.5. The artificial radionuclides speciation in soil of the conditionally "background" territories at the Semipalatinsk Test Site

One of stages of the radioecological studies at conditionally "background" STS territories was the study of artificial radionuclides speciation in soils. Unlike determining the total content of radionuclides is soil and assessment of their danger if the rated values are exceeded, the advantage of this method is the possibility to assess real and potential hazard rate from the radionuclides in soils of contaminated lands. This study allows for assessment of the radionuclide mobility (relative content of water soluble and exchangeable forms) and biological availability in soil [97].

A lot of both domestic and foreign research was dedicated to the study of artificial radionuclides behavior in soils. Majority of these works was dedicated to the study of ^{137}Cs and ^{90}Sr long-living fission products behavior in soil and fallouts. Directly in global fallouts (precipitations, snow, fallouts) ^{90}Sr radionuclide is mainly represented by water soluble and exchangeable forms, ^{137}Cs- in acid-soluble form (1norm HCl) [22]. After falling on the earth surface, radionuclides start participating in biogeochemical migration processes. As the result of their interaction with soil, radionuclides get distributed in soil cover. After some time from their fallout, the radionuclides behave according to their isotopic and non-isotopic carriers.

A so called "ageing" process when the radionuclide forms change stepwise with time from exchangeable to non- exchangeable forms [85] can be observed here. Solubility of ^{90}Sr from global fallouts in soil depends on many factors, including soil type and period of presence in soil. So, the 1961 research have shown that the content of water-soluble and exchangeable forms of ^{90}Sr in plough layer of typical black earth is 1.73 and 26% respectively, in derno-podzolic soil clay loam soils – 39 and 61%, respectively; and in non-exchangeable form (6 norm HCl) it was not found at all [22]. The study of ^{90}Sr radionuclide solubility in global fallouts in brown forest soils carried out in 1979 revealed the following ratio values: 7.0% in water soluble form, 57.7% – in exchangeable, 36.2% – in acid soluble (1norm HCl); in tightly bound state this radionuclide was not found [98]. ^{137}Cs radionuclide can be typically found in soil in tightly bound forms [99]. The 1979 research revealed: the concentration of this radionuclide brought by global fallouts into brown forest soils included 73.9% in tightly bound form, 4.2% in water soluble, 23.7% in exchangeable form, and 18.6% in acid soluble form (1norm HCl). Upon the results of various studies, 70-98% of ^{137}Cs from its total content in soil can be found in non-exchangeable form.

Model experiments aimed at studying ^{137}Cs radioisotope interaction with soil show that up to 95% of the source activity in solution is absorbed by water. Behavior of the radionuclides in soil depends in many respects on physical and chemical properties of soil. Numerous studies show that radionuclides become better fixed in soil with increase of humus, exchange bases or silts, and increase of acidity level of soil. In general, ^{90}Sr dominates in exchangeable form, while ^{137}Cs – in non-exchangeable ones thanks to inclusion into inter-wrapper space of the soil crystalline grid.

Behavior of transuranium radionuclides remains poorly studied [86, 100 – 102]. It is known that the radionuclides ^{241}Am and $^{239+240}$Pu in soil are mainly found in sorbed state, in particular, as a part of organic soil components and in tightly bound form. Up to 60% of $^{239+240}$Pu from global fallouts in soil was determined in organic form, a bit less than 40% – as a part of tightly bound form, about 1% – in exchangeable form. Unlike $^{239+240}$Pu, the ^{241}Am radionuclide is more mobile [103, 104].

We studied speciation of the artificial radionuclides ^{137}Cs, ^{241}Am, $^{239+240}$Pu and ^{90}Sr in soils of conditionally background" STS lands. Natural-climatic conditions and peculiarities of the soil contamination formation resulted from nuclear weapons testing at Semipalatinsk Test Site and duration of radionuclides interaction with soil differ this object of research from any other. The peculiarities of the radionuclides speciation in soils at conditionally "background" STS territories and affected to different extent by fallouts from nuclear tests allow to consider the methodology of planning of further research at the conditionally "background" STS lands and similar territories in a new light.

Objects of research. The objects of research are "Northern", "Western", "Southeastern" and "Southern"parts of the STS named according to their geoposition at the test site territory (Figure 1).

Table 18 provides mean concentrations of artificial radionuclides in soils at the conditionally "background" STS territories with different mechanisms of radioactive contamination [69, 77, 79, 105]. The conditionally "background" territories were divided into two groups according to the type of contamination as follows: "background" territories and fallout traces from two surface nuclear tests carried out on 24.09.1951 (yield - 38 kt) and 12.08.1953 (yield - 400 kt), carried out at the "Experimental Field" site of the STS.

Table 18.

Concentrations of artificial radionuclides in soils, Bq/kg

Object	^{137}Cs	^{90}Sr	^{241}Am	$^{239+240}$Pu
"Background" territory of the STS				
"Northern" territory	17.2	10.0	0.8	4.1
"Western" territory	18.0	5.8	1.1	6.5
"Southeastern" territory	18.0-30.2	3.4-15.0	0.7-10	3.7-7.4
"Southern"territory	20.3	14.4	0.7	3.5
Zones of fallout "plumes" from surface nuclear tests at conditionally "background" STS territory				
"Southeastern" territory	140	460	2.5	30
"Southern" territory	44.5	31.6	1.4	14.5
Global fallouts				
Northern hemisphere	4–29	1–19	-	0.02–5.0

Provided data shows that the content of the studied artificial radionuclides in soils of "background" STS lands lies within the level of global fallouts. At the fallout trace from the surface test (38 kt, 24.09.1951), crossing the "southern" part of the STS, the activity levels are much higher than the range of the background values. Maximum concentration of radionuclides in soils was found on the fallout "trace" from the thermonuclear test (400 kt, 12.08.1953).

The investigated part of the Semipalatinsk Test Site is located within the steppe natural-climatic zone and in geographical respect it forms a part of Kazakh low hill lands. The landscape of the territory is represented by low mountain massifs, individual mountain ranges, bald peaks and plains, lowlands under dry desertified steppes on zonal brown and light brown normal, incompletely developed and underdeveloped soils, quite widely distributed at the test site territory. The topography of the southeastern part of the territory is represented by low hills and hummocks, the main zonal soil types of those are mountain light-brown and light brown channery underdeveloped soils. All along the territory the meadow-brown and meadow soils combined with alkalinized and salt marsh soils can be found. The soil cover of the territory can be characterized by insignificant density of soft sediments, large content of crashed stone and organic matter [106 – 108]. In respect of humus content, these soils can be categorized as medium-humic type soils. Easily-soluble salts are mainly flushed out from these soils. The studied soils are mainly of carbonate type typical for this area. In terms of mechanical composition, the soils are of moderate clay loam, channery type.

Sampling (see figure 108) Soil was sampled in places with increased concentration of radionuclides. At each site, soil was sampled at the depth of 0-5 cm using envelope method. By mixing at least five single samples, collected at one sampling spot, an aggregate sample was obtained. The aggregate soil samples were dried to air-dry state, and upon removal of inclusions (stones, roots and etc.) mashed in a porcelain mortar and sieved via the mesh with 1 mm cells. The 150 g subsamples were analyzed.

The technique for extraction of various radionuclide speciation from soils. Speciation of the radionuclides in soils were investigated using the sequential extraction method. This method is widely used in research of large amounts of toxic elements in different types of samples [109].

A scheme of subsequent extraction proposed by F.I. Pavlotskaya was used (Table 19). The scheme includes determination of water-soluble, exchangeable and non-exchangeable forms of the radionuclides in soil [22]. The scheme was modified by adding an intermediate stage consisting of extraction of organically-bound radionuclides with 0.1 NaOH solution using the technique developed by I.V. Tyurin [110].

Table 19.

Subsequent extraction scheme

1M CH_3COONH_4	Exchangeable form
0.1M NaOH	Form, bound with organic part, either free or not tightly bound with the mineral soil component
1M HCl	Not exchangeable (mobile), potential reserve
Mixture of acids HNO_3-HF	Tightly bound (residual) form

The proportion of soil to leaching solution was 1:5 (g/ml). The duration of soil contact with leaching solution at all stages of the experiment was less than 12 hours. Obtained extracts were used to determine the content of radionuclides.

Determining ^{137}Cs, ^{241}Am, ^{90}Sr and $^{239+241}Pu$ radionuclide concentrations in soil extracts. Radionuclides ^{137}Cs and ^{241}Am in soil samples and soil extracts were determined using Canberra GX-2020 gamma-spectrometer [93]. Radionuclide ^{90}Sr in soils with high specific concentration of ^{90}Sr was determined employing "Progress" b-spectrometer [111]. Soil samples with low concentrations of ^{90}Sr radionuclide and extract samples were analyzed using the radiochemical method according to the certified methodology with complete sample decomposition (ashing) using a mixture of mineral acids [94]. $^{239+240}Pu$ concentration in the soil samples and the extracts was determined using the radiochemical $^{239+240}Pu$ extraction technique and alpha-spectrometric measurements [95].

Detection limit for radionuclides in the soil samples and the extracts was calculated based on weight of subsamples and volumes of the extracts taken for analysis and measurement period. Average detection period for ^{137}Cs radionuclide was 0.9 Bq/kg (within the range from 0.1 to 2.0 Bq/kg), for ^{241}Am and ^{90}Sr – 0.3 Bq/kg (from 0.2 to 14.4 Bq/kg), $^{239+240}Pu$ – 0.02 Bq/kg (from 0.01 to 4.2 Bq/kg). Error in the analytical measurements did not exceed 30 %.

Forms of radionuclide speciation in soils

Measured ^{241}Am, ^{137}Cs, $^{239+240}Pu$ and ^{90}Sr radionuclides speciation are presented in terms of specific activity of the radionuclide speciation per 1 kg of soil and as a percentage of the total content of all forms.

To find specific concentrations of soluble radionuclide speciation in soil, primary results of the specific activities of the radionuclide soluble forms in the extracts were converted into the values for soil (taking into account proportional ratio values of soil and leaching solution used in the technique – 1:5). The net content of the radionuclides in soil and in soil after extraction was taken as a total (net) concentration of the radionuclides in soil, i.e. as 100%.

In many cases, determination of the radionuclide relative content was complicated by large amount of the radionuclide specific activity readings in extracts below the detection limit of the method used. To avoid understatement of the results, the values at the detection limit level were taken in calculations as equal to the detection limit. Therefore, relative concentrations of soluble radionuclides were obtained as the upper estimate.

Speciation of ^{137}Cs radionuclide. Table 20 provides the data on ^{137}Cs.

Table 20.

The content of ^{137}Cs radionuclide speciation (Bq/kg, percentage of the total content of all speciation)

Point #	^{137}Cs content in soil	Exchangeable form (1M CH_3COONH_4)		Organic form (0.1 and NaOH)		Mobile form (1M HCl)		Tightly bound form (soil)	
		Bq/kg	%	Bq/kg	%	Bq/kg	%	Bq/kg	%
"Background"territories									
"Northern"part of the STS									
6	41 ± 8	< 0.9	< 1.7	-	-	< 0.7	< 1.4	50 ± 10	>96.9
2	24 ± 4	< 0.8	< 3.3	-	-	< 0.7	< 2.9	23 ± 4	>93.8
5	17.2*	< 0.8	< 3.4	-	-	< 0.7	< 2.7	23 ± 4	>93.9
1	19 ± 8	< 0.9	< 4.3	-	-	< 0.6	< 2.8	20 ± 4	>92.9
7	56 ± 10	3.2 ± 0.6	6.6	-	-	< 0.7	< 1.5	45 ± 10	>91.9
10	16 ± 3	< 0.8	< 5.0	-	-	< 0.6	< 4.2	14 ± 3	>90.8
9	19 ± 4	< 0.8	< 3.8	-	-	< 0.8	< 3.8	18 ± 3	>92.5
8	2 7± 5	< 0.8	< 3.0	-	-	< 0.6	< 2.3	26 ± 5	>94.7
4	19 ± 4	< 0.8	< 4.4	-	-	< 0.6	< 3.0	17 ± 3	>92.5
3	20 ± 4	< 0.9	< 4.2	-	-	< 0.7	< 3.2	20 ± 4	>92.6
Mean value, %**			<4.0		-		< 2.8		>93.3
"Western"part of the STS									
369	58 ± 12	< 1.0	< 2.1	-	-	< 0.9	< 2.0	44 ±12	>95.9
119	11 ± 2	< 0.9	< 6.5	-	-	< 0.8	< 5.6	12 ± 3	>87.9
77	49 ± 10	< 1.1	< 2.9	-	-	< 0.9	< 2.3	35 ± 7	>94.8
175	49 ± 10	< 1.8	< 5.0	-	-	< 1.3	< 3.7	32 ± 6	>91.3
560	42 ± 8	< 2.0	< 4.9	-	-	< 0.9	< 2.3	37 ± 7	>92.9
457	32 ± 6	< 0.9	< 3.1	-	-	< 0.9	< 3.1	26 ± 5	>93.8
503	30 ± 6	< 0.9	< 2.3	-	-	< 0.9	< 2.4	37 ± 7	>95.3
7	32 ± 6	< 1.0	< 4.0	-	-	< 0.8	< 3.0	24 ± 5	>93.0
Mean value, %**			< 3.9		-		< 3.0		>93.1
"Southeastern"part of the STS									
937	83 ± 17	1.2 ± 0.2	1.6	< 0.5	< 0.6	< 0.4	< 0.6	72 ± 14	97.2
1052	30 ± 6	0.6 ± 0.1	1.8	< 0.5	< 1.5	< 0.4	< 1.3	31 ± 1	>95.4
928	61 ± 10	< 0.9	< 1.5	< 0.2	< 0.4	0.7 ± 0.1	1.1	57 ± 9	>97.1
1159	41 ± 11	1.1 ± 0.2	3.2	< 0.5	< 1.6	< 0.4	< 1.3	32 ± 6	>94.0
1557	22 ± 5	< 0.7	< 4.6	< 0.3	< 1.9	< 0.4	< 2.5	14 ± 3	>91.0
1670	62 ± 12	0.9 ± 0.2	1.5	< 0.2	< 0.4	0.6 ± 0.1	1.0	60 ± 10	97.1
1760	23 ± 5	< 0.5	< 2.1	< 0.5	< 2.2	< 0.4	< 1.7	20 ± 4	>93.9
424	95 ± 19	3.3 ± 0.3	3.5	0.7 ± 0.1	0.8	1.4 ± 0.3	1.5	90 ± 18	94.3
365	23 ± 5	< 0.4	< 1.8	< 0.2	< 0.7	< 0.4	< 1.6	24 ± 5	> 95.9
258	66 ± 13	2.9 ± 0.3	4.4	< 0.2	< 0.3	1.2 ± 0.2	1.9	63 ± 12	93.5
97	27 ± 5	< 0.4	< 1.8	< 0.4	< 1.6	< 0.3	< 1.4	24 ± 5	> 95.2
113	76 ± 15	2.2 ± 0.2	3.0	< 0.4	< 0.5	1.4 ± 0.2	2.0	70 ± 14	94.5
189	42 ± 8	0.8 ± 0.1	1.8	< 0.1	< 0.3	< 0.5	< 1.1	43 ± 8	> 96.8
1,187	34 ± 6	< 0.5	< 1.5	< 0.5	< 1.7	< 0.4	< 1.4	28 ± 5	>95.3
Mean value, %**			2.3		< 1.0		1.4		95.4

Point #	^{137}Cs content in soil	Exchangeable form (1M CH_3COONH_4)		Organic form (0.1 and NaOH)		Mobile form (1M HCl)		Tightly bound form (soil)	
		Bq/kg	%	Bq/kg	%	Bq/kg	%	Bq/kg	%
"Southern"part of the STS									
5	49 ± 10	1.8 ± 0.4	3.5	< 0.3	< 0.6	0.5 ± 0.1	1.0	50 ± 10	94.8
7	31 ± 6	< 0.1	< 0.5	< 0.2	< 0.7	< 0.2	< 0.5	28 ± 5	> 98.3
8	34 ± 7	0.5 ± 0.1	1.8	< 0.2	< 0.7	< 0.1	< 0.4	29 ± 6	> 97.1
9	42 ± 8	1.6 ± 0.4	3.9	< 0.2	< 0.5	0.8 ± 0.2	1.9	38 ± 7	93.6
10	49 ± 10	0.6 ± 0.1	1.3	< 0.2	< 0.4	< 0.2	< 0.3	48 ± 10	> 98.0
Mean value, %**			2.2		<0.6		0.8		96.4
Zones of "traces"									
Thermonuclear test of 12.08.1953 (400 kt) "Southeastern" territory of the STS)									
1173	335 ± 65	1.7 ± 0.2	05	< 0.4	< 0.1	0.6 ± 0.1	0.2	330 ± 65	99.2
1274	475 ± 100	2.7 ± 0.5	0.5	< 0.6	0.1	1.4 ± 0.3	0.3	490 ± 100	99.1
1520	580 ± 110	2.4 ± 0.5	0.4	< 0.2	0.03	2.2 ± 0.4	0.4	580 ± 110	99.2
1748	130 ± 30	1.2 ± 0.2	0.9	< 0.5	< 0.3	0.6 ± 0.1	0.4	140 ± 30	98.4
1745	210 ± 40	1.7 ± 0.3	0.9	< 0.4	< 0.2	< 0.4	0.2	200 ± 40	> 98.7
1711	240 ± 45	1.1 ± 0.1	0.5	< 0.3	< 0.2	1.6 ± 0.2	0.7	215 ± 40	98.6
1915	85 ± 17	< 0.5	< 0.6	< 0.5	< 0.6	< 0.4	< 0.4	90 ± 20	> 98.4
725	40 ± 7	< 0.2	< 0.7	< 0.1	< 0.4	< 0.4	< 0.9	37 ± 7	> 98.0
838	140 ± 30	< 0.6	< 0.4	< 0.4	< 0.2	0.8 ± 0.2	0.5	160 ± 30	> 98.9
761	90 ± 10	0.7 ± 0.1	0.8	< 0.4	0.5	< 0.4	< 0.5	84 ± 10	> 98.2
855	180 ± 35	3.5 ± 0.7	2.0	< 0.4	< 0.2	< 0.5	< 0.3	180 ± 35	> 97.5
Mean value, %**			0.7		<0.3		0.4		98.6
Surface nuclear test of 24.09.1951 (38 kt) "Southern" part of the STS)									
1	100 ± 20	1.0 ± 0.2	1.1	< 0.4	< 0.4	< 0.4	< 0.4	90 ± 18	> 98.1
2	100 ± 20	0.6 ± 0.1	0.5	< 0.2	< 0.2	< 0.3	< 0.3	103 ± 20	> 98.9
3	93 ± 19	1.9 ± 0.2	2.1	< 0.3	< 0.3	0.5 ± 0.1	0.6	87 ± 17	97.0
4	150 ± 30	2.7 ± 0.3	2.1	< 0.3	< 0.3	0.4 ± 0.1	0.3	126 ± 25	97.4
6	56 ± 11	0.6 ± 0.1	1.1	< 0.3	< 0.5	< 0.2	< 0.3	52 ± 11	> 98.1
Mean value, %**			1.4		<0.3		<0.4		97.9

* - mean radionuclide concentration in soil of the studied STS lands

** - when radionuclide specific activities in extracts were below the detection limit of the technique, these detection limits were accounted in the calculations of the relative content of the radionuclide speciation

"-" not determined

Quantitative data obtained for the concentrations of exchangeable and mobile ^{137}Cs forms in soils show decrease in radionuclide solubility in soils from traces (compared to the background "Southeastern" and "Southern" parts of the STS). The content of ^{137}Cs exchangeable form in soils of the "Southeastern" part decreases for 3 times (from 2.3 to 0.7%), mobile form – for 3.5 times (from 1.4 to 0.4%). In the southern part of the STS, the percentage of exchangeable form decreases for 1.5 times (from 2.2 to 1.4%), mobile

form – at least for 2 times (from 0.8 to 0.4%). At the "trace" from the 1953 thermonuclear test the change is more evident than at the "trace" from the surface nuclear test made in 1951. Several authors consider the radiocaesium replaced by neutral salts solutions and diluted acids (acid soluble form) as mobile form available for plants [112-114]. Our data are consistent with the data on ^{137}Cs radionuclide accumulation by zonal plants at the territories: the differences were revealed between accumulation factors at the fallout "traces" and the "background" territories [69, 77, 79, 105].

The radionuclide mainly occurs in tightly bound form (at least 93.1%), which is typical for this radionuclide. This is also due to the specifics of this radionuclide interaction with soil. It is known that ^{137}Cs radionuclide is tightly sorbed by clay minerals and mica replacing isomorphically potassium in their crystalline structures. The differences in relative content of the ^{137}Cs tightly bound form at the "background" territory and in the traces are insignificant and remain at the level of the measurement errors.

Speciation of $^{239+240}$Pu radionuclide. The data for $^{239+240}$Pu radionuclide are given in the Table 21.

Table 21.

The content of $^{239+240}$Pu radionuclide (Bq/kg, percentage of total content of all forms)

Sampling point	$^{239+240}$Pu content in soil	Exchangeable form (1M CH_3COONH_4)		Organic form (0.1 and NaOH)		Mobile form (1M HCl)		Tightly bound form (soil)	
		Bq/kg	%	Bq/kg	%	Bq/kg	%	Bq/kg	%
"Background"territories									
"Northern"part of the STS									
6	3.4 ± 0.6	< 0.02	< 0.8	-	-	< 0.02	< 0.7	2.5 ± 0.3	> 98.5
2	5.2 ± 1.0	< 0.02	< 0.3	-	-	0.06	0.9	6.9 ± 1.4	> 98.8
5	4.1*	< 0.02	< 0.9	-	-	< 0.04	< 1.7	2.3 ± 0.5	> 97.4
1	2.7 ± 0.5	< 0.02	< 1.7	-	-	< 0.05	< 3.9	1.1 ± 0.2	> 94.5
7	4.1*	< 0.02	< 0.1	-	-	< 0.02	< 0.1	20 ± 3	> 99.8
10	4.9 ± 0.9	< 0.02	< 0.9	-	-	< 0.02	< 1.0	2.0 ± 0.3	> 98.1
9	12 ± 2.5	< 0.02	< 0.3	-	-	0.05	0.8	7.0 ± 1.3	> 98.9
8	14 ± 3	< 0.02	< 0.1	-	-	0.05	0.2	20 ± 4	> 99.7
4	3.5 ± 0.6	< 0.02	< 0.5	-	-	< 0.02	< 0.7	3.2 ± 0.6	> 98.8
3	12 ± 2	< 0.03	< 0.3	-	-	0.09	1.0	8.9 ± 1.7	> 98.7
Mean value, %**			< 0.6				< 1.1		> 98.3
"Western" part of the STS									
369	6.6 ± 1.3	< 0.02	< 0.5	-	-	< 0.02	< 0.4	4.6 ± 0.9	> 99.1
119	1.2 ± 0.2	< 0.02	< 0.3	-	-	< 0.02	< 0.2	0.8 ± 0.15	> 99.5
77	6.5*	< 0.02	< 0.4	-	-	< 0.02	< 0.4	5.9 ± 1.2	> 99.3
175	1.5 ± 0.2	< 0.03	< 2.0	-	-	< 0.02	< 1.8	1.3 ± 0.2	> 96.2
560	6.5*	< 0.03	< 0.4	-	-	< 0.04	< 0.5	7.5 ± 1.5	> 99.1
457	6.5*	< 0.03	< 0.2	-	-	< 0.02	< 0.2	14 ± 3	> 99.6
503	6.5*	< 0.04	< 0.8	-	-	< 002	< 0.4	4.8 ± 0.9	> 98.8
7	6.5*	< 0.02	< 1.5	-	-	< 0.02	< 1.4	1.4 ± 0.3	> 97.1
Mean value, %**			< 0.7				< 0.7		> 98.6

Sampling point	$^{239+240}$Pu content in soil	Exchangeable form (1M CH_3COONH_4)		Organic form (0.1 and NaOH)		Mobile form (1M HCl)		Tightly bound form (soil)	
		Bq/kg	%	Bq/kg	%	Bq/kg	%	Bq/kg	%
"Southeastern"part of the STS									
1052	20 ± 4	< 0.02	< 0.1	< 0.04	< 0.2	0.2 ± 0.01	0.6	23 ± 3	99.1
1159	7.7 ± 7	< 0.01	< 0.1	< 0..04	< 0.4	< 0.02	< 0.2	10 ± 2	> 99.3
1557	5.4*	< 0.02	< 0.04	0.3 ± 0.02	0.8	< 0.04	< 0.1	39 ±5	> 99.0
1670	5.4*	< 0.02	< 0.1	0.3 ± 0.02	1.3	0.1 ± 0.02	0.5	20 ±3	98.1
2132	7.4 ± 1.5	< 0.03	< 0.2	0.1 ± 0.01	0.6	< 0.03	< 0.2	16 ± 3	> 99.0
2110	18 ± 3	< 0.02	< 0.1	0.7 ± 0.03	3.0	0.07 ± 0.01	0.3	22 ± 3	96.6
2302	13 ± 3	< 0.02	< 0.1	0.1 ± 0.02	0.7	0.2 ± 0..02	1.1	19 ± 3	98.1
1187	< 4.2	< 0.01	< 0.2	0.1 ± 0.01	3.0	< 0.03	< 0.8	4.0 ± 0.8	> 96.1
Mean value, %**			< 0.1		1.6		0.5		> 98.2
"Southern"part of the STS									
5	9.0 ± 1.9	< 0.01	< 0.17	< 0.02	< 0.19	< 0.01	< 0.16	8.1 ± 1.6	> 99.5
7	4.6*	< 0.01	< 0.15	< 0.01	< 0.18	< 0.05	< 0.6	7.4 ± 1.5	> 99.0
8	4.7 ± 1.2	< 0.01	< 0.36	< 0.01	< 0.41	< 0.01	< 0.23	3.6 ± 0.7	> 99.0
9	5.4 ± 1.7	< 0.01	< 0.20	< 0.04	< 0.64	< 0.05	< 0.8	5.8 ± 1.1	> 98.3
10	9.2 ± 2.2	< 0.013	< 0.13	0.06 ± 0.01	0.6	< 0.01	< 0.09	9.8 ± 1.9	> 99.1
Mean value, %**			< 0.2.		< 0.4		< 0.4		> 99.0
Traces									
Thermonuclear test of the 12.08.1953 (400 kt) "Southeastern"part of the STS)									
1173	72 ± 8	< 0.01	< 0.02	< 0.08	< 0.1	0.07 ± 0.01	0.1	88 ± 8	99.8
1274	77 ± 10	< 0.01	< 0.01	0.4 ± 0.03	0.3	0.1 ± 0.02	0.1	130 ± 30	99.6
1520	137 ± 11	< 0.01	< 0.01	< 0.05	< 0.04	0.1 ± 0.01	0.1	117 ± 10	99.9
1745	31 ± 6	< 0.01	< 0.03	0.7 ± 0.05	1.5	0.8 ± 0.06	1.8	43 ± 5	96.7
1711	58 ± 8	< 0.01	< 0.01	0.3 ± 0.02	0.6	< 0.04	< 0.1	55 ± 11	99.3
1915	29 ± 4	< 0.01	< 0.1	< 0.05	< 0.2	< 0.04	< 0.2	22 ±3	> 99.5
725	7.0 ± 1.5	0.3 ± 0.02	2.2	0.4 ± 0.03	3.1	0.4 ± 0.04	3.2	11 ± 3	91.4
838	31± 6	0.1 ± 0.02	0.2	0.1 ± 0.02	0.2	0.1 ± 0.02	0.3	43 ± 7	99.2
761	19 ± 3	0.2 ± 0.02	0.9	0.2 ± 0.02	1.0	0.2 ± 0.03	1.0	18 ± 3	97.1
855	45 ± 5	< 0.05	< 0.1	0.1 ± 0.02	0.3	0.1 ± 0.02	0.3	37 ± 7	99.2
Mean value, %**			0.4		0.7		0.7		98.2
Surface nuclear test of the 24.09.1951 (38 kt) (" Southern" part of the STS)									
1	19.3*	< 0.01	< 0.03	< 0.01	< 0.04	< 0.016	< 0.04	36 ± 7	> 99.9
2	19.3*	< 0.01	< 0.02	< 0.01	< 0.03	< 0.03	< 0.06	52 ± 11	> 99.9
3	33 ± 4	< 0.01	< 0.04	0.06 ± 0.01	0.2	< 0.05	< 0.14	32 ± 4	> 99.6
4	55 ± 6	< 0.02	< 0.04	< 0.02	< 0.04	< 0.01	< 0.02	42 ± 6	> 99.9
6	18 ± 3	< 0.01	< 0.07	< 0.01	< 0.09	< 0.01	< 0.06	17 ± 3	> 99.8
Mean value, %**			< 0.04		< 0.01		< 0.01		> 99.8

* - mean radionuclide concentration in soil of the studied STS lands

** - when radionuclide specific activities in extracts were below the detection limit of the technique, these detection limits were accounted in the calculations of the relative content of the radionuclide speciation

"-" not determined

The peculiarity of the $^{239+240}$Pu radionuclide behavior in soils of the studied territories is the difference, although insignificant, between the content of the organically bound forms in the traces and on the background territories of the "southeastern" lands. There is no data available on organic form concentration at the "northern" and the "western" STS territories since a shorter scheme was used for determining the speciation, that excludes extraction of organically bound forms. The average content of $^{239+240}$Pu organically bound form in the trace from the thermonuclear test is 0.7 %, while at the "background" territory this value is twice higher – 1.6 % of the total content. This fact is in good agreement with the data, showing much lower parameters of $^{239+240}$Pu radionuclide transfer into the zonal plants growing at the fallout trace from the thermonuclear tests comparing with the background lands of the "southeastern" part of the STS [77, 105]. The impact of the relative content of organically bound $^{239+240}$Pu form and the root entry of the radionuclide into zonal plants at these territories should also be considered. Tightly bound form of radionuclide in soil dominates here (98.2 – 99.8 %). Easily available (exchangeable) form of the radionuclide has not been detected.

Speciation of ^{241}Am radionuclide. Table 22 reports on the ^{241}Am radionuclide speciation. Due to low concentrations of ^{241}Am and low solubility of the radionuclide typical for this territory, it is difficult to determine soluble forms of this radionuclide in soils. Low detection limits of the hardware and technique used did not allow to calculate the true relative content of ^{241}Am radionuclide speciation in soil. Therefore, the Table 22 provides only specific activities of the radionuclide speciation.

Table 22.

^{241}Am radionuclide speciation (Bq/kg)

Sampling point	^{241}Am content in soil	Exchangeable form (1M CH_3COONH_4)	Organic form (0.1norm NaOH)	Mobile form (1M HCl)	Tightly bound form(soil)
"Background"territories					
"Northern" part of the STS					
6	0.6 ± 0.2	< 0.3	-	< 0.6	< 0.5
2	0.6 ± 0.2	< 0.3	-	< 0.3	< 0.6
5	< 0.7	< 0.3	-	< 0.6	< 0.6
1	1.1 ± 0.3	< 0.3	-	< 0.3	< 0.5
7	1.7 ± 0.4	< 0.2	-	< 0.6	**1.9 ± 0.3**
10	1.3 ± 0.3	< 0.4	-	< 0.3	< 0.7
9	0.7 ± 0.2	< 0.2	-	< 0.3	< 0.5
8	2.2 ± 0.4	< 0.3	-	< 0.4	**2.5 ± 0.4**
4	0.9 ± 0.3	< 0.3	-	< 0.2	< 0.4
3	1.2 ± 0.2	< 0.4	-	**0.8 ± 0.2**	< 0.5
"Western" part of the STS					
369	1.3 ± 0.3	< 0.3	-	< 0.3	< 0.6
119	1.0 ± 0.3	< 0.6	-	< 0.3	< 0.5
77	< 0.8	< 0.5	-	**0.9 ± 0.2**	< 0.5
175	1.0 ± 0.4	< 0.8	-	< 0.3	< 0.5
560	1.4 ± 0.3	< 0.3	-	< 0.3	**1.0 ± 0.3**
457	0.7 ± 0.2	< 0.3	-	< 0.3	< 0.5
503	3.0 ± 0.4	< 0.4	-	**0.9 ± 0.2**	**1.1 ± 0.4**
7	1.3 ± 0.4	< 0.6	-	< 0.3	< 0.4

Sampling point	^{241}Am content in soil	Exchangeable form (1M CH_3COONH_4)	Organic form (0.1norm NaOH)	Mobile form (1M HCl)	Tightly bound form(soil)
"Southeastern" part of the STS					
937	4.4 ± 0.6	< 0.2	< 0.2	**1.8 ± 0.1**	**3.6 ± 0.3**
1052	4.4 ± 0.3	< 0.1	< 0.1	**0.8 ± 0.1**	**3.1 ± 0.3**
928	2.3 ± 0.5	< 0.2	< 0.2	**0.6 ± 0.1**	**1.2 ± 0.3**
1159	< 0.5	< 0.1	< 0.2	< 0.4	< 0.4
1557	< 0.52	< 0.1	< 0.2	< 0.2	< 0.3
1670	0.8 ± 0.2	< 0.1	< 0.2	**0.5 ± 0.1**	< 1.9
1760	1.8 ± 0.4	< 0.3	< 0.2	**0.5 ± 0.1**	< 1.7
2132	0.8 ± 0.2	< 0.1	< 0.3	< 0.3	< 0.3
2110	1.1 ± 0.4	< 0.1	< 0.2	**0.7 ± 0.1**	< 0.2
2011	2.2 ± 0.5	< 0.1	< 0.3	**0.4 ± 0.1**	**1.7 ± 0.3**
2302	0.8*	< 0.1	< 0.1	**0.3 ± 0.1**	< 0.2
424	2.4 ± 0.4	< 0.1	< 0.1	< 0.4	**4.2 ± 0.4**
365	1.0 ± 0.2	< 0.1	< 0.1	< 0.1	**1.1 ± 0.3**
258	< 0.7	< 0.1	< 0.1	**0.5 ± 0.1**	< 0.7
97	0,8 ± 0.2	< 0.1	< 0.2	< 0.3	< 0.6
113	1.7 ± 0.3	< 0.1	< 0.2	< 0.3	**1.0 ± 0.3**
189	0.9 ± 0.2	< 0.1	< 0.2	< 0.3	< 1.0
1187	0.8 ± 0.2	< 0.3	< 0.1	< 0.5	< 0.4
"Southern" part of the STS					
5	< 1.8	< 0.1	< 0.1	< 0.2	**1.1 ± 0.2**
7	< 2.4	< 0.1	< 0.1	< 0.2	<0.5
8	< 1.3	< 0.1	< 0.1	< 0.1	**0.6 ± 0.1**
9	< 1.3	< 0.1	< 0.1	< 0.4	< 0.2
10	< 1.8	< 0.1	< 0.18	< 0.2	**0.8 ± 0.2**
Zones of the "plume" passage					
Thermonuclear test of the 12.08.1953 (400 kt) ("Southeastern" part of the STS)					
1173	4.0 ± 0.8	< 0.2	< 0.2	**0.3 ± 0.1**	**4.3 ± 0.4**
1274	2.5*	< 0.2	< 0.2	**0.5 ± 0.1**	**9.5 ± 0.6**
1520	4.2 ± 0.6	< 0.1	< 0.2	**0.9 ± 0.1**	**5.4 ± 0.6**
1748	0.7 ± 0.2	< 0.1	< 0.2	**0.6 ± 0.1**	< 1.9
1745	3.2 ± 0.8	< 0.1	< 0.2	**1.2 ± 0.1**	**1.2 ± 0.3**
1711	4.5±1.0	< 0.1	< 0.2	**0.5 ± 0.1**	**2.0 ± 0.4**
1915	1.8 ± 0.4	< 0.2	< 0.3	**0.5 ± 0.1**	< 1.8
725	< 0.8	< 0.2	< 0.1	< 0.2	< 0.4
838	< 3.0	< 0.2	< 0.2	**0.7 ± 0.1**	**1.2 ± 0.3**
761	< 0.6	< 0.1	< 0.2	**0.3 ± 0.1**	< 0.4
855	< 3.0	< 0.1	< 0.2	**0.5 ± 0.1**	**1.2 ± 0.3**
Surface nuclear test of 24.09.1951 (38 kt) "Southern"territory of the STS)					
1	< 3.7	< 0.1	< 0.2	< 0.3	**2.4 ± 0.1**
2	< 3.7	< 0.1	< 0.1	**0.4 ± 0.1**	**3.2 ± 0.2**
3	< 3.3	< 0.1	< 0.2	< 0.2	**2.0 ± 0.2**
4	< 7.2	< 0.2	< 0.1	< 0.1	**3.8 ± 0.3**
6	< 1.9	< 0.1	< 0.1	< 0.1	**1.4 ± 0.2**

*- average radionuclide contents in soils of the studied STS lands
"-" not determined
Quantitative data are marked with bold

The radionuclide concentrations in almost all samples of exchangeable and organic forms were below the detection limit of the equipment and technique used. Quantitative amounts of ^{241}Am were detected in acid extracts and in tightly bound form. Almost in all samples taken at the trace zones, maximal concentration of the radionuclide is associated with the tightly bound form. The percentage of the mobile form varies from 5.0 to 36.8 % from the tightly bound form concentration, except for the point 1745, where the concentration of the tightly bound form can be compared with that of the mobile form of this radionuclide. At the "background" territories in most of the samples, specific concentration of the mobile form is not less than a half of the tightly bound form concentration, and in some individual cases, even exceeds its concentration. Comparative analysis of the speciation for the studied transuranium radionuclides allows to make a conclusion on better solubility of ^{241}Am in soils comparing with $^{239+240}$Pu isotopes.

Speciation of ^{90}Sr radionuclide. ^{90}Sr radionuclide study is of particular interest. As a rule, ^{90}Sr radionuclide in soils can be characterized by high mobility and biological availability due to physical and chemical properties of the radionuclide and mechanisms of its interaction with soil components. ^{90}Sr data are shown in the Table 23.

Table 23.

The content of ^{90}Sr radionuclide speciation (Bq/kg, percentage of the total content of all forms)

Sampling point	^{90}Sr content in soil	Exchangeable form (1M CH_3COONH_4)		Organic form (0.1 and NaOH)		Mobile form (1M HCl)		Tightly bound form (soil)	
		Bq/kg	%	Bq/kg	%	Bq/kg	%	Bq/kg	%
"Background" territories									
"Northern" part									
6	12 ± 3	4.7 ± 0.4	51.4	-	-	< 2.0	< 21.5	2.5 ± 0.7	27.2
2	10*	5.1 ± 0.4	> 63.3	-	-	< 1.1	< 13.1	< 1.9	< 23.6
5	61 ± 12	44 ± 4	77.0	-	-	10 ± 1	17.7	3.0 ± 1.0	5.3
1	10*	4.7 ± 0.5	> 57.7	-	-	< 1.3	< 16.3	< 2.1	< 26.0
7	10*	6.0 ± 0.7	56.2	-	-	2.2 ± 0.6	20.3	< 2.5	< 23.4
10	10*	3.8 ± 0.4	> 57.5	-	-	< 1.1	< 16.9	< 1.7	< 25.6
9	10*	3.3 ± 0.5	46.2	-	-	< 1.4	< 20.1	< 2.4	< 33.6
8	19 ± 3	4.5 ± 0.5	> 60.9	-	-	< 1.2	< 16.1	< 1.7	< 23.0
4	10*	3.7 ± 0.4	> 63.8	-	-	< 0.7	< 11.9	< 1.4	< 24.3
3	10*	4.0 ± 0.5	> 62.4	-	-	< 1.0	< 15.7	< 1.4	< 22.0
Mean value, %**			>59.6%		-		< 17.0		< 23.4
"Western" part									
369	8.1 ± 3.0	6.6 ± 0.7	60.4	-	-	2.3 ± 0.6	21.3	< 2,0	< 18.3
119	16 ± 3	3.8 ± 0.6	28.1	-	-	< 1.5	< 11.2	8.0 ± 3.0	60.7
77	6 ± 1.2	5.1 ± 0.6	50.4	-	-	2.8 ± 0.5	27.7	< 2.2	< 21.9
175	5.8*	1.5 ± 0.6	5.1	-	-	3.6 ± 0.5	11.9	25 ± 2	83.0
560	7.9 ± 3.0	4.1 ± 0.6	40.8	-	-	2.9 ± 0.8	29.2	3.0 ± 1.0	30.0
457	5.8*	2.0 ± 0.6	18.5	-	-	6.0 ± 0.6	56.8	< 2.6	< 24.6
503	8.2 ± 0.8	3.5 ± 2.0	35.2	-	-	2.6 ± 0.6	25.6	4.0 ± 1.0	39.2
7	2.8 ± 0.5	2.8 ± 0.6	> 42.8	-	-	< 1.5	< 23.2	< 2.2	< 34.0
Mean value, %**			35.2		-		25.9		39.0

Sampling point	^{90}Sr content in soil	Exchangeable form (1M CH_3COONH_4)		Organic form (0.1 and NaOH)		Mobile form (1M HCl)		Tightly bound form (soil)	
		Bq/kg	%	Bq/kg	%	Bq/kg	%	Bq/kg	%
"Southeastern"part of the STS									
937	119 ± 20	2.6 ± 0.3	2.6	<0.6	< 0.6	1.1 ± 0.3	1.0	99 ± 19	95.8
1052	84.5 ± 20	< 0.3	< 0.5	6.5 ± 0.5	10.6	1.8 ± 0.3	2.9	53 ± 8	86.0
928	8.8 ± 1.3	4.6 ± 0.3	264	<0.4	< 2.3	2.5 ± 0.3	14.5	< 9,8	< 56.7
1159	21 ± 5	3.8 ± 0.3	16.4	<0.5	< 2.0	2.0 ± 0.4	8.6	17 ± 2.6	73.0
1557	5.5 ± 1.4	2.5 ± 0.4	34.4	<0.5	< 74	2.8 ± 0.3	37.9	2.0 ± 0.5	20.3
1670	< 8.3	1.5 ± 0.3	24.1	<0.5	< 7..6	1,5 ± 0.3	24.1	3.0 ± 1,0	44.1
1760	< 8.3	2.1 ± 0.3	42.5	<0.5	< 10.7	< 0.7	< 14.7	< 1.6	< 32.1
2132	11± 2	4.5 ± 0.4	50.1	<0.5	< 5.5	3.0 ± 0,3	34.2	< 0.9	< 10.1
2110	3.4± 0.8	1.9 ± 0.4	37.9	<0.5	< 9.3	1.3 ± 0,3	26.5	< 1.3	< 26.3
2011	4.0± 1.0	2.5 ± 0.3	46.1	<0.5	< 10.0	1.4 ± 0,3	25.3	< 1.0	< 18.5
2302	4.4± 0.9	2.9 ± 0.4	48.3	<0.6	< 9.2	1.3 ± 0,3	21.3	< 1.3	< 21.3
424	6.2*	5.3 ± 0.4	26.2	<0.5	< 2.6	3.7 ± 0,3	18.3	11 ± 3	52.8
365	6.2*	2.6 ± 0.3	13.8	<0.3	< 1.7	1.5 ± 0.3	8.2	< 14.4	< 76.3
258	8.5 ± 0.9	5.4 ± 0.4	31.4	<0.4	< 2.2	3.2 ± 0.3	18.8	< 8.2	< 47.7
97	8.3 ± 1.1	1.9 ± 0.3	17.1	<0.3	< 2.9	0.8 ± 0.2	7.4	< 8.0	< 72.6
113	6.2*	6.1 ± 0.4	23.0	<0.3	< 1.3	3.3 ± 0.3	12.2	17 ± 5	63.5
189	10.2 ± 2.0	5.1 ± 0.4	32.8	<0.4	< 2.5	2.4 ± 0.3	15.4	< 7.6	< 49.4
1187	4.1 ± 1.0	2.7 ± 0.3	21.3	<0.4	< 3.5	1.0 ± 0.3	7.7	< 8.7	< 67.5
Mean value, %**			27.5		< 5.1		16.6		50.8
"Southern" part of the STS									
5	5.1 ± 0.8	2.9 ± 0.3	19.3	< 0.5	< 3.6	1.5 ± 0.3	9.9	< 10.1	< 67.2
7	14.4*	1.3 ± 0.3	10.3	< 0.3	< 4.1	< 0.8	< 6.4	10 ± 4	79.2
8	14.4*	2.9 ± 0.3	14.5	< 0.6	< 3.2	< 0.6	< 2.8	16 ± 4	79.5
9	14.4*	3.6 ± 0.3	18.9	< 0.6	< 3.0	2.8 ± 0.4	14.6	12 ± 4	63.5
10	14.4*	3.6 ± 0.3	17.8	< 0.7	< 3.3	1.4 ± 0.3	7.1	14 ± 4	71.8
Mean value, %**			16.2		< 3.4		8.2		72.3
Traces									
Thermonuclear test of the 12.08.1953 (400 kt) (**"**Southeastern**"** part of the STS)									
1173	1,750 ± 350	9.2 ± 0.4	0.6	< 1.0	< 0.1	4.2 ± 0.3	0.3	1,500 ± 300	99.0
1274	2,500 ± 400	3.9 ± 0.3	0.2	< 0.5	< 0.02	3.7 ± 0.4	0.2	2,170 ± 390	99.6
1520	2,400 ± 400	6.3 ± 0.4	0.3	< 0.5	< 0.02	4.3 ± 0.4	0.2	2,400 ± 360	99.5
1745	650 ± 130	6.0 ± 0.4	0.9	< 0.7	< 0.1	2.2 ± 0.3	0.3	660 ± 130	98.7
1711	810 ± 160	2.7 ± 0.3	0.3	< 0.5	< 0.05	2.1 ± 0.3	0.2	1,020 ± 150	99.5
725	118 ± 24	3.8 ± 0.3	2.7	< 0.4	< 0.3	2.6 ± 0.4	1.9	130 ± 25	95.1
838	430 ± 90	4.9 ± 0.3	0.8	< 0.4	< 0.1	3.9 ± 0.4	0.7	580 ± 130	98.4
761	240 ± 50	5.0 ± 0.4	2.3	< 0.7	< 0.3	4.2 ± 0.4	2.0	204 ± 40	95.4
855	520 ± 855	6.9 ± 0.4	1.1	48	7.9	5.1 ± 0.3	0.8	550 ± 110	90.2
Mean value, %**			1.0		< 1.0		0.7		97.3
Surface nuclear test of 24.09.1951 (38 kt) (**"**Southern**"** part of the STS)									
1	31,6*	5.3 ± 0.4	8.6	< 0.6	< 1.0	1.9 ± 0.4	31	54 ± 6	87.3
2	31,6*	4.4 ± 0.4	5.7	< 0.9	< 1.3	2.8 ± 0.6	3.7	68 ± 7	89.3
3	31,6*	3.5 ± 0.4	7.2	< 0.6	< 13	< 0.8	< 1.5	44 ± 9	89.9
4	66 ± 16	3.6 ± 0.3	4.6	< 0.4	< 0.5	2.3 ± 0.3	2.9	72 ± 8	92.0

Sampling point	^{90}Sr content in soil	Exchangeable form (1M CH_3COONH_4)		Organic form (0.1 and NaOH)		Mobile form (1M HCl)		Tightly bound form (soil)	
		Bq/kg	%	Bq/kg	%	Bq/kg	%	Bq/kg	%
6	31,6*	2.8 ± 0.3	8.8	< 0.5	< 1.6	< 0.4	< 1.2	29 ± 7	88.4
Mean value, %			7.0		<1.1		2.5		89.4
"Experimental Field" site									
1	29,000±3.800	105 ± 15	0.3	< 2.6	< 001	126 ± 17	0.4	35,000±4,200	99.3
2	7,600±1,200	55 ± 5	0.7	< 1.3	< 0.02	55 ± 5	0.7	7,800±1,200	98.6

* - mean radionuclide concentration in soil of the studied STS lands

** - when radionuclide specific activities in extracts were below the detection limit of the technique, these detection limits were accounted in the calculations of the relative content of the radionuclide speciation

"-" not determined

The ^{90}Sr investigation showed the presence of significant amounts of easily accessible forms (exchangeable forms) and those pose potentially accessible reserve for plants (mobile form) in soil in addition to the tightly bound forms. At that, the ratio between the exchangeable and the non-exchangeable forms is different for both the background sites and the zones with increased radiation background.

Maximum concentrations of the exchangeable and the mobile ^{90}Sr forms were found at the "northern" and the "western" territories which were subjected least of all to the impact of the fallouts from STS tests. The exchangeable form content at the "northern" and the "western" territories is over 59.6%, and less than 35.2% of the total amount of all forms, respectively. The percentage of the mobile form is about 17% and 25.9% at the "northern" and the "western" territory, respectively. Therefore, these territories are characterized by minimal concentrations of ^{90}Sr tightly bound form (less than 23.4 and 39.0%, respectively). For the "western" part, significant dispersion in data comparing with the mean values is typical. Background territories of the "southeastern" and the "southern" parts of the STS were certainly impacted by nearby zones of fallout from surface tests at the " Experimental Field". So, at the "southeastern" territory, mean concentration of the ^{90}Sr exchangeable form falls to 27.5%. At that, minimum concentration of ^{90}Sr in the exchangeable form was found in points closest to the trace boundary (p. 1052, p. 937). The percentage of the tightly bound form is less than 51.6%. In the "southern" part of the STS the impact of the trace is more clearly observed: percentage of the exchangeable form here is minimal – 16.2%, while percentage of the tightly bound form is maximal among the considered zones – i.e. in average 72.3% from the total amount of all forms. Significant variability in concentrations of these radionuclides speciation due to non-uniform radionuclide contamination of soil was revealed at the "southeastern" territories.

In the zones of fallouts traces from the surface nuclear tests at the "Experimental Field" site, ^{90}Sr radionuclide behavior differs fundamentally. The tightly bound form dominates here. Its concentration at the "southeastern" and the "southern"territories is up to 97.3% and 89.4%, respectively. Average percentage of the exchangeable ^{90}Sr form at the trace and within the "southeastern" territory decreases by two orders of magnitude if compared to the background territories, while in the "southern" part of the STS – for more than 2 times. According to the character of the radionuclide speciation distribution

in soils, the fallout traces from the surface tests are similar to the "Experimental Field" site. It should be noticed, that the "Experimental Field" site typically has minimal values of the relative mobility and the radionuclides bioavailability in the STS soils [115].

Figure 118 shows the dependence of ^{90}Sr radionuclide solubility in soil at the axis of trace from the 1953 thermonuclear explosion as a function of distance to the "P-1" site, the test venue. An insignificant increase in percentage of the exchangeable and the mobile forms of this radionuclide was found on the areas maximally distant to the test epicenters (points 838, 855) at the trace axis.

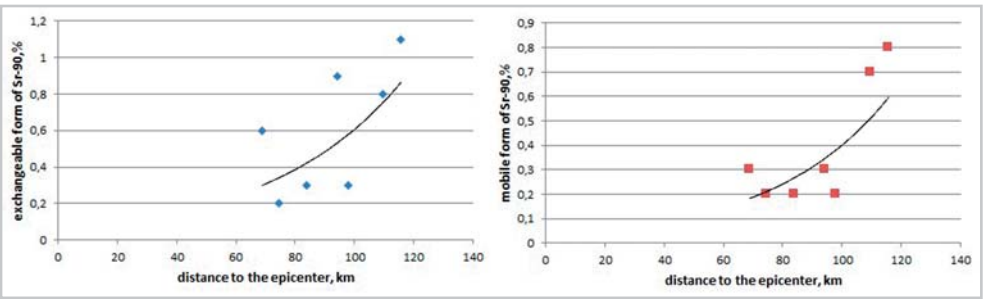


Figure 118. Increase of relative content of the exchangeable and the mobile forms of ^{90}Sr in soil at the trace axis as a function of the distance to the explosion epicenter

Provided results are consistent with the previous studies which revealed an increase in the radionuclides accumulation by zonal plants along the trace axis at higher distances from the test epicenter [116].

Therefore, the ^{90}Sr speciation indicate absolutely different character of the radioactive contamination in soils of the conditionally "background" STS territories suffered from global fallouts and radioactive fallouts from local surface nuclear tests.

Based on the studies performed at the conditionally "background" STS territories subjected to various contamination sources such as global fallouts and radioactive fallouts resulted from local nuclear tests at the "Experimental Field", the following peculiarities were found:

– differences were found in the content of the exchangeable and the mobile forms of the ^{137}Cs radionuclide at the "background" territories and within the traces, which can determine the difference in bioavailability of ^{137}Cs for plants growing at these territories. A decrease of the exchangeable and the mobile form contents was found in the zone of the fallout traces from the surface nuclear tests at the "southeastern" (3 and 3.5 times, respectively) and the "southern"(1.5 and 2 times, respectively) parts of the STS if compared with its "background" territories (those not influenced by the local tests). At that, this change is more clearly expressed within the trace zone from the 1953 thermonuclear test than at the trace from the 1951 surface test. A dominating part of ^{137}Cs radionuclide in studied soil can be found in the tightly bound form (at least 93 %), that is typical for this radionuclide;
– some insignificant difference in quantity of the $^{239+240}$Pu organic fraction at the "southeastern" part of the STS was found. This difference in the trace from the 1953 thermonuclear test is 0.7 %; at the "background" part of this territory this value

is twice higher: 1.6%. ^{241}Am radionuclide was not found in the easily accessible (exchangeable) form. The radionuclide $^{239+240}$Pu in the conditionally "background" soils of STS territory can be mainly found in the tightly bound form (at least 98%);

– quantitative amounts of ^{241}Am were found in the acid extracts and in the tightly bound form. In the trace zones, the radionuclide was mainly found in the tightly bound form. At the "background" territories, insignificant increase of the radionuclide mobile form percentage against the trace zones (and in some cases its dominating concentration over the tightly bound form) was found. No ^{241}Am radionuclide was found in either exchangeable or organic forms;
– the quantitative ratio of the ^{90}Sr radionuclide speciation in soils of the conditionally "background" territories is not uniform. Soils of the STS "background" territories ("Northern" and "Western" parts) typically have maximum percentage of the exchangeable (at least 59.6 and 35.2%) and the mobile (17.0 and 25.9%) forms of the radionuclide. In vicinity of the traces at the "Southeastern" and the "Southern" parts of the STS, the content of the exchangeable (27.5 and 16.2%) and the mobile (16.6 and 8.2%) forms decline significantly. These parts of the STS are characterized by minimal percentage of the exchangeable (1.0 and 7.0%) and the mobile (0.7 and 2.5%) forms of the radionuclide and by the dominating tightly bound form (97.3 and 89.4%), according to their character at the "Experimental Field" – the venue of surface nuclear explosions. Respective changes in the ^{90}Sr radionuclide speciation was found along the trace axis of the 1953 thermonuclear surface test (P-1). At higher distances, the percentage of exchangeable and mobile forms of the radionuclides also increases. Differences revealed in the ^{137}Cs, $^{239+240}$Pu and ^{241}Am speciation at the traces from the surface tests and the "background" territories with the radionuclides concentrations at the level of background fallouts are insignificant. Available data can be applied as basic criteria to characterize the speciation of these radionuclides in soils at the conditionally "background" STS territories. This would allow for optimizing the further studying of ^{137}Cs, $^{239+240}$Pu and ^{241}Am speciation at the conditionally "background" STS territories. The ^{90}Sr radionuclide speciation at STS serve as an indicator for differences in the character of the radioactive contamination resulted from the fallouts (both, surface nuclear tests and global fallouts). This indicator can be used as an additional parameter for identification of the traces from surface nuclear explosions.

3.2. VEGETATION COVER

Vegetation cover at the STS territory is investigated with the purpose of the lands' transfer for economical turnover; this is one of the most important stages of the radioecological works, since the plants are the integral part of "soil-plants-animals-humans" food chain. The key parameter in this case is the specific activity of the radionuclides in the aboveground part of the plants that can be determined in direct measurements or calculated using specific activity of the radionuclides in soil. For quantitative assessment of the radionuclides transfer from soil into plants, one of the most widely used factors is the accumulation factor (A_r) – the ratio between a radionuclide content per weight unit in vegetation and soil [117].

At the present time quite a lot of data is available on natural vegetation of pasture cenoses in respect of A_fs of ^{137}Cs (n > 120) and ^{90}Sr (n > 55). At that, A_f values available for various radioactively contaminated territories vary within quite a wide range: ^{137}Cs A_f– from 0.01 to 2.6; ^{90}Sr A_f– from 0.4 to 2.6 [118]. There are quite limited and rare published data on A_f for the ^{241}Am (n ≈ 11) and $^{239+240}$Pu (n ≈ 10) transuranium radionuclides [118], which are common for the STS contamination.

Considering large area of the STS, use of the accumulation factors A_f for assessment radioactive contamination in vegetation is more cost-effective. The nature of the processes during nuclear tests and experiments with radioactive substances determine the character of radioactive contamination at various STS territories; one can therefore expect that the A_fs can significantly vary for different STS areas. To get the reliable radionuclide A_f mean values for all the STS territories, a focused study should take into account the variety of types of the tests and the mechanisms of the related radioactive contamination. The works focused on the determination of the average A_fs for the dominating plants of natural grazing cenoses both at the main technical sites and at the conditionally "background" territories has been in progress at STS for many years [119].

3.2.1. Review of the data on accumulation factors (A_f) of the artificial radionuclides at the technical sites of the STS

To obtain the artificial radionuclides accumulation factors (A_fs) at the STS technical sites, the focused studies have been performed in the zones of radioactively contaminated streamflows at the "Degelen" test site [120], in the epicenters of surface tests at the "Experimental Field" [121] and at the testing grounds for warfare radioactive agents testing at the "4A" site [122]. Additionally, the traces from radioactive fallouts were identified and outlined [123].

The distribution of ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}$Pu A_f values for the abovementioned territories is presented in a form of an occurrence histogram log A_f below (Figure 119).

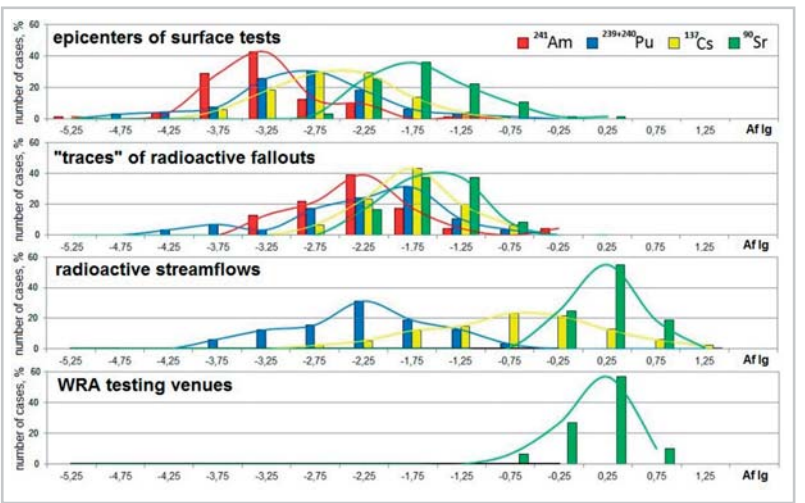


Figure 119. Distribution of ^{241}Am, $^{239+240}$Pu, ^{137}Cs and ^{90}Sr log A_f at the studied territories

As one can see from the histograms, the A_f ranges are different both for different radionuclides and for different territories. Accumulation parameters of the considered radionuclides change within quite a broad range. At average, minimal accumulation of all the radionuclides was noticed at the "Experimental Field". Relatively higher accumulation rate was found at the traces of radioactive fallouts. At that, the highest ^{137}Cs and ^{90}Sr accumulation factors are typical for the zones of radioactively contaminated streamflows and WRA testing grounds.

The histogram also demonstrates that the distribution character of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am log A_f is almost normal; therefore, the geometrical mean (GM) values can be reliably used as average A_f values for these radionuclides at the studied territories. Therefore, Table 24 provides the determined A_fs for ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am radionuclides.

Table 24.

Average accumulation factors determined for ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am radionuclides at the investigated territories

Territory	Average radionuclides accumulation factors			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
	n = 275	n = 276	n = 159	n = 96
Epicenters of surface tests	0.0028	0.023	0.0014	0.00052
Traces from radioactive fallouts	0.020	0.026	0.0068	0.0056
Zones of radioactively contaminated streamflows	0.20	1.7	0.0059	-
WRA testing venues	-	1.2	-	-
n – total number of cases				

In average, the differences in A_fs for ^{137}Cs can be as high as 71 times, ^{90}Sr – 74 times, $^{239+240}$Pu – 14 times, ^{241}Am – 11 times. Nevertheless, the radionuclides decrease sequence in terms of their accumulation in plants looks as follows: ^{90}S A_f > ^{137}Cs A_f > $^{239+240}$Pu A_f > ^{241}Am A_f. ^{90}Sr A_f exceeds that for ^{137}Cs in average for 8 times and is up to 16 times higher than that for $^{239+240}$Pu. A_f values for $^{239+240}$Pu exceed those for ^{241}Am for 3 times.

In general, it can be assumed that the A_fs at the "Experimental Field" is a kind of a minimum that could be found at the STS territory and the A_fs at the radioactively contaminated streamflows and the WRA testing sites are maximal. The most important in terms of the lands transfer into economical turnover are the A_fs at the radioactive fallout traces at conditionally "background" territories.

3.2.2. Investigation of the accumulation factors (A_fs) of artificial radionuclides at conditionally "background" territory of the STS

Artificial radionuclides accumulation factors (A_fs) were investigated at the background territories for 5 years (2009-2013) at the "northern", the "western" and the "southeastern" parts of the STS [69, 77, 79] (Figure 120).

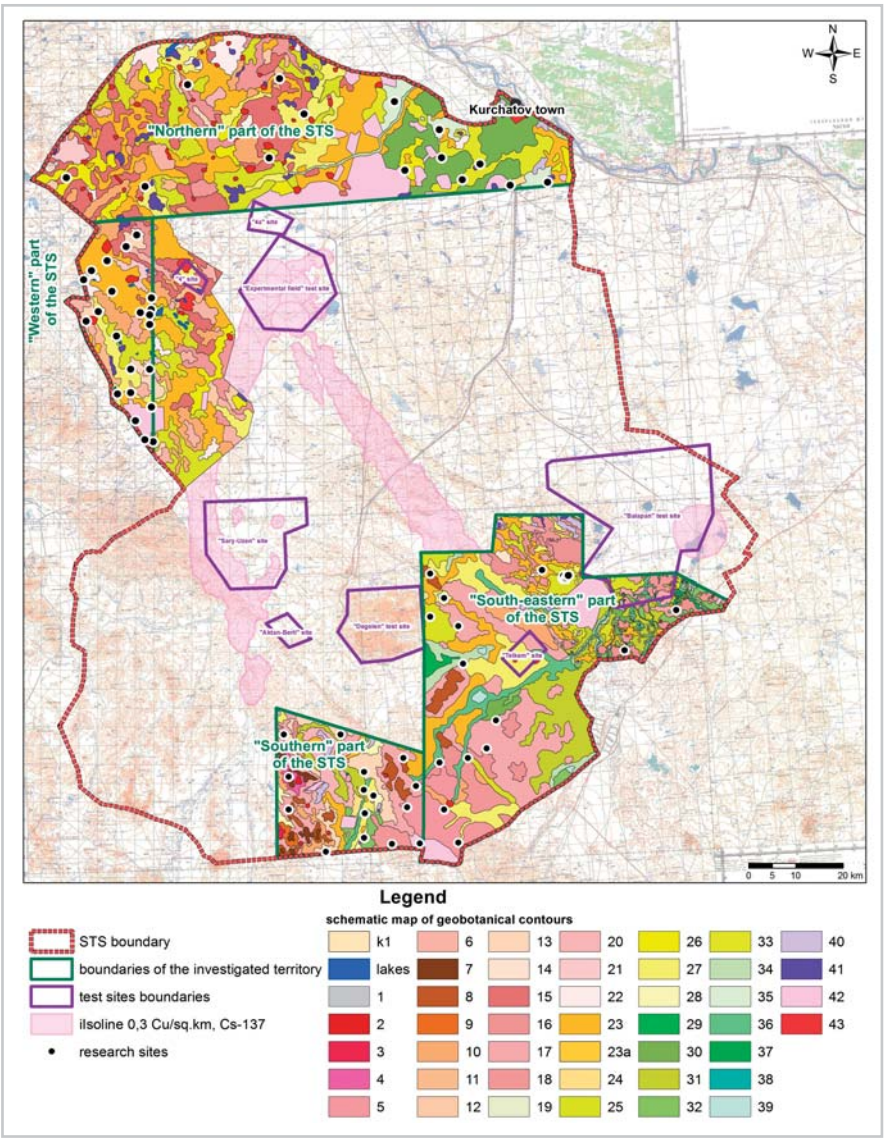


Figure 120. Location of the conditionally "background" territories

Geobotanic researches were conducted at all the abovementioned territories as well as the "southern" part of the STS, including description of the land cover with emphasizing vegetation communities, species composition and dominating plants. As the result, schematic maps of geobotanic contours (Figure 120) were built for "northern", "western", and "southern" parts of the STS were built. The legend is given in the Appendix.

In total, 55 research sites were arranged at the territory including: 14 – in the "northern" part, 22 – in the "western" part and 19 – in the "southeastern" part (Figure 120).

At each of the sites, mixed samples of soil (using the envelop method to the depth of 5 cm) and the aerial parts of plants (sampling area ~ 2 sq. m) were taken. Herbage of the area is represented by steppe herbs with dominating feather-grass (*Stipa capillata*, *S. sareptana*, *S. lessingiana*), sheep fescue (*Festuca valesiaca*) and wormwoods (*Artemisia gracileccens*, *A. frigida*).

Vegetation samples were flushed, rinsed 2-3 times with distilled water, dried at the temperature of 80-100 °C and grinded in a laboratory mill. After that, the samples were subjected to thermal concentration (carbonization, ashing). Dry residue was carbonized, preventing sample inflaming, until the black residue was formed. After that the samples were cooled, mashed and put into porcelain cups or bowls for further ashing. Initial temperature was increased to 200˚C for 50-60 minutes, with further switching the muffle furnace to the maximum temperature: ashing temperature for further determining of ^{137}Cs and ^{241}Am was 400 ^{0}C, ^{90}Sr – 550 ^{0}C, $^{239+240}$Pu – 650 ^{0}C. Soil samples were dried to air-dry state at the temperature of 60-70 ^{0}C, and weighted after removal of large stones and inclusions (roots of plants). After that, the whole sample was carefully mixed (portion by portion) and mashed with pounder in a porcelain jar and sieved through a 1-mm sieve.

Specific activity of the radionuclides in the soil and plant samples was measured using standard techniques [93, 124]. Specific activity of ^{137}Cs and ^{241}Am radionuclides was determined using Canberra GX-2020 gamma-spectrometer, while ^{90}Sr and $^{239+240}$Pu were measured after radiochemical extraction at the TRI-CARB 2900 TR beta-spectrometer and Canberra (mod.7401) alpha-spectrometer, respectively. Radionuclide concentrations in plants were determined in ash with subsequent re-calculation per dry matter. The detection limit for ^{137}Cs was 1 Bq/kg (for plant samples) and 4 Bq/kg (for soil samples), ^{241}Am – 0.02 and 0.5 Bq/kg, $^{239+240}$Pu – 0.1 and 1 Bq/kg, ^{90}Sr – 1 and 5 Bq/kg, respectively. Measurement error for ^{137}Cs and ^{241}Am did not exceed 10-20 %, ^{90}Sr – 15-25 %, $^{239+240}$Pu – 30 %.

Specific activity values for ^{137}Cs in soil of the studied area ranged from 4.5 to 110 Bq/kg, ^{241}Am – below 17 Bq/kg. ^{90}Sr and $^{239+240}$Pu contents in soil in some individual cases was as high as 200 Bq/kg (Table 25).

Table 25.

Specific activity of the radionuclides in soil

Sampling point	Range of specific activity values, Bq/kg							
	^{137}Cs		^{90}Sr		^{241}Am		$^{239+240}$Pu	
	min	max	min	max	min	max	min	max
"Northern" part of the STS	24±1	110±2	-*	13±6.4	0.5±0.2	7.3±0.4	6.2±0.3	14.2±0.7
"Western" part of the STS	4.5±0.5	79±2	-*	28±8	-*	17±4	-*	101±6
"Southeastern" part of the STS	24±2	87±2	-*	200±10	-*	5.3±0.5	1.7±0.2	190±6
* – below the detection limit								

Accumulation factors were found for the radionuclides ^{137}Cs, ^{90}Sr and $^{239+240}$Pu. For ^{241}Am the A_f value was not found due to lack of quantitative values for this radionuclide activity in plants (Table 26).

Table 26.

^{137}Cs, ^{90}Sr and $^{239+240}$Pu accumulation factors in plants

Radionuclides	n	min – max	GM	GSD	AM	SD
"Northern" part of the STS						
^{137}Cs	15	0.003 – 0.056	0.014	2.6	0.020	0.016
^{90}Sr	1	–	–	–	–	–
$^{239+240}$Pu	9	0.012 – 0.095	0.024	2.1	0.033	0.031
"Western" part of the STS						
^{137}Cs	12	0.01 – 0.15	0.034	2.6	0.052	0.050
^{90}Sr	3	0.15 – 1.73	0.53	3.4	0.81	0.82
$^{239+240}$Pu	13	0.002 – 0.21	0.018	4.1	0.042	0.060
"Southeastern" part of the STS						
^{137}Cs	13	0.012 – 0.3	0.063	2.8	0.10	0.10
^{90}Sr	14	0.0079 – 0.84	0.22	4.2	0.39	0.29
$^{239+240}$Pu	11	0.00075 – 0.11	0.018	3.6	0.031	0.031
n – number of cases; GM – geometrical mean, GSD –standard deviation from geometric mean value, AM – arithmetic mean, SD – standard deviation from arithmetic mean						

According to the study results, parameters of radionuclide accumulation in plants at conditionally "background" territories of the STS vary within a wide range. ^{137}Cs A_f values range within 2 orders of magnitude while for ^{90}Sr and $^{239+240}$Pu - 3 orders of magnitude. ^{90}Sr is the most intensively accumulated radionuclide in plants and $^{239+240}$Pu is the least accumulated one.

For better demonstration, all the obtained A_f values for conditionally "background" territories were generalized. Relative distribution of the A_fs obtained for ^{137}Cs, ^{90}Sr and $^{239+240}$Pu is presented as a histogram of occurrence, expressed as denary logarithms (log A_f) (Figure 121).

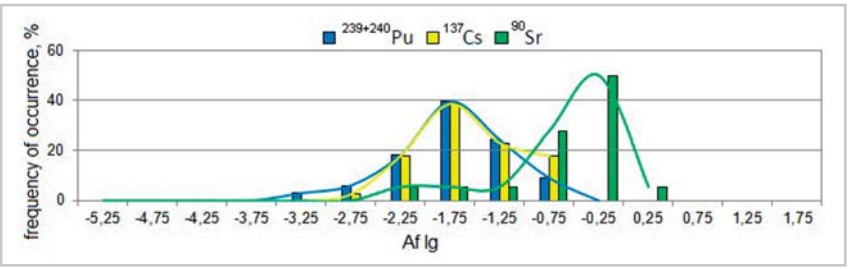


Figure 121. ^{137}Cs, ^{90}Sr and $^{239+240}$Pu Log A_F values distribution for steppe herbs at the conditionally "background" territories

The above histograms demonstrate that accumulation of all the studied radionuclides varies within the wide range in the decreasing sequence as follows:

$$^{90}\text{Sr}\ A_f > {}^{137}\text{Cs}\ A_f > {}^{239+240}\text{Pu}\ A_f$$

For quantitative assessment of the difference in the radionuclides accumulation in plants, the following ratio values were calculated:

$^{90}Sr\ A_f$ / $^{137}Cs\ A_f \approx 8.3$;

$^{137}Cs\ A_f$ / $^{239+240}Pu\ A_f \approx 1.6$;

Therefore, taking ^{90}Sr radionuclide accumulation as 1, the decrease sequence looks as follows:

$^{90}Sr\ A_f$	>	$^{137}Cs\ A_f$	>	$^{239+240}Pu\ A_f$
1		0.12		0.075

Character of the lg A_f distribution at the conditionally "background" territories is close to the normal one, therefore, use of geometrical mean values (GM) as a mean A_f values is appropriate:

$^{137}Cs\ A_f = 0.030$; $^{90}Sr\ A_f = 0.25$; $^{239+240}Pu\ A_f = 0.019$

3.2.3. Methodology for assessment of radionuclide contamination of soil cover

3.2.3.1. Recommendations for assessment of radionuclide contamination of soil cover

Considering the difference in the accumulation factors (A_fs) of artificial radionuclides for technical sites and conditionally "background" territories for assessment of the radionuclide contamination of the STS soil cover we recommend to separate the conditionally "background" territories themselves and the areas radiologically impacted due to surface tests, radioactive fallouts (near or distant), radionuclides proliferation with water streams and WRA tests.

Studying the radionuclide contamination of soil cover at the areas contaminated due to surface tests, its recommended to use the A_fs obtained for epicenters of the surface tests at the "Experimental Field" as follows: A_f of ^{137}Cs – 0.0028; ^{90}Sr – 0.023; $^{239+240}Pu$ – 0.0014; ^{241}Am – 0.00052.

To assess the radionuclide contamination of land cover due to radioactive fallouts (near or distant), it is recommended to use the A_fs obtained for the radioactive fallout traces as follows: $^{137}Cs\ A_f$ – 0.020; ^{90}Sr – 0.026; $^{239+240}Pu$ – 0.0068; ^{241}Am – 0.0056.

To determine radionuclide contamination of land cover in the zones of radionuclide take out with streamflows, it is recommended to use the following A_fs obtained for the "Degelen" site in areas of radioactively contaminated streamflows from the tunnels: ^{137}Cs – 0.20; ^{90}Sr – 1.7; $^{239+240}Pu$ – 0.0059.

To assess radionuclide contamination of the land cover at the conditionally "background" territories, it is recommended to use the A_fs obtained in "northern", "western" and "southeastern" parts of the STS: ^{137}Cs – 0.030; ^{90}Sr – 0.25; $^{239+240}Pu$ – 0.019. The same values of ^{137}Cs and $^{239+240}Pu\ A_f$s are recommended for use at the WRA testing sites since it is expected that this territory is only contaminated with ^{90}Sr radionuclide. Therefore, as

^{90}Sr A_f for WRA testing venues it is recommended to use the value 1.2 obtained for the testing ground "4A" .

Due to the lack of the ^{241}Am A_f quantitative data for conditionally "background" territories, zones of radioactively contaminated streamflows and WRA testing venues, it is recommended to use the value 0.002 from the IAEA data on loamy soils and pastures typical for the (2009) [118].

3.2.3.2. Applicability verification of the proposed recommendations

To verify the applicability of the proposed recommendations, the territory of the "southern" part of the STS was considered (Figure 120): for that, according to the data on radionuclides areal distribution, two zones were identified in soil as follows: 1 – zone of radioactive fallout and 2 – conditionally "background" territory (Figure 122).

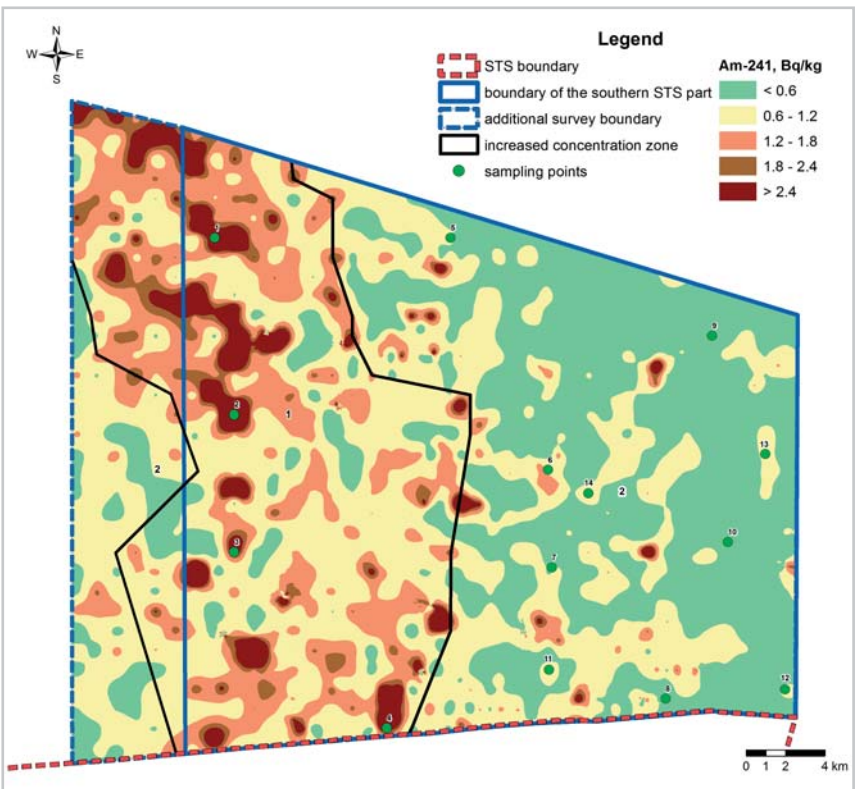


Figure 122. Location of the sampling sites (sampling points)

The accumulation factors obtained previously for the radioactive fallout traces were used to theoretically assess the radionuclide contamination of the vegetation cover in the 1st zone ("southern" part of the STS), and those for the conditionally "background" STS territories were used in the 2nd zone (sections 3.2.1 and 3.2.2). Due to the lack of quantity values for the conditionally "background" territories, the 2009 IAEA data on

^{241}Am A_fs[118] were used as mean A_fs of this radionuclide. Considering the mean A_fs and the mean specific activity (SA) values for radionuclides in soil, mean concentrations of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am in plants were calculated (Table 27).

Table 27.

Calculated specific activities of artificial radionuclides in plants at the studied lands

Zone	Mean values	Artificial radionuclides			
		^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
1	A_f	0.020	0.026	0.0068	0.0056
	Mean SA in soil, Bq/kg	44.5	31.6	19.3	1.4
	Calculated SA in plants, Bq/kg	0.89	0.082	0.1	0.0078
2	A_f	0.030	0.25	0.019	0.002
	Mean SA in soil, Bq/kg	20.3	14.4	4.6	0.7
	Calculated SA in plants, Bq/kg	0.6	3.6	0.087	0.0014
Permissible values for plants , Bq/kg		74	111	~10*	~10*
Note: * – assumed permissible levels, see below.					

Assumed concentration of ^{137}Cs and ^{90}Sr radionuclides in the plants does not exceed maximal permissible levels of radioactive contamination for forage plants (^{137}Cs – 74 Bq/kg, ^{90}Sr – 111 Bq/kg) set by the Ministry of Agriculture of the Republic of Kazakhstan (1994) [68]. Concentration of $^{239+240}$Pu and ^{241}Am in plants is not regulated, however, based on the level of total radiotoxicity of each of them, it can be assumed that the permissible levels for $^{239+240}$Pu, ^{241}Am could be roughly an order of magnitude lower than those for ^{90}Sr [46]. At that, expected permissible levels of these radionuclides in the plants do significantly exceed the average calculated SA values.

To verify the calculations, field works were performed at the selected "southern" part of the STS; during those in 2 radioactively contaminated zones 15 sites were selected for sampling (Figure 122). At 10 sampling sites the aboveground parts of plants (sampling area ~ 2 sq. m) represented by two species – feather grass (*Stipa sareptana*) and wormwood (*Artemisia gracileccens*) – were sampled in 5 aggregated samples of steppe herbs. In the 1st zone (radioactive fallout trace) the plants were sampled in places with increased concentrations, in the 2nd zone (directly at the conditionally "background" territory) – at the territory with low and moderate concentrations of radionuclides in soil.

Sampling procedure and the radionuclide analysis technique are described in the section 3.2.2. The "Progress" beta spectrometer was used to assess ^{90}Sr with the detection limit of 100 Bq/kg. To calculate mean specific activity of radionuclides in plants, values below the detection limit were taken as quantitative values. Table 28 provides measured and calculated specific activity values for ^{137}Cs, ^{90}Sr and ^{241}Am radionuclides in the collected plant samples.

Table 28.

Measured and calculated specific activity values for radionuclides

Zone	Sampling point	Plants	Specific activity (SA) of radionuclides, Bq/kg		
			^{241}Am	^{137}Cs	^{90}Sr
1	1	feather grass	< 0.2	0.5 ± 0.1	< 100
		wormwood	< 0.1	0.8 ± 0.2	< 100
	2	feather grass	< 0.4	< 0.7	< 100
		wormwood	< 0.6	< 2.3	< 100
	3	wormwood	< 0.1	< 0.13	< 100
		feather grass	< 0.1	< 0.2	< 100
	4	feather grass	< 0.1	< 0.4	< 100
		wormwood	< 0.4	< 1	< 100
Mean SA of radionuclides in plants , Bq/kg			0.25	0,75	*100*
Estimated SA of radionuclides in plants, Bq/kg			***0.0078***	***0,89***	***0.082***
2	5	feather grass	< 0.1	< 0.1	3 ± 0.7
		wormwood	< 0.1	< 0.5	< 100
	6	feather grass	< 0.1	< 1	< 100
		wormwood	< 0.1	< 0.7	< 100
	7	feather grass	< 0.2	< 1	< 100
		wormwood	< 0.1	2.3 ± 0.5	< 100
	8	feather grass	< 0.1	< 0.4	< 100
		wormwood	< 0.7	2.3 ± 0.5	< 100
	9	feather grass	0.33 ± 0.07	< 0.1	12 ± 2
		wormwood	< 0.1	< 0.3	8.3 ± 1.2
	10	feather grass	< 0.1	1.2 ± 0.2	< 100
		wormwood	< 0.2	1.4 ± 0.3	< 100
	11	herbs	< 0.084	< 0.5	-
	12	herbs	< 0.099	< 0.2	-
	13	herbs	< 0.08	< 0.3	-
	14	herbs	< 0.2	< 0.2	-
	15	herbs	< 0.068	< 0.4	-
Mean SA of radionuclides in plants, Bq/kg			*0.16*	*0.76*	*77*
Estimated SA of radionuclides in plants, Bq/kg			***0.0014***	***0.6***	***3.6***
- not available					

Obtained specific activity values in the samples taken at the radioactive fallout traces (1st zone) were found to be almost comparable to the calculated mean values. Directly at the conditionally "background" territories (2nd zone), individual values of the specific activities in the plant samples sometimes exceeded the mean estimated specific activity of the radionuclides in plants. This fact can be explained by the non-uniform distribution of the radionuclides in plant cover and characterize possible increased (or maximal)

specific activities in the plants at the investigated territory. In most cases, however, the obtained specific activities are below the detection limit of the equipment used and are in agreement with the calculated values. Therefore, the proposed recommendations on the assessment of the land radiological contamination employing the A_f values have been verified and can be generally considered as effective and optimal.

3.3. WATER OBJECTS

3.3.1. Study of the artificial radionuclides concentration in water objects at the STS territory

3.3.1.1. Characteristics of water objects

The test site territory conditionally classified as a "background" one is the place of permanent and temporary living for the local population practicing agricultural activities and cattle breading. Therefore, all water objects at this territory are categorized as potential objects of water use, which under some definite circumstances can be used both for household, technical and drinking purposes.

Since the test site territory has radiation hazardous objects with impact on the environment, in particular on the adjacent territories, the radiological quality of water objects is to be assessed.

To select a methodological approach, all the studied water objects were divided into two groups depending on their location with respect to nuclear tests sites as follows:

– water objects located at the conditionally " background" territories;
– water objects allied to the radiation hazardous objects of the test site.

Water objects located at the conditionally "background" territories

Upon the results of previous radiological studies, "northern", "western", "southeastern" and "southern" parts of the test site were categorized as the conditionally "background" STS territories [69, 77, 79, 125].

Venues of water use objects at the investigated territories were revealed by decoding high resolution satellite images, as well as using hydrogeological maps and a detailed fixed-route surveying. In the course of works, geographical coordinates were determined for each of the water objects and for the surface streamflows (creeks, lake) – quite exact boundaries were determined.

The water objects were classified based on their main features. According to this classification, the following types of the objects were considered:

– borehole-type;
– well-type;
– surface streamflow;
– spring.

The overview of the water objects is given at the Figure 123.

Borehole Surface streamflow (lake) Well

Figure 123. Types of water objects

In total 250 water objects were surveyed in the course of research; their locations are shown at the Figure 124 below.

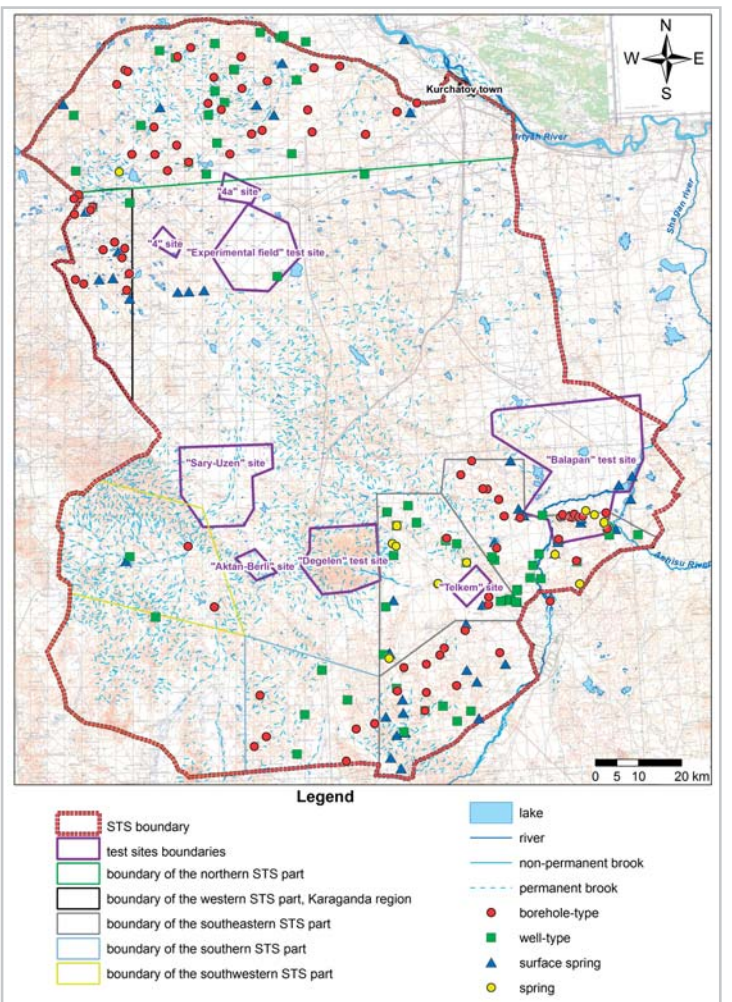


Figure 124. The map of water objects at the STS

Boreholes, wells and springs are fed by ground waters. Some of these objects are acting and located on inhabited territories where summer huts and winterings are equipped with drinking-bowls for domestic animals. Other objects are located separately, spread over the entire territory or in vicinity to the abandoned sites – places of temporary residence of people. Such water objects were also surveyed the same way as the abandoned summer huts in the season of active pasturing. Such objects of water use are frequently restored, and abandoned boreholes and wells usually located along the cattle grazing paths restart their operation.

Surface streamflows include salt and highly salty lakes, surface water run-offs, and small seasonally appearing creeks. Kettles and channels of such streamflows are filled up with melt water and rainwater in the spring-autumn period and get almost completely dried in summer. In spite of this, surface streamflows were also carefully studied, since multiple pasturelands were found nearby that evidenced of their use for economic purposes.

Absolute majority of the lakes is represented by drainless, shallow objects with the depth of 0.5 to 14 m. Lakes and small surface streamflows are supplied from groundwater for 70 – 80 %, the rest part belongs to atmospheric precipitation.

Water objects allied with radiation hazardous objects

A part of the territory has sites with increased concentrations of radionuclides in environmental objects, in vicinity of radiation hazardous objects. One of such sites requiring special attention when carrying out radiological studies is the territory adjacent to the "Degelen" site. The main way of radioactive contamination of this territory is takeout of radionuclides with tunnel streamflows, coming out UNE tunnels at "Degelen" site. Increased concentrations of artificial radionuclides (ARN) in environmental objects (water, soil, vegetation) were found along the banks and bottom lands of the tunnel streamflows as follows: ^{90}Sr – $n\cdot10^{3}\div n\cdot10^{5}$ Bq/kg, ^{137}Cs – $n\cdot10^{4}\div n\cdot10^{5}$ Bq/kg, $^{239+240}Pu$ – up to $n\cdot10^{4}$ Bq/kg, ^{3}H – up to $n\cdot10^{5}$ Bq/kg [126].

In total, there are 12 streamflows of such kind at the "Degelen" site, but they are all allied with the main streamflows (creeks), running out far beyond the test site. These streamflows are Uzynbulak, Toktakushyk, Baitles, Aktybay and several unnamed seasonal streamflows.

Beyond the "Degelen" site, these creeks become the potentially freely accessible objects of water use, those can be used by local inhabitants for cattle watering, drinking or household needs (Figure 125).

Taking into account the radiological situation at the brook bottom lands and other peculiarities, radiation surveying of such potential water use objects becomes of importance.

Detailed investigations were performed for Uzynbulak creek (the creek with largest water catchment area). Uzynbulak creek is allied with the streamflow from the tunnel 177 and runs beyond the boundary of the "Degelen" test site across the southeastern part of the STS territory for approximately 12 km.

According to previous data, the main contaminating agent of the streamflow from the tunnel 177 and Uzynbulak creek is ^{3}H, whose specific activity in water is about $n\cdot10^{5}$ Bq/kg. Also, in the streamflow of the tunnel 177 at the site in close vicinity to the

tunnel entry, presence of ^{137}Cs and ^{90}Sr radionuclide with activity of $n \cdot 10^2 \div n \cdot 10^3$ Bq/kg was found [38].

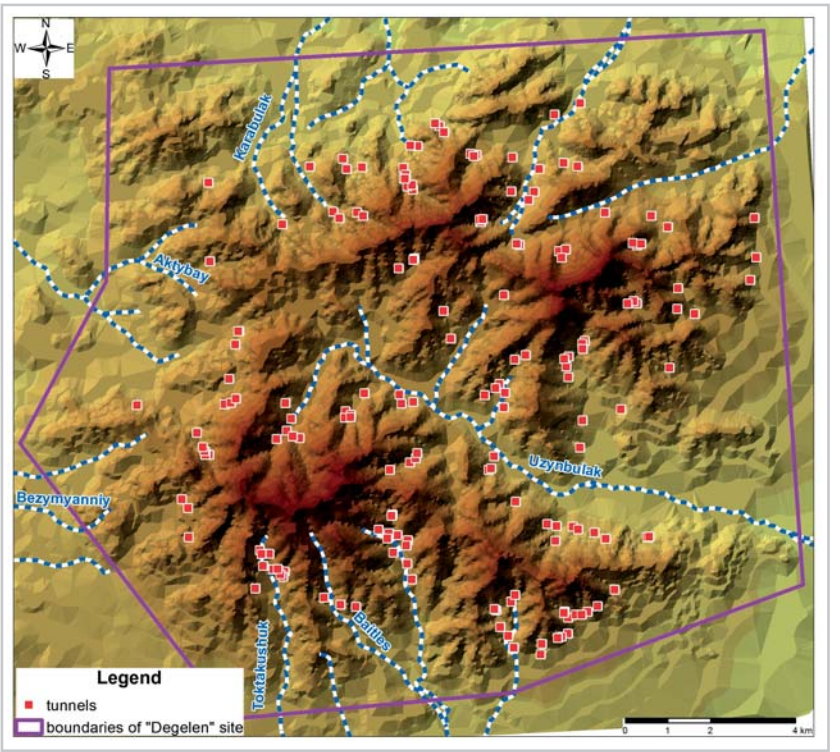


Figure 125. The main creeks and brooks running beyond the "Degelen" test site

3.3.1.2. Concentration of artificial radionuclides in water objects

General research methodology included the following stages:

- visual examination of the object of water use;
- collection and temporary storage of water samples;
- transporting collected samples to the laboratory;
- laboratory studies.

Visual examination

Visual examination on site involved photographing the object, measurement of radiation parameters for assessment of radiation situation, assessment of physical condition of the object (active / not active, presence /absence of water, presence of residential structures, residence of people, signs of cattle pasturing/living, and etc.).

Based on visual examination it was decided whether it is possible or not possible to carry out further research of this object.

Sampling and temporary storage of samples

Sampling venue, samples quantity and periodicity depended on type and state of water objects.

Water samples were collected into carefully washed chemically resistant glass or transparent polyethylene vessels with non-painted twist cap. Right before sampling the vessels were rinsed with water from the sampling location and then filled up till the top and sealed with a cap. The volume of each sample was 10l.

When possible, the samples were collected right before delivery to the laboratory. If preliminary sampled (the time period between sampling and analysis was over 3 days), preliminary operations were applied to the samples for their preservation, depending on assumed duration of storage. In this case the sample was acidified with nitric acid to reach the pH value of 1 (approximately 3 ml of HNO_3 per 1l sample) to prevent radionuclides micro quantities from sorption at the inner surface of the vessel.

Objects of water use located at conditionally "*background*" *territories*. Water was sampled in boreholes and wells after preliminary pumping via water drawing mechanism at the well or using a bathometer.

Water from the surface reservoirs was sampled via bathometer at the depth of 0.3–0.5 m at the distance of approximately 0.5–1.0 to the bank (if possible). If needed, at large reservoirs, water was sampled from various sides in several points if water was freely accessible.

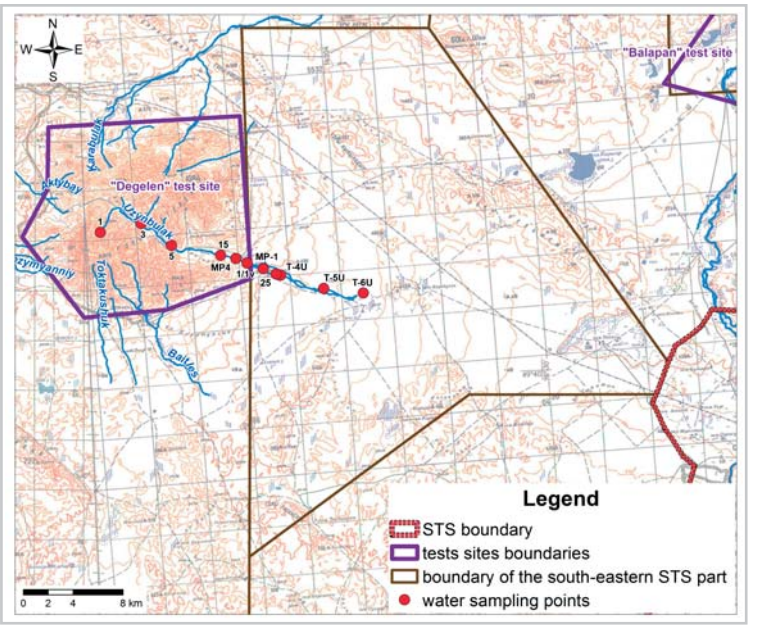


Figure 126. Surveyed sites in the channel of Uzynbulak creek

Uzynbulak creek. The water from Uzynbulak creek was sampled with a bathometer at the depth of 0.3–0.5 m at the distance of approximately 0.5–1.0 m to the bank (if possible). Taking into account the fact that the creek is associated with a tunnel streamflow,

water was sampled along the whole creek channel starting from the creek appearance at the surface near the portal of the tunnel 177 till the zone of the creek final outflow beyond the "Degelen". To control possible takeout of radionuclides to the "southeastern" part of the STS, being conditionally "background" land, 2 additional survey spots (MP4 and MP1) located at the test site boundary and at the distance of approx. 2 km to the boundary of the "Degelen"site were arranged. Joint sampling of surface and ground waters was performed at these sites (Figure 126).

Taking into account the creek location, special attention was paid to the channel part beyond the "Degelen" test site to assess possible takeout of radionuclides beyond its boundary. The creek channel within the test site was surveyed only for ^{3}H radionuclide concentration (sites 1, 3, 5 and 15) in water (Figure 126). Water samples collected at the boundary of the " Degelen" site and beyond it were investigated for all the main artificial dose-forming radionuclides – ^{3}H, ^{137}Cs, ^{90}Sr, and $^{239+240}Pu$.

Transporting

To transport the samples to the laboratory, each sample was supplied with a passport specifying the place and the date of sampling, coordinates and radiation parameters as well as other sampling conditions. When preliminary samples preparation was carried out, this was indicated in the sample passport specifying the date, type of preparation and materials/reagents used. According to the requirements, the samples were transported in vessels providing safety and preventing water from freezing and overheating [127].

When transporting, the vessels with samples were kept inside of a package (container, box), preventing contamination, damage or accidental take out of plugs. The samples were packed according to the date of their delivery to the laboratory.

Laboratory studies

Collected samples were analyzed for ^{3}H, ^{137}Cs, ^{90}Sr and $^{239+240}Pu$ content.

^{3}H content. Preparation of water samples and ^{3}H specific activity measurement was carried out according to the certified technique [128]. From the filtered sample, a subsample of 5 ml was taken and placed into a 20 ml plastic vial with addition of scintillation cocktail in 1:3 ratio (sample - scintillator). The Ultima Gold LLT scintillation cocktail specially developed for ^{3}H measurement in natural samples was used (efficiency of ^{3}H registration within the range of 0 - 18 keV is approximately 60%). To determine ^{3}H activity concentration in the collected samples, TriCarb 2900 TR liquid scintillation spectrometer was used. Energy region for ^{3}H varied within the range of 0 to 15 keV. Each sample was measured for approximately 120 minutes. Sensitivity of the ^{3}H specific activity measurement in free water was 12 Bq/l.

Study of ^{137}Cs, ^{90}Sr and $^{239+240}Pu$ content. Sample preparation and determination of ^{137}Cs, ^{90}Sr and $^{239+240}Pu$ specific activity was carried out according to the technique of ^{137}Cs, ^{90}Sr and $^{239+240}Pu$ radionuclides determination in natural water via concentration method. To control chemical yield, isotopic tags of ^{134}Cs, ^{85}Sr and ^{242}Pu were introduced into the sample [129].

Plutonium-(239+240). Chemical yield of $^{239+240}Pu$ was calculated upon the results of alpha-spectrometric measurements, based on known activity of introduced ^{242}Pu isotopic tag. Plutonium concentration was determined using iron hydroxide. For this purpose, 40-70 ml of chloric iron (III) with concentration of 10μg/cm^{3} was introduced into the solution. 20% NaOH was then added into the solution in portions to deposit iron hydro-

xide to H=7. The solution was stored for 12 hours with subsequent decanting. The sediment of iron hydroxide, being plutonium concentrate, was further sent for radiochemical analysis to extract $^{239+240}$Pu isotope. Specific activity of $^{239+240}$Pu in the prepared samples was determined using an alpha-spectrometer [130].

Strontium-90. Chemical yield of ^{90}Sr, after sedimenting carbonates, and ^{90}Y was determined upon the results of gamma-spectrometric measurements based on known activity of introduced ^{85}Sr and ^{88}Y isotopic tags, respectively. Strontium isotopes were concentrated by means of co-deposition with calcium carbonate. For this purpose a 20 % solution of Na_2CO_3 was introduced until the pH reached the value ≥ 9. After deposition, ^{85}Sr concentration was measured to determine chemical yield, and then ^{88}Y isotopic tags were introduced into the resulted solution. Specific activity of ^{90}Sr was calculated via ^{90}Y specific activity after 2-week accumulation of ^{90}Y from ^{90}Sr. Beta source of ^{90}Y was measured via beta-spectrometer [111].

Cesium-137. ^{137}Cs chemical yield was calculated upon the results of gamma-spectrometric measurements based on known activity of introduced ^{134}Cs isotopic tag. ^{137}Cs was concentrated by means of co-deposition with cooper ferrocyanides. Ferrocyanide sediment with deposited cesium was measured with gamma-spectrometer [93].

Objects of water use located at the conditionally territories

To study the character of possible radiological contamination in details, the radionuclide contents in water use objects at each territory was studied with double repetition during 2 subsequent years. The results are given in the Table 29.

Table 29.

Specific activities of ARN in water

№	Specific activity of radionuclides, Bq/kg			
	^{137}Cs	^{90}Sr	$^{239/240}$Pu	^{3}H
Borehole type				
1	<0.07 - <0.1	<0.001 - <0.08	<0.0004 – <0.06	<7 - <12
Well type				
2	<0.05 - <0.1	<0.004 - <0.08	<0.0010 - <0.08	<7 - <12
Surface source				
3	<0.01 - <0.2	<0.005 - <0.08	<0.0006 - <0.08	<7
Spring				
4	< 0.01 - <0.2	< 0.001 - < 0.01	< 0.0012 - <0.01	<7

Based on the obtained data, no artificial radionuclides were found in water. Specific activities of radionuclides in samples analyzed was as follows: ^{137}Cs < 0.2 Bq/kg, ^{90}Sr < 0.08 Bq/kg, $^{239+240}$Pu < 0.09 Bq/kg and ^{3}H < 15 Bq/kg.

ARN specific activity values in water use objects did not exceed the intervention level (IL) based on concentrations of individual radionuclides in potable water as follows: ^{137}Cs – 11 Bq/kg, ^{90}Sr – 4.9 Bq/kg, $^{239+240}$Pu – 0.55 Bq/kg, ^{3}H – 7,600 Bq/kg [46].

According to this research, water in the objects of water use at the conditionally "background" territories distant to the sites with increased radiation background does not contain ARNs. The water in the studied objects pose no radiological hazard.

Since upon the radiological surveying these territories were recognized as the territories with background level of radioactive contamination, obtained results were quite expectable [69, 77, 79, 125].

No artificial radionuclides in amounts exceeding IL for potable water are expected to be found in surface and ground waters of this territory since there are no either sources of ARN or obvious migration mechanisms. Even assuming that ARN migration from radiation-hazardous STS objects could take place, appearance of such radionuclides as $^{239+240}$Pu and ^{137}Cs at such a large distance from the test venues is very unlikely. The complex studies carried out in different times at the STS territory have shown that, taking into account the character of testing sites contamination, the radionuclides $^{239+240}$Pu and ^{137}Cs do not spread to the distance over 2-3 km from the places of their origin limited, as a rule, is by the territory of the testing site [131, 132]. Therefore, there is no need for continuous all-round control over the content of these radionuclides in water of the objects of water use.

As for ^{90}Sr and ^{3}H radionuclides, taking into account their migration capabilities, the decision on the need in further investigations should be made in each individual case taking into account specific character of radioactive contamination and the distance from the object under research to a testing site.

If the object is in vicinity of a testing ground or a radioactively-contaminated site, as well as in case of presence of an extensive water object contacting with radioactively contaminated territories, it is necessary to control the content of ^{90}Sr and ^{3}H in water objects.

Uzynbulak creek

Results of the surface and ground water studies at Uzynbulak creek are given in the Table 30 below.

Table 30.

Specific activity of artificial radionuclides in water of Uzynbulak creek

№	Sampling point	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg	^{3}H, kBq/kg
Surface water					
1	site 15	-	-	-	45, 000 ± 5, 000
2	site 5	-	-	-	35, 000 ± 3, 000
3	site 3	-	-	-	85, 000 ± 7, 000
4	site 1	-	-	-	10, 000 ± 1, 000
5	site 25	<0.02	<0.005	<0.003	45, 000 ± 5, 000
6	1/1v	<0.02	<0.005	<0.003	60, 000± 6, 000
77	T-3U	<0.02	<0.005	<0.003	60, 000± 6 ,000
8	T-4U	<0.02	<0.005	<0.003	57, 000 ± 7 000
9	T-5U	<0.02	<0.005	<0.003	55, 000 ± 5, 000
10	MP4	<0.02	<0.005	<0.003	30, 000 ± 4, 000
11	MP1	<0.02	<0.005	<0.003	35, 000± 6, 000
Ground water					
1	MP4	<0.02	1.25 ± 0.02	<0.003	40, 000 ± 5, 000
2	MP1	<0.02	1.30 ± 0.02	<0.003	40, 000 ± 5,000

The main radionuclide contaminating the water of Uzynbulak creek is ^{3}H, significant amounts of which were found in both surface and ground waters. Specific activity of ^{3}H in all studied water samples was approximately $1 \cdot 10^{4}$ Bq/kg. The obtained values exceed the IL values for ^{3}H (7.6×10^{3} Bq/kg) for an order of magnitude [46]. Specific activity of ^{3}H in surface waters of Uzynbulak creek in several cases exceeds IL_{pop} for up to 11 times and remains quite high even in the zone of the creek final discharge, at the distance of approximately 10-12 km from the boundary of the "Degelen" site. In respect of ^{3}H content, Uzynbulak creek is categorized as a radiation hazardous object and cannot be used as a source of water.

Presence of ^{90}Sr with specific activity of about 1.3 Bq/kg in water was found only in ground waters in the channel of Uzynbulak creek in both monitoring boreholes (Table 30). The obtained values did not exceed IL_{pop}, which for this radionuclide comprises 4.9 Bq/kg [46]. However, in terms of the ^{90}Sr migration estimations, these values are significant: they demonstrate in ground waters beyond the "Degelen" site, migration processes with take out of this radionuclide from nuclear test sites take place. Special attention is to be paid to this fact.

No ^{137}Cs or $^{239+240}Pu$ was found in water, specific activity values of these radionuclides were as follows: < 0.02 for ^{137}Cs and < 0.005 for $^{239+240}Pu$, that is significantly below the IL.

As one can see on the Uzynbulak creek example, the impact zones of extensive streamflows allied with nuclear test venues and running beyond the boundary of the testing sites require continuous radiation control. First of all, it is necessary to monitor ^{3}H content in water, whose migration capabilities allow it to migrate with water streams to large distances, and then the content of ^{90}Sr, whose migration capabilities are worse, but nevertheless this radionuclide can be detected far beyond the nuclear test venues.

It should be understood that studying rivers and creeks (extensive water objects), the required monitoring needs creating a network of monitoring sites, and possible migration of artificial radionuclides both with surface and ground waters is to be assessed and controlled. To determine what kinds of analyses are needed for research of water quality at various territories, it is important to study first of all the hydrographic network of this region to understand the nature of the streamflows (creeks, rivers, seasonal streamflows, mountain drainages, and etc.) and to assess their water catchment areas.

Water quality at the "conditionally" background territories of the STS was studied to assess possible impact from the nuclear tests consequences on the environment; the studies were based on the character of the assumed contamination. It was assumed that artificial radionuclides such as ^{3}H, ^{137}Cs, ^{90}Sr, $^{239+240}Pu$ could be found in water, and the main task was to study the radionuclide composition of water.

According to the performed study, the content of artificial radionuclides in the water use objects located at the background territories do not exceed the intervention levels. However, we cannot reliably declare the radionuclides total absence, and in each individual case the standard methods and approaches are to be adjusted.

In general, the results of the research allowed to make the following recommendations for the radiological assessment of water quality:

1. When studying the water objects, one should first of all describe the hydrographical network of the territory. This would allow to get their hydrographical characteristics

and to determine possible hydrographical connection with the radiation hazardous objects.
2. If such connections are revealed, water is to be analyzed for ^{3}H content and then selectively for ^{90}Sr content. According to the obtained results a decision would be made on the need in further complex radiological studies.
3. Studying wells and boreholes located at distances 3-5 km and more to radiation-hazardous objects, it is unnecessary to determine ^{137}Cs and $^{239+240}Pu$ concentrations in water. ^{3}H and ^{90}Sr concentrations can be measured selectively in some objects.

In general, the results of the conducted research show that the water in all objects of water use located at the background territories of the STS is radiation-safe.

3.3.2. Study of the levels and the character of the radionuclide contamination distribution in water objects at the Semipalatinsk Test Site territory and adjacent lands

Surface waters are essential for human economic activities, that is why assessment of radionuclide contamination of surface waters is the first-priority task at the former STS territory.

Surface waters of the STS territory can be divided into 2 types – water reservoirs and streamflows. Water reservoirs at the territory of the testing sites ("Experimental Field", "Balapan", "Telkem") are as a rule represented by craters resulted from either surface or excavation explosions, filled up with water. Beyond the testing sites, water reservoirs are the small lakes. The main streamflows at the STS territory are represented by creeks at the "Degelen" site and the Shagan river running along the boundary of the "Balapan" site and crossing the STS boundary.

According to previous studies, artificial radionuclides concentrations in surface waters at the territories beyond the STS testing sites range as follows: $^{239+240}Pu < 0.0004$ to 0.0045 Bq/kg, $^{90}Sr < 0.068$ to 0.1 Bq/kg. ^{137}Cs and ^{3}H specific activity lies below the detection limit of the equipment used, equal to < 0.07 and 8 Bq/l, respectively [79].

To detect such concentration of artificial radionuclides in water, large volume samples (10 to 100 l) were taken with preliminary sample preparation and determining artificial radionuclides. Sample preparation involves either physical or chemical concentration with subsequent radiochemical extraction of ^{90}Sr and $^{239+240}Pu$ or direct spectrometric measurement of ^{137}Cs. These are very labor and time consuming processes.

According to literary data, bottom sediments play extremely important role in formation of hydrochemical water regime, functioning of water reservoir and streamflow ecosystems. They actively participate in intrareservoir circulation of elements and energy [133]. Bottom sediments, their composition and properties, reflect the complex of physical, chemical and biological processes occurring in water reservoirs and streamflows, and they are more stable, unlike such a dynamic environment as the water body [134]. Most of contaminating agents entering water objects are adsorbed on mineral and organic particles, sedimented on the bottom and accumulated in bottom sediments [135, 136]. Therefore, contamination of bottom sediments can serve as the most important source of information about the state of water ecosystems. In this respect, it is recom-

mended to optimize the studies of radionuclide contamination in water objects by analyzing bottom sediments first.

The ability of bottom sediments to accumulate radionuclides is quantitatively characterized by a concentration factor (C_f, concentration factor) calculated as a ratio between the radionuclides content in water and the radionuclide content in bottom sediments. Alternatively, the transfer factor (T_f, transfer factor) calculated as a ratio of the radionuclides content in bottom sediments to radionuclides content in water can be used [137]. Physical meaning of the T_f is that it indicates the degree of the radionuclides transfer from water into bottom sediments as follows: the higher T_f is, the more intensive this transfer is. According to numerous literary sources, T_f values in average decrease from $n\times10^5$ to $n\times10^0$ for the radionuclides in the sequence $^{239+240}Pu$ >

Table 31.

Water objects at the STS and adjacent territories

Object type	Location	Name of the object	Saline content, g/l
Water reservoirs	"Experimental Field"	P3-P5, site № 3	4.5
		P3-P5, site № 4	6.3
		P1, K-1	1.3
		"Trotyl"lake	12
	"Balapan"	"Atomic"lake	12 - 18
		External reservoir	13 - 14
	"Telkem"	"Telkem-1"	23
		"Telkem-2"	7
	Kanonerka village	"Bolshoe" lake	0.2
		"Maloe" lake	0.16
		Lake (salt)	10
	Dolon village	Lake	0.4
Streamflows	"Balapan"	Shagan river	10 - 12
	"Degelen"	Uzynbulak creek (MP -4)	0.44
		Baytles creek (MP-2)	0.24
		Toktakushyk creek (MP -3)	0.3
		Karabulak creek (MP-5)	0.77
		Irtysh river	0.1

Water objects at the "Experimental Field" are actually craters resulted from surface nuclear tests; they are filled up with water and overgrown with reed all around. Within the frame of this work, 4 objects were considered as follows: at the P3-P5 site – craters with water at sites № 3 and № 4, at P1 site – a crater with water in K-1 point and "Trotyl" lake at the P2-P7 site.

The "Atomic"lake and the lakes "Telkem-1"and "Telkem-2"are the water reservoirs resulted from excavation explosions with ground outburst: the tests were designed to create artificial water reservoirs.

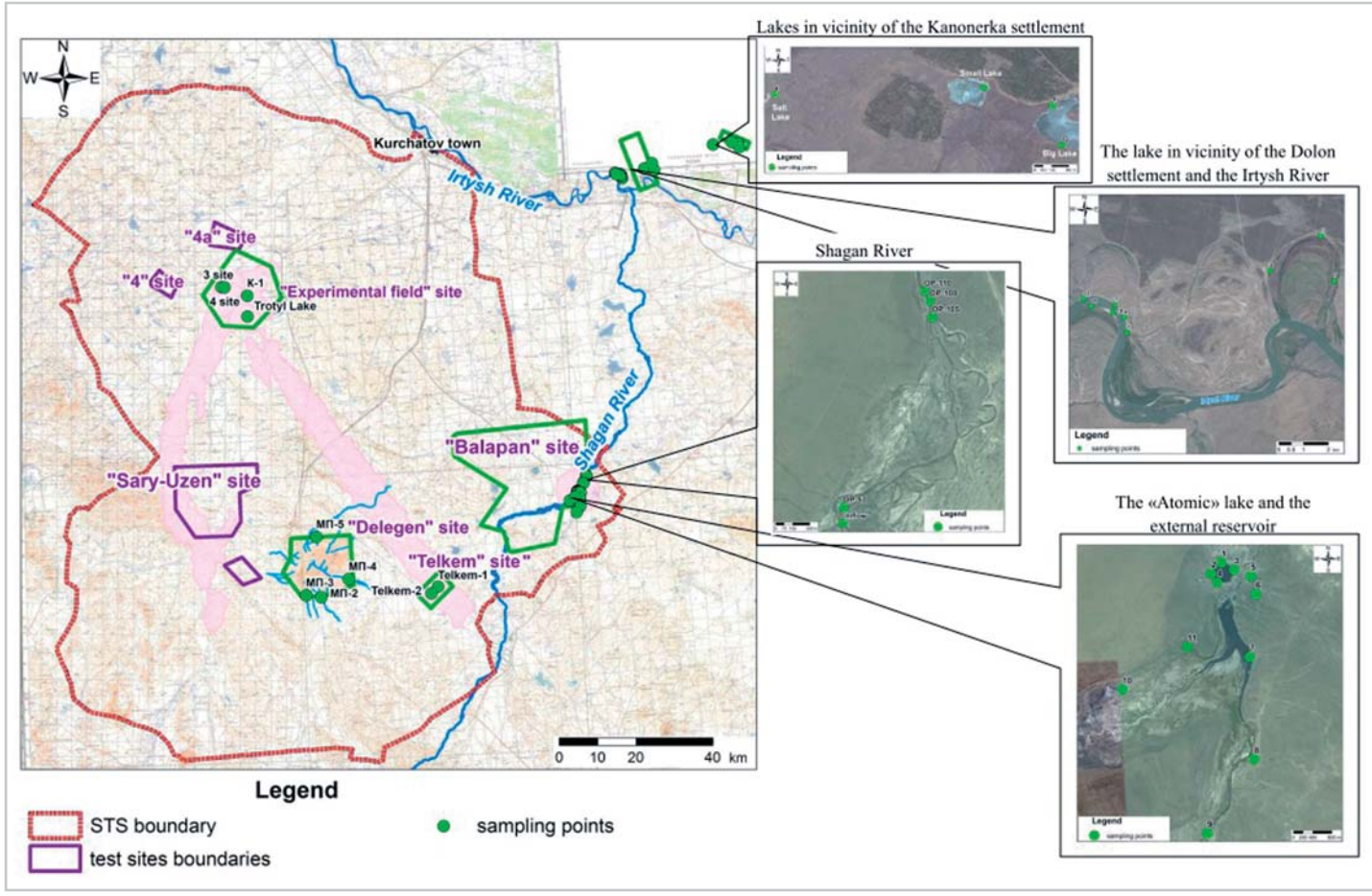


Figure 127. Water objects at the STS and adjacent territories

The “Atomic” lake resulted from the explosion on 15.01.65 with the yield of 140 kt at the place of confluence of Shagan and Ashisu rivers, resulted in forming a crater with the depth of over 100 m and diameter of 400 m filled up with water. In the southern and southeastern direction from the embankment of the “Atomic” lake, a water reservoir was formed. The area of the reservoir changes and in 2014 it covered approximately 9 km^2.

In the southeastern part of the STS, two underground nuclear tests with ground outburst were performed: a single explosion “Telkem-1” (21.10.1968) and the group explosion (consisting of three nuclear charges put in line) – “Telkem-2” (12.11.1968). Resulted craters have been filled with water and that way the lakes “Telkem-2” with the diameter of 90 m, and the depth of 15 m and “Telkem -2” – the lake stretched in shape with the length of 120 m, the width of 60 m and the depth of 10 m were formed.

At adjacent territories, a site subjected to radioactive contamination as the result of the test in 1949 was chosen. At this site, one lake in vicinity to Dolon village and 3 small lakes near Kanonerka village are located. Near Kanonerka village the following objects are located: “Bolshoe” lake with the area of approximately 1 km^2, and the depth of approximately 1.5-2 m; “Maloe” lake with the area of approximately 0.5 km^2, and the depth of approximately 1-1.5 m; “Solenoe” lake with the area of approximately 0.02 km^2, with a little of water.

Shagan river is the main surface streamflow within the STS territory. It flows along the eastern boundary of the “Balapan” site, runs beyond the STS and into Irtysh river representing its left tributary. Within the STS territory, the length of the river channel is approximately 50 km. The flow rate of the river in summer is 3 m^3 per minute. The river Shagan is characterized by low flow rate, branching, blind dead channels, bogged banks [148]. Based on the previous studies by the Institute of Radiation Safety and Ecology, high ^3H concentrations were detected and confirmed several times at the distance of 5 km from the “Atomic” lake. Below the lower interval of Shagan river less than 5 km from the “Atomic” lake is therefore considered.

Creeks within the impact zone of streamflows from the tunnels of the “Degelen” site: Uzynbulak, Karabulak, Toktakushyk and Baytles are also of some interest. The largest source of water from all creeks of the Degelen massif is Uzynbulak creek. Having the length of about 20 km, the creek valley has the largest water catchment area. Approximately 50 tunnels adjoin the creek and its tributaries [38]. The width of the creek at the sampling point on the boundary of the “Degelen” site is about 1 m, and the depth is 0.5 m. Toktakushyk and Baytles creeks are located in the southern part of the “Degelen” site. Toktakushyk creek does not have tributaries. Baytles creek is formed by two basic tributaries. The third tributary at the left bank flows into the main channel already beyond the massif. The length of Toktakushyk creek valley is approximately 10–12 km, Baytles creek valley is over 15 km long. Karabulak creek is located in the northern part of the site and is formed by two tributaries, the third tributary flows into the main channel beyond the massif. Total length of the creek is about 30 km, within the “Degelen” site – approximately 4 km. Sampling points of these creeks were located at the boundary of the “Degelen” site, where the width of channels was approximately 0.5 m, the depth – 20-25 cm.

The main streamflow of the adjacent territories is Irtysh river – the largest river in Kazakhstan which is the tributary of Ob river. The length of Irtysh river is 4,248 km, that

exceeds the length of Ob itself. Irtysh river flows over the territory of three states – China, Kazakhstan and Russia. The total water catchment area is 1, 643, 000 sq. km. Water discharge of Irtysh river at the border between China and the Republic of Kazakhstan is 9 km^3 per year [149]. For the purpose of research, the area where the plume from the 1949 test passed was chosen.

In spite of the close location of these water objects, and in some cases – similar character of water bodies formation, water there significantly differs in chemical composition. Both fresh water objects with salt load of up to 1 g/l and saline water objects with salt load of over 10 g/l can be found here. Saline content values in studied water are given in the Table 31.

Sampling. Conjugated sampling of water and bottom sediments was performed at the selected objects late in summer and early in autumn of 2014 when the amount of water was much lower than that in the springtime when the snow melts. The data on sampling points, i.e. the distance to the bank and the depth in the sampling point, are given in the Table 32. Bottom sediments were sampled at the depth of 0–10 cm. Water was sampled at the depth of 0–15 cm from the surface. The volume of water samples from the objects at the STS territory and those from the objects at the adjacent territory was 10 and 100 l, respectively. All the samples were delivered to the laboratory in the shortest time possible. Samples of bottom sediments were transferred for analysis. Water samples were filtered and preserved using concentrated nitric acid to reach the pH=2. Preserved samples were stored till the beginning of the analysis, but not longer than for 30 days [150, 151].

Table 32.

Data on sampling points

Sampling venue	Sampling point	Distance to the bank, m	Depth at the sampling point, m	Note
"Experimental Field"	site. №3	0.2 – 0.25	0.5	
	site. №4	0.3 – 0.35	0.45 – 0.5	
	K-1	0.6	0.3	
	"Trotyl" lake	0.3 – 0.35	0.5	
"Atomic" lake	p.1 – p.4	0.1 – 0.15	0.5 – 0.6	
Water reservoir	p.5 – p.9	0.5	0.2 – 0.25	
	p. 10	100	0.3 – 0.35	
	p. 11	20	0.3 – 0.35	
"Telkem-1"		45 (center)	15	
"Telkem-2"		30 (center)	10	
Kanonerka	"Maloe" lake	2.5 - 3	0.2 – 0.25	
	"Bolshoe" lake	1 – 1.5	0.2 – 0.25	
	"Solenoe" lake	4	0.2 – 0.25	
Dolon	p.4, p.7, p.13	0.5	0.2 – 0.25	

Sampling venue	Sampling point	Distance to the bank, m	Depth at the sampling point, m	Note
Shagan river	OP-53	1	0,3	Left bank
	OP-105	1	0,6	Left bank
	OP-108	1	0,3	Left bank
	OP-110	1	0,3	Left bank
	Tributary	1	0,3	Left bank
"Degelen"	"Baytles" creek	0.2 – 0.25	0.15 – 0.2	Channel center
	"Toktakushyk" creek	0.2 – 0.25	0.15 – 0.2	Channel center
	"Uzynbulak" creek	0.4	0.3 – 0.35	
	"Karabulak"-creek	0.2 – 0.25	0.15 – 0.2	Channel center
Irtysh river	p.1, p.4, p.7, p.13	2.5 - 3	0.2 – 0.25	
	p.19, p.25	1 – 1.5	0.2 – 0.25	

Measurements. Content of ^{90}Sr, $^{239+240}$Pu, ^{241}Am and ^{137}Cs artificial radionuclides was determined in the collected samples.

After preliminary drying, bottom sediments were sent for γ-spectrometry measurements to determine ^{241}Am and ^{137}Cs concentrations [93]. After radiochemical extraction, ^{90}Sr content was determined with β-spectrometry measurements of its daughter radionuclide ^{90}Y. $^{239+240}$Pu content was determined employing α-spectrometric analysis after chromatographic extraction and electrolyte deposition [152].

^{241}Am content in the 10 l samples was determined with "direct" γ-spectrometric measurements. After that, the samples were concentrated by means of codeposition. ^{137}Cs content was determined by means of γ-spectrometric measurements after codeposition with copper hexacyanoferrate. ^{90}Sr content was determined by β-measurements using the ^{90}Y daughter radionuclide after codeposition with calcium carbonate and radiochemical extraction. To determine $^{239+240}$Pu concentration, α-spectrometric analysis was carried out after preliminary codeposition with iron hydroxide (III), extraction chromatography and electrolyte deposition [129]. Water samples of 100 l were concentrated by evaporating them to dry residue. Then the content of radionuclides in dry residue was determined the same way as in the bottom sediment samples.

The content of artificial radionuclides in the samples of water and bottom sediments from the water reservoirs and streamflows at the STS and adjacent territories as well as transfer factors are given in Tables 33 and 34, respectively.

According to the obtained data, all water objects can be conditionally divided into 4 types as follows.

The 1st type incudes water reservoirs at the territory of the test sites "Experimental Field" and "Telkem" and the "Atomic" lake. These are craters resulted from either surface or excavation explosions and filled up with water. Their depth varies from 10 to 80 m. These reservoirs (except for the "Atomic" lake) do not have tributaries and they are drainless, i.e. in fact their water does not mix. Considering the "Atomic" lake, based

on previous studies [153] it was proven that even having an influx changes occur only in the top 15-20 m layer, while the lower layers near the bottom remain unchanged. Such water objects are characterized by very high T_{f-}, even for such a mobile radionuclide as ^{90}Sr: T_f values for $^{239+240}Pu$ are approximately > 1.5×10^7 to 2.8×10^5, ^{137}Cs – from > 3.3×10^5 to 2.3×10^3, ^{90}Sr – > 1.6×10^5 to 1.1×10^2.

The 2nd type incudes water bodies at the adjacent territories: natural lakes without tributaries and outflows. The depth of these lakes does not exceed 1.5-2 m, therefore water mixing and impact on coastal bottom sediments occurs due to natural-climatic conditions, as well as anthropogenic factor (these water bodies are located in vicinity of inhabited localities). Nevertheless, T_fs for these water bodies are also very high, in some cases they are just an order or two orders of magnitude lower than in the 1st type water objects: $^{239+240}Pu$ T_f values range within > 1.5×10^6 to > 4.3×10^3, ^{137}Cs – from > 1.5×10^5 to 3.2×10^3, ^{90}Sr –> 2.6×10^3 to 4×10^1.

The 3rd type incudes streamflows: creeks at the "Degelen" site and Shagan river. Low T_f values were obtained for these objects: $^{239+240}Pu$ T_f value ranges within 2×10^4 to 8.5×10^2, ^{137}Cs –> 3.5×10^3 to > 9×10^2, ^{90}Sr – > 3×10^3 to 7×10^0. This is due to the fact that water in this system is a mobile dynamical environment not allowing for radionuclides complete accumulation in bottom sediments.

The 4th type includes Irtysh river, the flow rate of that exceeds the flow rate of the 3rd type streamflows by 3 orders of magnitude. An interesting fact is that the numerical values of ^{90}Sr concentrations of several mBq/l, not typical for a water object of the adjacent territories, were found in water of Irtysh river. Possibly this occurs due to large water catchment area of the river – over 1.5 mln.km^2. In general, this river typically has the same T_fs as the 3rd type streamflows.

As for ^{241}Am, it is hard to assess its T_f, since in none of the objects any quantitative meaning of this radionuclide content in water was obtained.

In spite of the fact that T_fs of various artificial radionuclides differ by several orders of magnitude for various water objects, in average from $n\times10^4$ to $n\times10^2$, that significantly exceeds 1, this justifies that most of the radionuclides considered in "water – bottom sediments" system is concentrated in bottom sediments. An exception is ^{90}Sr: in some cases, its T_f value equals to $n\times10^0$, that indicates equal distribution of ^{90}Sr in the "water – bottom sediments" system. In this case, when numerical values of this radionuclide are registered in bottom sediments, its concentration in water is also to be determined.

So, the state of bottom sediments is the most informative index in radioecological assessment of a water object. Such an approach allows significantly decreasing the expenses for more labor-intensive process of water research.

At that, the bottom sediments study allows to determine the most radiologically unfavorable water reservoirs and streamflows, and to optimize the volume and the scope of radioecological studies of water objects.

Table 33.

Contents of artificial radionuclides in the samples of bottom sediments and water in the streamflows

Sampling venue	Sampling point	Specific activity ^{241}Am, Bq/kg		T_f*	Specific activity ^{137}Cs, Bq/kg		T_f	Specific activity ^{90}Sr, Bq/kg		T_f	Specific activity $^{239+240}$Pu, Bq/kg		T_f
		Bottom sediments	Water		Bottom sediments	Water		Bottom sediments	Water		Bottom sediments	Water	
"Experimental Field"	site №3	$(2.6\pm0.5)\cdot10^{3}$	< 3	>	$(2.6\pm0.5)\cdot10^{4}$	< 0.08	>	$(2.3\pm0.3)\cdot10^{3}$	120±10	20	$(1.6\pm0.1)\cdot10^{4}$	$(5.8\pm0.7)\cdot10^{-2}$	$2.8\cdot10^{5}$
	site №4	$(5.9\pm1.2)\cdot10^{4}$	< 3	>	$(1.5\pm0.3)\cdot10^{5}$	4 ± 1	$3.8\cdot10^{4}$	$(1.4\pm0.2)\cdot10^{4}$	13 ± 2	$1.1\cdot10^{3}$	$(9.7\pm1.1)\cdot10^{4}$	$(3.1\pm0.3)\cdot10^{-2}$	$3.1\cdot10^{6}$
	K-1	15±3	< 3	>	12±2	< 0.01	>	10 ± 2	$(8.8\pm1.3)\cdot10^{-2}$	$1.1\cdot10^{2}$	120±10	$(3.0\pm1.1)\cdot10^{-3}$	$4\cdot10^{4}$
	"Trotyl" lake	95±20	< 3	>	3.1±0.6	< 0.01	>	1.8 ± 0.6	$(8.2\pm1.2)\cdot10^{-2}$	22	940±130	$(2.6\pm1.2)\cdot10^{-3}$	$3.6\cdot10^{5}$
"Atomic" lake	p. 1	210 ± 20	< 3	>	$(2.4\pm0.2)\cdot10^{3}$	< 0.01	>	330 ± 50	$<0.7\cdot10^{-2}$	>	$(4.5\pm0.4)\cdot10^{3}$	$< 0.3\cdot10^{-3}$	$1.5\cdot10^{7}$
	p. 2	< 3	< 3		90 ± 9	< 0.01	>	10 ± 2	$(5.8\pm0.9)\cdot10^{-2}$	$1.7\cdot10^{2}$	36 ± 4	$(2.1\pm0.9)\cdot10^{-3}$	$1.7\cdot10^{4}$
	p. 3	500 ± 50	< 3	>	$(4.3\pm0.4)\cdot10^{3}$	< 0.02	>	940 ± 140	$<0.6\cdot10^{-2}$	$1.6\cdot10^{5}$	$(1.1\pm0.1)\cdot10^{4}$	$(2.8\pm1.0)\cdot10^{-3}$	$3.9\cdot10^{6}$
	p. 4	< 3	< 3		< 3	< 0.02		4.8 ± 0.7	0.9 ± 0.1	5	< 0.5	$(3.0\pm1.4)\cdot10^{-3}$	$<1.7\cdot10^{2}$
Water reservoir	p. 5	< 3	< 3		55 ± 5	< 0.03	>	7.9 ± 1.2	0.7 ± 0.1	11	35 ± 4	$(1.3\pm0.8)\cdot10^{-3}$	$2.7\cdot10^{4}$
	p. 6	< 3	< 3		< 3	< 0.01		2.8 ± 0.6	0.7 ± 0.1	4	3.1 ± 1.3	$(2.0\pm0.9)\cdot10^{-3}$	$1.5\cdot10^{3}$
	p. 7	10 ± 3	< 3	>	< 3	< 0.02		5.5 ± 1.6	0.6 ± 0.1	9	6.6 ± 3.0	$(1.8\pm1.0)\cdot10^{-3}$	$3.7\cdot10^{3}$
	p. 8	25 ± 3	< 3	>	20 ± 3	< 0.02	>	11 ± 2	0.6 ± 0.1	18	44 ± 10	$< 0.2\cdot10^{-3}$	$2.2\cdot10^{5}$
	p. 9	< 3	< 3		25 ± 3	< 0.01	>	11 ± 2	0.6 ± 0.1	18	12 ± 2	$(2.7\pm1.3)\cdot10^{-3}$	$4.4\cdot10^{3}$
	p. 10	< 3	< 3		5 ± 3	< 0.01	>	7.6 ± 1.1	0.8 ± 0.1	9.5	4.6 ± 1.2	$(1.8\pm0.7)\cdot10^{-3}$	$2.6\cdot10^{3}$
	p. 11	< 3	< 3		3 ± 1	< 0.01	>	3.3 ± 0.7	0.7 ± 0.1	5	6.9 ± 1.6	$(1.8\pm 1.1)\cdot10^{-3}$	$3.8\cdot10^{3}$
"Telkem-1"		850 ± 80	< 3		$(1.4\pm0.1)\cdot10^{3}$	< 0.02	>		70 ±10			0.12±0.01	
"Telkem-2"		1,550 ± 100	< 3		$(1.4\pm0.1)\cdot10^{3}$	< 0.02	>		130±20			$(4.4\pm0.8)\cdot10^{-2}$	
Kanonerka	"Maloe" lake	< 3	$<1\cdot10^{-3}$		23 ± 3	$(7.0\pm0.7)\cdot10^{-3}$	$3.2\cdot10^{3}$	<1.1	$(2.3\pm0.1)\cdot10^{-2}$	<48	2.7 ± 0.2	$<3.0\cdot10^{-5}$	$8.8\cdot10^{4}$
	"Bolshoe" lake (p. 1)	< 3	$<1\cdot10^{-3}$		6 ± 1	$(1.5\pm0.1)\cdot10^{-3}$	$4\cdot10^{3}$	5.7 ± 0.9	$(3.4\pm0.3)\cdot10^{-3}$	$1.7\cdot10^{3}$	< 0.24	$(7.3\pm0.7)\cdot10^{-4}$	$<3.3\cdot10^{2}$
	"Bolshoe" lake (p. 12)	< 3	$<1\cdot10^{-3}$		7 ± 3	$(2.0\pm0.2)\cdot10^{-3}$	$3.5\cdot10^{3}$	1.3 ± 0.5	$<5.2\cdot10^{-4}$	$2.6\cdot10^{3}$	15 ± 3	$<4.1\cdot10^{-5}$	>
	"Solenoe" lake	< 3	$<1\cdot10^{-2}$		12 ± 3	$(7.0\pm0.7)\cdot10^{-3}$	$1.7\cdot10^{3}$	5.5 ± 0.8	$<1.4\cdot10^{-2}$	>	7.9 ± 1.9	$<1.8\cdot10^{-3}$	$4.3\cdot10^{3}$
Dolon	p.4	< 3	$<9\cdot10^{-4}$		30 ± 3	$<2\cdot10^{-4}$	>	2.5±0.6	$(1.3\pm0.1)\cdot10^{-3}$	$2\cdot10^{3}$	53 ± 5	$(4.0\pm0.4)\cdot10^{-4}$	$1.3\cdot10^{5}$
	p.7	< 3	$<2\cdot10^{-3}$		8 ± 3	$<3\cdot10^{-4}$	$2.7\cdot10^{4}$	1.2±0.6	$(1.3\pm0.1)\cdot10^{-3}$	$9\cdot10^{2}$	52 ± 7	$<3.5\cdot10^{-5}$	$1.5\cdot10^{6}$
	p.13	< 3	$<1\cdot10^{-3}$		15 ± 3	$<2\cdot10^{-4}$	>		$(1.7\pm0.3)\cdot10^{-3}$		12 ± 3	$<3.3\cdot10^{-5}$	>

Table 34.

Contents of artificial radionuclides in the samples of bottom sediments and water in the streamflows

Sampling venue	Sampling point	Specific activity of ^{241}Am, Bq/kg		T_f	Specific activity of ^{137}Cs, Bq/kg		T_f	Specific activity of ^{90}Sr, Bq/kg		T_f	Specific activity of $^{239+240}Pu$, Bq/kg		T_f
		Bottom sediments	Water		Bottom ediments	Water		Bottom sediments	Water		Bottom sediments	Water	
Shagan river	Tributary	< 3	< 3		20 ± 3	< 0.01	>	14 ± 2	0.17 ± 0.03	82	9.7 ± 2.9	$(3.2\pm1.9)\cdot10^{-3}$	$3\cdot10^{3}$
	OP-53	< 3	< 3		35 ± 3	< 0.01	>	16 ± 2	0.17 ± 0.03	94	6.2 ± 2.3	$<0.6\cdot10^{-3}$	>
	OP-105	< 3	< 3		35 ± 3	< 0.01	>	24 ± 4	$(7.6\pm1.1)\cdot10^{-2}$	$3.2\cdot10^{2}$	6.5 ± 2.3	$(1.7\pm0.8)\cdot10^{-3}$	$3{,}8\cdot10^{3}$
	OP-108	< 3	< 3		35 ± 3	< 0.01	>	22 ± 3	$(2.2\pm0.4)\cdot10^{-2}$	$1\cdot10^{3}$	12 ± 3	$(1.4\pm0.7)\cdot10^{-3}$	$8{,}5\cdot10^{3}$
	OP-110	< 3	< 3		30 ± 3	< 0.01	>	24 ± 4	$<0.8\cdot10^{-2}$	>	6.4 ± 2.7	$(2.1\pm0.9)\cdot10^{-3}$	$1\cdot10^{4}$
"Degelen"	Baytles creek	< 3	< 3		10 ± 3	< 0.01	>	18 ± 3	2.5 ± 0.4	7	< 0.3	$<4.1\cdot10^{-3}$	
	Toktakushik creek	< 3	< 3		14 ± 3	< 0.01	>	28 ± 4	0.15±0.02	$1.9\cdot10^{2}$	2.2 ± 1.1	$<0.4\cdot10^{-3}$	>
	Uzynbulak creek	< 3	< 3		9 ± 3	< 0.01	>	62 ± 9	0.7±0.1	88	< 0.7	$(2.4\pm1.1)\cdot10^{-3}$	$<2{,}9\cdot10^{2}$
	Karabulak creek	< 3	< 3		25 ± 3	< 0.02	>	360 ± 50	5.3 ± 0.8	68	50 ± 11	$(2.4\pm1.2)\cdot10^{-3}$	$2\cdot10^{4}$
Irtysh river	p.1	< 3	$<2\cdot10^{-3}$		< 3	$<4\cdot10^{-4}$		2.6±0.5	$(2.7\pm0.4)\cdot10^{-3}$	$9.6\cdot10^{2}$	< 0.3	$(4.7\pm2.2)\cdot10^{-4}$	$<8{,}5\cdot10^{2}$
	p.4	< 3	$<9\cdot10^{-4}$		< 3	$<2\cdot10^{-4}$		< 0.7	$(2.8\pm0.3)\cdot10^{-3}$	$<2.9\cdot10^{2}$	< 0.2	$(3.7\pm0.2)\cdot10^{-5}$	$<5{,}5\cdot10^{3}$
	p.7	< 3	< 3		< 3	< 0.01		< 0.8	$(1.8\pm0.4)\cdot10^{-2}$	<44	< 0.3	$<3.1\cdot10^{-3}$	
	p.13	< 3	< 3		< 3	< 0.02		1.4 ±0.6	$(4.5\pm0.7)\cdot10^{-2}$	30	< 0.3	$<5.0\cdot10^{-4}$	
	p.19	< 3	< 3		< 3	< 0.01		< 0.8	$(1.4\pm0.3)\cdot10^{-2}$	<57	< 0.4	$<0.3\cdot10^{-3}$	
	p.25	< 3	< 3		< 3	< 0.01		0.9 ±0.6	$<0.7\cdot10^{-2}$	$1.3\cdot10^{2}$	< 0.3	$<0.3\cdot10^{-3}$	

3.3.3. Development of recommendations for assessment of radionuclide contamination of water use objects at the STS

Radionuclide analysis of bottom sediments is recommended for primary assessment of water objects state at the STS territory. This analysis is less labor and time consuming than laboratory investigations of water samples, especially for large water objects.

The performed studies (section 3.3.2) show that the majority of artificial radionuclides in "water – bottom sediments" system is accumulated in bottom sediments. An exception is only ^{90}Sr, for that the T_f of n*×10 was obtained. Based on the analysis of T_fs (see 3.3.2), the content of artificial radionuclides in water can be estimated using their content in bottom sediments, i.e. it is possible to calculate maximal radionuclide concentrations in bottom sediments at which their content in water does not exceed the regulatory level (intervention level) [46] (table35).

Table 35.

Assumed concentration of artificial radionuclides in bottom sediments

№	Radionuclide	IL, Bq/kg	Water reservoirs		Streamflows	
			T_f (average)	Assumed concentration in bottom sediments, Bq/kg	T_f (average)	Assumed concentration in bottom sediments, Bq/kg
1	$^{239+240}$Pu	0.55	2.5×10^5	1.4×10^5	5.3×10^3	2.9×10^3
2	^{137}Cs	11	2.6×10^4	2.8×10^5	6.3×10^2	6.9×10^3
3	^{90}Sr	4.9	2.3×10^2	1.1×10^3	50	250

According to the Table 35, for the $^{239+240}$Pu and ^{137}Cs artificial radionuclides content in water below the intervention level, their concentration in bottom sediments should be $n\times10^5$ – $n\times10^3$ Bq/kg. Such values are typical only for the "Experimental Field" site and the "Atomic" lake. The situation with ^{90}Sr artificial radionuclide is a bit different: in some cases, T_f of $n\times10^0$ was obtained (i. 3.3.2). This fact indicates uniform ^{90}Sr distribution in the "water – bottom sediments" system. Therefore, when numerical values of this radionuclide content in bottom sediments are found, its specific activity in water should also be determined.

3.4. Air basin

Increased concentrations of artificial radionuclides (ARN) in air can significantly contribute to radiation load because of inhalational intake of the radionuclides. To assess radiation exposure from the intake of radionuclides with inhaled air, one should have an idea of current situation of radioactive contamination of the air basin and the mechanisms of its formation. In addition, a theoretical assessment of ARN content in air should be carried out. This would allow to determine maximum possible levels of ARN concentration in air environment using calculation method and to compare the calculated data with the experimental ones. To assess the level and the character of radioactive contamination of air environment, experimental studies allowing to determine volumetric activities of artificial radionuclides in the air were carried out at the following objects:

– radiation hazardous objects of the STS “Experimental Field”, “Degelen”, “Telkem”, “Sary-Uzen”, the “Atomic” lake and other testing sites) with high concentrations of artificial radionuclides in soil;
– in vicinities of the radiation hazardous objects;
– Karazhyra and Karadzhal mineral deposits;
– territories with unauthorized economic activities (STS winterings);
– in Kainar, Sarzhal, Bodene and Kurchatov inhabited localities, located at the territory, adjacent to the STS.

The Figure 128 provides the map of the studied objects at the STS and adjacent territories.

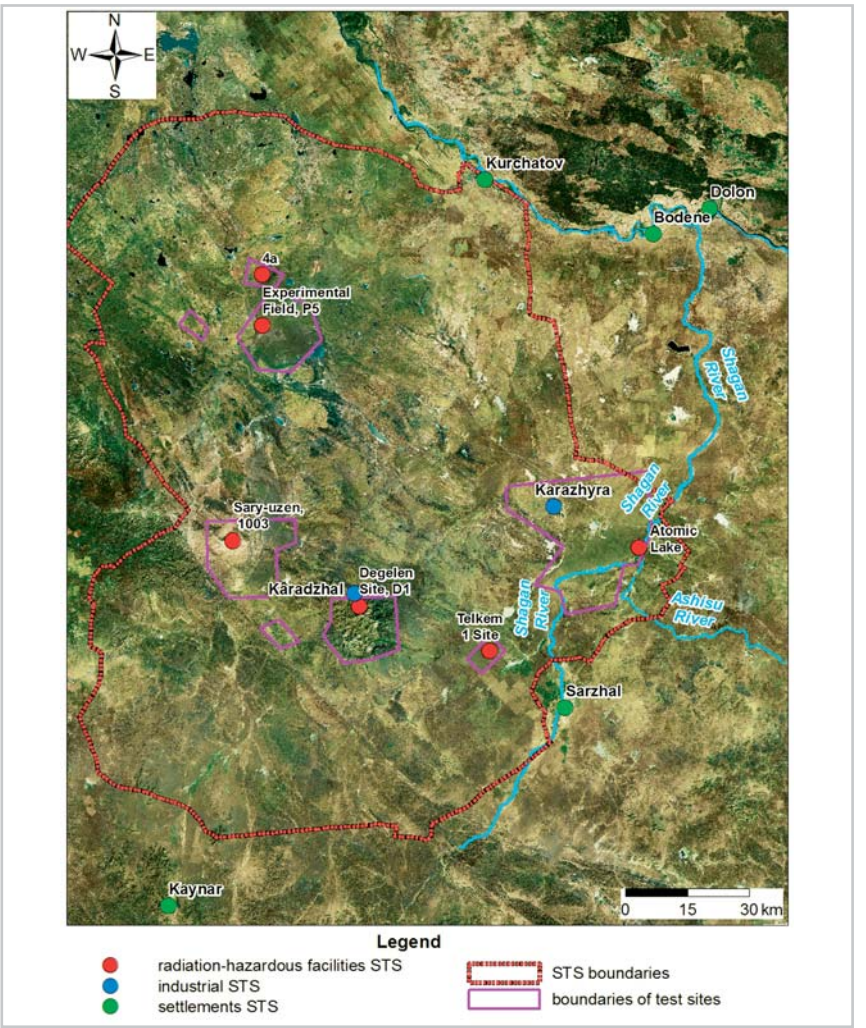


Figure 128. Studied objects

At each of the studied objects, aerosols were sampled employing a mechanical air sampler with a filter. Depending on the type of the object, either portable or stationary air samplers with the air flow rate from 60 to 30,000 m^3/h were used. As the filter, a 0.2 thick Petryanov's synthetic perchlorvinyl filtering fabric (FPP-15-1,5) was used. The volume of air pumped through the filter was 600 to 30,000 m^3.

The filters with air aerosols were analyzed for ^{241}Am and ^{137}Cs artificial radionuclides content using gamma-spectrometry and for $^{239+240}Pu$ and ^{90}Sr radionuclides content using the radiochemical method. Obtained activities, taking into account the volume of air pumped through, were converted into the volumetric activities (Bq/m^3).

3.4.1. State of air environment at the radiation hazardous objects of the STS

Since industrial and agricultural works associated with artificial impact on radioactively contaminated soil cover contribute to artificial radionuclides distribution beyond contaminated sites by air, air environment was researched both with and without impact on the soil cover.

3.4.1.1. Determination of the radionuclide contamination levels for air environment at radiation hazardous objects of the STS

Studies were performed on the STS at the radiation hazardous objects with increased contamination of soil cover with artificial radionuclides and different radionuclide compositions. The following objects were chosen for the research:

- a tunnel with emergency situation at the "Degelen" site;
- places of excavation nuclear tests at the sites "Telkem", "Balapan" and "Sary-Uzen";
- a site for testing warfare radioactive agents;
- surface and atmospheric tests venues at the "Experimental Field" site.

Volumetric activity of artificial radionuclides in air environment was determined to assess maximum levels of air environment contamination with ARN at each of the radiation hazardous objects of the STS, in points with maximum concentrations of radionuclides in soils.

Resulted concentrations of artificial radionuclides in air environment at the territory of the STS radiation hazardous objects are given in the Table 36. For comparison, the same table provides levels of artificial radionuclides concentration in the subsoil.

Table 36.

Concentrations of artificial radionuclides in air environment at the radiation hazardous objects of the STS

Object	Volumetric activity of radionuclides, μBq/m³ (Specific activity in soil, Bq/kg)			
	^{137}Cs	^{90}Sr	^{241}Am	$^{239+240}$Pu
"Atomic"lake	<180 ($2.2\cdot10^4$)	<200 ($5.6\cdot10^3$)	1,300±300 ($3.0\cdot10^3$)	6,000±400 ($1.7\cdot10^4$)
"Telkem-1"	<600 ($2.5\cdot10^3$)	<400 ($5.0\cdot10^1$)	<400 ($6.3\cdot10^3$)	1,200±200 ($5.2\cdot10^4$)
"Telkem-2"	<80 ($2.7\cdot10^3$)	<300 ($2.3\cdot10^2$)	<100 ($3.5\cdot10^3$)	700±100 ($2.8\cdot10^4$)
"Sary-Uzen", borehole 1003	<200 ($1.0\cdot10^3$)	<200 ($2.0\cdot10^1$)	<400 ($8.0\cdot10^2$)	11,000±1,000 ($7.0\cdot10^3$)
" Degelen", tunnel 138	<800 ($3.0\cdot10^3$)	<300 ($2.6\cdot10^2$)	<300 ($1.0\cdot10^3$)	320±100 ($1.0\cdot10^4$)
"Experimental Field", P1	<80 ($6.0\cdot10^2$)	<200 ($1.0\cdot10^2$)	<100 ($1.0\cdot10^4$)	110±40 ($8,0\cdot10^4$)
"Experimental Field", P3	<200 ($1.3\cdot10^3$)	<400 ($3.0\cdot10^2$)	3,000±300 ($7.4\cdot10^4$)	16,000±1,000 ($5.8\cdot10^3$)
"Experimental Field", P5	<100 ($1.4\cdot10^4$)	<300 ($3.5\cdot10^3$)	<100 ($2.0\cdot10^4$)	120±30 ($7.0\cdot10^5$)
"Experimental Field", "4A"	<350 ($3.0\cdot10^2$)	1,000±300 ($1.3\cdot10^6$)	<100 ($1.0\cdot10^3$)	140±50 ($5.0\cdot10^2$)
PVA for population, μBq/m³	$2.7\cdot10^7$	$2.7\cdot10^6$	$2.9\cdot10^3$	$2.5\cdot10^3$

^{137}Cs content in soil of the radiation hazardous objects of the STS reaches the value of $n\cdot10^4$ Bq/kg, however, experimental studies at these objects did not reveal any presence of ^{137}Cs radionuclide in the air environment.

At the ^{90}Sr content in soil cover ranging from $n\cdot10^1$ to $n\cdot10^3$ Bq/kg, this radionuclide was not detected in the air environment. At ^{90}Sr concentration in soil of $n\cdot10^6$ Bq/kg, ^{90}Sr was detected, however, even at these concentrations the content of ^{90}Sr in air does not exceed 1,000 μBq/m³, that is for 3 orders of magnitude below the permissible volumetric activity for population – $PVA_{pop,}$ according to HS SERPRS [46].

^{241}Am was detected only in air at the " Atomic" lake and "P3" site of the "Experimental Field", at that ^{241}Am concentration values reached permissible volumetric activity for population PVA_{pop} ($2.9\cdot10^3$ μBq/m³).

Since even with high radioactive contamination of soil ($n\cdot10^4$ Bq/kg) with artificial radionuclides the content of radionuclides ^{137}Cs, ^{241}Am, ^{90}Sr in air is 1-3 orders of magnitude below the PVA_{pop}, then at other objects and the conditionally background STS territories the concentrations of these radionuclides in air cannot exceed PVA_{pop}.

At all objects with soil radioactively contaminated with $^{239+240}$Pu, presence of $^{239+240}$Pu in air environment was detected. At that, volumetric activity of $^{239+240}$Pu artificial radionuclide in air environment of the radiation hazardous objects (RHO) varied from 10^2 to 10^4 μBq/m³, i.e. the maximal value exceeded the PVA_{pop} value ($2.5\cdot10^3$ μBq/m³) for

an order of magnitude. Maximum levels of air environment radioactive contamination, exceeding the PVA_{pop} values, were found near the crater from the excavation nuclear explosion at the "Atomic" lake and at the borehole 1003, as well as in places of surface and atmospheric nuclear tests at "P3" technical site of the "Experimental Field".

Based on the above, it can be concluded that assessing air environment contamination with artificial radionuclides, attention should be mainly paid to determination of $^{239+240}Pu$ radionuclide volumetric activity in air. Concentrations of ^{137}Cs, ^{90}Sr and ^{241}Am radionuclides in air environment can be theoretically estimated based on the known $^{239+240}Pu/^{241}Am/^{137}Cs/^{90}Sr$ isotopic ratios.

3.4.1.2. Air environment in vicinity of the radiation-hazardous objects at the STS when undertaking agricultural activities

To reveal the maximal possible levels of air environment radioactive contamination when influencing soil cover at the "Experimental Field" site (Figure 129), special experiments were arranged [154]. In the places of agricultural activities (production zone, garden) air was sampled during a working shift (6-8 hours). At the distance of 300 m from the place of agricultural activities (living zone), air was sampled day and night.

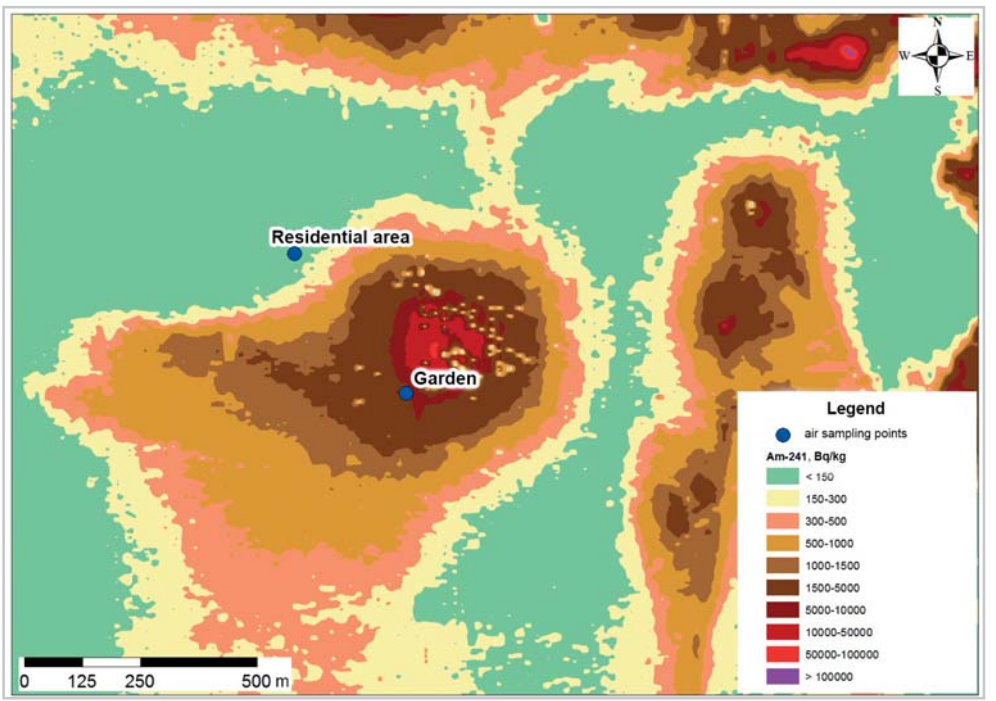


Figure 129. Location of the experimental objects at the "Experimental Field" site

Production zone was located directly at the site with radioactively contaminated soil (content of transuranium radionuclides in soil is $n \cdot 10^4$ Bq/kg). At this site, agricultural

works were carried out as follows: soil ploughing and harrowing, field leveling, crop planting and weeding, watering, harvesting, and etc.

Table 37 provides the data on radionuclides concentrations in air environment during the farm works in the production zone.

Table 37.

Concentrations of artificial radionuclides in air environment during agricultural works in the production zone

Types of works	Sampling period	Volumetric activity of radionuclides, μBq/m³			
		^{137}Cs	^{90}Sr	^{241}Am	$^{239+240}$Pu
Soil ploughing	24.05.11	<1,000	<1,000	<700	1,300±100
Digging, planting crops	28-29.05.11	<600	<400	<300	7,400±900
	03-08.06.11	<500	<300	<300	1,000±200
Field harrowing	07.06.11	<7,000	<500	<3,000	16,000±6,000
	09.06.11	<6,000	<400	<5,000	30,000±1,000
Planting crops	06-12.07.11	<200	<100	<100	2,600±300
PAC for personnel		**$1.7\cdot10^9$**	**$3.3\cdot10^8$**	**$2.1\cdot10^5$**	**$3.2\cdot10^4$**
PAC for population		**$2.7\cdot10^7$**	**$2.7\cdot10^6$**	**$2.9\cdot10^3$**	$2.5\cdot10^3$

Maximal $^{239+240}$Pu concentrations were found during the period of agricultural works associated with artificial impact on soil cover (Table 37), such as soil ploughing, harrowing, leveling and planting. During the harrowing period, volumetric activity of $^{239+240}$Pu radionuclide was 30,000 μBq/m³ reaching permissible volumetric activity (PVA_{pers} – 32 000 μBq/m³) and significantly exceeding the PVA_{pop} level.

Air was sampled at the distance of over 300 m from the site with radioactively contaminated soil ($n\cdot10^4$ Bq/kg), at conditionally "clean" territory as follows:

– during 3 days filter was changed 2 times per day, (daily and the night time air pumping);
– during 3 days filter was changed once a day;
– during 3 or 5 days filter was changed once per 3 or 5 days of continuous work.

Obtained data was used to assess and compare air environment contamination in a day time (1,300 m³), night time, for 24 hours (2,800 m³) and for 3-5 days' periods (7,500-9,000 m³).

Table 38 provides average concentrations of artificial radionuclides in air environment for the living zone. According to the obtained data, no increased concentrations of ^{241}Am, ^{137}Cs, ^{90}Sr radionuclides were found in all the studied sites and the radionuclide concentrations did not exceed the detection limits.

During the whole research period (4 months), maximum concentration of $^{239+240}$Pu radionuclide in living zone did not exceed 54 μBq/m³; at that, average daily concentration was 24 μBq/m³. At the distance of 300 m to the site with radioactively contaminated soil (in the living zone), $^{239+240}$Pu radionuclide concentration was found at the level of 24 μBq/m³.

Table 38.

Average concentrations of artificial radionuclides in air environment in different periods of air sampling

Sampling period (number of measurements, n)	Volumetric activity of radionuclides, μBq/m³			
	^{137}Cs	^{90}Sr	^{241}Am	$^{239+240}$Pu
Mean daily (17)	<92	<14	<51	22±7
Mean night time (16)	<83	<19	<50	10±4
Average for 24 hours (30)	<36	<14	<29	24±8

Obtained data allows assuming that even when soil cover is contaminated with artificial radionuclides, with a man-made impact on soil cover, significant distribution of radionuclides by air does not exceed several hundreds of meters.

3.4.2. Determination of the ARN concentration levels in air basin at the conditionally "background" STS territory

Experimental studies of air environment aimed at determining artificial radionuclides activity concentration were carried out at industrial objects, in inhabited localities and researched STS territories ("northern", "western" and "southeastern"parts).

3.4.2.1 Industrial facilities of the STS

Environmental monitoring has been carried out in 2007-2013 at the territory of the following mineral deposits: "Karazhyra" coal mine, located at the territory of "Balapan" site (Figure 128). The nearest radiation hazardous object is located at the distance of 3-5 km to the production zone of the deposit; "Karadzhal" fluorite deposit, located at the distance of 3-5 km to "Degelen" site near the site with emergency radiological situation.

Table 39.

Mean concentrations of artificial radionuclides in air environment at mineral deposits of the STS

Deposit name	Average volume of pumped air, m³	Volumetric activity of radionuclides, μBq/m³ (number of measurements, n)			
		^{137}Cs	^{90}Sr	^{241}Am	$^{239+240}$Pu
Karadzhal	38,000	< 4 (41)	< 1 (7)	< 1 (41)	0.4 ± 0.1 (8)
Karazhyra	20,000	< 6 (58)	< 2 (5)	< 5 (58)	1.2 ± 0.6 (18)
PVA for population		$\mathbf{2.7 \cdot 10^7}$	$2.7 \cdot 10^6$	$2.9 \cdot 10^3$	$2.5 \cdot 10^3$
Concentration of $^{239+240}$Pu, ^{137}Cs, ^{90}Sr in soil, $n \cdot 10^1$ Bq/kg, ^{241}Am – 10^0 Bq/kg					

Investigation of air environment for artificial radionuclides concentrations allowed to assess the present state of air environment under conditions of production activities. Table 39 provides generalized data on artificial radionuclides content in air environment when carrying out production activities.

Continuous air sampling of large volume allowed to determine the level of radioactive contamination of air environment with artificial radionuclides. For the whole period

of research, quantitates of artificial radionuclides content in air environment were obtained only for the $^{239+240}$Pu radionuclide. Volumetric activity of $^{239+240}$Pu artificial radionuclide in air environment of the STS industrial facilities is 0.4−1.2 μBq/m^3, that is for 3-4 orders of magnitude below the PVA_{pop} set by the health standards [46].

Obtained results allow to assume that proliferation of artificial radionuclides by air from the territory of these STS lands is either insignificant or does not occur at all.

3.4.2.2. Inhabited localities, adjacent to the STS territory

Kurchatov, Bodene, Sarzhal and Kainar inhabited localities are located beyond the STS boundary. Nevertheless, plumes of radioactive fallouts from atmospheric and surface nuclear explosions at the STS run for several dozens or even hundreds of kilometers towards Bodene and Sarzhal villages.

Table 40 provides summary concentrations of artificial radionuclides in air environment of Kurchatov, Bodene, Sarzhal and Kainar inhabited localities.

Table 40.

Average concentrations of artificial radionuclides in air environment of inhabited localities adjacent to the STS

Inhabited localities (period of study)	Average volume of pumped air, m^3	Volumetric activity of radionuclides, μBq/m^3 (number of measurements, n)			
		^{137}Cs	^{90}Sr	^{241}Am	$^{239+240}$Pu
Kurchatov (2009-2014)	13,000	< 70 (150)	< 15 (6)	< 2 (150)	< 2 (19)
Bodene (2013)	19,000	< 50 (1)	< 10 (1)	< 4 (1)	< 0.5 (1)
Sarzhal (2012-2013)	30,000	< 80 (7)	< 4 (1)	< 4 (7)	1,0 ± 0.4 (7)
Kainar (2012)	18,000	< 10 (2)	< 5 (1)	< 5 (2)	0.3 ± 0.1 (2)
PVA for population		**$2.7\cdot10^7$**	**$2.7\cdot10^6$**	**$2.9\cdot10^3$**	$2.5\cdot10^3$
Concentration of $^{239+240}$Pu, ^{137}Cs, ^{90}Sr in soil, n·10^1 Bq/kg, ^{241}Am – 10^0 Bq/kg					

Volumetric activity of $^{239+240}$Pu radionuclide in air environment of inhabited localities is 0.3-1 μBq/m^3. Probably, the source of $^{239+240}$Pu radionuclide found in the air environment of Sarzhal village is the soil cover. Wind uplift forms the background concentration of $^{239+240}$Pu in air environment ~ 1 μBq/m^3 at the territory of the village.

3.4.2.3. Experimental determination of ARN concentration at the "background" territories

To study the state of air environment at the "northern", "western" and "southeastern" lands of the STS, experimental studies aimed at determining the volumetric activities of artificial radionuclides were carried out. At inhabited winterings and in summer huts of the STS, in the summertime, one-off investigations of air environment were carried out. Location of the investigated objects (winterings) is shown at the Figure 128.

Table 41 provides average concentrations of artificial radionuclides in air environment at the conditionally "background" lands (northern, western and southeastern parts of the STS).

Table 41.

Average concentrations of artificial radionuclides at the conditionally background STS territories

Parts of the STS territory	Name of wintering	Volumetric activity of radionuclides, μBq/m³			
		^{137}Cs	^{90}Sr	^{241}Am	$^{239+240}$Pu
"Northern"	Bapay, Aktas, Bulak, Dostyk, Tortkuduk	<300	-	<200	<10
"Western"	Altynkuduk, Tokyl, Teskuduk, Mausymbek	<400	-	<200	-
"Southeastern- 1"	Akshakee, Tileubek, Sholandyr, Tolegen, Akbiik, Sunkar, Samay, Kyzyl	<200	<800	<90	<100
"Southeastern- 2"	Taylan-1, Taylan -2, Taylan -3, Shurek, Masten-1	<100	<100	<70	<30
"Southeastern- 3"	Atymtay, Bakizhan-1, Enbektas, Zhezbike, Kan	<200	<200	<100	<20
PVA for population		**$2.7 \cdot 10^7$**	**$2.7 \cdot 10^6$**	**$2.9 \cdot 10^3$**	$2.5 \cdot 10^3$

Volumetric activity of artificial radionuclides in air environment of all investigated winterings at the STS was below the detection limit. No quantitative amounts of radionuclides were found at the conditionally "background" territories of the STS. This is first of all due to low volume of air pumped through (150-300 m³) during sampling; nevertheless, experimentally obtained values of radionuclides volumetric activity in air are for 2-3 orders of magnitude below the $PVA_{pop.}$

3.4.3. Theoretical estimation of artificial radionuclides content in air

To get quantitative values employing conventional methods of α-, β-, γ-spectrometric analyses, one needs to sample air aerosols from significant amounts of air, that is frequently associated with significant technical complexities. As an alternative to the direct determining of ARN in air, a theoretical assessment can be used. There are no large industrial objects at the STS territory, therefore it can be assumed with enough certainty that the main source of contamination is the subsoil.

Depending on type of the object or the territory, the main source of particulate matter in air can be fine soil fractions (< 40 μm). Therefore, ARN concentrations in air can be determined as concentration of artificial radionuclides in soil multiplied by average annual dust content in air:

$$C_{air} = C_i \bullet \rho_{sus}\,, \qquad (1)$$

where C_i – concentration of artificial radionuclides in air aerosols, Bq/kg;

ρ_{sus} – average annual dust content in air, kg/m³;

Determining C_i, ρ_{sus} hazard level of any fractions of particulate matter in soil and air for people should be considered. Concentration of particulate aerosol particles <2.5 μm (PM2.5) and <10 μm (PM10) in atmospheric air is usually taken in the international literature [155] for assessment of the air environment quality. This is first of all because

the particulate matter smaller than 1-10 μm easily enters breathing organs and in high concentrations can pose a danger for people. To determine ρ_{sus} special investigation of dust content in air environment have been carried out [i. 3.4.3.1].

Concentrations of artificial radionuclides in air (C_i) were calculated using the following formula:

$$C_i = C_{soil} \bullet E_f, \quad (2)$$

where C_{soil} – specific activity of radionuclides in soil, Bq/kg;
E_f – enrichment factor for the fraction of <8 μm.

Specific activity of radionuclides in soil was determined with gamma-spectrometry and radiochemical method. Calculated enrichment factors are given in the i. 3.1.4.

Therefore, the formula for theoretical calculation of volumetric activity of radionuclides in air looks as follows:

$$C_{air} = C_{soil} \bullet K_O \bullet \rho_{sus} \bullet 10^{-9}, \quad (3)$$

where 10^{-9} – kg to μg conversion factor.

3.4.3.1. Experimental investigations of dust content in air environment

Dust content in air environment was measured using "Kvant-1M" aerosol particles analyzer. The size of particulate matter ranged within 1-10 μm (<10 μm). Using the analyzer, mass concentration of aerosol particles in air was determined. Dust content in air environment was determined in the STS objects as follows:

- inside the living premises and in the industrial zone of Karadzhal deposit;
- inside the laboratory premises and outdoors in Kurchatov city;
- outdoors in Dolon village;
- in residential and agricultural zones at the "Experimental Field" site;
- at the radiation hazardous objects of the STS.

At each of the objects, 15-20 measurements of aerosol particles mass-concentration in air were carried out, in 30-60 min intervals. To reveal the dependence of the particulate matter concentration in air on climatic conditions, some meteorological parameters were recorded while measuring the dust content (wind velocity, air humidity and etc.). Dust content in air environment was measured in groups (formed according to the conditions):

- natural (normal) conditions, without sources of dust;
- carrying out of farm works, associated with artificial impact on soil cover;
- artificial dusting.

Natural conditions During the research period no sharp changes were observed in climate (dust storms, precipitation), wind velocity was 1-3 m/s, relative humidity of atmospheric air ranged from 25 to 40 %. The temperature of atmospheric air varied from 22 to 28 ºC. Table 42 provides average concentrations of particulate aerosol matter at the investigated objects of the STS in natural conditions. For convenience, the data on mass concentration of aerosol particles is given in μg/m^3.

Table 42.

Average mass concentration of aerosol particles in air environment under natural conditions

Object	Date of measurement	Range of particles concentration, μg/m³	Average concentration of particles, μg/m³	Range of relative humidity of air, %
Inhabited localities and industrial facilities of the STS				
Karadzhal deposit, premises	07.08.2012	6.1-8.6	7.1	-
Karadzhal deposit, reservoir	07.08.2012	4.6-7.0	5.8	25-31
Kurchatov city, premises	15.05.2012	9.6-10.6	10.2	-
Kurchatov city, open area	16.05.2012	7.8-9.6	8.8	21-28
Dolon village, outdoors	20.05.2014	10.5-13.2	12.3	28-32
Radiation hazardous objects of the STS				
"Experimental Field", inhabited area	30.05.2012	3.0-4.2	3.7	32-40
"Experimental Field", P5	06.06.2013	6.3-7.6	6.7	-
"Degelen", tunnel 138	07.06.2013	6.1-7.2	6.4	-
"Telkem"	07.06.2013	4.9-7.0	6.1	-
Mean value for the STS, μg/m³		**-**	**7.4**	**-**

Average concentration of particulate matter in air environment of the studied objects varied from 3.7 to 12.3 μg/m³. Increased dust content in air was found in Kurchatov city and Dolon village. It also can be noted that concentration of particulate matter in indoors air is higher than that at the open area.

Dust content in air environment during agricultural activities To determine the level of dust content in air environment during agricultural works (weeding), experimental studies were carried out at the "Experimental Field" site. An analyzer was installed 0.3, 1, 1.3 and 1.5 m above the ground surface at the distance of 3-5 m to the site of agricultural works. Table 43 provides average mass concentrations of particulate matter during weeding at various elevations above the ground.

Table 43.

Average concentrations of particulate matter in air environment during agricultural works

Level above the ground, m	Date of measurement	Range of particles concentrations, μg/m³	Average particles concentration, μg/m³
0.3	30.05.2012	3.9-50	20.5
1	30.05.2012	3.2-9.1	5.9
1.3	30.05.2012	3.7-12.9	7.8
1.5	30.05.2012	4.3-6.7	6.0

When planting crops, one-time concentration of particulate matter in air 0.3 m level above the soil surface was 50 μg/m³; at that average concentration of particles was 20 μg/m³. So, when carrying out agricultural works, the concentration of particulate

matter in air can exceed the background concentrations of particulate matter for this area for 3-5 times.

Artificial dusting. Artificial dusting intensity has been experimentally determined at the "Experimental Field" site. Increased dusting was arranged mechanically using square-point shovel (a part of soil was showeled and then poured out from the height of 1.5m). Dust content was measured 0.3, 1, 1.3 and 1.5 m above the soil surface 0.5 m away from the dusting source. Before the start of such artificial dusting, background concentration of dust in air was measured.

Table 44 provides background concentrations of particulate matter in air and during the artificial dusting.

Table 44.

Particulate matter concentrations in air environment before and during artificial dusting

Level above the ground, m	Date of measurement	Particle concentration, μg/m³		
		Background measurements		
		Range	Average	Artificial dusting, average
0.3	30.05.2012	3.4-4.2	3.8	181.0
1	30.05.2012	2.9-3.4	3.2	27.4
1.3	30.05.2012	2.8-3.2	3.0	48.8
1.5	30.05.2012	3.2-3.6	3.3	30.9

Maximal concentration of suspended dust particles in air registered at the height of 0.3m above the ground level is 180 μg/m³. At that, at the level of 1.5 m above the ground, concentration of particulate matter in air is 30 μg/m³ that exceeds the average background concentrations of dust in air under natural conditions for 3 times (Table 42). No dependence of particulate matter content in air on climatic conditions was found.

So, in natural conditions the level of particulate matter concentration in air ranges from 4 to 13 μg/m³. Obtained level of dust content in air is in good agreement with the dust content in air of America and countries of European Union. So, when carrying out a theoretical estimate of air environment contamination with artificial radionuclides in natural conditions (1.5 m above the ground), the most conservative value of the average annual dust content in air equal to 10 μg/m³ ($1.0 \cdot 10^{-8}$ kg/m³) is recommended for use.

3.4.3.2. Source data for calculation of artificial radionuclides concentration in air environment

For the estimations (formula 1), artificial radionuclides ^{137}Cs, ^{241}Am, ^{90}Sr and $^{239+240}$Pu were chosen. Specific activity of artificial radionuclides in soil was determined upon the results of areal distribution of artificial radionuclides at the conditionally "background" STS territories [i. 3.1.2]. Table 45 provides mean concentrations of artificial radionuclides in soil of the conditionally "background" STS territories.

Table 45.

Mean specific activity of radionuclides in soil of the conditionally "background"territories of the STS

Investigated territory	Mean specific activity values in soil, Bq/kg			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
"Northern"	17.2	10.0	4.1	0.8
"Western"	29.0	-	8.4	3.7
"Southeastern- 1"	31.0	8.8	8.2	0.8
"Southeastern- 2"	43.3	0.9	1.0	1.3
"Southeastern- 3"	17.8	8.9	15.4	2.2

The grain size analysis of the top 5-cm soil layer was performed to determine the enrichment factors. Detailed description of the grain size analysis technique is given in the section [i. 3.1.4]. The Table 46 provides mean enrichment factor values for the granulometric fractions as follows: <100, <40 and <8 μm at the conditionally "background" territories of the STS.

Table 46.

Average enrichment factors of granulometric soil fraction at the conditionally "background" territory of the STS

Investigated territory	Enrichment factor [3.1.4]			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
"Northern" (<100 μm fraction)	1.9	1.6	1.2	1.4
"Western" (<100 μm fraction)	2.1	1.5	2.9	2.1
"Southeastern" - 1 (<40 μm fraction)	0.7	0.2	0.8	1.8
"Southeastern" - 2 (<40 μm fraction)	1.6	0.9	1.0	1.3
"Southeastern" - 3 (<8 μm fraction)	2.7	3.4	2.0	2.4

3.4.3.3. Theoretical assessment

In the theoretical assessment (formula 3), the following parameters were used: specific activity of the *i*-th radionuclide in soil (Table 45), enrichment factor of this radionuclide for <8 μm fraction (Table 46), average annual dust content in air – 10 μg/m^3. Table 47 provides estimated volumetric activity values of the artificial radionuclides in air at the conditionally "background" territories of the STS taking into account specific activity of the radionuclides in soil, enrichment factor and dust content in air.

Table 47.

Calculated volumetric activities of radionuclides in air environment at the conditionally "background" STS territories

Investigated territory	Volumetric activity of radionuclides in air, μBq/m³			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
"Northern"	0.32	0.16	0.05	0.01
"Western"	0.61	-	0.24	0.07
"Southeastern- 1"	0.22	0.02	0.01	0.07
"Southeastern- 2"	0.68	0.26	0.14	0.02
"Southeastern- 3"	0.49	0.30	0.05	0.31
PVA_{pop}, Bq/m³	$2.7 \cdot 10^7$	$2.7 \cdot 10^6$	$2.5 \cdot 10^3$	$2.9 \cdot 10^3$

Estimated volumetric activity values for artificial radionuclides in air at the conditionally "background" STS territories are for 1-4 orders of magnitude below the detection limit of the experimental method applied [i. 3.4.2.3]. It is therefore impossible to obtain experimentally the numerical quantitates for air environment contamination with artificial radionuclides. Nevertheless, obtained experimental and theoretical data are consistent; at that, expected volumetric activities of the artificial radionuclides are for 3-5 orders of magnitude below the PVA_{pop}.

3.4.4. Recommendations for assessment of ARN concentration levels in air basin at the conditionally "background" STS territories

No exact techniques or recommendations were found in the available international literature for assessment of air environment at the territories suffered from nuclear tests. As a rule, researches include determining volumetric activity of artificial radionuclides in the air of large inhabited localities and industrial facilities. Obtained data is compared with permissible volumetric activity, set by the regulatory standards [46]. The main disadvantage of this method is a large amount of time needed for such studies, as well as significant material expenses for the field and laboratory research. The fact that these studies can characterize only a point (local) survey area or an object, whose area is $n \cdot 10^{-2}$ km² can also be categorized as a disadvantage.

Analysis of the research results shows that the level of artificial radionuclides concentration in soil is proportional to the radionuclides concentration in air environment. So, there is no need for experimental studies in air environment at the territories with artificial radionuclides concentrations in soil found at the level of global fallouts.

When the focus territory is closely located to radiation hazardous objects of the STS or on the traces from radioactive fallouts, theoretical assessment of possible radioactive contamination of air environment is needed followed by the identification of objects or sites with increased concentrations of artificial radionuclides in soil and finally, by qualifying experimental studies to determine volumetric activity of artificial radionuclides in air.

Directly at the territory of radiation hazardous objects at the STS in venues of maximal concentrations of artificial radionuclides in soil (epicenters of nuclear tests), regular

and special monitoring studies of air environment are to be performed. Regular studies would allow to understand the dynamics of artificial radionuclides concentration change in air, while the special monitoring would allow to assess the extent of artificial radionuclides distribution beyond the STS testing sites.

When carrying out regular and special studies of the air environment, in venues with maximal radionuclides concentrations in soil, single sampling of air pumped with the volume of at least 200 m^3 could be enough. When determining artificial radionuclides content in samples of air aerosols, special attention should be paid only to determining the $^{239+240}Pu$ concentration. First of all, this is due to the fact that $^{239+240}Pu$ is the most toxic artificial radionuclide, its concentration at the contaminated STS areas is for an order of magnitude higher than ^{241}Am concentration in the environmental objects. It should be noted also that the radiochemical method of determining $^{239+240}Pu$ content in air is more sensitive if compared with the gamma-spectrometric method. Concentrations of ^{137}Cs, ^{241}Am, ^{90}Sr artificial radionuclides in air environment are recommended to be determined theoretically using the known isotopic ratios of the radionuclides $^{239+240}Pu/^{241}Am/^{137}Cs/^{90}Sr$.

3.5. Revealing potentially-hazardous artificial objects and assessment of radiological situations there

During the operation of the Semipalatinsk Test Site, besides nuclear tests, various studies involving radioactive substances were carried out at its territory. These activities generated various wastes, including radioactive ones which were, most probably, buried at the test site territory. While some information about the nuclear tests is available, there is absolutely no information about researches and experiments and, especially, about the places of the waste burial. Therefore, complex assessment of the radiological situation is to include the works aimed at identification of the potentially hazardous objects.

For example, small in size burial sites (fractions of square kilometers), cannot be discovered using direct search afield, taking into account large sizes of the territories. Therefore, to reveal and assess the potentially hazardous objects, a specially developed methodology was used.

3.5.1. Methodology for revealing and assessing potentially hazardous artificial objects

To reveal and assess the potentially-hazardous objects, a methodology involving the following stages was applied:

1. Reveal of artificial objects by decoding satellite images;
2. Visual assessment of the revealed objects afield;
3. Selection of potentially-hazardous objects;
4. Radiation assessment of selected objects.

Identification of artificial objects by decoding satellite images

Decoding of satellite images (obtaining information about objects at the territory) is performed for detailed terrain study and identification of artificial objects at the STS.

Satellite images – are the data resulted from remote sensing of earth (RSE), presented as visual images allowing to work with large territories irrespective of their remoteness or inaccessibility. Not a scale of satellite images but their spatial resolution, i.e. size of the smallest detail afield reproduced on a shot, matters. For convenience, the images are downloaded (for example, *SAS.planet* software), according to map sheet designation 1:25000 and 1:50000, with maximum available resolution.

The most complicated and critical stage in RSE processing is selection of objects. For artificial objects the main decoding feature is geometrical shape of the object. Satellite image decoding procedure consists of stages as follows:

– selection and processing of high-resolution satellite images;
– search for the objects using decoding features (shape of the object, size, color, shade, tone, structure of the image) and contouring of the object;
– determining object coordinates;
– object description (approximate dimensions, shape).

Upon the results of decoding, a catalogue with the following data is created: schematic location of the object at the satellite image, object number according to the scheme, geographical coordinates and approximate characteristics of the object are arranged.

Visual assessment of revealed objects afield

Visual assessment of revealed objects afield (field decoding) involve comparison of satellite images with the territory. This way assures completeness, good quality and reliability of the decoding results.

Field decoding of satellite images involves the following stages:

– auditing an object location (using geographical coordinates obtained as a result of in-house decoding);
– visual identification of an object matching the description and the satellite image;
– detailed description of an object (size, origin (either artificial or natural), distinguishing features or characteristics);
– verification of an object's geographical coordinates;
– photography of an object.

Upon the results of visual assessment, a catalogue is also arranged including: the number of the object at the decoding scheme, object photo, geographical coordinates and detailed characteristics of the object.

Identification of potentially hazardous objects

To analyze the data upon the results of decoding, the objects were grouped according to basic characteristics most frequently found at the studied territory. Any unique objects found just once and not belonging to any of the groups are marked on the map separately, to avoid "loss" of potentially-hazardous objects.

So, from the general catalogue, the objects that can be categorized as potentially-hazardous objects by their characteristics, for example, pits, visually similar to explosion craters, trenches, objects where items related to chemical, physical or biological equipment, reservoirs, laboratory materials, glassware or their fragments and etc. were found.

Radiological assessment of the selected objects

Radiation parameters – equivalent dose rate (EDR) and beta particles flux rate are measured at the selected objects. EDR values are measured at the ground surface and 1 m above, beta particles flux rates are measured at the object surface.

When increased radiation parameters values at the object, or "suspicious" items were found, then the object is investigated in details by grid with sampling environmental objects and collecting specimens of human activities, with subsequent laboratory analysis. Besides that, ground is sampled in all pits, in spite of remoteness of such objects from the test sites.

Such an approach allows to avoid "loss" of radiation hazardous objects and to get radiation characteristics of the objects.

3.5.2. Results

Today the high-resolution images are available for the most of the STS and adjacent territories. Using *SAS.planet* software, satellite images with different resolutions were obtained (*Here.com* resolution 0.38-1 MPX, *Bing Maps* – 0.38-1 MPX, *Google Maps* – 0.76-40 MPX), images with maximal available resolutions were downloaded (Figure 130).

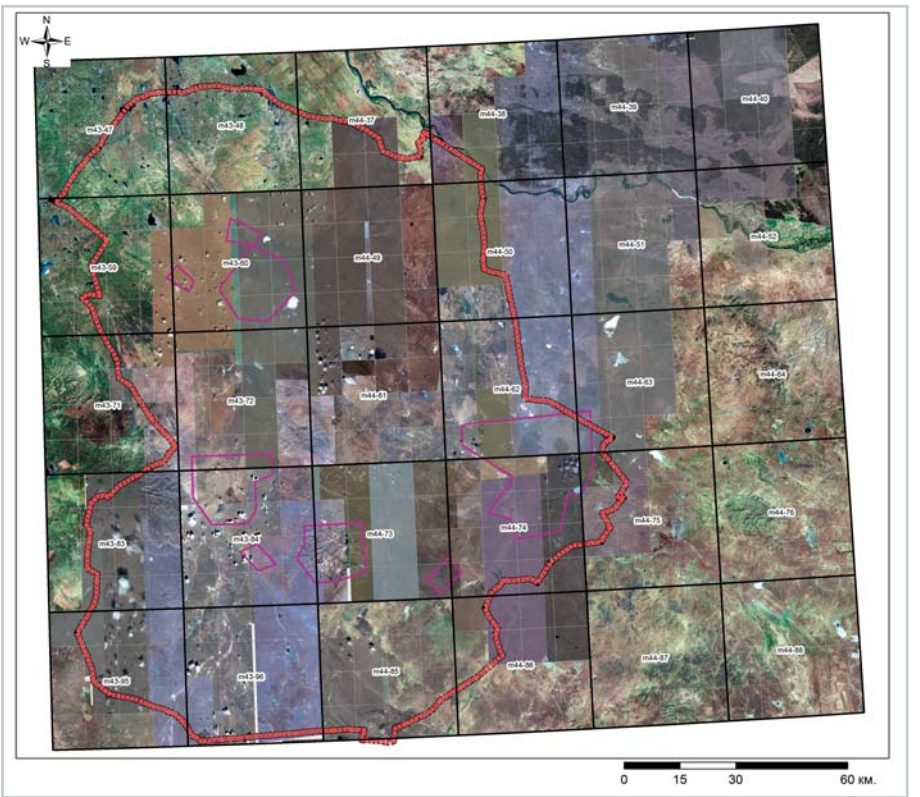


Figure 130. Satellite images according to map sheet designation

The total decoded area covers 6,850 square kilometers, at that about 1,600 objects, i.e. approximately 4 objects per 1 square kilometer were found. Upon the decoding, the objects were grouped based on their basic characteristics, have been most frequently detected at the territory of interest as follows: ruins, trenches and pits, winterings and water objects. Objects that cannot be categorized as any of the above were marked as others and signed (Figure 131).

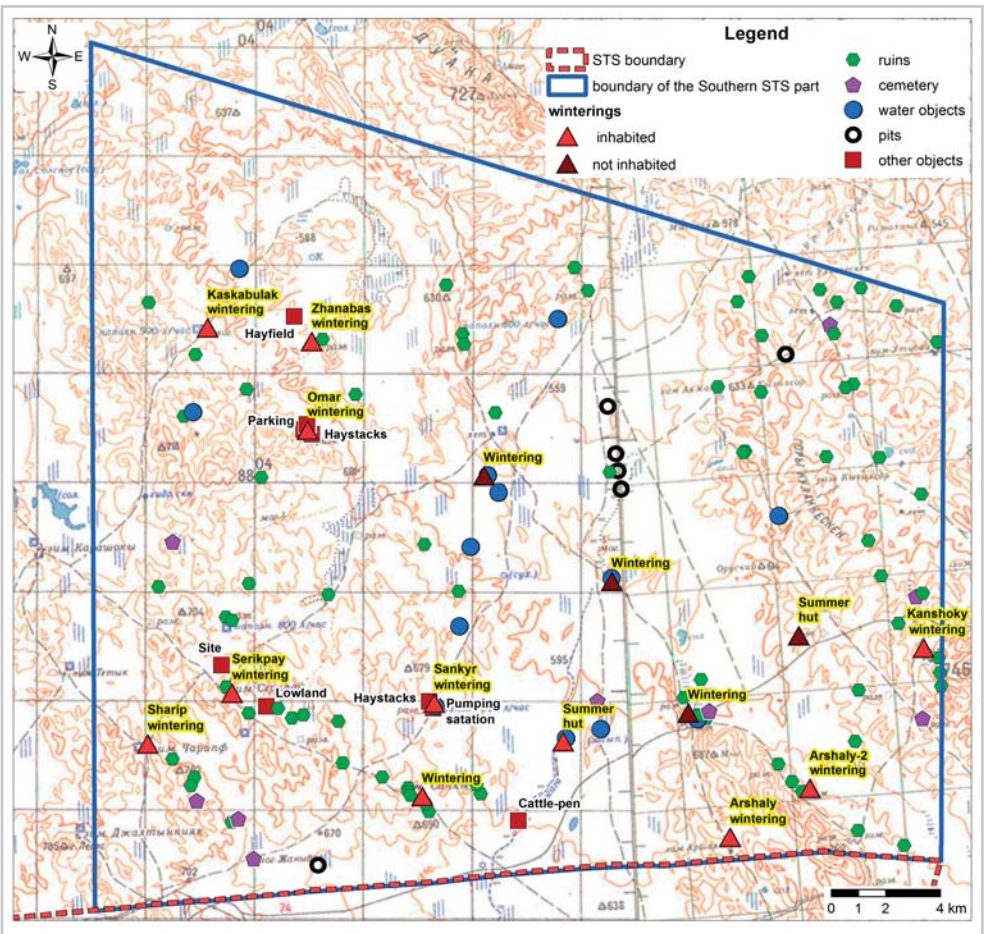
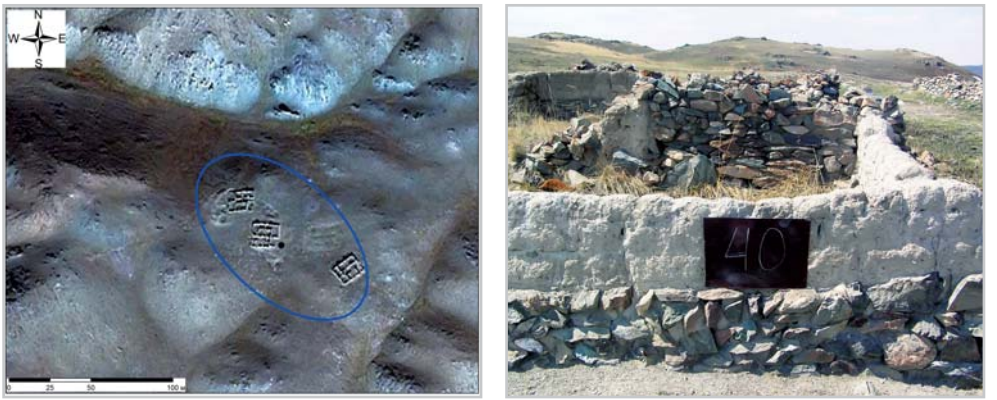


Figure 131. Decoding results for the "southern" part of the STS

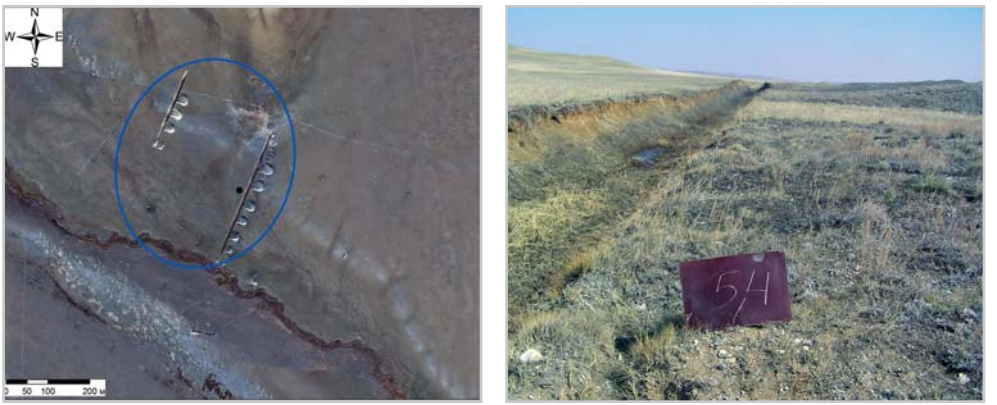
The first type of objects, "ruins" is the most typical for the territory of interest, the percentage of objects of this type is about 80% of the total amount. Typical dimensions are shown at the Figure 132. Upon the decoding, such an object was identified as "ruins". Visual assessment confirmed that the object is really a group of destructed structures rectangular in shape.



a) b)

Figure 132. Object view upon the results of a) satellite image decoding, b) visual assessment

The second typical object type is trenches and pits. Typical example is given at the Figure 133. Upon the decoding, this object was classified as "an object with two linear contours", visual assessment revealed that linear contours are actually man-made trenches.

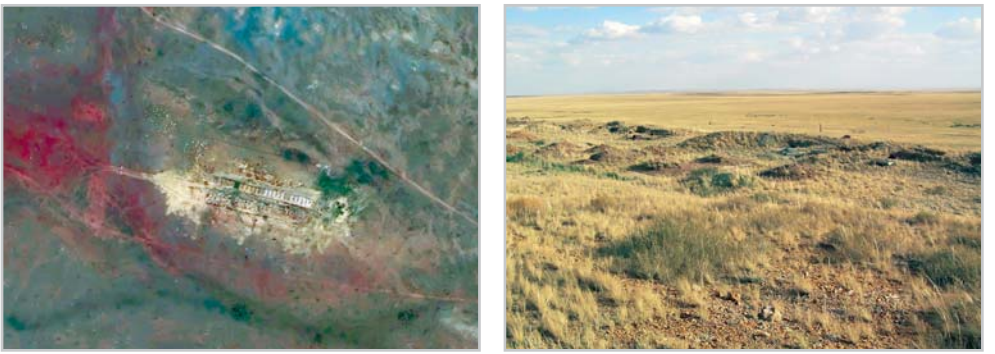


a) b)

Figure 133. Object view upon the results of a) satellite image decoding, b) visual assessment

Having complete catalogue with the results of decoding, visual assessment and characteristics of the objects, information was analyzed; objects were selected where the radiation situation should necessarily be assessed and a conclusion about their radiological state should be obtained. The most typical example, proving efficiency of using this technique is the revealed "burial" object.

Upon the decoding results, the object was identified just as "an artificial object". Visual assessment allowed to categorize the territory as a "burial", located at the distance of 5 km to the east of the "Degelen" site. The object covers the area of 200×200 m (Figure 134).



a) b)

Figure 134. "Burial" object near the Degelen site upon the results of:
a) satellite image decoding b) visual assessment

Radiological situation at the territory of "burial" object was assessed with pedestrian gamma-spectrometric surveying using 20×20 m grid in 209 points. The dimensions of the surveyed site are 200×360 m. Analysis of pedestrian gamma-spectrometric survey results has shown that the concentration of artificial radionuclides at the surface of the inspected "burial" does not exceed minimal detectable activity (MDA), whose values under actual measurement conditions for ^{241}Am and ^{137}Cs are 500 and 200 Bq/kg, respectively. Also, during the gamma-spectrometric survey, EDR values were registered in the points where spectra were taken. The measured EDR values ranged from 0.14 to 0.19 μSv/h. I.e. no contamination was detected at the surveyed territory. However, functional purpose of this object was clearly determined as the "burial" of chemical and physical equipment and laboratory materials.

The effectiveness of the technique used for identification and radiation assessment of the objects that can possibly contain radioactive materials has therefore been verified. Approximately 20 potentially hazardous artificial objects were found including 2 burials" [i. 2.10].

CHAPTER 4
DEVELOPMENT OF THE FORECAST FOR CHANGES IN THE RADIOECOLOGICAL SITUATION

4.1. Artificial radionuclides migration beyond the test sites

4.1.1. "Degelen" site

4.1.1.1. General hydrogeological data

Degelen massif is scoured with relatively incomprehensive valleys having drainage in various directions. There are no transitional valleys within the site.

Significant area of the massif is occupied by dismembered rocky landscape and it serves as a precipitation drainage zone. During the periods of significant precipitation and in springs, melting snow waters travel with surface streamflows beyond the massif and some water penetrates into open fractures. The level of ground waters in intermountain valleys lies at the depth of 0 to 2 – 6m. Beyond the mountain area, the level falls to 12 m.

The following types of waters can be found in Degelen mountains:

– pore water of modern deluvial-proluvial deposits, restricted in distribution;
– pore water of deluvial-proluvial deposits, including infrabed water;
– fracture water in Paleozoic rocks.

As a variety of vein waters, the water bearing zones of cracks can be singled out. Deposits of Neogene aquifuge clays can be found in some valleys. They divide pore and vein waters development areas. In other cases, pore and fraction waters are directly interrelated.

Hydrodynamic parameters of the massif directly depend on the hydrometeorological characteristics of the region. The performed study revealed about 20 regular springs with the debits varying within 0.5 – 0.6 dm^3/min to 1,000 dm^3/min. The most watered springs are located at the elevation of 545 – 650 m. They are associated with the main water bearing fractures and serve as discharge zones for fissure-vein water.

By its chemical composition, groundwater of the Degelen massif can be categorized as water of sulphate and hydrocarbonate-sulphate types. Ca^{2+} prevails among the cations: it can be found almost in all sampled water points. Cations Na^{+}+K and Mg^{2+} occupy a subordinate place. These are very soft fresh waters with mineralization of less than 1 g/dm^3. Composition of waters is stable and almost does not depend on season. The Figure 135 provides hydrogeological map of the Degelen site.

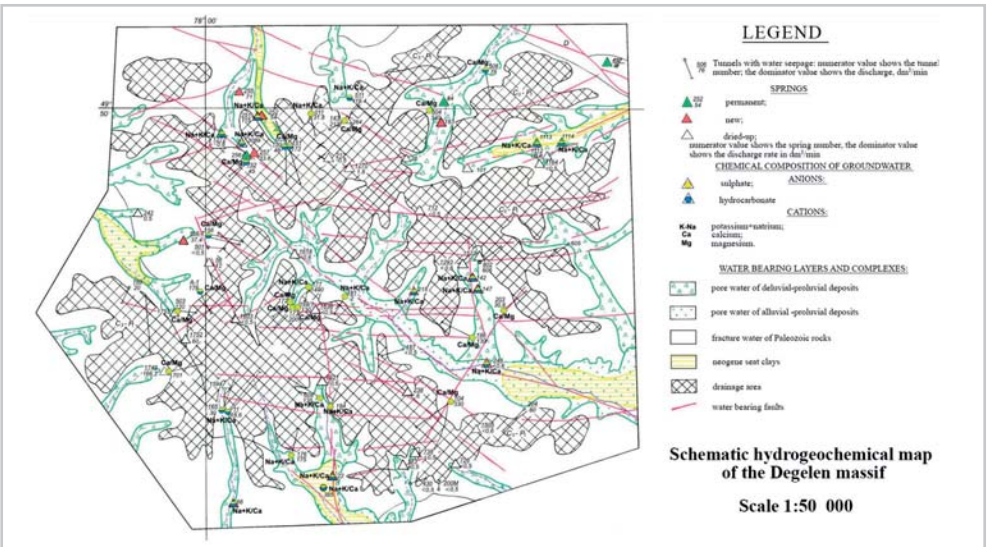


Figure 135. Hydrochemical map of the **"**Degelen**"** site

4.1.1.2. Mechanisms of the groundwater contamination with artificial radionuclides

An UNE in a tunnel creates several irreversible deformations zones, different in fracturing degree of the rocks: cavity, shear zone, crushing zone, induced fracturing zone, split-off zone and fracture chimney (Figure 136).

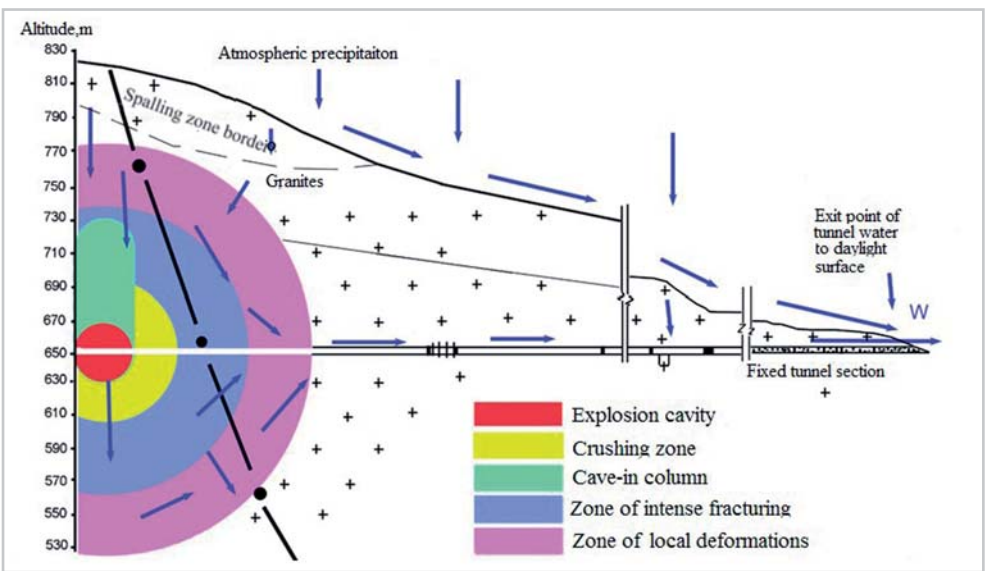


Figure 136. A scheme of irreversible deformation zones

Two main sources of radionuclides can be met in the zones of irreversible deformation. The first one is radioactive glass scoriaceous rocks, containing up to 80% of all fission products and all plutonium. Most of melted rocks remain within the explosion cavity. The second source is radioactive components of dust particulate matter, localized at the surface of crashed rocks and the surface of petrogenetic and anthropogenic fractures. Such distribution can be explained by fact that ^{90}Sr and ^{137}Cs have gaseous precursors krypton-90 and xenon-137, those during UNEs can proliferate to significant distances through the fractures [132].

The radionuclide composition of tunnel waters is formed as a result of atmospheric precipitation proliferation into the zone of irreversible deformations. Passing through the fractures system and the tunnel cavity, radioactively contaminated water replenishes ground water basin or reaches the daily surface in the area of the tunnel portals.

4.1.1.3. Radionuclide composition of tunnel waters

Discharge of water-bearing tunnels. Almost all tunnels at the "Degelen" site are located above the regional basin level of fracture waters in the zone of vertical filtration of atmospheric moisture. UNEs have resulted in irreversible changes in structure of host rock, that led to disturbance of water regime. Under various conditions, all newly appeared structures in the host medium may become draining systems, temporary moisture storage or new migration pathways. As the result, such events as unexpected interruption of water inflow into the tunnel, penetration of significant water amounts, entry of water, accumulated in tunnel because of concrete walls were observed.

After sealing all water-bearing tunnels water kept coming through the sealing structures at portals of the following 8 tunnels: 104, 165, 176, 177, 503, 504, 511 and 802 (Figure 137).

Figure 138 shows results of long-term observations over the tunnel streamflow discharge after sealing the tunnels.

The diagrams show averaged values upon the results of quarterly measurements. Based on the data provided, it can be stated that the majority of tunnel streamflows has a misbalanced (pulsing) character.

Radionuclide monitoring. Results of the long-term radionuclide monitoring of tunnel waters show that specific activity of radionuclides in each stream remains stable for a long time [156] varying within a narrow range depending on the debit level.

^{3}H. Starting from 2000 (Figure 139), tritium concentrations in streams from the tunnels 177 and 176 have been close in their values (630 – 810 kBq/kg). However, they have been higher than those in other streamflows, and highly variable. The highest specific activity of ^{3}H in the tunnel 177 remains during the whole observation period, and the maximum concentration of 1,900 kBq/kg was registered in 1997.

^{90}Sr. In all the tunnel water streams, the content of ^{90}Sr exceeds the maximal permissible concentrations. Concentrations vary from 7.9 to 1,950 Bq/kg. Maximal concentration of ^{90}Sr (2,100 Bq/kg) was found in water from the tunnel 177 in 2004.

^{137}Cs. The highest concentrations of cesium-137 were found in the streams of the tunnels 504 and 165 in 1999 and 2003, respectively (Figure 139). Specific activity of cesium in these streamflows was 1,100 and 950 Bq/kg, respectively. Since 2004, specific activity

in the tunnel 165 has been continuously decreasing to 190 Bq/kg. At that, change in the radionuclide content from one quarter to another was relatively steady, i.e. contamination of the streamflows was characterized by some predictability. ^{137}Cs concentration in the tunnel 504 has been gradually decreasing from 2000 to 2002 with further variability in subsequent years. Variations in concentrations reached 260 Bq/kg. It should be noted that the content of cesium-137 in the streamflows from the tunnel 504 are the highest nowadays, but usually it does not exceed 700 Bq/kg.

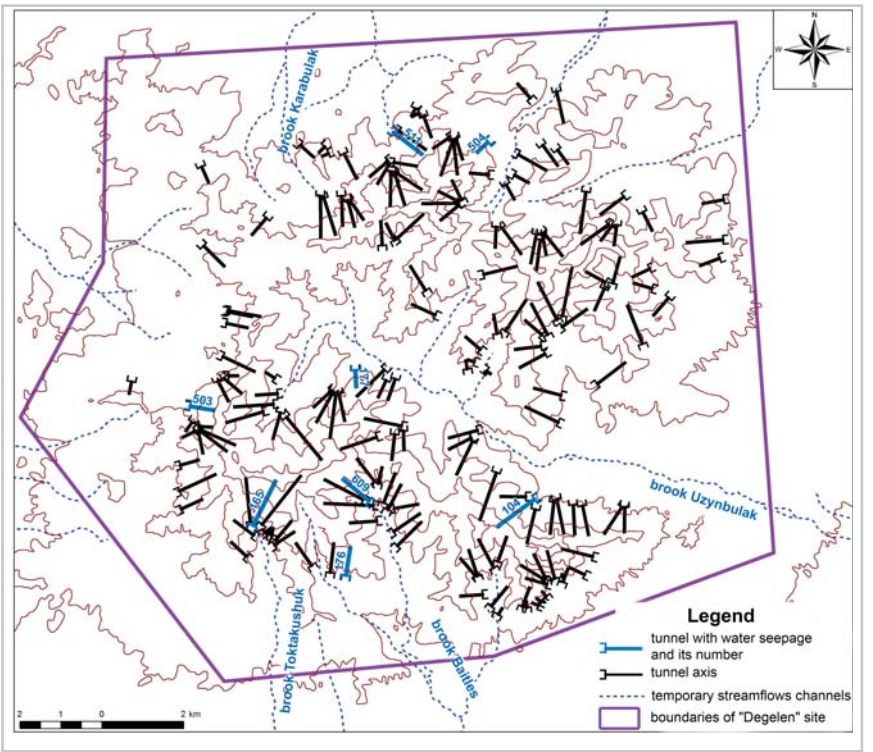


Figure 137. Location of the tunnels at the Degelen site

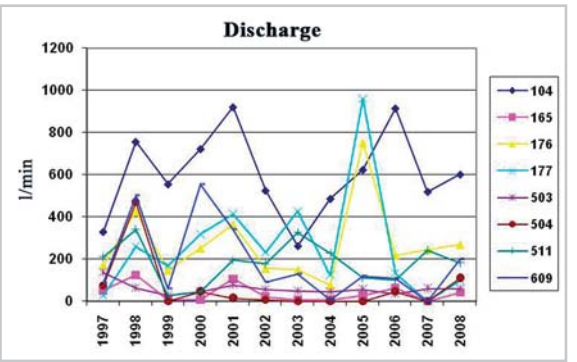


Figure 138. Discharge of streamflows from the tunnels

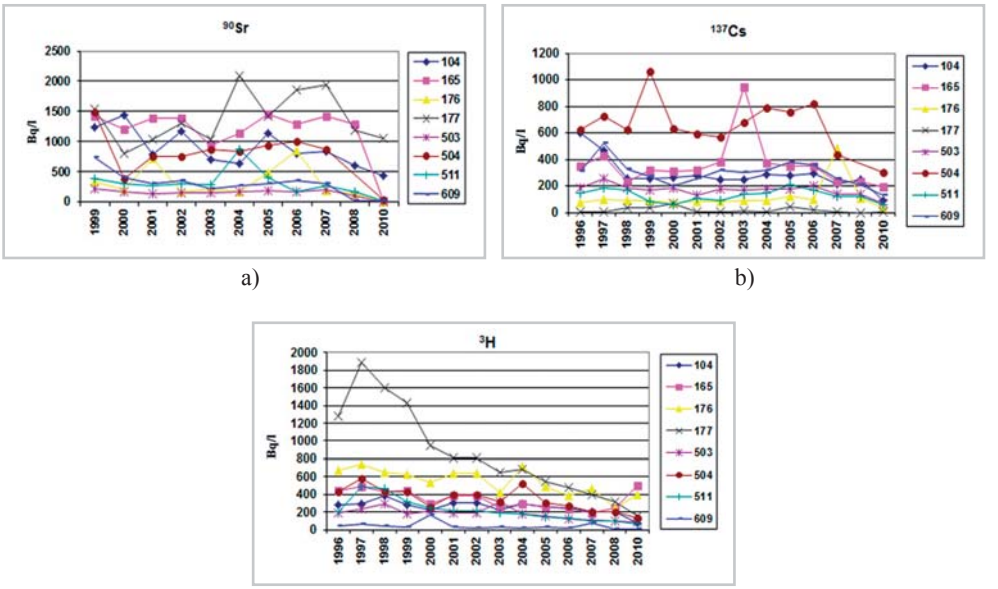


Figure 139. Results of the ground water radionuclide monitoring: a) ^{90}Sr; b) ^{137}Cs; c) ^{3}H

So, the content of ^{137}Cs, ^{3}H, ^{90}Sr artificial radionuclides almost in all streamflows have been slightly changing with the time for the whole observation period.

$^{239+240}$Pu. $^{239+240}Pu$ concentration was below the detection limit in the majority of the taken samples. At that, sharp "bursts" of $^{239+240}Pu$ concentrations were frequently detected. Sharp changes in the $^{239+240}Pu$ concentration from <0.02 to 6.4 Bq/kg are typical for the water in the tunnel 503. In some particular cases, changes in $^{239+240}Pu$ concentrations in the tunnels from <0.02 to 5.3 Bq/kg (tunnel №104), 2 Bq/kg (tunnel №176), 3 Bq/kg (tunnel №177), 1.2 Bq/kg (tunnel №504), 0.2 Bq/kg (tunnel 802) were found. Such a variety in radionuclides concentration dynamics can most probably be explained by presence of various sources of their entry into water. ^{137}Cs, ^{3}H, ^{90}Sr are leached from zones of irreversible deformation, flooded all the time, and $^{239,240}Pu$ is leached directly from the gopher cavity, whose flooding depends on water level in water-bearing tectonic structures.

^{241}Am. Minimal ^{241}Am concentrations of <0.04 Bq/kg were found in all the tunnel waters. An exception is ^{241}Am concentration in water from the tunnel 176 equal to 9.9 Bq/kg.

Assessment of the total radionuclides takeout. The monthly debit monitoring of the streamflows from the tunnels [156] and specific activity measurement of the radionuclides taken out with tunnel waters allowed to assess the quarterly takeout of the radionuclides ^{137}Cs, ^{3}H, ^{90}Sr and $^{239,240}Pu$ (see Figure 140). The figure demonstrates seasonal variations, whose maximal values belong to the second quarters of each year, while minima – to the first and the fourth ones. Total takeout of the radionuclides for the period was as follows: ^{3}H – 5.4*$\times 10^{14}$ Bq, ^{137}Cs – 5.7*$\times 10^{11}$ Bq, ^{90}Sr – 2.3*$\times 10^{12}$ Bq and

^{239,240}Pu – 2.5*×10^9 Bq. Since specific activity of the radionuclides in each of the streamflows is relatively stable, the main factor determining the amount of the radionuclides takeout is the precipitation level and, therefore, the streamflows discharge rates.

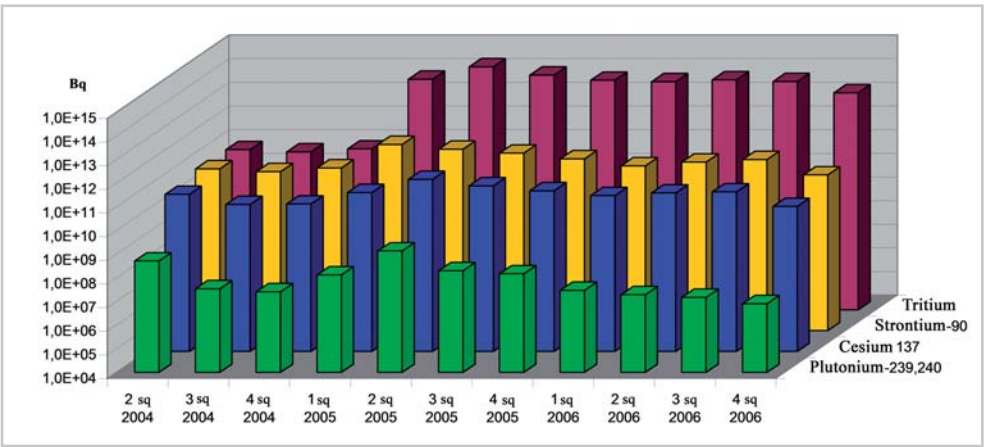


Figure 140. Quarterly dynamics of the radionuclides takeout

It will be interesting to consider the dynamics of the radionuclides takeout from year to year for the whole monitoring period. The histogram (Figure 141) shows the dynamics of the radionuclides takeout based on the monitoring results starting from 1999.

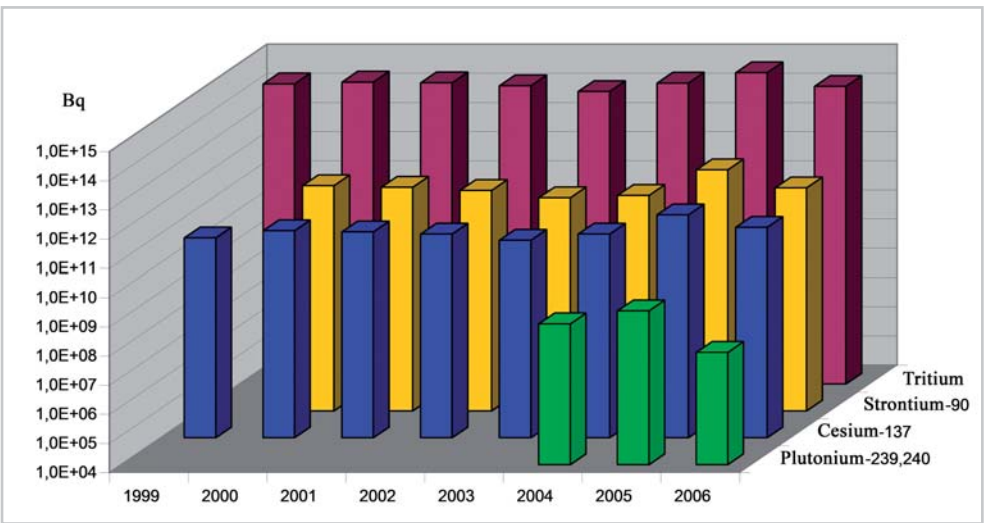


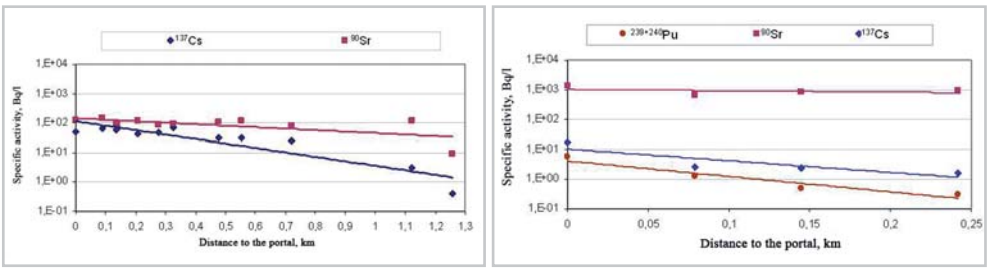
Figure 141. Dynamics of the radionuclides takeout by years for the period from 1999 to 2006

As one can see, annual variations of the radionuclides takeout are much lower than the quarterly ones – the radionuclides takeout is very stable from year to year. Annual amount of the radionuclides takeout is 6*×10^{11} Bq; 5*×10^{11} Bq and 2*×10^{11} kBq for

^{137}Cs; ^{90}Sr and ^{3}H, respectively. The annual $^{239+240}$Pu takeout amount is hard to assess since this radionuclide has been monitored just for three years only. Some small variations in the radionuclides takeout from year to year are probably caused by climate - in the years with higher precipitations the takeout also gets higher. Stability of the radionuclides takeout from one year to another allows extending this value to both past and future and to forecast the radioactivity takeout from the tunnels at least for several years even without continuing monitoring.

Radionuclides behavior in surface water of the investigated streamflows as exemplified by the tunnels 177 and 176. Study of the radionuclides behavior in the streamflows originating from the tunnels of the "Degelen" site allowed to reveal some regularities in radionuclides redistribution with water streamflows [38].

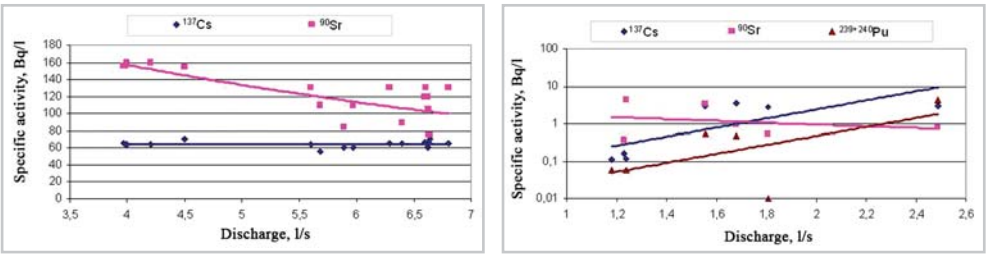
Concentrations of the artificial radionuclides fall with increasing distance to the tunnel portals. The lines reflecting the decrease in $^{239+240}$Pu and ^{137}Cs concentrations in water of the streamflows show sharp decrease comparing to the lines showing ^{90}Sr behavior (Figure 142). So, in water of the streamflow from the tunnel 177, concentrations of $^{239+240}$Pu and ^{137}Cs are close to the lower detection limits of the equipment used (<0.001 Bq/kg) already at the distance of 250 meters from the portal, while ^{90}Sr concentration has an insignificant decrease. In the streamflow water of the tunnel 176 ^{137}Cs (<0.01 Bq/kg) was detected at larger distance from the portal – 1,250 m.



a) tunnel # 176 b) tunnel # 177

Figure 142. Horizontal distribution of the radionuclides in surface waters vs. distances from the tunnel portals in the studied ecosystems

There was also found a dependence of the radionuclide concentrations on the streamflow water discharge rate when it reaches the day surface. ^{90}Sr concentrations in both the streamflows decreases at discharge rates, but in the tunnel 176 this dependence is more clearly expressed. So, the correlation factor between the streamflow discharge and Sr concentration is r = -0.76 for this tunnel, while in the tunnel 177 r = -0.42. Dependence of ^{137}Cs concentration on the discharge rate of each studied streamflow appears differently. No evident dependence of the concentration on debit was found for the tunnel 176 (r = 0.04), while in the borehole 177 direct dependence was noted, i.e. increased water debit leads to higher ^{137}Cs (r = 0.88) and $^{239+240}$Pu (r = 0.87) contents (Figure 143).



a) Tunnel # 176 b) Tunnel # 177

Figure 143. Dependence of the radionuclide concentrations vs. water discharge in water of the investigated streamflows

Such contradictory dependences of the concentrations on debits at the investigated objects can result from various hydrogeological peculiarities of these objects. Water from the tunnel 176 near the portal has only one source point, which is actually a tap from the tunnel cavity. Water from the tunnel 177 appears not only from one single place, since the whole bottom of the bald peak drains here. Therefore, in this case the increasing debit can lead to additional supply of ^{137}Cs and $^{239+240}Pu$ with uncontrolled water discharge.

4.1.1.4. Character of radioactive contamination in the springs

Springs discharge. Nuclear tests have caused destructive failures in the rock massif. Extension of fractions have resulted in decrease of hydrostatical pressure, that leads to groundwater mound roof lowering. Water bearing tectonic structures where linear ground water circulation grows get refreshed. Redistribution in linear streams and reorientation of ground water streaming directions takes place. The springs, located at high hypsographic levels disappear replaced by absolutely new springs. Some of the springs are pulsing. Based upon rich vegetation in some venues, springs of seasonal character also take place.

One can get a general idea of springs discharge upon the results of the observations carried out in 2002. During the 2002, two springs and one artesian well 385 were monitored (Figure 144). In the first half of the year, water character was quite stable. An intensive flow from the spring 251/252 was observed during this period. The most stable water discharge was found in the spring 3089 and the borehole 385. The water regime stabilized in May, and the total flow have decreased to the values observed in the winter time. However, in June the flows increased due to intensive precipitations. The peak of precipitations in 2002 occurred at the end of the spring time and in the first two summer months. Precipitations in May-June significantly exceeded the average for the long-term observations, that directly impacted the increase in the streams' discharge rates. In July the discharge kept increasing. The discharge of the spring 251/252 was 1,528 l/min. This value is almost 4 times higher than the June debit. The debit of the spring 3089 and the borehole 385 raised for two times.

Figure 144 clearly shows the difference in the peak periods of maximal precipitations and maximal total discharge for the springs and the borehole 385.

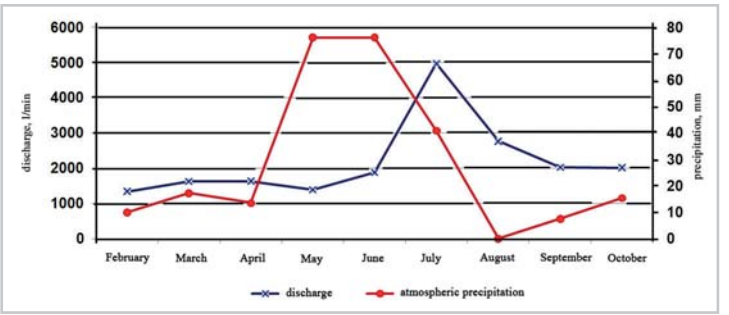


Figure 144. Dependence of the radionuclide concentrations in water on the discharge in the considered streamflows

The diagram shows that the period of maximal total discharge of the streams from the beginning of intensive precipitations delays from the intensive precipitations period for almost 2 months. This period can be taken as the period of precipitations infiltration via vein waters in the Degelen mountains. In August, the discharge in all water inflows starts decreasing, while in September and October it normalizes and stops at a normal level.

Before the start of nuclear tests, over 30 various springs were found in Degelen mountains at different altitudes. Upon the results of a research in 2005, 17 active springs were found (Figure 145).

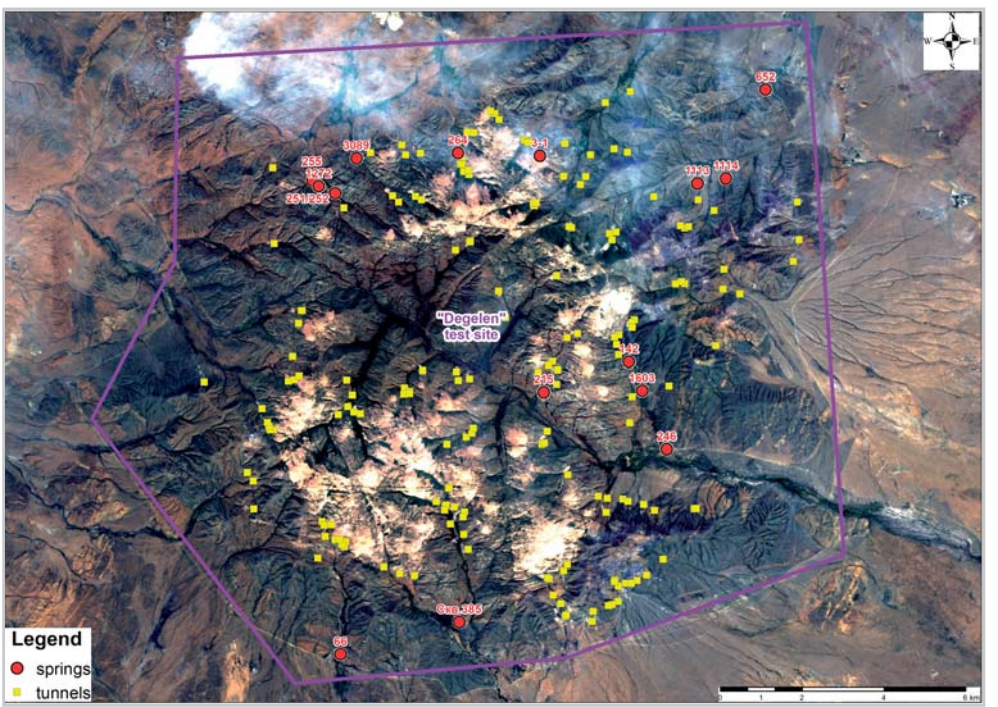


Figure 145. Springs at the "Degelen"site

Only in the springs 652 and 1114, concentrations of artificial radionuclides do not exceed the following values: ^{90}Sr <0.1 Bq/kg, ^{137}Cs – 0.5 Bq/kg and ^{3}H – 1.3 kBq/kg [132]. At that, ^{137}Cs concentration is <0.4 Bq/kg in water of most of the springs. ^{90}Sr concentration in spring waters varies from <0.1 to 125 Bq/kg. High ^{90}Sr concentrations in water cannot be explained yet and need further more detailed study. This has purely scientific value for understanding the radionuclide migration with water courses and, at the same time, it is a problematic issue for the development of the radioecological situation there. This is related to ^{90}Sr sorption by bottom sediments from water and its gradual accumulation at the territory of springs in considerable amounts posing radiation hazard on people and animals.

The main contaminating agent for the spring water is ^{3}H. Only in the springs 652 and 1114, ^{3}H concentrations remain within the permissible values for potable water. Concentration of this radionuclide varies from 15 to 200 kBq/kg in other springs. It should be noted that the described sources have low mineralization and hardness, low temperature and high palatability irrespective of season. Therefore, measures should be taken to prevent usage of this water for drinking.

4.1.1.5. Takeout of the radionuclides with ground waters beyond the Degelen massif

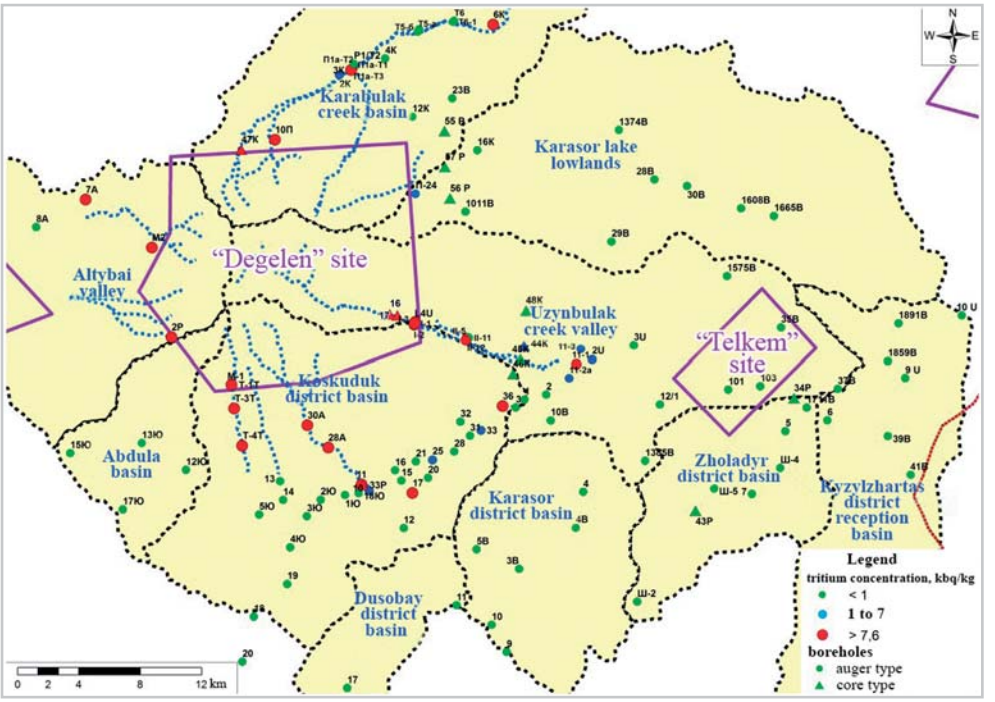


Figure 146. Migration of radionuclides beyond the boundary of Degelen mountains

The whole ground water front running beyond Degelen mountains is divided into individual flows according to their local catchment basins, where feeding, transit and discharge take place within the local water catchment basins (LCB) up to 20 km long. Migration of radioactive products with ground waters beyond the "Degelen" site is therefore limited by the maximal distance of 20 km. Figure 146 shows the boundaries of LCB.

Migration of artificial radionuclides with ground waters beyond the Degelen mountains was studied according to their belonging to some exact catchment basins. Upon decoding of satellite images, temporary and permanent streamflows were mapped and points for further drilling of hydrological boreholes were arranged. To study pore and vein waters, auger type and cored boreholes with the maximum depths of 10 and 50 m, respectively, were drilled. At some sites, geophysical studies were carried out to reveal flooded structures [157].

LCB of Koskuduk district

Pore waters. Within this LCB, 26 boreholes with the maximum depth of 5.4 m were drilled. The content of ^{137}Cs and ^{90}Sr in pore waters of the basin lies within <0.02 Bq/kg. The main radioactive contaminator of the ground water is ^{3}H. ^{3}H concentrations in the ground water vary from 0.1 to 260 kBq/kg. The highest values are typical for infrabed creek flow during the whole its length from Degelen mountain to Koskuduk district. Maximal ^{3}H concentration was detected in the borehole at the boundary of the Degelen massif. ^{3}H concentration decreases significantly with the distance, however in the area where the creek channel completely disappears in the Koskuduk valley, ^{3}H concentration in the ground water reaches the value of 10 kBq/kg.

Fracture waters. At the distance of 10 km to Degelen mountains, ^{3}H concentration in fracture water reaches the value of 9,500 Bq/kg. Almost the same value is typical for pore waters, that indicates possible interrelation between pore and fracture waters at this site.

LCB of Karabulak creek valley

Pore waters. 18 auger type boreholes up to 6.5 m deep were drilled at the site. Maximal concentration of tritium (95 kBq/kg) was detected in the borehole just 700 m away from the boundary of the "Degelen" site.

A site associated with the main channel of Karabulak creek was inspected for 36 km from the northern boundary of Degelen massif. The main contaminating agent here is ^{3}H. Amid general decrease of ^{3}H concentration in ground waters of the researched range (95 to 21 kBq/kg), essential drops in concentration values were found in several points. This peculiarity can probably be explained by derivative character and configuration in terms of contamination front, as well as vein type of the radionuclide migration pathways at this site.

Fracture waters. To study fracture waters, 3 boreholes with the depth of up to 42 m have been drilled.

Concentrations of ^{137}Cs, ^{90}Sr in water from the borehole 31P equals to <0.01 Bq/kg, ^{3}H <12 Bq/kg. This fact shows that ground waters of this area are not connected to the ground water layer associated with the exogenous fracturing zone. In the water from the borehole 32P, ^{3}H was found with concentration of 60 Bq/kg. Concentrations of ^{137}Cs and

^{90}Sr are <0.02 Bq/kg. Tritium concentration near the eastern boundary of the "Degelen" site in the borehole is <9 Bq/kg.

LCB of Karasor lake

Pore waters. 10 boreholes with the maximum depth of 9 m have been drilled at this territory. High tritium concentration (6,000 Bq/kg) was only found in the borehole located within the boundary of Degelen massif; such tritium concentrations are typical for ground waters there. No tritium was found in the rest of the LCB.

Fracture waters. Within the basin, 2 hydrogeological boreholes with the maximum depth of 45 m located 3 km away from the eastern boundary of the Degelen massif were drilled. Upon the results of laboratory analyses, tritium concentration in fracture water stream was <9 Bq/kg, ^{137}Cs, ^{90}Sr – <0.02 Bq/kg, $^{239+240}$Pu – approximately <0.006 Bq/kg.

LCB of Altybay valley

Pore waters. 4 boreholes up to 4 m in depth have been drilled. ^{3}H concentration in ground waters within the main channel is up to 17 kBq/kg.

Fracture waters. To study fracture waters at Altybay site, one 38m deep hydrogeological borehole 35P was drilled. ^{3}H concentration in water from the boreholes is up to 14 kBq/kg. This concentration lies within the ^{3}H concentrations in pore waters, that speaks of close relation between pore and fracture waters at this site.

LCB of Uzynbulak creek valley

Pore waters. To study pore waters, 25 auger type boreholes with the depth of up to 9 m were drilled. The main radioactive contaminant of ground waters there is ^{3}H. ^{3}H concentration at the mountains boundary varies from 50,000 to 130,000 Bq/kg; at the distance 10 km from the mountains, it falls to 30,000 Bq/kg, and at the distance 16 km tritium concentration sharply decreases to 120 Bq/kg.

Unlike other basins, pore waters distribution has clear areal character at the LCB territory of Uzynbulak creek. In this case two main types of ground waters are joint into one single layer as follows: waters of alluvial–proluvial deposits, in particular, infrabed water, as well as pore waters of modern deluvial-proluvial deposits, limited in distribution. Within the valley, ground waters of alluvial-proluvial deposits are spread only along the creek channel in the bottomland. The creek channel is visible at the distance of 12-15 km to Degelen mountains and disappears in Telkem district, southeast from the massif.

Fracture waters. To study fracture waters, 6 boreholes 40 m deep were drilled. Upon the laboratory analyses ^{137}Cs concentration in fracture water was <0.02 Bq/kg; ^{90}Sr – <0.01 Bq/kg; tritium –<9 to 1,500 Bq/kg. Maximal concentration of 1,500 Bq/kg was found in the borehole 44K 830 m away from the main channel. In the borehole located directly within the creek channel, tritium concentration was just 65 Bq/kg.

LCB of Abdula crater

To study pore waters, 4 auger type boreholes with the depth of up to 5 m were drilled. The quantitative amount of 80 Bq/kg was found only in the borehole at the boundary of the Main Chingiz fault. In all other boreholes, the values did not exceed the level of <11 Bq/kg.

LCB of Dusobay, Karasor, Zholadyr and Kyzylzhartas districts

There were drilled 6 auger-type boreholes with the depth up to 7.2 m in each of Karasor and Zholadyr district basins, in Kyzylzhartas – 8 boreholes up to 9 m, Dusobay – 2 boreholes up to 5 m deep. Upon drilling and sampling from the boreholes, ^{3}H content in pore waters assessed at the territory of these basins was at the level of <9 Bq/kg.

UNEs have caused significant deformation of rock massif with multiple crushing zones, failed craters and open fractures formation resulted in significant increase of rock permeability contributed to straighten downward filtration and partial transfer of surface streamflow into ground streamflow.

After sealing the tunnels, the amount of water entering the daily surface from the radioactively contaminated tunnels have decreased, that contributes to improvement of environmental situation. By the present time, stable water seepages have been found at the portals of 8 tunnels. The main surface watercourses and those of the mountain massif – Uzynbulak, Karabulak and Baytles are seasonal.

The process of ground and surface waters radioactive contamination at the "Degelen" site is still taking place, and according to the radionuclide monitoring there, it is relatively stable. The character of artificial radionuclides distribution with ground water flows beyond Degelen mountain massif is not clear. In most cases, migration pathways have veined (web like) configuration; less frequently, local contamination of ground waters takes place. At that, the main streams of contaminated ground waters are associated with channels of temporary and surface streamflows.

Beyond the Degelen massif, the main streams of contaminated groundwaters are within the valleys of Uzynbulak, Altybay, Karabulak creeks and in the Koskuduk district.

Beyond the Degelen massif boundary, artificial radionuclides concentrations (except for ^{3}H) fall to the level of <0.01 Bq/kg. ^{3}H concentration in water beyond the Degelen massif is up to 300 kBq/kg. Activity value falls to 30 kBq/kg 10 km away from the mountains, while tritium concentration in the main directions at the distances of 15-20 km does not exceed 1.0 kBq/kg, that is 7.6 times below the intervention level.

4.1.2. "Balapan" site

4.1.2.1. General hydrogeological characteristics

Two hydrogeological complexes 100-150 m thick, frequently associated with one another can be identified within the test site (Figure 147). The first complex includes waters occurring in local hydrogeological basins. Enclosing rocks are presented by crumbly formations aged from Neogene to Modern age. The second complex forms the part of the regional hydrogeological system. It includes fraction waters of Paleozoic basement, waters of Mesozoic weathering crust and the water of Paleogene deposits. Local hydrogeological basins, with insignificant depth of water occurrence (up to 50 m), are associated with:

a) deluvial-proluvial deposits of valleys and fragments of aggradation plains of Middle Quaternary and Modern period (Q II-IV);

b) alluvial-proluvial deposits of Late Quaternary – Modern period (Q III-IV), forming terrace above the flood-plain of Shagan river.

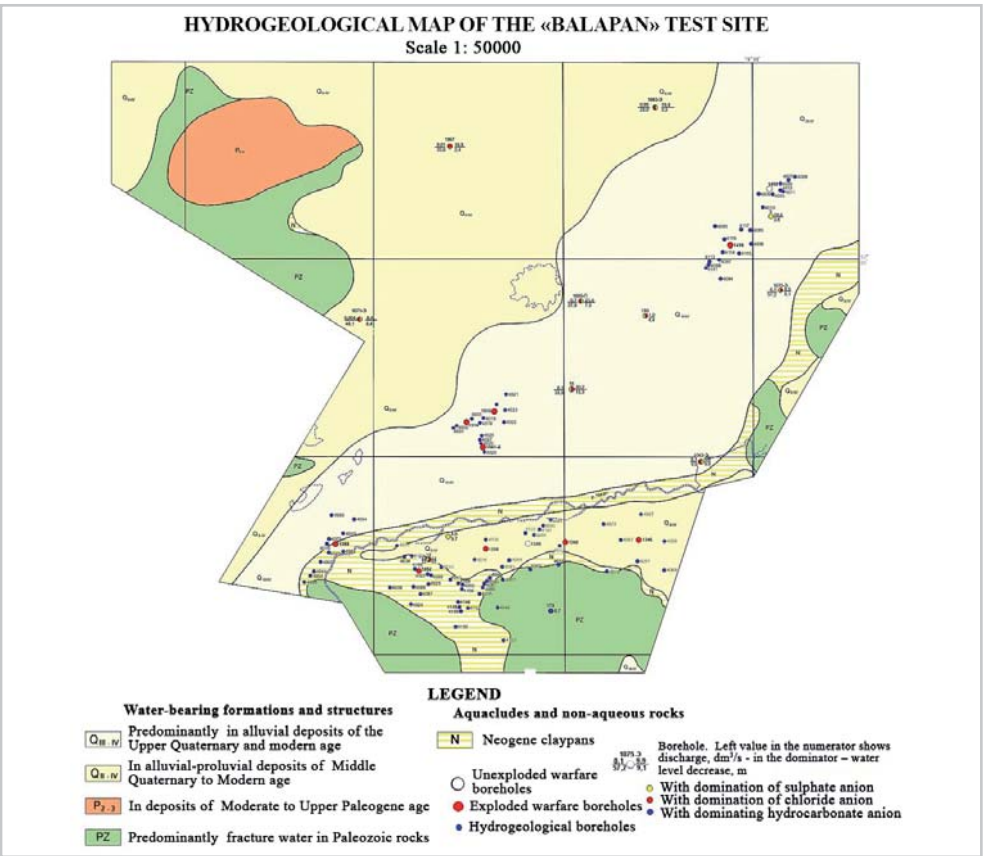


Figure 147. Hydrogeological map of "Balapan" site

Ground waters associated with regional water basin can be divided into three types as follows: waters of Paleogene deposits, water of Mesozoic weathered layer and fraction waters of Paleozoic basement themselves. They are usually interrelated forming a united system.

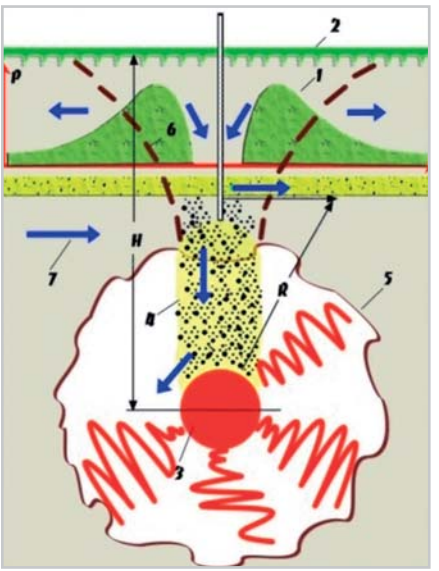
Fracture waters themselves are concentrated in exogenous fracturing zone, and depending on geological structure they can appear at various depths from 4 to 70 m. The bottom of fracture waters is found at the depth of 150-170 m. The thickness of the aquifer depends on the depth of exogenous weathering development and grow up at the sites associated with the discontinuous faults. Catchment zone is associated with low hills and "erosion windows" developed at the sites of relative aquacludes outcrop. Fraction waters are divided into waters occurring in intrusive formations, in terrigenous sedimentary deposits and effusive-sedimentary complexes.

4.1.2.2. Mechanisms of groundwater contamination

Unlike UNEs made in horizontal tunnels, cavities resulted from nuclear explosions in the boreholes are found much below the ground water level. High temperature in the ca-

vity remains for a long time thanks to overlying rock layer. High temperature contributes to thermal convection. After reaching the cavity, water heats up, washes out chemical elements and radionuclides and turns back to the aquifer with them [158].

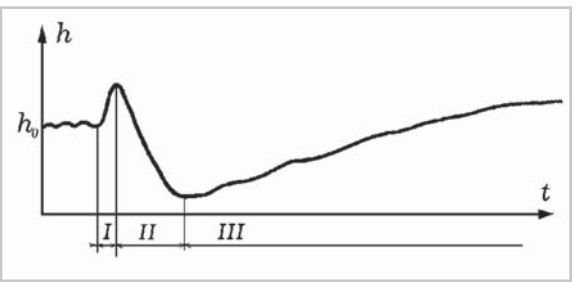
The main peculiarities of hydrodynamic processes, caused by an underground explosion, can be observed at the following schematic figure (Figure 148).



1 – ground water pressure distribution when fracture chimney forms; 2 – day surface;
3 – camouflet cavity; 4 – fracture chimney; 5 – zone of induced fracturing;
6 – subsurface decompression zone; 7 – direction of groundwater flow

Figure 148. Hydrodynamic effects from an UNE in rock strata

Wave processes related to an explosion cause environmental deformation; at that, the state of reservoir bed changes to bigger extent, unlike the changes in relatively solid enclosing rocks. Dynamical compression of the reservoir causes increase of fluid pressure to some extent contributing to ground water level increase [159].



(stages: I –" dome"formation; II – induced fracturing filling up; III – level recovery)

Figure 149. Scheme of ground water level change resulted from an UNE

This process is accompanied with water injection into pores and fractures of the rock massif, fractures existed before and those resulted from the explosion. The moment when the camouflet cavity formation is finished determines disturbance duration of the aqueous reservoir bed. Subsequently forming fracture chimney causes central depression in the formed ground water dome.

General scheme of change in ground water level affected by explosion is shown at the Figure 149 [158]. Existence of increased ground water pressure zone (dome) over the explosion epicenter naturally causes increase of piezometric level (section I). Second stage (section II) is specified by ground water drainage into explosion-resulted induced fracturing zone. For example, high permeability of rocks in the fracture chimney (penetrability factor reaches the value of 10^{-9} m^2), causes sharp relief and fall of excessive flow much below the natural level in the explosion epicenter area. General tendency for the decrease in ground water level contributes to forming of the cone of depression. The final stage (section III) – piezometric level recovery starts from filling up the induced fracturing zones.

4.1.2.3. Distribution of radionuclides with ground waters

Artificial radionuclides distribution in ground water was assessed at the following 10 individual sites: “Northern”, “Northeastern”, “Central”, “Zarechie”, “Southwestern”, “Karazhyra”, № 1, № 2, № 3 and № 4 (Figure 150).

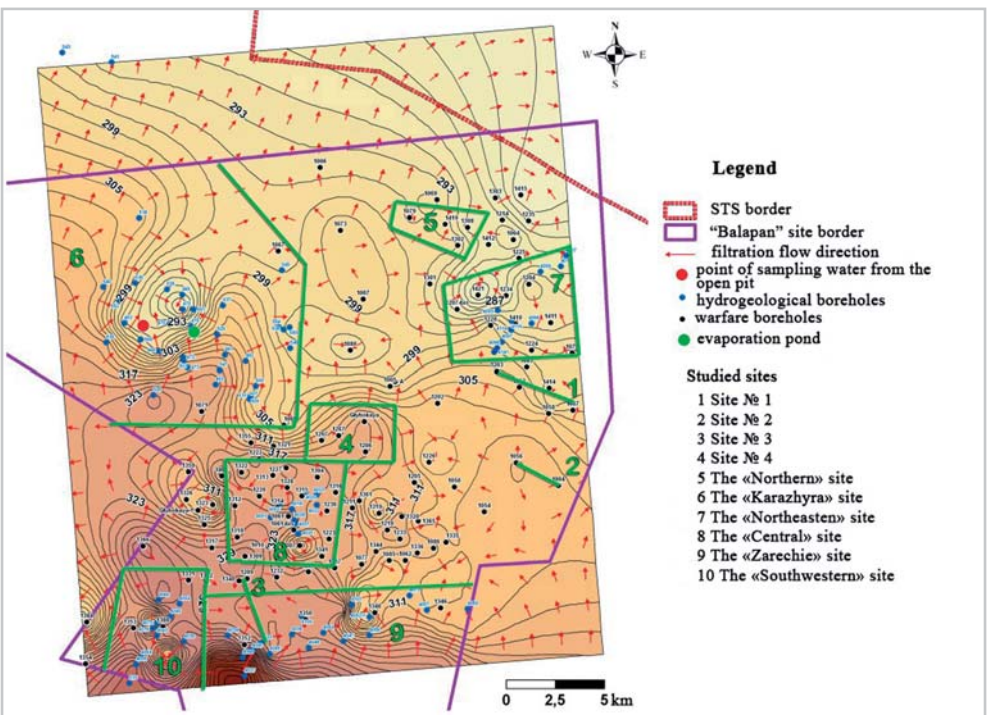


Figure 150. Arrangement of the research sites

"Northern" site. The "Northern" site is located in the northern part of the "Balapan" site (Figure 150). Based on the results of geophysical studies [157], three hydrogeological boreholes were drilled: 15a (the depth- 71m) – in the boreholes 1419 - 1302, 250 m away from 1302, 16p (depth -60 m) – in the boreholes 1419 - 1079, 1500 m away from the boreholes 1079, 17a (depth 114m) – in the boreholes 1419-1308, 950 m away from the borehole 1308 (Figure 151).

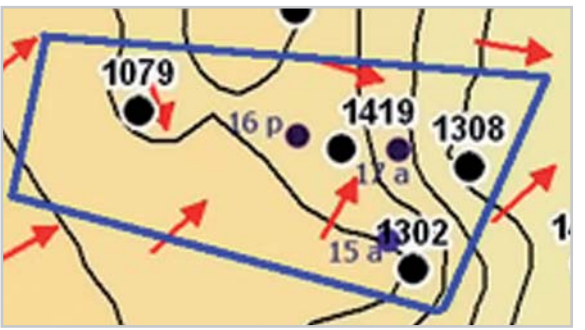


Figure 151. Arrangement of the boreholes at the "Northern" site

Upon the preliminary groundwater study at the site, in the borehole 1419 drilled for an UNE but not used due to the test site liquidation, the highest concentrations of artificial radionuclides ^{3}H and ^{90}Sr were found.

Upon the result of hydrogeological sampling, high tritium concentrations were found in the borehole 17a (4,800 kBq/kg). At that, ^{90}Sr concentration remained extremely low (0.5 Bq/kg) comparing with its concentration in the borehole 1419 (220 Bq/kg). High concentrations of tritium were found in the borehole 15a and the borehole 1419 (1,215 Bq/kg) as well, while ^{90}Sr concentration (1.9 Bq/kg) was much lower than in the borehole 1419.

Judging by the structure of filtration flow shown at the figure, contaminated water most probably comes to the borehole 1419 from the "warfare" boreholes 1069, 1079 and 1302. At that, high concentrations of ^{90}Sr in water from the borehole 1419 cannot still be explained.

"*Northeastern***"** *site.* This site is located in the northeastern part of the "Balapan" site. Radioactive contamination of ground waters within the site is caused by consequences of UNEs carried out in the "warfare" boreholes 1204, 1228, 1203, 1410, and 1411 (Figure 152).

Upon the sampling in 9 observation boreholes, 4 sites with ground water radioactive contamination caused by UNEs in the boreholes 1204, 1228, 1203 and 1411 can be identified [156, 157].

In all the studied water samples, concentrations of ^{90}Sr (0.01 to 1.3 Bq/kg) and ^{137}Cs (from <0.02 to 0.2 Bq/kg) are insignificant. At the same time, tritium concentration varies within the wide range. Maximal concentration of tritium was found in the observation borehole 4093 (380 kBq/kg). The stream of contaminated water comes into this borehole from the borehole 1228 located at the distance of 0.9 km to the southwest.

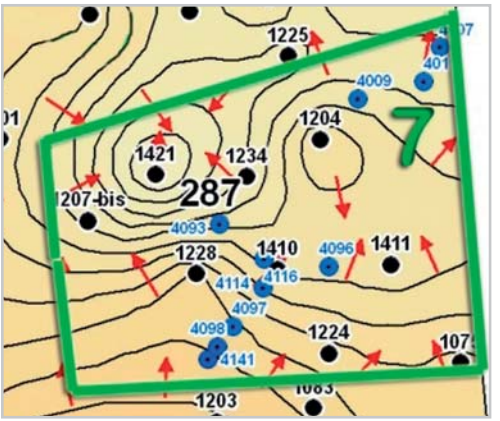


Figure 152. Arrangement of the boreholes at the "Northeastern" site

Observation boreholes 4114, 4098 and the testing borehole 1203 are located within Zhananskaya shear zone, to the south from Bayguzin-Bulak fault. The highest tritium concentrations were found in the borehole 4141 if compared with the borehole 4098 since the borehole 4141 penetrates into the same aquifer system of vein and fissure-vein water of intrusive formations as the borehole 1203. Higher concentrations of tritium in the borehole 4097 compared with the borehole 4098 possibly arise from contaminated water entry from the "warfare" boreholes 1083 and 1224 located within Bayguzin-Bulak fault.

Laboratory analysis of water sampled in 2010 from the boreholes 4093, 4096, 4097 indicates continuously decreasing tritium concentration in ground waters.

"South western" site. Special attention was paid to this site due to possible takeout of UNE radioactive products with groundwater beyond the "Balapan" test site. The point is that the site is located within the southeastern part of the "Balapan" site and the UNE was conducted near the northern impact zone of Kalba-Chingiz regional fault. Schematically, arrangement of hydrogeological boreholes is given at the Figure 153.

^{137}Cs concentration in all water samples ranges from <0.01 to 1.5 Bq/kg. For the majority of the samples, ^{90}Sr concentration ranges from <0.01 to 1,5 Bq/kg. Maximal ^{90}Sr concentration of 37 Bq/kg was found in water from the borehole 4075. Tritium concentration in groundwater varies within a wide range from 0.1 to 55 kBq/kg. Maximal tritium concentration of 440 kBq/kg was found in the borehole 4075 [157].

Rocks are characterized by significant filtration, non-uniform by area, caused by presence of various faults at the site. Underground water flow can be additionally discharged in northeastern and northern directions. Abovementioned peculiarities explain presence of high tritium concentrations in the boreholes 4075 and 4076 (440 and 55 kBq/kg, respectively). At that, these boreholes are closer to the "warfare" borehole 1388 than the others. Quite high tritium concentrations in the borehole 4045 result from the fact that this borehole is also located downrange of one of the ground water flows from the borehole 1388. Tritium concentration in the borehole 4043 is much lower than that in the borehole 4045, although it is located almost at the same distance to south-

west from the borehole 1388. This explains the fact that ground water transfer from the borehole 1388 to the southwest is much lower than in other directions. Low tritium concentrations in the boreholes 4064, 4055, 4054 and 4066 can first of all be explained by their remoteness from the borehole 1388.

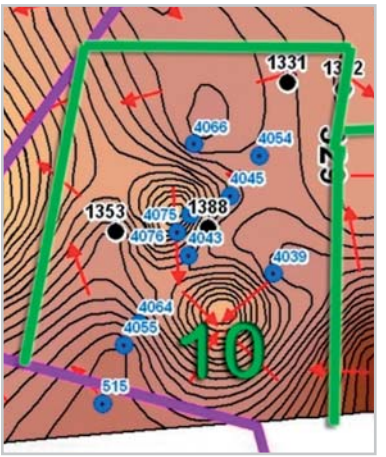


Figure 153. Arrangement of the hydrogeological boreholes at the "Southeastern" part

"Central site. As it is seen from the name, the site is located in the central part of the "Balapan" site. The main sources of ground water contamination with artificial radionuclides at this site are central zones of UNEs carried out in the "warfare boreholes 1061bis, 1061, 1314, 1315 and 1236 (Figure 154).

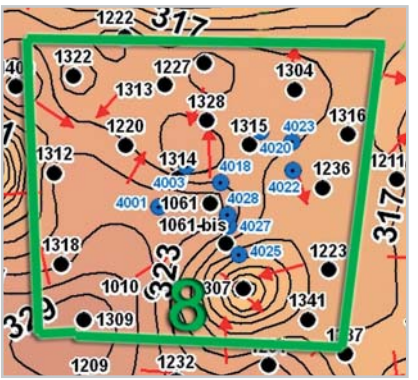


Figure 154. Arrangement of the boreholes at the "Central" site

Revealed tritium concentrations in ground waters vary within the range from <0.007 to 1.44 kBq/kg. Maximal concentration of 1.8 kBq/kg was found in the 2010 in the borehole 4027. In all water samples, ^{137}Cs concentration lies within the low values range from 0.012 to 0.18 Bq/kg with the maximum concentration of 1.2 Bq/kg in the borehole 4022. No quantitative values of $^{239+240}Pu$ activity were found in the samples, and concentration did not exceed <0.002 Bq/kg. For ^{90}Sr, very low concentrations from <0.01 to 0.78 Bq/kg are also typical. An exception is the value of 6.4 Bq/kg in the borehole 4025.

So, the typical feature of this site is presence of relatively low concentrations of artificial radionuclides; at that, hydrogeological boreholes are located in close vicinity to 5 "warfare" boreholes. One of the explanations of this feature can be the fact that mainly free-surface waters are widespread at this site. Therefore, radionuclides are less intensively washed out from central zones than it was found for other sites. On the other hand, as it was mentioned before, this site is characterized by the zone of increased filtration outflow against its mean values that speaks of local groundwater recharge zone. In this case, it can be stated that decreased concentrations of radionuclides come from continuous dilution with atmospheric precipitations. At that, radioactive contamination of groundwater decreases at larger distances from the UNE epicenters.

"Zarechie" site. To study the radioactive contamination character, 16 previously drilled hydrogeological boreholes were investigated at the site (Figure 155).

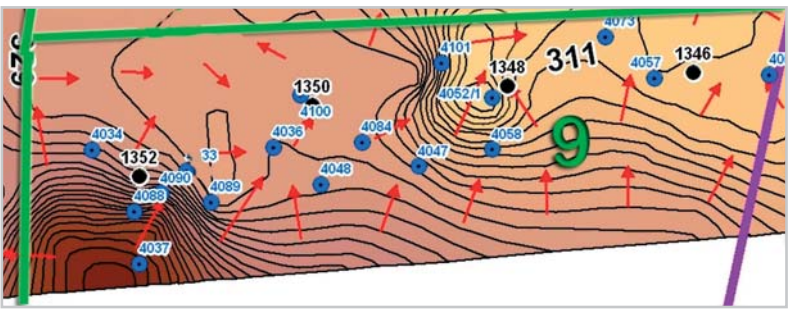


Figure 155. Arrangement of the boreholes at the "Zarechie" site

^{137}Cs concentration in ground waters ranges from 0.02 to 0.62 Bq/kg. ^{90}Sr concentration varies from 0.01 to 1.5 Bq/kg. These values impose no radiation hazard. Tritium concentrations in ground waters vary within a wide range from <0.01 to 55 kBq/kg.

Within the radius of up to 2 km from the UNEs' centers, tritium concentrations do decrease at larger distances to the epicenter. Basic radionuclides content in heterochronous aquifer systems typically decreases with increasing distance to the basic supply zone (low hills) due to bigger involvement of ground water flow.

"Karazhyra" site. Radionuclide contamination of ground waters at this site have been monitored since 2003 using sampling data on 42 hydrogeological boreholes (Figure 156) as well as drain waters of acting open pit and the evaporation pond (Figure 150).

Concentrations of artificial radionuclides in ground water range as follows: ^{137}Cs – from <0.005 to 0.3 Bq/kg; ^{90}Sr <0.01 to 1.3 Bq/kg; tritium <7 to 760 Bq/kg; $^{239+240}$Pu <0.001 to 0.016 Bq/kg.

Upon the ground water monitoring, relative stability in migration processes was noticed. A tendency for general decrease of artificial radionuclides concentrations in ground waters has been noticed.

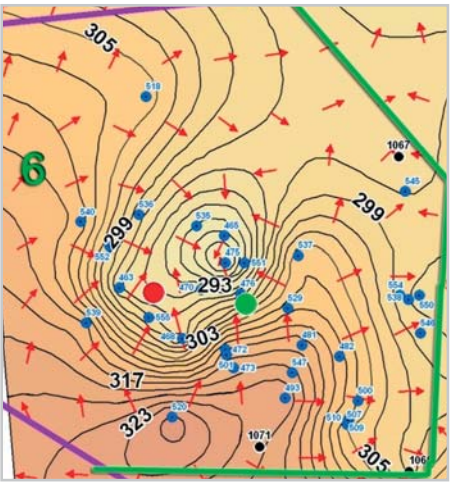
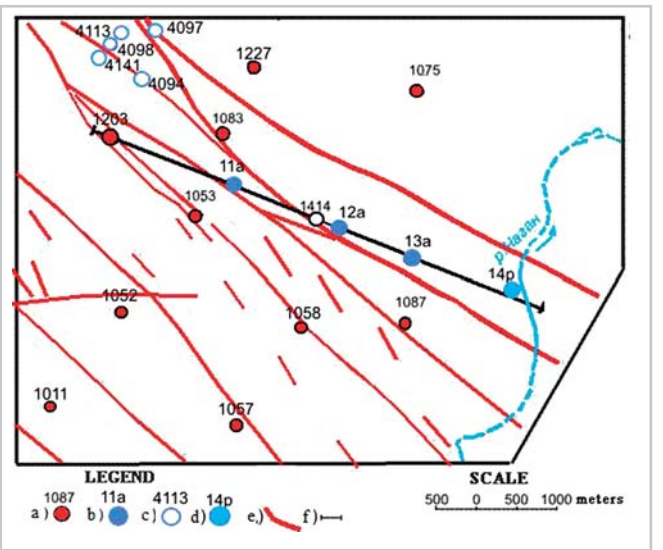


Figure 156. Arrangement of the boreholes within the "Karazhyra" deposit

Site № 1 (Profile of the boreholes 1203, 1414 till Shagan river). The site is located in the eastern part of the "Balapan" site (Figure 150). Analysis of hydrogeological conditions of the site allowed identifying it as a one having the most critical direction of possible contaminated groundwater discharge into Shagan river.

Analyses of water sampled in the drilled boreholes (Figure 157) have shown high tritium and ^{90}Sr concentrations in the borehole 12a (3,000 kBq/kg and 114 Bq/kg, respectively) and concentration of tritium in the borehole 13a (20 kBq/kg).



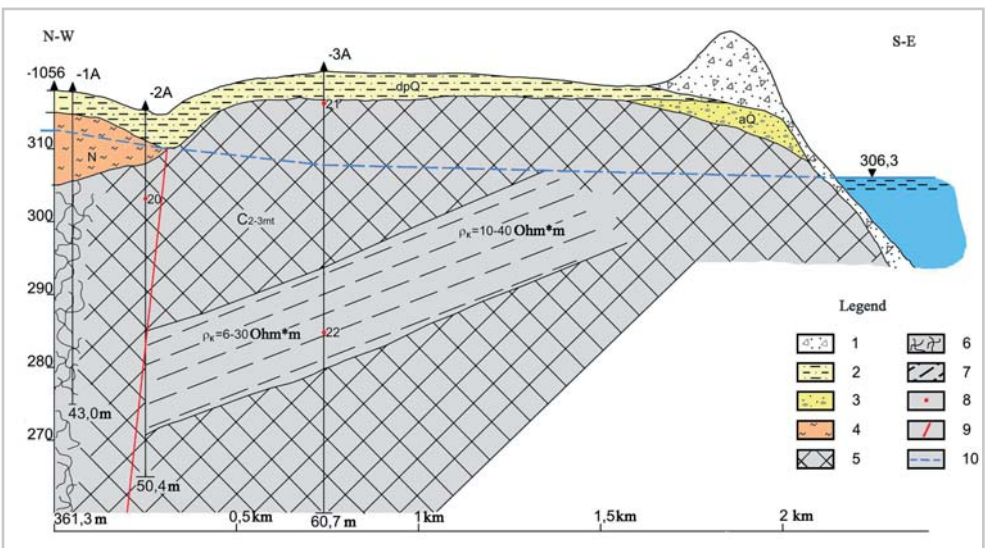
Boreholes: a) – warfare; b) – hydrogeological, 2006; c) – hydrogeological, drilled before; d) – observation borehole; e) – tectonic disturbances; f) – a line of geological –geophysical cross-section

Figure 157. Site № 1. Arrangement of the boreholes drilled along the profile near Shagan river

Within the considered erosion "window", pronounced hydraulic connection was found between the heterochronous aquifers spread in fractured rocks, alluvial sediments and surface waters. Therefore, these sites of hidden ground water discharge represent potentially active zones of radioactive contamination of Shagan river surface water, in particular, with tritium.

Site № 2 (Profile of the borehole 1056 – "Atomic" lake). The site is located in the eastern part of the "Balapan" site (Figure 150). The main purpose of works at this site was revealing possible relation between ground vein waters and surface water in the artificial water reservoir – "Atomic" lake.

According to the laboratory analyses of water samples taken from the boreholes 1A, 2A, 3A, ground vein waters in the profile under study (Figure 158) are contaminated with radionuclides; at that, the highest contamination can be observed near the borehole 1056 [157]. Maximal registered tritium concentration was 280 kBq/kg (the borehole 1A). ^{137}Cs concentration near the borehole 1056 equals to 4 Bq/kg, and ^{90}Sr – 1,200 Bq/kg.



1– rock pile blasted out; 2 – deluvial-proluvial sandy loams and sands (dpQ); 3 – alluvial sands and pebble (aQ); 4 – Neogene seat clay (N); 5 – terrigenous coarse deposits of Maityubay Suite of Moderate Upper Carbone (C_{2-3}mt); 6 – caved zone of the explosion in the borehole 1056; 7– rock horizon with decreased natural electrical resistance; 8 – increased gamma-activity upon the results of well survey log (μR/hour); 9 – tectonic disturbance; 10 – ground water level.

Figure 158. Profile section (borehole 1056 – borehole 1004) at the "Atomic" lake

The radionuclides distribution character along the borehole profile shows that the rocks uncovered by the borehole 3A serve as the boundary between contamination resulted from the tests in the "warfare" boreholes 1056 and 1004. Minimal tritium concentration was found in water of the borehole C-3A, in the central part of the profile and

partly after passing the drained zone of exogenous weathering. High tritium content in the artesian aquifer, uncovered by the borehole C-2A, indirectly proves limited migration of tritium with ground water towards the "Atomic" lake. Radioactively contaminated waters can mainly proliferate along the pale shallows, in the roof of Paleozoic basement rocks to the east of the borehole C-2A, according to discharge character of the aquifer.

Site № 3 (Profile of the boreholes 1209 and 4033). The investigated site is located at the profile between the "warfare" borehole 1209 and the hydrological borehole 4033 (Figure 159).

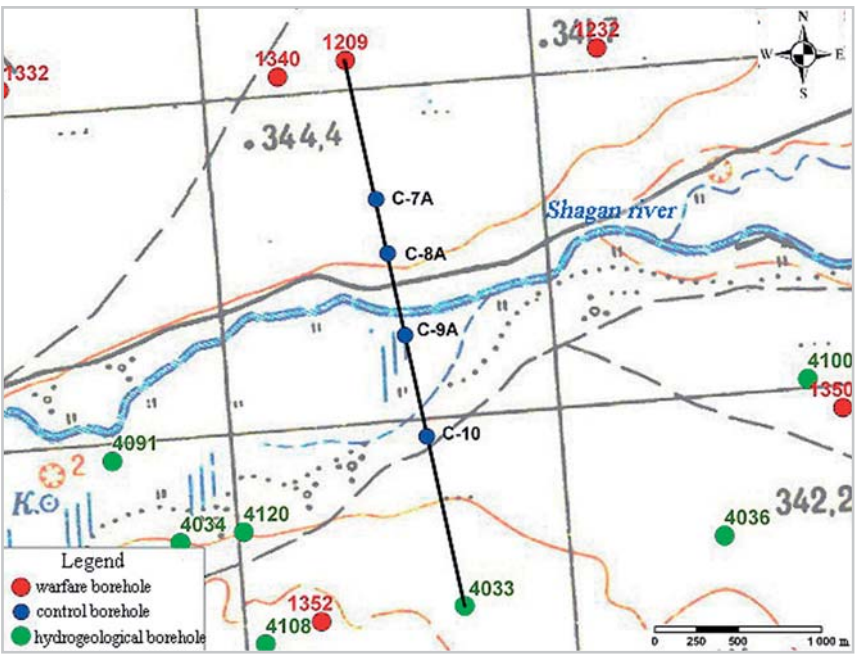


Figure 159. Site № 3. Arrangement of the boreholes drilled along the profile 1209 – 4033

Radionuclide analysis of water samples from the boreholes C-8A and C-9A drilled on the 3.3.km-long profile crossing the channel of Shagan river showed low contents of ^{137}Cs and ^{90}Sr (0.01 and 0.02 Bq/kg, respectively).

The monitoring in the boreholes 1209 – 4033 revealed the southward slope in underground stream declining from 0.003 to 0.001 except for the C-9A borehole site. Within the considered erosion "window", ground waters are supplied with additional water infiltration recharge. Radionuclide analysis also proves this fact. In the water sample taken from the borehole C-9A, tritium content is minimal – up to 0.02 kBq/kg. At the same time, relatively high concentrations of ^{137}Cs and ^{90}Sr were found in the boreholes S-7A and S-10A located within the hydrodynamic impact of UNEs: 0.31 and 0.25 Bq/kg, respectively.

Therefore, a water stream coming from the valley upland is intensive enough and it prevents fracture waters from penetration from the left boundary of the site. An assump-

tion can be made that during a drought season when filtration in alluvial deposits get decreased, contaminated fracture waters can proliferate from the "warfare" boreholes into river water.

Site № 4. This site is located in the central part of the "Balapan" site in the junction zone of Chinrau and Karazhyra faults. 5 UNEs were carried out here in the following "warfare' boreholes: "Glubokaya", 1206, 1267, 1207 and 1287 (Figure 160).

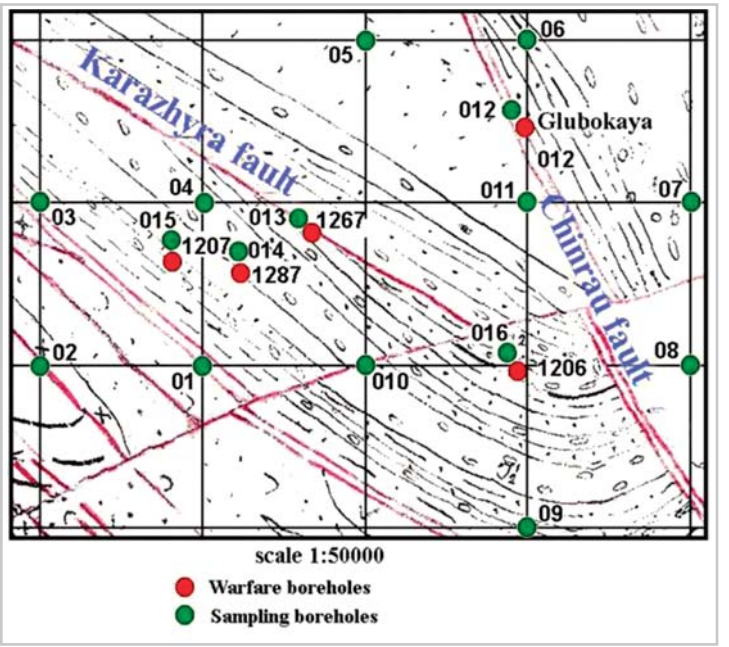


Figure 160. Site № 3. Arrangement of the drilled boreholes

^{90}Sr concentration in all samples does not exceed 0.19 Bq/kg and ^{137}Cs concentration does not exceed 0.82 Bq/kg.

Areal distribution of tritium in ground waters is determined by peculiarities of geological structure and hydrological situation at this site. ^{3}H concentrations in ground water in the impact zone of Chinrau fault are significantly higher and vary from 140 to 160 kBq/kg, while for Karazhirskiy fault this value ranges from 0.02 to 0.04 Bq/kg. Therefore, the northwestern boundary of the area with increased tritium concentrations in ground waters was outlined more precisely.

The artificial radionuclides distribution in ground water has the following peculiarities:

- **^{137}Cs**. In all the studied water samples, ^{137}Cs concentration did not exceed permissible values for potable water. The highest concentration of 4 Bq/kg was found in a hydrogeological borehole 50 m away from the "warfare" borehole.
- **^{90}Sr.** At the most of the territory, ^{90}Sr concentrations in ground water do not exceed 1.0 Bq/kg. The highest ^{90}Sr concentration of 1,240 Bq/kg, was found in the borehole

located 50 m away from the "warfare" borehole. At the distance of couple hundred meters from the "warfare" borehole, the concentration of this radionuclide falls to several mBq/kg.

Based on the above, ^{137}Cs and ^{90}Sr proliferated for not more than 50 m away from the "warfare" boreholes.

- **$^{239+240}$Pu.** $^{239+240}$Pu concentration in ground waters of the investigated sites does not exceed minimal detectable concentration of 0.002 Bq/kg.
- **^{3}H.** ^{3}H concentration in ground water varies within the wide range from the minimal detectable concentration of 0.007 to 4,760 kBq/kg.

The main carriers of UNEs radioactive products at the "Balapan" site are fracture and fracture-vein ground waters. High concentrations of ^{137}Cs and ^{90}Sr in ground waters were detected only in close proximity to the "warfare" boreholes. Upon the results for the majority of studied samples, at larger distances to the "warfare" boreholes (up to several hundred meters), ^{137}Cs and ^{90}Sr concentrations fall below 1.0 Bq/kg. At the same time, ^{3}H concentration in ground water samples varies from 0.007 to 4,760 kBq/kg.

4.1.3. "Sary-Uzen" site

4.1.3.1. General data on geological structure and hydrogeological conditions

The following types of water can be found at "Sary-Uzen" site:

- fracture waters associated with the upper fractured Paleozoic rocks weathering zone;
- fracture-vein waters in the zones adjacent to tectonic faults and in rock crushing zones;
- sporadic pore waters in quaternary alluvial-proluvial and alluvial sediments.

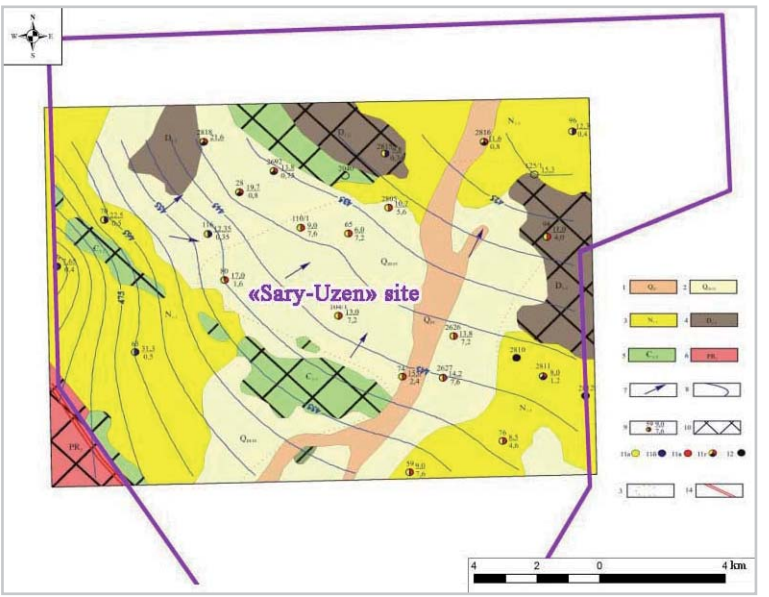
Unfavorable water supply conditions arising from lack of atmospheric precipitation and evaporation dominating over infiltration in summer period, as well as difficult water exchange, predetermine increased mineralization of ground water and form chloride-sulphate, less frequently sulphate-chloride-sodium type mineralization typical for arid and unsaturated zones. Intensive water exchange in the zones of tectonic disruptions make accumulation of non-saline or slightly alkalinized ground water accumulation possible. This water can be used for local water supply.

Lack of obvious focal points of ground water discharge and regional aquacludes within the site allow to consider ground waters of fractured zones as a single hydrogeological basin. Broadly speaking, ground waters of fracturing zones have the following parameters. Water-bearing materials include: fractured limestones, sandstones, conglomerates, gravelstones, siltstones, carbonaceous-argillaceous shales, porphyrites, tuffs, various effusives, granodiorites, granites, diorites-porphyries and gabbro-diorites. Aquiferous layer thickness is 50 to 110 m. The depth of ground water occurrence is up to 14 m. Underground waters are mainly zero-head; in places where water-bearing sediments are covered with Neogene clays they reach the pressure of 40 m. Waters are mainly of non-saline and sub-saline type with mineralization level up to 14.7 g/l with the

average mineralization of 3-5 g/l. Permeability value is determined by fracturing degree and it varies within a wide range from 0.001 to 4.4 m/day, with increase in fault zones.

The waters are sporadically spread in alluvial-proluvial, alluvial and lake sediments (apQ). Water-bearing rocks are spread in interhummocky lowlands, ancient drainage shallows, lake basins and are represented by gravel-cobble sediments, less frequently – by sandy and clay loams. The thickness of water bearing rocks varies from 1.3 to 20 m. The depth of ground water occurrence is 7-15 m. Underground waters are mainly zero-head; at the territories with clays their localhead reaches 3-15 m. Waters are of non-saline and sub-saline type having mineralization level of 0.7-5.7 g/l. Water discharge value varies from hundredth to 0.1 l/s.

To analyze the structure of underground runoff at the "Sary-Uzen" site, a schematic hydrogeological map was used (Figure 161). Regional filtration flow runs from catchment zone to drainage (discharge) zone. The direction of this flow allows to determine spatial attitude of ground water catchment and discharge zones. In this case the valley of Irtysh river serves as a drainage way, while the catchment zone belongs to elevated zones in the western part of the site. Absolute elevations vary from 500 m in the western part of the site, near regional accumulation zone confined to Murzhyk and Arkalyk mountains (The main Chingiz fault), lowing to 200-220 m in the northeastern part of the site, in the transit area.



1 and 2 – aquifer in quaternary deposits; 3 – Neogene seat clay; 4 and 5 – aquifer of Paleogene basement fracture waters; 6 – the Proterozoic formations; 7 – direction of fracture waters; 8 – groundwater and piezometric contours; 9 – hydrogeological boreholes; 10 – fracture water catchment basins (surface water infiltration); 11 – chemical composition of ground waters (a-sulphated anion, b-chloride anion, c-hydrocarbonate anion, g-mixed type); 12 – [illegible]rless borehole; 13 – area of saltish water distribution; 14 – Main Chingiz Fault

Figure 161. Schematic hydrogeological map of the "Sary-Uzen"site

The situation with ground water heads distribution shows changes in the filtration stream directions at the common regional background within some individual sites. This fact explains inhomogeneous structure of fracture space of the water-absorbing rocks and significant inhomogeneity of their filtering properties. In the central part of the territory, at the site where the warfare boreholes are located, the discharge of hydroisohypses provides an evidence of decreasing pressure gradient and filtration speed and therefore, of slowing water exchange.

This fact is proven by high water mineralization (1.3-7.6 g/dm^3). At the site surrounded by low hills with the only entrance along the dry channel of Sary-Uzen, the ground waters in the northeastern direction have chloride-sulphate composition, while in a circumferential direction of the site, closer to the feeding zones, ground waters are non-saline with mineralization of 0.3 to 0.8 g/dm^3 with chloride-sulphate-hydrocarbonate composition from calcium sodium to magnesium-calcium type.

4.1.3.2. Radionuclide contamination of ground water

Arrangement of the "warfare" and the hydrogeological boreholes is shown at the Figure 162.

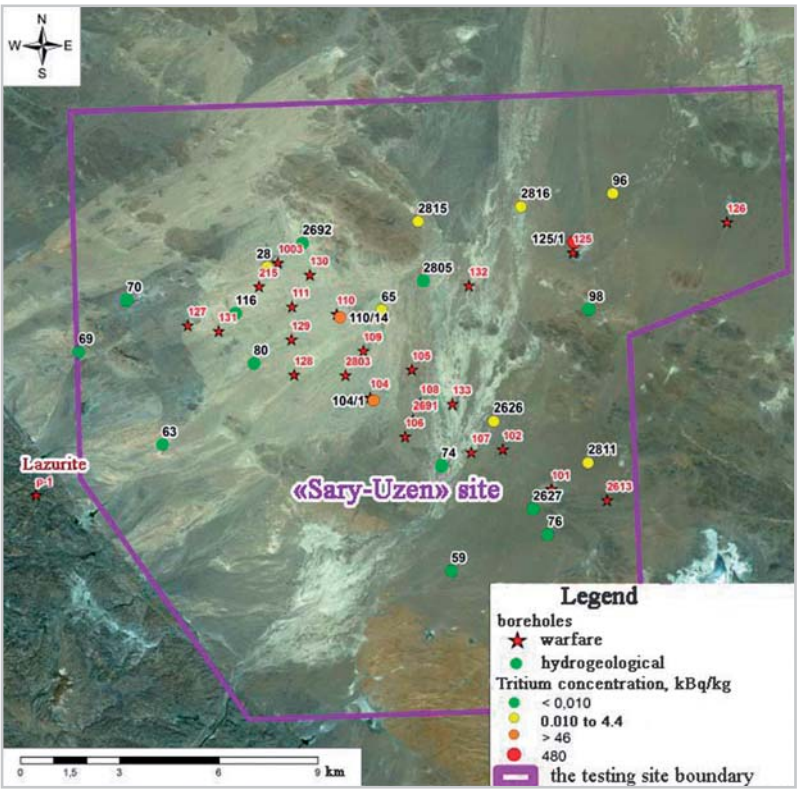


Figure 162. "Sary-Uzen" site. Arrangement of the hydrogeological boreholes

According to the laboratory analyses, radionuclides concentrations in ground water, widespread within the site, reach the following values: ^{137}Cs – up to 3 mBq/kg, ^{90}Sr – up to 10 mBq/kg, ^{3}H – up to 500 kBq/kg. It can be noted based on these data that the main contaminating agent for ground waters at this site is ^{3}H. At that, concentrations of ^{137}Cs and ^{90}Sr in water do not pose radiation hazard.

The data analysis has shown that the ^{3}H concentration dynamics at the site has an ambiguous character. Peculiarities of tritium areal distribution in ground waters mainly depend on the directions of underflow. This is clearly demonstrated by tritium concentrations shown at the Figure 162. Analyzing the data, several boreholes with extremely low tritium concentrations of < 7 Bq/kg can be emphasized. These are the hydrogeological boreholes (№№ 59, 63, 69, 70, 74, 76) located beyond the contaminated water migration front. The data on these boreholes show that, in spite of complex geological structure within the site, artificial radionuclides do not migrate with ground waters in the direction opposite to the regional ground water flow.

Maximal concentration of tritium (480 kBq/kg) was registered in the borehole 125/1, 460 m away northward of the "warfare" borehole 125. For comparison purposes please note that the borehole 104/1 is only 80 m away from the "warfare" borehole 104, but tritium concentration is still for an order of magnitude lower than that in the borehole 125/1. This difference can be explained by the following facts: first of all, the borehole 125/1 is located to the north (within the main ground water stream direction) from the contamination source, which is the "warfare" borehole 125. Also, confined groundwaters are spread within the borehole 125, that contributes to more active washing out of the radionuclides from the central UNEs zones into ground water. Unlike 125/1, the borehole 104/1 is located to the east from the "warfare" borehole 104, and within the territory of the borehole № 104/1 still ground waters are distributed.

It should be noted that tritium concentrations decrease sharply at the distance of several kilometers from the "warfare"boreholes. This fact is clearly demonstrated by the borehole 96 located 2 km away to the north-east from the"warfare" borehole 125, as well as by several other boreholes.

Therefore, the artificial radionuclides distribution in ground waters of the "Sary-Uzen" site has a similarity with the "Balapan" site. UNE radioactive products at the "Sary-Uzen" site proliferate mainly with fracture and vein ground waters. High concentrations of ^{137}Cs and ^{90}Sr in ground waters were found only in vicinity of the "warfare" boreholes. For the majority of the samples, concentrations of ^{137}Cs and ^{90}Sr fall below 1.0 Bq/kg at the distance of couple hundred meters from the "warfare" boreholes. ^{3}H concentration in ground water samples changes from 0.007 to 500 kBq/kg.

Two main source types of the STS ground waters radioactive contamination have been considered. The first type is central UNE zones at "Balapan" and "Sary-Uzen"sites. The main peculiarity of this type is the fact that it is located below the regional water bearing horizon. In this case, artificial radionuclides proliferate from central zones into water-bearing horizon mainly as the result of thermal convection of ground waters.

In the source of the second type, the radionuclides "leached" from central zones occur due to precipitations from the day surface through fractures and faults with subsequent takeout with tunnel streamflows into ground waters.

Obtained data allow to describe the main peculiarities of these sources.

Radionuclides ^{137}Cs, ^{90}Sr and $^{239+240}Pu$ are not carried out with ground waters beyond the boundaries of the test sites. Tritium is the main radioactive contaminator of these ground waters.

Summarizing the above results we can state that at the present time the radionuclides transport with ground water beyond the boundary of the STS testing sites has no significant effect on the further radioecological situation.

4.2. FORCASTED DYNAMICS OF GROUND WATERS CONTAMINATION WITH RADIONUCLIDES

4.2.1. "Degelen" site

According to the forecast analysis of radioactive products migration from central UNEs zones performed by FSUE SPA "Klopin Radium Institute" (Russian Federation), if no sharp changes occur in ground waters of the Degelen massif running beyond the UNEs central zones, ^{90}Sr and ^{137}Cs concentrations would slowly decrease together with $^{239+240}Pu$ concentration increase in the next 100 years [160]. According to their studies, artificial radionuclides are almost completely removed from the tunnel water (except for tritium) in immediate vicinity of the tunnel portals [132, 161].

So, no increase in ^{90}Sr and ^{137}Cs concentrations in ground waters running beyond the Degelen massif towards the studied territory is expected in the nearest future. Also, no significant increase in $^{239+240}Pu$ concentration is expected due to the high sorption properties of this radionuclide.

Tritium is and will remain the main contaminating agent for groundwater in the nearest future. No significant increase in tritium concentration in ground waters is expected due to the following factors. According to the long-term tunnel water monitoring, tritium keeps coming from the central UNE zones on a relatively stable manner. I.e. migration channels of tritium contaminated waters have finally been formed, and in the foreseeable future, gradual decrease in tritium concentration would be observed due to its radioactive decay, as well as gradual depletion of its main source.

At that, favorable infiltration conditions take place beyond the Degelen mountains. I.e. due to lack of uniform cover of crumbly poorly permeable deposits, continuous precipitation entry into groundwater takes place resulting in decrease of tritium concentration up to safe levels for potable water. Therefore, ^{3}H concentration can possibly vary both during a season or some individual years depending on precipitation amount.

To assess the time needed for possible entry of groundwater contaminated with artificial radionuclides into Irtysh river waters, let us use the data obtained during the hydrogeological studies and the detailed survey of Karadzhal deposit. Karadzhal deposit is located in the northern part of the"Degelen" site. Regarding tritium, it travels with ground waters in form of tritiated water and cannot be sorbed by host rocks. Due to this, estimated time for tritium to reach the boundary of the "northern" lands was determined considering the distance from the nearest tunnel with the streamflow of the Degelen massif to the southern boundary of the "northern" lands. Upon the hydrogeological studies, maximal speed of ground water in the deposit area is 2.5 m/day. So, at this speed

of ground water flow and with the distance from the "Degelen" site to the "northern" territories of 85 km, one can estimate the time needed for proliferation of ground waters at this site: approximately 95 years. Considering the fact that 35 years have passed since the first nuclear explosion was made at the "Degelen" site, ground water from "Degelen" contaminated with tritium can appear at the southern boundary of the northern territory approximately in 60 years. Taking into account radioactive decay and tritium dilution due to precipitation entry into ground waters, the time needed for contaminated water appearance will be significantly longer.

4.2.2. "Balapan" site

The data obtained as the result of radioecological study of ground water allow to think that the radionuclides ^{137}Cs and ^{90}Sr have got spread in rock massif of the "Balapan" site during the years after the end of nuclear tests in two main sources as follows:

1) up to 40% of ^{90}Sr and ^{137}Cs after UNEs got localized in solidified melted rocks. Radionuclides virtually have not been migrating from the solidified melted rocks for the first years, or may be decades, since leaching of the radionuclides has a factor of approximately $10^{-3} – 10^{-7}$ g/cm^2×day. Step by step proliferation of the radionuclides into aquifer would not affect general situation with radioactive contamination of ground water. In any case, if no sharp changes occur, ^{90}Sr and ^{137}Cs concentrations would slowly decrease;

2) the second part of the radionuclides was adsorbed on surfaces of fragments and rock fractures in the zones of irreversible deformations.

Based on the long-term radionuclide monitoring of groundwater at the most of the "Balapan" site territory, ^{137}Cs concentration in ground waters of the regional basin ranges from 0.01 to 1.5 Bq/l (average – 0.2 Bq/l), and ^{90}Sr –from 0.02 to 4.0 Bq/l (average 0.4 Bq/l). I.e. concentration values are almost similar. At that, ^{137}Cs concentration in 10 hydrogeological boreholes is higher than that of ^{90}Sr, and in 40 boreholes ^{137}Cs concentration is lower than that of ^{90}Sr.

So, the results of theoretical assessments and long-term monitoring demonstrate that no increase in ^{137}Cs and ^{90}Sr radionuclides concentrations or their occurrence in ground waters beyond the "Balapan" test site can be expected in the foreseeable future.

The main carriers of UNE radioactive products beyond the test site are fracture and ground waters. Tritium is the main radionuclide contaminating ground waters at the present and would remain so in the future. No significant increase in tritium concentration in ground waters is expected. Some insignificant variations in ^{3}H concentration can possibly occur in different seasons and in some individual years depending on the amount of precipitations.

Two local zones of ground water discharge were found within the site territory. The first site (artificial) – is a coal strip mine at the "Karazhyra" deposit. This zone has been formed as a result of the open pit dewatering (sump). Current radionuclides concentrations in drain waters of the strip mine do not exceed permissible values for potable water. The second zone is located in Shagan river valley, where ^{3}H concentration is up to 700 kBq/l, that exceeds permissible values for potable water for almost 100 times. The main discharge zones of radioactively contaminated ground water from the "Balapan" site into surface and pore waters are the zones of relative aquaclude – Neogene clays

pinching-out (in the erosion windows). At that, besides the inflow of radioactively contaminated water into Shagan river within the local discharge zone, tritium migrates with ground water in the southeastern direction beyond the "Balapan" site. This fact needs a more detailed study, because radioactively contaminated ground water can potentially proliferate beyond the STS.

Within the northeastern boundary of the "Balapan" site, tritium concentration in ground waters, in the influence zone of Chinrau fault, is approximately 0.75 kBq/kg (concentrations of ^{137}Cs and ^{90}Sr do not exceed MDA). Within the southeastern boundary of the "Balapan" site, tritium concentration is approximately 0.2 kBq/kg in ground waters associated with influence zone of Kalba-Chingiz regional fault (concentrations of ^{137}Cs and ^{90}Sr do not exceed MDA). Therefore, territories within the influence zones of the regional faults should be classified as restricted areas. Within these zones, cattle breeding and haymaking activities may be carried out provided that water objects are regularly monitored.

Limitations should be applied to the mining operations. Excavation works with water drainage can result in inflow of contaminated water from the "Balapana" test site UNE venues into ground water of this territory. Therefore, survey planning for this territory should involve special ground water studies taking into account a proposed type of activity.

To assess the real time needed for possible entry of ground waters contaminated with artificial radionuclides into Irtysh river, let us use the hydrogeological data from the detailed survey of "Karazhyra" deposit. According to the hydrogeological studies, average velocity of ground water transport in the area of the deposit is 170 m/year. Taking this as a basis and the distance between the "Balapan" site and Irtysh river, tritium contaminated ground waters from the "Balapan" site can appear near the river not faster than in 480 years.

It can be envisaged based on these data and taking into account the radioactive decay and dilution of the radionuclides concentration due to atmospheric precipitations that no entry of contaminated ground waters from STS nuclear tests venues into Irtysh river water is expected.

4.2.3. "Sary-Uzen" site

The character of the radioactive contamination as well as the conditions of ground water migration at the "Sary-Uzen" site is similar to those at the "Balapan" site. Therefore, predictive estimates of ground water contamination, based on situation at the "Balapan" site can be used for the "Sary-Uzen" site as well. It can then be stated for the near future that no increase in ^{137}Cs and ^{90}Sr concentrations or the radionuclides proliferation to the ground waters beyond the "Sary-Uzen" site boundary is expected.

The main carrier of UNEs radioactive products beyond the site is fracture groundwater. Tritium would remain the main radionuclide contaminating ground waters at the present time and in the future. No significant increase in tritium concentration is expected. Some insignificant changes in ^{3}H content can take place varying from season to season and in some individual years depending on amounts of precipitations.

4.3. Develolpment of recommendations for creating monitoring systems for the conditionally "background" STS territories

As was noted before, the concentrations of ^{137}Cs, ^{90}Sr and $^{239+240}Pu$ radionuclides within the testing sites do not exceed the following values: ^{137}Cs and $^{90}Sr < 0.01$ Bq/kg, $^{239+240}Pu < 0.001$ Bq/kg. The long-term monitoring and theoretical calculations show that concentrations of these radionuclides in ground water streamflows, running beyond the boundaries of the "Degelen", "Sary-Uzen" and "Balapan" sites would not rise in the nearest future. Tritium remains the main artificial radionuclide in ground water. The main peculiarity of this radionuclide is the fact that being a component of water, it does not get sorbed by rocks. Therefore, it is an ideal indicator for the state of ground water. After the character of ^{3}H migration with ground water beyond the testing sites is studied, one can think of possible basic migration pathways of such artificial radionuclides as ^{137}Cs, ^{90}Sr and $^{239+240}Pu$.

Concentrations of the artificial radionuclides (including tritium) in all the boreholes drilled beyond the test sites at the distance of over 20 km do not exceed the following values: ^{137}Cs <0.01 Bq/kg, ^{90}Sr <0.005 Bq/kg, $^{239+240}Pu$ <0.001 Bq/kg and ^{3}H <0.012 kBq/kg. I.e. at the present time, there is no need to arrange ground water radionuclide monitoring posts at the territories planned for transfer into economic turnover. Monitoring points should be arranged as follows: in close vicinity to the boundaries of testing sites, in zones of regional faults, as well as on sites where tritium migrates with infrabed water.

"Balapan" site. Groundwater monitoring points at the "Balapan" site are recommended to be equipped considering the factors listed below. Now there are two functional sites of ground water discharge at the "Balapan" site. The first site (man-made) – is a strip mine of "Karazhyra" coal deposit. This site was formed due to the pit dewatering. Now there is a dispersion crater proliferated far enough to influence the territories with the "warfare" boreholes. The second is located in the valley of Shagan river, where tritium concentration is up to 700 kBq/l. In this case, to predict possible development of radiological situation, monitoring points should be arranged not only within the area of these sites, but also in the proximity to the contamination sources. Ground water should be monitored in direct proximity of the "warfare" boreholes first of all to assess the dynamics of artificial radionuclides takeout beyond the UNE zones. Planning future works, it is recommended to check out all existing boreholes at "Balapan" site. Upon the results of sampling, 5-7 boreholes should be selected for the long-term monitoring. The main radionuclide to be controlled is tritium.

Besides that in the zone of discharge of tritium contaminated waters into Shagan river 3-5 boreholes should be drilled along the banks of the river (downstream) at the distance of 15 km from the STS boundary (Figure 163).

Finally, when arranging the continuous monitoring system at the STS territory it will be extremally important to have an information on the state of ground waters in the impact zones of regional faults. For this purpose monitoring points are recommended to

be equipped in zones of regional faults impact at the sites where their routes cross the boundary of "Balapan" site (Kalba-Chingiz, Chinrau, and Bayguzin-Bulak faults).

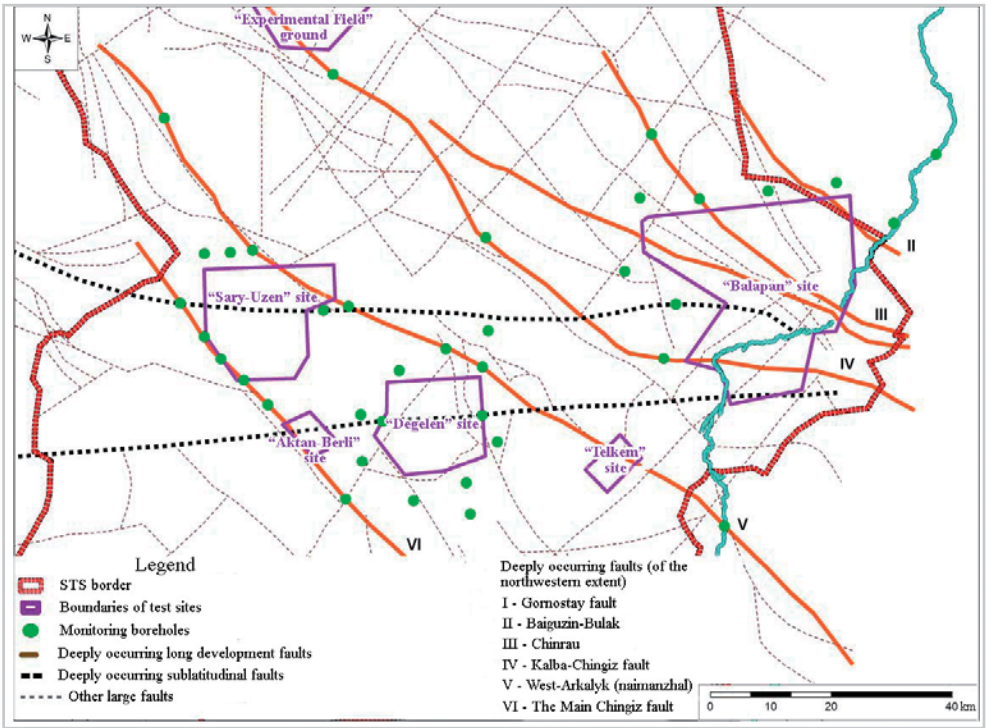


Figure 163. Arrangement of the boreholes drilled for ground water monitoring at the STS territory

"Degelen" site. Since the main contaminated water flows are associated with the channels of temporary and permanent surface streamflows, it is recommended to arrange the monitoring points at the sites maximally distant from the boundary of the Degelen massif (Figure 163), where quantitative amounts of tritium were detected, i.e.:

- channels of Karabulak, Baitles and Uzynbulak creeks located at the distance of 15, 10 and 15 km from Degelen mountains, respectively;
- Altybay valley, all along from Degelen mountains to the "Sary-Uzen" site;
- the site where Karabulak creek crosses the trace of the West Arkalyk regional fault;
- the site where the Main Chingiz regional fault crosses the fault extending in north-eastern direction, passing the Degelen site;
- the site of Western Arkalyk fault intersection with Shagan river channel;
- the sites of Uzynbulak creek valley intersection with Shagan river valley;
- at the sites of sublatitudinal fault traces intersection with the "Degelen" site boundaries;
- at the sites of tunnel waters appearance at the daily surface (8 tunnels with stable streamflows).

Tunnel streamflows monitoring is not less important in respect of the assessment of ^{90}Sr, ^{137}Cs, $^{239+240}Pu$ and tritium artificial radionuclides spreading beyond the central zones.

Sary-Uzen" site. Like at the "Balapan" test site, it is reasonable to arrange 5-7 boreholes in close proximity to the "warfare" boreholes. The boreholes of this type should be also drilled at the site of trace of the regional Main Chingiz fault line intersection with the boundary of the "Sary-Uzen" site (Figure 163).

Since groundwater of the "Sary-Uzen" site runs in northern and northeastern direction, existing hydrogeological boreholes to the north from the site can be used to control contaminated water crossing the site boundary.

Results of the 18-year period of ground water monitoring show that the radionuclide composition and contamination levels do not change with time. No significant seasonal variations in ^{137}Cs, ^{90}Sr, $^{239+240}Pu$ and tritium concentrations were found for the observation period.

So, the periodicity of tritium concentrations observations in ground water can be once per year, and for ^{137}Cs, ^{90}Sr, $^{239+240}Pu$ – once per three years.

Chapter 5
QUALITY ASSESSMENT OF AGRICULTURAL PRODUCTS PRODUCED AT THE CONDITIONALLY "BACKGROUND" TERRITORIES OF THE STS

5.1. Quality assessment of crop products produced at the conditionally "background" territories of the STS

When farm works are carried out at radioactively contaminated territories, one of the main agricultural issues is getting crop products safe for use by population [162 – 165]. Investigations at the territories radioactively contaminated due to accidents at nuclear fuel cycle enterprises show that, in the majority of the radiological situations, contribution of internal population exposure from consumption of radionuclides containing food products into summary dose can be either equal or exceed contribution of external exposure [162, 166].

Since the STS was closed, these lands have been actively used for economic purposes, mainly for cattle grazing, while the lands adjacent to the test site have been used all the time. STS adjacent lands have been used since a lot of inhabited localities are found here (villages, winterings and etc.), those inhabitants actively carry out economic activities.

Quality of crop products in respect of radiation parameters can be assessed in two ways:

– Via **direct assessment** of crop products quality, i.e. standard determining radionuclides concentrations in crop products with the sampling venue either known or unknown in advance;
– Via indirect assessment or employing the crop products **calculation method** based on some definite indexes of radionuclides transfer from soil into crops and radionuclides content in soil.

Quality of crop products can be assessed directly only provided that real, not potential crops, are used i.e. forecasted data is not suitable. Calculation assessment of crop products quality can be used both if the products are available or in their absence, where only radionuclides content in soil and quantity index of the radionuclides transfer from soil into plant are needed.

At present time, the main conventional quantitative indexes of radionuclides transfer from soil into plants are as follows: accumulation factor (A_F) – the ratio between the radionuclide specific activity and the mass unit of plants and soil, or transfer factor (T_F) – the ratio between the specific activity of the radionuclides in plants to soil contamination density per area unit. For the STS territory, characterized by significant scatter in data on the radionuclides content in soil of small contaminated sites, A_F – the most suitable quantitative index, which in this case accurately shows the radiation situation in any STS part. In addition, A_F – the common quantitative index used internationally since the transfer factor (F_v or T_F) is an analogue of the accumulation factor [118, 167].

Global experience in farm radioecology gives a significant amount of information [26, 168 – 173]. All significant results of the research performed worldwide on the radionuclides transfer from soil into plants were generalized by the IAEA and are provided in a special guide [118]. IAEA data can be used for theoretical assessment of the contamination level of potential crop products at the STS territory. However, accumulation factors (Fv) by the IAEA differ by their high variability of values (up to 5-6 orders of magnitude), they were designed for joint groups of cultures and obtained under various soil-climatic conditions, that causes doubt in possibility of using the world data for predictive assessment of crop products quality under various soil and climatic conditions of the STS. Therefore, the world data provide quite generalized A_fs and can hardly be used in the quality assessment of the local crop products.

We have got a large data base on the radionuclides concentration in crop products produced at the STS adjacent lands [174 – 178]. A_fs obtained in these studies can be used in the quality assessment of potential crop products both from the STS territory and beyond.

For further quality assessment of the crop products, the most suitable is the calculation method. In this case only soil analysis is needed for the site to determine the radionuclide concentrations with further conversion into the A_fs.

5.1.1. Quality assessment of the products produced in Sarzhal and Bodene villages

The STS and adjacent territories have suffered from repeated radioactive contamination formed mainly by the atmospheric tests at the "Experimental Field" site.

In 2010-2012, the main inhabited localities studied in vicinity of the STS were Sarzhal and Bodene villages. These villages were chosen first of all due to passage of so-called radioactive fallout plumes from the surface tests over their territories.

The "southeastern" part of the STS is located near Sarzhal village, 120 km away from the center of the "Experimental Field". Radiation situation of this territory is determined first of all by the surface and atmospheric nuclear explosions at the "Experimental Field": the first thermonuclear test in 1953 (yield ~400 kt) and the model experiments (hydronuclear and hydrodynamic) in 1961 and 1963.

Bodene village is located at the left bank of Irtysh river, approximately 90 km away from the "Experimental Field". Main contamination of Bodene village and adjacent territory could result from the test on 29.08.1949 (yield of ~22 kt). Axis of the trace was found at the distance of 3 km from the northern part of Bodene village (Figure 164). Radioactive fallout traces from the nuclear tests carried out on 22.11.1955 and 29.07.1955 (yield ~1,600 kt and ~1,3 kt, respectively) are located at the distance of over 10 km from Bodene village and, therefore, could either affect or not affect their territories. Location of the nuclear test trace axes at the studied territories is shown at figures 164 – 165.

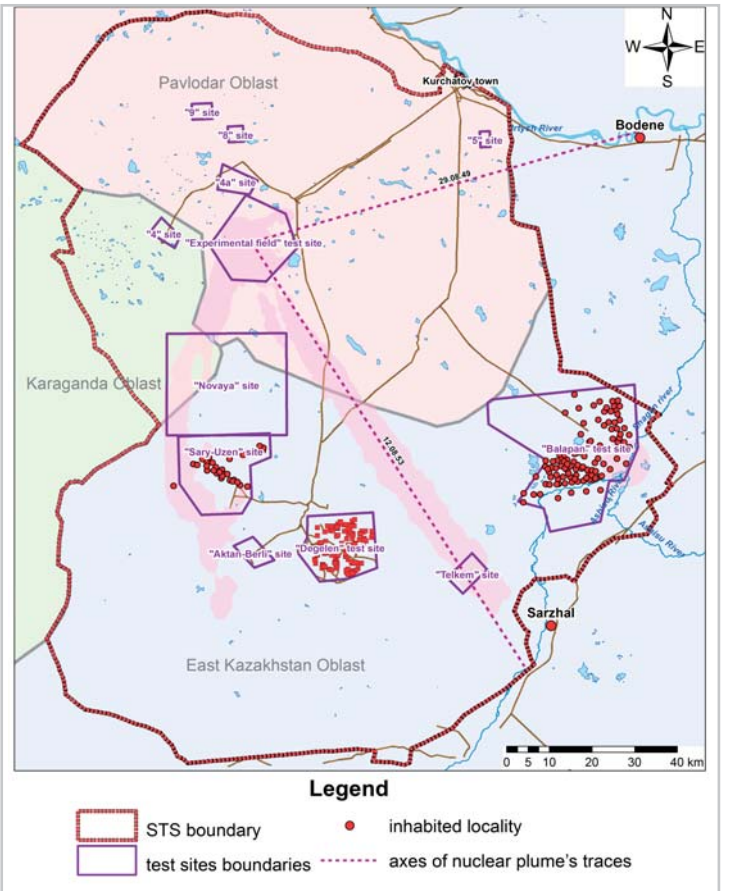
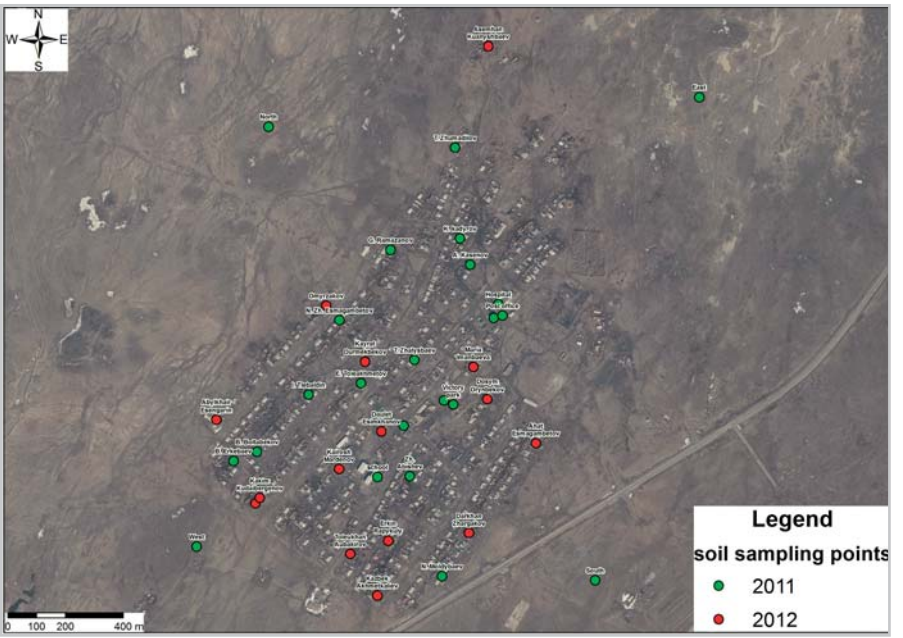


Figure 164. STS maps with the radioactive fallout traces and location of Bodene and Sarzhal villages

Main stages and objects of research. Samples were collected in summer-autumn period (August-September), when the most of the crops get ripped. In each of considered villages (Sarzhal and Bodene), crop products were presented by the local inhabitants who cultivate vegetables, tomatoes and etc. As objects of research, the following cultures were taken: potato, tomato, cucumber, carrot, beet, eggplant, pepper and pumpkin.

Sampling of agricultural plants and soil. The main agricultural products (fruits, bulbs, cabbage-heads, root crops) were sampled in raw condition, with the weight of at least 0.5 kg, together with the above soil was sampled at kitchen gardens of the inhabitants to the root depth (0-20 cm). Soil and vegetation samples were packed into plastic bags and supplied with passports [179]. In venues of vegetation sampling, EDR and density of β-particle fluxes were measured at the soil surface. Measurements were carried employing the MC-AT6130 dosimeter-radiometer [180]. After sampling, vegetation was divided into individual parts (fruits, root crops, leafage, stalk, root and bulbs) and prepared for radionuclide analyses.



a)

b)

Figure 165. Inhabited localities: a) Sarzhal village; b) Bodene village

Radionuclide analysis. Specific activities in soil and plant samples were determined according to the standardized methodology at the certified laboratory equipment [93, 111]. Specific activities of ^{137}Cs and ^{241}Am radionuclides in soil and plants were determined using Canberra GX-2020 gamma-spectrometer. Concentrations of ^{241}Am and ^{137}Cs in plants were determined in dried milled samples, ^{90}Sr and $^{239+240}$Pu – in ash with further conversion into dry matter. Detection limits depending on a sample and a subsample type were as follows: ^{137}Cs - 1-10 Bq/kg (of dry matter for plants and soil samples), ^{241}Am – 1-10 Bq/kg, $^{239+240}$Pu – 0.1 and 1 Bq/kg, ^{90}Sr – 1-10 Bq/kg. Measurement error for ^{137}Cs and ^{241}Am did not exceed 15-25 %, ^{90}Sr – 15-25 %, $^{239+240}$Pu – 30%.

Assessed radionuclide contents in plant and soil samples, taken at household plots in Sarzhal village (Abay district) and Bodene village (Beskarahay district) in 2011-2012 are given in Tables 48 – 51. As the average concentrations of radionuclides, mean arithmetical values for all available quantitative values were used in the Tables. If more than two quantitative values were used, the values below the detection limit of the equipment were not considered.

Table 48.

^{137}Cs content in crop products produced at the territory of Sarzhal and Bodene villages

Plants	^{137}Cs content in crop products, Bq/kg (dry weight)							
	Sarzhal				Bodene			
	min	max	average	n (n*)	min	max	average	n (n*)
potato (bulbs)	<0.2	<5.6	-	12	<0.6	<0.9	-	2
potato (leafage)	<0.6	4.6±0.9	3.6±0.74	13 (3)	-	-	-	-
potato (stalk)	<0.8	<3.5	-	6	-	-	-	-
potato (root)	<1	2.3±0.5	-	12 (1)	-	-	-	-
soil	9±1	42±8	20.1±3.4	13 (13)	4.4±0.9	5±1	4.7±0.9	2 (2)
carrot (leafage)	<0.5	<9	-	8	-	<1.1	-	-
carrot (root crop)	<0.8	<3	-	4	<1.7	<2	-	5
soil	11±2	16±1	14.5±2.2	8 (8)	2.2±0.4	4.4±0.9	3.2±0.6	5 (5)
beet (leafage)	<0.7	11.2±0.6	-	6(1)	<0.3	<1.1		4
beet (root crop)	<0.5	<1.4	-	3	<0.7	<2		4
soil	12±2	19±1	14.5±2.3	6 (6)	2,8±0,6	13±3	6.0±1.4	4 (4)
tomato (fruit)	<0.4	<1.7	-	5	<0.8	<3	-	4
tomato (leafage)	<0.8	6±1	-	5 (1)	-	-	-	-
tomato (stalk)	<1.6	<4	-	3	<1.3	2±0.4	-	2 (1)
tomato (root)	<2	<8	-	5	<2	<5	-	2
soil			17.2±2.6		<1.6	4.4±0.9	3.0±0.6	4 (3)
pepper (fruit)	<0.4	<5	-	4	-	<3	-	1
pepper (leafage)	<1.6	<5	-	4	-	-	-	-
pepper (stalk)	<1.9	<6.5	-	4	-	-	-	-
pepper (root)	<1.3	<8	-	4	-	-	-	-
soil	8±1	22±4	13.1±1.5	4 (4)	-	2.2±0.4	-	1
cucumber (fruit)	<0.7	<3	-	4	-	<1.8	-	1
cucumber (leafage)	<1.8	3.4±0.5	-	3 (1)	-	-	-	-

Plants	^{137}Cs content in crop products, Bq/kg (dry weight)							
	Sarzhal				Bodene			
	min	max	average	n (n*)	min	max	average	n (n*)
cucumber (stalk)	<1.9	3±0.6	-	4 (1)	-	<2	-	1
cucumber (root)	<2.2	<5.3	-	4	-	-	-	-
soil	8±1	23±1	16.2±0.9	4 (4)	-	2.8±0.6	-	1
pumpkin (fruit)	-	<0.3	-	1	-	-	-	-
pumpkin (leafage)	-	<1.6	-	1	-	-	-	-
pumpkin (stalk)	-	<4	-	1	-	-	-	-
pumpkin (root)	-	<9	-	1	-	-	-	-
soil	-	19±1	-	1	-	-	-	-
eggplant (fruits)	-	-	-	-	<0.7	<3		2
eggplant (leafage)	-	<0.9	-	1	-	-	-	-
eggplant (stalk)	-	-	-	-	-	-	-	-
eggplant (root)	-	<1.6	-	1	-	-	-	-
soil	-	11±2	-	1	2.4±0.5	5±1	-	2 (2)
onion(leafage)	-	<0.9	-	1	-	-	-	-
onion(heads)	-	<1.2	-	1	-	-	-	-
Soil	-	17±3	-	1	-	-	-	-
marrow (fruits)	-	-	-	-	-	<1.8	-	1
marrow (halm)	-	-	-	-	-	<1.6	-	1
soil	-	-	-	-	-	1.6±0.3	-	1
cabbage (fruits)	-	-	-	-	-	<3	-	1
soil	-	-	-	-	-	7±1	-	1

Note: n – total quantity of samples analyzed; n* - number of values with qualitative data;
"-" – not available.

Table 49.

^{90}Sr content in in crop products produced at the territory of Sarzhal and Bodene villages

Plants	^{90}Sr content in crop products, Bq/kg (dry weight)							
	Sarzhal				Bodene			
	min	max	average	n (n*)	min	max	average	n (n*)
potato (bulbs)	<0.6	3.1±1.4	-	10(1)	0.5±0.2	0.6±0.2	0.6±0.2	2(2)
potato (leafage)	-	-	-	-	-	-	-	-
potato (stalk)	<2.12	12.3±1.8	6.8±1,5	4(3)	-	-	-	-
potato (root)	-	-	-	-	-	-	-	-
soil	2.7±0.8	22±2	10.8±1.7	8(8)	<1.8	2.9±1.2	-	2 (1)
carrot (leafage)	-	-	-	-	-	-	-	-
carrot (root crop)	<2.4	< 20	-	5	-	-	-	-
soil	5.2±1.1	18±4	11.9±1.5	8(8)	<0.8	1.9±0.9	-	5 (1)
beet (leafage)	-	-	-	-	-	-	-	-
beet (root crop)	<2.8	<22.3	-	3	-	-	-	-
soil	2.4±0.7	13±2	9.1±1.3	6(6)	<1.1	6.3±0.9	-	4 (1)

Plants	^{90}Sr content in crop products, Bq/kg (dry weight)							
	Sarzhal				Bodene			
	min	max	average	n (n*)	min	max	average	n (n*)
tomato (fruit)	< 1.4	5.9±1.1	-	5(1)	-	-	-	-
tomato (leafage)	-	-	-	-	-	-	-	-
tomato (stalk)	21.6±2.4	33±2.4	27.3±2.5	2(2)	-	-	-	-
tomato (root)	-	5.1±1.1	-	1	-	-	-	-
soil	2.6±0.6	12±1	7.3±1.1	2(2)	<0.9	<1.9	-	4
pepper (fruit)	< 1.9	24±7	-	3(1)	-	-	-	-
pepper (leafage)	-	-	-	-	-	-	-	-
pepper(stalk)	-	18.5±2.1	-	1	-	-	-	-
pepper(root)	-	-	-	-	-	-	-	-
soil	8±1	12±1	10±1.1	2(2)	-	<0.8	-	1
cucumber(fruit)	<0.9	<2.4	-	2	-	-	-	-
cucumber(leafage)	-	-	-	-	-	-	-	-
cucumber(stalk)	-	<1.46	-	1	-	-	-	-
cucumber(root)	-	-	-	-	-	-	-	-
soil	2.6±0.6	11±1	8.2±1.1	4(4)	-	<0.9	-	1
pumpkin(fruit)	-	<0.8	-	1	-	-	-	-
pumpkin(leafage)	-	-	-	-	-	-	-	-
pumpkin(stalk)	-	-	-	-	-	-	-	-
pumpkin(root)	-	-	-	-	-	-	-	-
soil	-	10±1	-	1 (1)	-	-	-	-
eggplant(fruit)	-	< 31	-	1	-	-	-	-
eggplant(leafage)	-	-	-	-	-	-	-	-
eggplant(stalk)	-	-	-	-	-	-	-	-
eggplant(root)	-	-	-	-	-	-	-	-
soil	-	5.2±1.1	-	1 (1)	1.9±0.9	3.8±1.1	2.8±1.1	2 (2)
onion(leafage)	-		-	-	-	-	-	-
onion(head)	-	15±4	-	1 (1)	-	-	-	-
soil	-	-	-	-	-	-	-	-

Note: n – total quantity of samples analyzed; n* - number of values with qualitative data;
"-" – not available.

Table 50.

$^{239+240}$Pu content in crop products produced at the territory of Sarzhal and Bodene villages

Plants	$^{239+240}$Pu content in crop products, Bq/kg (dry weight)							
	Sarzhal				Bodene			
	min	max	average	n (n*)	min	max	average	n (n*)
potato(bulbs)	0.068±0.02	0.94±0.29	0.35±0.11	8 (6)	-	-	-	-
potato(leafage)	-	-	-	-	-	-	-	-
potato(stalk)	< 0.3	1.5±0.4	1.3±0.3	5 (2)	-	-	-	-
potato(root)	-	< 0.8	-	1	-	-	-	-

Plants	$^{239+240}$Pu content in crop products, Bq/kg (dry weight)							
	Sarzhal				Bodene			
	min	max	average	n (n*)	min	max	average	n (n*)
soil	<3.3	35±7	13.4±3.6	8 (7)	< 2.8	< 4		2
carrot(leafage)	-	-	-	-	-	-	-	-
carrot(root crop)	< 0.4	0.9±0.2	-	2(1)	-	-	-	-
soil	1.7±1.2	53±10	18.0±5.1	8(6)	< 2.7	4±2	-	5 (1)
beet(leafage)	-	-	-	-	-	-	-	-
beet(root crop)	0.3±0.1	3.3±0.5	-	2 (2)	-	-	-	-
soil	1.7±1	94±17	28.7±9.4	6 (4)	< 3	10±4	-	4 (1)
tomato(fruit)	0.38±0.15	0.46±0.13	-	2	-	-	-	-
tomato(leafage)	-	-	-	-	-	-	-	-
tomato(stalk)	-	-	-	-	-	-	-	-
tomato(root)	-	< 2,2	-	1	-	-	-	-
soil	<2.,2	21±4	11.6±3.7	2 (2)	< 2.6	< 4	-	4
pepper(fruit)	-	0.74±0.27	-	1	-	-	-	-
pepper(leafage)	-	-	-	-	-	-	-	-
pepper(stalk)	-	-	-	-	-	-	-	-
pepper(root)	-	-	-	-	-	-	-	-
soil	5.6±3.5	6.1±3.5	5.8±3.5	2	-	4±2	-	1
cucumber(fruit)	-	< 0.7	-	1	-	-	-	-
cucumber(leafage)	-	-	-	-	-	-	-	-
cucumber(stalk)	-	< 0.4	-	1	-	-	-	-
cucumber(root)	-	-	-	-	-	-	-	-
soil	< 1.7	16±6	9.7±3.0	4 (3)	-	-	-	-
pumpkin(fruit)	-	< 0.13	-	1	-	-	-	-
pumpkin(leafage)	-	-	-	-	-	-	-	-
pumpkin(stalk)	-	-	-	-	-	-	-	-
pumpkin(root)	-	-	-	-	-	-	-	-
soil	-	69±20	-	1	-	-	-	-

Note: n – total quantity of samples analyzed; n* - number of values with qualitative data;
"-" – not available.

Table 51.

^{241}Am content in crop products produced at the territory of Sarzhal and Bodene villages

Plants	^{241}Am content in crop products, Bq/kg (dry weight)							
	Sarzhal				Bodene			
	min	max	average	n (n*)	min	max	average	n (n*)
potato(bulbs)	<0.2	<1.1	-	12	<0.5	<0.6	-	2
potato(leafage)	<0.6	<1.9	-	13	-	-	-	-
potato(stalk)	<0.5	<3.5	-	6	-	-	-	-
potato(root)	<0.6	<1.8	-	12	-	-	-	-
soil	<0.21	13±2	5.2±0.8	13 (4)	<0.5	4.6±0.9	-	2 (1)

Plants	^{241}Am content in crop products, Bq/kg (dry weight)							
	Sarzhal				Bodene			
	min	max	average	n (n*)	min	max	average	n (n*)
carrot(leafage)	<0.2	<2.4	-	8	-	<1.4	-	1
carrot(root crop)	<0.4	<1.8	-	4	<0.8	<1.1	-	5
soil	<0.4	35±1	-	8 (1)	<0.4	4.6±0.9	-	5 (1)
beet(leafage)	<0.3	<2.1	-	6	<0.4	<0.8	-	4
beet(root crop)	<0.3	<0.7	-	3	<0.6	<1.2	-	4
soil	<0.2	0.7±0.2	-	6 (1)	<0.5	4.6±0.9	-	4 (1)
tomato(fruit)	<0.3	<1.3	-	5	<0.5	<1.5	-	4
tomato(leafage)	<0.3	<1.6	-	5	-	-	-	
tomato(stalk)	<0.4	<2.1	-	3	<0.8	<1	-	2
tomato(root)	<1.3	<3	-	5	<1.4	<3	-	2
soil	<0.4	8,3±0,5	6.6±0.9	5 (3)	<0.4	4.6±0.9	-	4 (1)
pepper(fruit)	<0.2	<1.8	-	4	-	<1.5	-	1
pepper(leafage)	<0.8	<1.7	-	4	-	-	-	-
pepper(stalk)	<1	<3	-	4	-	-	-	-
pepper(root)	<0.4	<4	-	4	-	-	-	-
soil	<0.33	<0.7	-	4	-	<0.5	-	1
cucumber(fruit)	<0.6	<1.1	-	4	-	<0.9	-	1
cucumber(leafage)	<0.3	<0.8	-	3	-	-	-	-
cucumber(stalk)	<0.6	<1.4	-	4	-	<2.8	-	1
cucumber(root)	<0.7	<3.4	-	4	-	-	-	-
soil	<0.4	37±1	14.6±2.6	4 (3)	-	<0.5	-	1
pumpkin(fruit)	-	<0.2	-	1	-	-	-	-
pumpkin(leafage)	-	<0.4	-	1	-	-	-	-
pumpkin(stalk)	-	<0.5	-	1	-	-	-	-
pumpkin(root)	-	<5	-	1	-	-	-	-
soil	-	0.93±0.04	-	1	-	-	-	-

Note: n – total quantity of samples analyzed ; n* - number of values with qualitative data;
«-" – not available.

The content of the studied artificial radionuclides in plants and soil was very low; therefore, in several cases only the values below the detection limit of the equipment were obtained. Nevertheless, quantitative values were obtained for some individual crops: potato, tomato and beet.

There are some limits for the radionuclide content in crop products provided in the state regulatory doc HS SERPRS PK [46]. Unlike ^{137}Cs and ^{90}Sr, the content of $^{239+240}$Pu and ^{241}Am in food products is not regulated. However, considering the fact that the annual limit of intake (ALI) for $^{239+240}$Pu and ^{241}Am with food for population is for an order of magnitude lower than that for ^{90}Sr, it can be assumed that the permissible levels for these radionuclides would also be for an order of magnitude lower. Permissible concentrations of these radionuclides in crop products are given in the Table 52.

Table 52.

Permissible specific activities (PSA) of the radionuclides in crop products calculated for the dry weight

Type of product	PSA, Bq/kg (dry weight)			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu*	^{241}Am*
potato	245	82	8	8
carrot	632	211	21	21
beet	571	190	19	19
tomato	471	353	35	35
pepper	400	300	30	30
eggplant	571	429	43	43
cucumber	800	600	60	60
pumpkin	533	400	40	40
onion	364	273	27	27
cabbage	429	143	14	14
Note: $^{239+240}$Pu* and ^{241}Am* - approximate norms				

According to the comparative assessment of the crop products in villages employing the acting norms of the radionuclides content in crop products, the values registered in the studied villages were lower than the limits provided by the HS SERPRS doc: ^{137}Cs for 2 orders of magnitude, ^{90}Sr, $^{239+240}$Pu and ^{241}Am are not less than for 1 order of magnitude. Obtained results indicate that in the villages Sarzhal and Bodene, there is no exceedance above the permissible levels registered for the artificial radionuclides in crop products. Considering the fact that Sarzhal and Bodene villages are located at the territory of traces from the surface nuclear explosions, and low concentrations of the radionuclides were found in the crop products produced in these villages, it can be assumed that in other villages either not affected at all or less affected by the nuclear tests, the radionuclide concentrations would be even lower. Therefore, one can conclude that the crop products that can be produced at the territory adjacent to the STS and the "background" territories of the STS are safe for consumption by people in terms of the artificial radionuclides content.

5.1.2. Quality assessment for crop products using the calculation method

5.1.2.1. Calculation of accumulation factors

To assess the level of agricultural products contamination, one needs to know concentrations of the radionuclides in soil of the focus territory and the radionuclide accumulation factors (A_{Pl}) for various agricultural products. Therefore, we have carefully analyzed all available worldwide and local experimental data (for the STS and the villages) to select optimal A_{Pl}s for the "background" STS territory and its adjacent lands.

Calculation of accumulation factors. Accumulation factors used in quantification of the radionuclides transfer from soil into various parts of plants were calculated as a ratio of the radionuclide content per unit of the vegetation mass to the radionuclide content per unit of soil mass [118, 167].

Experimental A_fs for plant products of the villages Sarzhal and Bodene. The radionuclide contents in the plant products obtained for Sarzhal and Bodene villages (Tables 48 – 51) allow not only for assessment of the product quality, but also for calculation of A_fs (Tables 54 – 57, column 3). The A_fs were calculated as follows:

– when several A_f values (more than 3) found using quantitative values of specific activity (SA) of the radionuclides in plants and soil are available, mean geometric values of A_fs can be recommended for use in assessment of the crop products;
– when the only A_f is obtained using SA, and several T_fs are obtained using SAs below the detection limit of the equipment (<2 etc.), A_fs found using the SA quantitates are recommended for use in the crop quality assessment; all other data should be omitted;
– when only the A_fs obtained using SAs below the detection limit of the equipment (<2 etc.) are available, then the geometric average values of the estimative A_fs (<) are recommended for use in the crop quality assessment.

Experimental A_fs for crop products at the STS territory. As a result of a full scale experiments carried out in 2010-2013 at the "Experimental Field" site of the STS, experimental data was obtained on the radionuclides accumulation in various kinds of agricultural plants (Tables 54 – 57, column 4) [174 – 178]. Calculation of the A_fs is performed the same way as for the calculations for the villages.

Generalized worldwide A_fs for the crop products. If no data is available on the radionuclide content in the crop products produced in the villages and on the STS territory, the A_fs taken from the IAEA international database (Table s 54 – 57, column 5) can be used as the values recommended for the crop products quality assessment. The IAEA guide provides the data for various groups of plants and soils. First of all, A_fs for soils typical for the region of interest (light and moderate clay loam soils) should be used [118].

Studies of the wild plants carried out at various STS sites indicate significant difference in radionuclides accumulation depending on soil characteristics speciation of radionuclides in soils, radioactive contamination level, intensity of use in agricultural activities, and etc. [177]. Considering the above, use of the A_fs obtained at the STS territory for the villages needs some data correction, i.e. finding a correction factor. The correction factor for the plants in villages ("background" territory of the STS) is actually a ratio of the accumulation factors ($A_f s_{\text{"background"}}$), obtained for the plant products at the "background" territory of the STS to the accumulation factors ($A_f s_{\text{"epicenter"}}$) obtained for the plant products from the "epicenters of nuclear tests" at the STS territory. The factor value is given in the Table 53.

Table 53.

Correction accumulation factor for the plants at various STS zones

AFs of various zones	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
"background" / "epicenter"	10.7	10.8	13.5	3.8

Using the correction factor, recommended AF values for the "background" territories were found as follows: experimental values for the agricultural plants ("Experimental Field") were multiplied by the respective correction factors for each radionuclide. The correction factor was not used for the IAEA data which cover various soil-climatic conditions.

When the A_fs were found for the "background" territories, these data should be used as the recommended ones, when not – the A_fs found for the STS territory with some special data corrections should be used. When even these data are not available, then the generalized IAEA data is used.

Accumulation factors that could be recommended for assessment of the radionuclides content in the crop products at the STS background territory are given in Tables 54 – 57.

Table 54.

^{137}Cs accumulation factors for the crops

Culture	Organ	Accumulation factor ^{137}Cs			
		Villages Sarzhal and Bodene	According to the studies at the STS [174–176]	According to the international sources [118]	Recommended values
potato	bulbs	<4.4E-02	**3.3E-03**	3.5E-02 (40)****	3.6E-02
	leafage	**1.4E-01***	**1.8E-02**	-	1.4E-01
	stalk	<1.1E-01	**1.3E-02**	-	1.4E-01
	root	1.2E-01**	**1.2E-02**	-	1.2E-0
carrot	leafage	<1.9E-01***	**1.9E-02**	-	2.1E-01
	root crop	<2.9E-01	**1.4E-02**	3.0E-02 (21)	1.5E-01
beet	leafage	8.0E-01	**2.1E-02**	-	8.0E-01
	root crop	<1.4E-01	**6.5E-03**	3.0E-02 (21)	7.0E-02
tomato	fruits	<1.2E-01	**2.3E-02**	3.3E-02 (5)	2.4E-01
	leafage	6.0E-01	**5.5E-02**	-	6.0E-01
	stalk	4.5E-01	**2.2E-02**	-	4.5E-01
	root	<4.2E-01	**6.4E-02**	-	6.8E-01
pepper	fruits	<2.4E-01	2.1E-03	3.3E-02 (5)	2.2E-02
	leafage	<2.2E-01	**2.3E-02**	-	2.5E-01
	stalk	<4.0E-01	**1.3E-02**	-	1.4E-01
	root	<2.8E-01	**1.0E-02**	-	1.1E-01
cucumber	fruits	<1.6E-01	3.2E-03**	3.3E-02 (5)	3.5E-02
	leafage	1.6E-01	**11E-02****	-	1.6E-01
	stalk	1.3E-01	**25E-02****	-	1.3E-01
	root	<2.4E-01	**38E-02****	-	4.1E-01

Culture	Organ	Accumulation factor ^{137}Cs			
		Villages Sarzhal and Bodene	According to the studies at the STS [174–176]	According to the international sources [118]	Recommended values
pumpkin	fruits	<1.6E-02	**9.6E-03**	3.3E-02 (5)	1.0E-01
	leafage	<8.4E-02	**2.9E-02**	-	3.1E-01
	stalk	<2.1E-01	**1.3E-02**	-	1.4E-01
	root	<4.7E-01	**1.4E-02**	-	1.5E-01
eggplant	fruits	<4.2E-01	4.3E-02	3.3E-02 (5)	4.7E-01
	leafage	<8.2E-02	**3.1E-02**	-	3.3E-01
	stalk	-	**9.0E-03**	-	9.6E-02
	root	<1.5E-01	**2.7E-02**	-	2.9E-01
onion	leafage	<5.3E-02	**8.1E-03**	3.3E-02 (5)	8.6E-02
	bulbs	<71E-02	**8.6E-03**	-	9.3E-02
cabbage	leafage	<4.3E-01	**1.1E-02**	7.4E-02(119)	1.2E-01
	stalk	<4.3E-01	**3.3E-03**	-	3.5E-02
	root	-	**2.2E-02**	-	2.4E-01
wheat	grain	-	4.1E-04	2.0E-02(158)	4.4E-03
	stalk	-	**1.0E-02**	1.1E-01 (36)	9.2E-01
	root	-	**8.6E-02**	-	7.9E-02

Note: 3.3E-03* – geometrical mean (GM); 4.1E-04** – singular quantities;
<0.62*** – geometrical mean of the guide values;
3.5E-02**** – geometrical mean of the worldwide data obtained for clay loams, in brackets – the number of values used

Table 55.

^{90}Sr accumulation factors for crops

Culture	Organ	Accumulation factor ^{90}Sr			
		Villages Sarzhal and Bodene	According to the studies at the STS [174-176]	According to the international sources [118]	Recommended values
potato	bulbs	**4.7E-01***	**1.9E-02**	1.3E-01 (41)****	4.7E-01
	leafage	-	**2.1E-01**	-	2.3E+00
	stalk	**6.9E-01***	**3.5E-01**	-	6.9E-01
	root	-	**2.6E-01**	-	2.8E+00
carrot	leafage	-	**7.4E-02**	6.1E-01 (16)	8.0E-01
	root crop	<5.8E-01***	3.8E-01	-	4.1E+00
beet	root crop	<1.4	-	6.1E-01 (16)	6.1E-01
tomato	fruits	<8.9E-01	<7,9E-04	3.6E-01 (**19**)	3.6E-01
	leafage	-	**1.3E-01**	-	1.4E+00
	stalk	1.8	**1.1E-01**	-	1.8E+00
	root	1.7E-01	2.6E-01	-	1.7E-01

Culture	Organ	Accumulation factor ^{90}Sr			
		Villages Sarzhal and Bodene	**According to the studies at the STS [174-176]**	**According to the international sources [118]**	**Recommended values**
pepper	fruits	<8.3E-01	<6,3E-03	3.6E-01 (**19**)	3.6E-01
	leafage	-	3.8E-01	-	4.1E+00
	stalk	1.5	6.5E-01	-	1.5E+00
	root	-	**1.0E-01**	-	1.1E+00
cucumber	fruits	<2.7E-01	1.5E-02	3.6E-01 (**19**)	1.6E-01
	leafage	-	1.8E-01	-	1.9E+00
	stalk	<1.3E-01	7.5E-02	-	8.1E-01
pumpkin	fruit	<0.08	5.9E-03	3.6E-01 (**19**)	6.4E-02
	leafage	-	1.8E-01	-	2.0E+00
	stalk	-	8.4E-02	-	9.0E-01
	root	-	3.0E-02	-	3.2E-01
eggplant	fruits	<5.9	<2.6E-03	3.6E-01 (**19**)	3.6E-01
	leafage	-	7.9E-01	-	8.5E+00
	stalk	-	**3.9E-01**	-	4.2E+00
	root	-	**1.3E-01**	-	1.4E+00
onion	leafage	-	**5.2E-02**	3.6E-01 (**19**)	5.6E-01
	Bulbs	-	4.7E-01	-	5.1E+00
cabbage	leafage	-	**1.1E-01**	1.2 (84)	1.2E+00
	steam	-	**1.5E-02**	-	1.6E-01
	root	-	**1.9E-02**	-	2.0E-01
wheat	grain	-	2.6E-02	1.1E-01 (71)	2.8E-01
	glume	-	3.5E-02	-	5.5E-01
	stalk	-	6.2E-03	1.8 (3)	6.7E-02
	root	-	**1.2E-01**	-	1.3E+00

Note: 6.9E-01* – geometrical mean (GM); 8.2E-01** – singular quantities;
<5.8E-01*** – geometrical mean of the guide values;
1.3E-01(41)**** – geometrical mean for the worldwide data obtained for clay loams,
brackets – the number of values used

Table 56.

$^{239+240}Pu$ accumulation factors for the crop products

Culture	Organ	Accumulation factor $^{239+240}Pu$			
		villages Sarzhal and Bodene	**According to the studies at the STS [174-176]**	**According to the international sources [118]**	**Recommended values**
potato	bulbs	**1.2E-02***	**4.3E-04**	1.5E-04 (9)****	1.2E-02
	leafage	-	**2.2E-02**	-	3.0E-01
	stalk	**1.1E-01**	**8.0E-03**	-	1.1E-01
	root	<6.0E-02***	**4.7E-02**	-	6.4E-01

Culture	Organ	Accumulation factor $^{239+240}$Pu			
		villages Sarzhal and Bodene	According to the studies at the STS [174-176]	According to the international sources [118]	Recommended values
carrot	leafage	-	6.9E-02**	2.2E-03 (5)	9.3E-01
	root crop	<4.9E-02	**3.9E-02**	3.9E-04 (**5**)	5.2E-01
beet	leafage	-	**1.0E-02**	2.2E-03 (5)	1.4E-01
	root crop	**4.2E-01**	**1.6E-03**	3.9E-04 (**5**)	4.2E-01
tomato	fruits	<1.4E-01	<1.0E-03	6.2E-05 (8)	7.5E-05
	leafage	-	**4.8E-03**	-	6.5E-02
	stalk	-	**1.7E-03**	-	2.3E-02
	root	<1.4E-01	2.9E-01	-	3.9E+00
pepper	fruits	-	1.1E-04	6.2E-05 (8)	1.4E-03
	leafage	-	1.1E-02	-	1.5E-01
	stalk	-	1.8E-03	-	2.4E-02
	root	-	**9.0E-03**	-	1.3E-01
cucumber	fruits	<2.2E-01	1.9E-04	6.2E-05 (8)	2.6E-03
	leafage	-	5.0E-03	-	6.7E-02
	stalk	<2.3E-01	3.7E-03	-	5.0E-02
pumpkin	fruits	<1.9E-03	3.1E-05	6.2E-05 (8)	4.2E-04
	leafage	-	3.4E-03	-	4.5E-02
	stalk	-	7.4E-04	-	1.0E-02
	root	-	6.6E-03	-	8.9E-02
eggplant	fruits	-	5.5E-02	6.2E-05 (8)	7.4E-01
	leafage	-	5.1E-02	-	6.9E-01
	stalk	-	**9.5E-04**	-	1.3E-02
	root	-	1.6E-02	-	2.2E-01
onion	leafage	-	**2.8E-03**	-	3.8E-02
	bulbs	-	**1.3E-02**	6.2E-05 (8)	1.7E-01
cabbage	leafage	-	1.2E-03	8.3E-05 (**13**)	1.7E-02
	stalk	-	**7.1E-03**	-	9.6E-02
	root	-	**2.8E-02**	-	3.8E-01
wheat	grain	-	**8.1E-04**	9.5E-06 (**105**)	1.1E-02
	stalk	-	**2.6E-03**	4.4E-05 (**10**)	1.1E+00
	root	-	**8.3E-02**	-	9.7E-03

Note: 1.2E-02* – geometrical mean (GM); 6.9E-02** – singular quantities;
<4.9E-02*** – geometrical mean of the guide values;
1.5E-04 (9)**** – geometrical mean for the worldwide data obtained for clay loams,
in brackets – the number of values used

Table 57.

^{241}Am accumulation factors for crop products

Culture	Organ	Accumulation factor ^{241}Am			
		Villages Sarzhal and Bodene	According to the studies at the STS [174-176]	According to the international sources [118]	Recommended values
potato	bulbs	<1.7E-01***	**1.1E-03***	1.5E-04 (8)****	4.2E-03
	leafage	<4.9E-01	**9.9E-03**	-	3.8E-02
	stalk	<4.9E-01	**2.7E-03**	-	1.0E-02
	root	7.0E-01**	**1.1E-02**	-	7.0E-01
carrot	leafage	<1.0E-02	**8.6E-03**	6.7E-04 (**4**)	3.3E-02
	root crop	<7.0E-02	**6.8E-03**	-	2.6E-02
beet	leafage	<4.8E-01	**1.4E-02**	6.7E-04 (**4**)	5.2E-02
	root crop	<8.3E-01	**2.8E-03**	-	1.1E-02
tomato	fruit	<1.4E-01	**5.6E-03**	3.6E-04 (**9**)	2.1E-02
	leafage	<1.8E-01	**1.7E-02**	-	6.6E-02
	stalk	<2.7E-01	**1.3E-02**	-	5.1E-02
	root	<6.4E-01	**7.1E-02**	-	2.7E-01
pepper	fruit	-	<4.4E-03	3.6E-04 (**9**)	3.6E-04
	leafage	-	3.6E-03	-	1.4E-02
	Stalk	-	**1.7E-03**	-	6.4E-03
	root	-	**3.4E-02**	-	1.3E-01
cucumber	fruits	<1.4E-01	1.9E-04	3.6E-04 (**9**)	7.2E-04
	leafage	<8.9E-02	**1.2E-02**	-	4.7E-02
	stalk	<1.8E-01	2.6E-03	-	1.0E-02
	root	<2.6E-01	**1.4E-02**	-	5.2E-02
pumpkin*	fruits	<2.2E-01	1.1E-04**	3.6E-04 (**9**)	4.2E-04
	leafage	<4.3E-01	**1.2E-02****	-	4.5E-02
	stalk	<5.4E-01	3.2E-04**	-	1.2E-03
	root	<5.4	**1.3E-02****	-	4.8E-02
eggplant	fruits	-	**4.5E-03**	3.6E-04 (**9**)	1.7E-02
	leafage	-	**2.1E-02**	-	8.0E-02
	stalk	-	**1.0E-03**	-	3.8E-03
	root	-	**1.2E-02**	-	4.4E-02
onion	leafage	-	**1.4E-03**	3.6E-04 (**9**)	5.4E-03
	bulbs	-	**2.4E-03**	-	9.2E-03
cabbage	leafage	-	**8.1E-04**	2.7E-04 (**10**)	3.1E-03
	stalk	-	**1.3E-03**	-	5.0E-03
	root	-	**1.1E-02**	-	4.3E-02
wheat	grain	-	**1.1E-03**	2.2E-05 (**83**)	4.2E-03
	stalk	-	**5.7E-03**	7.9E-05 **(5)**	4.8E-01
	root	-	**1.3E-01**	-	9.1E-03

Note: 1.1E-03* – geometrical mean (GM); 7.0E-01** – singular quantities;
<1.7E-01*** – geometrical mean of the guide values;
1.5E-04 (8)**** – geometrical mean of the worldwide data obtained for clay loams, in brackets – the number of values used

5.1.2.2. Quality assessment of the crop products employing the calculation method

Since it is impossible to assess directly the quality of crop products at the "background" territories of the STS, the calculation method was used to evaluate the radionuclides content in the crop products at this territory. The radionuclides concentrations in the crop products were found using average values of the radionuclides content in soil (Table 58) and the recommended values of the radionuclide A_is (Tables 54 – 57) for various kinds of plants.

Table 58.

Average specific activity values of the radionuclides in soil

STS territory		Content of the radionuclides in soil, Bq/kg [2, 69, 77]			
		^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
"Northern" part		17.2	-	4.1	0.8
"Western" part		16.7	6	4.9	0.9
"Southeastern" part	zone 1	19	3.4	3.6	0.7
	zone 2	43.9	18.9	14.3	0.8
	zone 3	30.2	4.2	5.6	0.8
Average		**25.4**	**8.1**	**6.5**	0.8

We used dry masses in plants provided in the IAEA recommendations and experimental values obtained at the STS to calculate the radionuclides content in the crop products per wet weight [118, 174, 175]. Forecasted concentrations of the radionuclides in the basic crop products (grain, fruits, leafage, bulbs and root crops) produced in the considered villages, and permissible concentrations of the radionuclides in food products according to HS SERPRS PK are given in the Table 59 [46].

Table 59.

Forecasted contents of the radionuclides in the crop products (per wet weight) for the "background" territories of the STS

Product type	Predicted concentration, Bq/kg (permissible concentration (on wet weight basis), Bq/kg)			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Tuberous roots				
Potato	0.43 (120)	1.9 (40)	0.040 (4.0)	0.0017 (4.0)
Carrot	0.71 (120)	6.3 (40)	0.64 (4.0)	0.0039 (4.0)
Beet	0.36 (120)	1.0 (40)	0.57 (4.0)	0.0018 (4.0)
Fruit vegetables				
Tomato	0.51 (40)	0.25 (30)	0.000041 (3.0)	0.0014 (3.0)
Pepper	0.055 (40)	0.29 (30)	0.00092 (3.0)	0.000029 (3.0)
Eggplant	0.80 (40)	0.20 (30)	0.34 (3.0)	0.0010 (3.0)
Cucumber	0.043 (40)	0.065 (30)	0.00084 (3.0)	0.000029 (3.0)
Pumpkin	0.19 (40)	0.039 (30)	0.00021 (3.0)	0.000025 (3.0)

Product type	Predicted concentration, Bq/kg (permissible concentration (on wet weight basis), Bq/kg)			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Bulbous vegetables				
Onion	0.25 (40)	4.5 (30)	0.12 (3.0)	0.00081 (3.0)
Leafy vegetables				
Cabbage	0.81 (120)	2.6 (40)	0.031 (4.0)	0.00069 (4.0)
Cereals				
Wheat	0.10 (70)	2.0 (40)	0.063 (4.0)	0.0030 (4.0)

Expected concentrations of the radionuclides in the crop products have shown that in average ^{137}Cs concentration would be for 2-3 orders of magnitude lower than the permissible levels, same for ^{90}Sr – 1-2, $^{239+240}$Pu – 2-4 and ^{241}Am – for 3-4 orders of magnitude lower than the permissible levels.

Obtained for the crop products, predicted concentrations of the radionuclides at the "background" territories are in general similar to the experimental data obtained for the studied villages (Tables 48 – 51). The match between the predicted and the experimental data shows that the recommended A_fs are correct, and expected concentrations are valid, that in fact verifies the radionuclide concentrations in the crop products for the studied villages.

5.1.2.3. Calculation of the radioactive contamination boundary parameters

One can calculate permissible concentration of the radionuclides in soil using the A_fs obtained for the crop plants and the specific activity values of the radionuclides in the crop products (Table 44) at the territory of interest; at that, the crop products of an adequate quality, i.e. not exceeding the regulatory norms, can be produced [46]. Maximal permissible concentration (PC) of the radionuclides in soil was calculated as follows:

$$PC_{soil} = PSA_{dry}/AF,$$

where PC_{soil} – permissible concentration of a certain radionuclide in soil,
PSA_{dry} – permissible specific activity of the radionuclides in the crop products per dry weight,
AF – accumulation factor of the radionuclide.

Permissible concentrations of the considered artificial radionuclides in soils are shown in the Table 60 based on the radionuclides concentrations in the basic plant products (generative organs).

Table 60.

Estimated permissible concentrations of the radionuclides in soil

Crop	Product	Permissible concentration of the radionuclide in soil, Bq/kg			
		^{137}Cs	^{90}Sr	$^{239+240}$Pu*	^{241}Am*
Potato	bulbs	6,800	170	650	1,900
Carrot	root crops	4,100	**50**	**40**	820

Crop	Product	Permissible concentration of the radionuclide in soil, Bq/kg			
		^{137}Cs	^{90}Sr	$^{239+240}$Pu*	^{241}Am*
Beet	root crops	8,200	300	46	1,800
Tomato	fruits	1,900	980	473,000	1,700
Pepper	fruits	17,800	830	21,100	83,000
Eggplant	fruits	1,200	1,200	60	2,500
Cucumber	fruits	23,000	3,700	23,200	83,000
Pumpkin	fruits	5,200	6,200	94,600	94,000
Onion	bulbs	3,900	50	160	2,900
Cabbage	leafage	3,600	120	850	4,650
Wheat	grain	18,000	160	420	1,070

In general, obtained permissible concentrations of the radionuclides show that it is possible to produce crop products of acceptable quality even at the STS territory with high level of radionuclide contamination in soil. However, some crops (carrot, onion, beet, carrot and eggplant) are critical in respect of accumulation of such radionuclides as ^{90}Sr and $^{239+240}$Pu. Permissible concentrations of these radionuclides in soil for critical species were found to be for one order of magnitude or higher than those in the other crops. This fact shows that ^{90}Sr and $^{239+240}$Pu, not ^{241} Am and ^{137}Cs would limit the production of the crop products at the STS, and this fact should be considered further when assessing the quality of the crop products produced at the STS territory.

It has been found that expected concentrations of the artificial radionuclides in the crop products produced at the territories with radioactive contamination at the level of global fallouts (Table 58) would not exceed the permissible norms. Therefore, total intake of the artificial radionuclides with crop products produced at these territories as considered for the population during 1 year would remain below the regulatory limits (according to HS SERPRS RK) of ^{137}Cs and ^{90}Sr for 2 orders of magnitude, for ^{241}Am and $^{239+240}$Pu – for one order of magnitude.

When assessing the quality of the crop products that can be commercially produced at the STS territory, the following should be considered:

– in the assessment of the quality of agricultural products it is recommended to use A_rs as in the Tables 46 – 49.
– when concentrations of the artificial radionuclides in soil remain below the level of the radionuclide contamination in the soils at the "background" territories, the quality assessment of the crop products can be omitted since the expected concentrations in the crop products would certainly stay below the permissible levels.

5.2. Quality assessment of the animal products

One of the main routes of radionuclides intake into human body is via crop products usually dominating in human diet. Radionuclides can enter animal bodies by various ways. It can be either peroral intake, i.e. via digestive tract with feed, water and soil, with air, i.e. via lungs with contaminated air and dust, and by percutaneous route via soil

surface, mucosae and wound [182]. It is known that peroral intake is the largest route for the radionuclides intake by animals.

Radionuclides intaken by animal organisms intervene metabolism, including soaking, traveling via organs and tissues, deposition and excretion. As a final result, intensity of these processes affect accumulation of radionuclides in animal products [183]. Transfer of radionuclides into cattle breeding products is determined by the following factors: speciation of radionuclides in environmental components, animal specimen and age, type and composition of diet, productivity of animals, and their stockkeeping technology [184].

The main dose forming and the widely spread radionuclides at the STS are ^{3}H, ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am. Therefore, assessing the quality of animal products produced at the STS, these are exactly the radionuclides to be considered. Radionuclides ^{3}H, ^{137}Cs, ^{90}Sr are mobile enough. They transfer into organs and tissues of animals and birds, as well as into their products (milk, eggs) quite easily. At that ^{3}H and ^{137}Cs are spread quite uniformly in the organisms, ^{90}Sr mainly gets deposited in bone tissues [162]. Transuranium radionuclides are hardly accumulated in the organism, for example only 1/100, 000 part of $^{239+240}$Pu or ^{241}Am amount intaken by an organism can transfer into muscular tissue of the animal. The main organs for accumulation of these radionuclides are liver and muscular tissue [185].

The Republic of Kazakhstan Heath Standards "Sanitary-Epidemiological Requirements for Provision of Radiation Safety" [46] provide permissible levels (PL) of ^{137}Cs and ^{90}Sr content in food products. Some key data is given in the Table 61.

Table 61.

Permissible concentrations of ^{137}Cs and ^{90}Sr radionuclides in cattle breeding products

№	Groups of food products	Specific activity radionuclides, Bq/kg (l)				
		^{137}Cs	^{90}Sr	$^{239+240}$Pu*	^{241}Am*	^{3}H*
1	Meat, meat products and byproducts	200	50	5	5	50,000
2	Deers, meat of wild animals	300	100	10	10	100,000
3	Birds, and their byproducts	180	80	8	8	80,000
4	Fish and fish products	130	100	10	10	100,000
5	Eggs and derivatives	80	50	50	50	50,000
6	Raw milk, raw creams	100	25	2.5	2.5	25,000
Note: *– values obtained employing the calculation method						

Concentrations of ^{3}H, $^{239+240}$Pu and ^{241}Am radionuclides in food products are not regulated.

However, according to HS SERPRS PK (Appendix 3), annual limit of intake (ALI) with food for population is for an order of magnitude lower than similar value for ^{90}Sr ($^{239+240}$Pu –2.4×10^{3} Bq/year, ^{241}Am – 2.7×10^{3} Bq/year, ^{3}H – 2.1×10^{7} Bq/year; ^{90}Sr – 1.3×10^{4} Bq/year), it can be assumed that the permissible levels for them would be for an order of magnitude lower than those for ^{90}Sr. Vice versa, ^{3}H ALI with food is approximately three orders of magnitude higher than for ^{90}Sr. Therefore, PL value would

be for three orders of magnitude higher than that for ^{90}Sr. The data provided for $^{239+240}$Pu, ^{241}Am and ^{3}H in the table is based on this calculation.

The main kind of animal breeding at the test site and in the adjacent territory is black and small cattle as well horse breeding. Produced animal products – goat meat, cow and goat milk, as well as chicken eggs and meat are used only for needs of the farmers breeding these animals. Mutton, beef, horse beef and mare milk are produced for selling in the nearby regions.

42 acting farms have been found by the present time at the test site territory (40 % of the total STS area). Over 250 persons live and carry out cattle breeding activities at these enterprises. In total over 2,500 heads of black cattle, 13,000 small cattle and 1,600 horses are kept there [69, 70, 77 – 79].

Farm animals bred at the test site territory are mainly represented by outbred fat-tailed hair sheep. In black cattle breeding, low-yielding mixtures of beef and milk breeds are bred. In horse breeding, mainly outbred horses are bred. Cattle is kept in stabling and pastured at pasture ground. Pasturing system is free or nonsystematic. Pasture lands of this territory are used year-round. Some parts of this territory are used only in summer when the pasturing of animals at natural meadows continues from the first decade of May till the beginning of October.

5.2.1. Radionuclide concentrations in the animal products produced at the STS

To assess the animal products quality, meat and milk consumed by farm inhabitants at the STS territory were purchased for further spectrometry. The measured data are given in the Table 62.

Table 62.

Maximal concentrations of the radionuclides in the milk and meat samples

Ser. №	Test site area	Products (n – quantity of samples)	Specific activity of radionuclides, Bq/kg (permissible concentration, Bq/kg)		
			^{241}Am	^{137}Cs	^{90}Sr
1	Shagan river area	meat	–	–	–
		milk, (n=2)	–	1.7±0.4	0.8±0.2
2	“Northern” part	meat			
		milk			
3	“Western”part	meat	–	–	–
		milk	–	–	–
4	“Southeastern” part	meat, (n=10)	< 0.6	< 0.8	–
		milk, (n=12)	< 0.4	< 0.7	<0.09
5	“Southern” part	meat, (n=6)	< 0.6	< 0.8	–
		milk, (n=4)	< 0.4	< 0.7	–
6	“Southwestern”part	meat, (n=2)	< 0.6	< 0.8	–
		milk, (n=3)	< 0.4	< 0.7	–

As one can see in the Table, the content of the radionuclides ^{137}Cs, ^{90}Sr in the samples of meat and milk was below the detection limit of the instruments and methodology used. Certainly, the fact that very low concentrations were found in the products on the STS territory can seem strange. However, it should be understood that the test site contamination has local or spotty character, i.e. during a day animals can be pastured at both "clean"and "contaminated" areas.

Mare milk production is one of the main activities at the STS. In 2010, the amount of its production was over 900 l/day. Most of the horse stock is concentrated in the south-eastern part of the test site near the "Degelen" site where ^{3}H can be intaken by cattle with high probability.

So, to assess the ^{3}H content in mare milk, some individual studies were carried out; the results have shown [186] that the ^{3}H content in most cases does not exceed the lower detection limits of the equipment. The measured quantities in some cases are well below the intervention level for potable water, that according to Health Standards is 2,000 Bq/kg [46]. ^{3}H concentrations in mare milk are shown at the Figure 166.

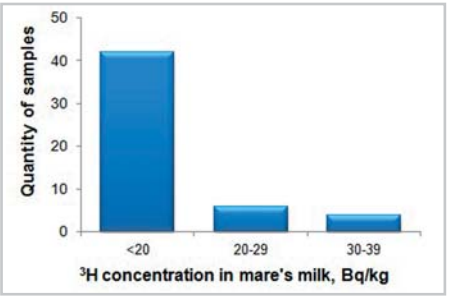
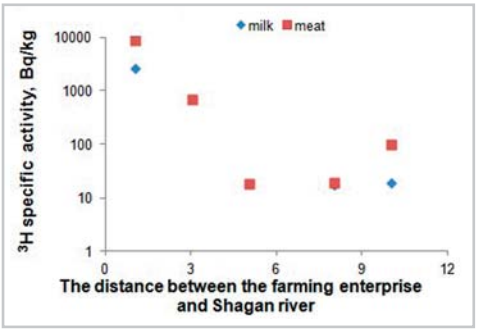
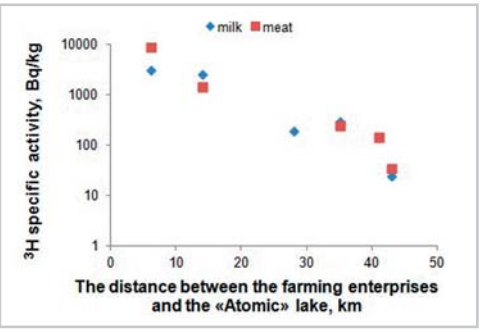


Figure 166. ^{3}H concentration in mare milk

The territory adjacent to Shagan river is the area where high concentrations of ^{3}H can enter animal bodies. Results of ^{3}H content assessment in cattle breeding products, given in the work [187], have shown the high activities in sampled meat and milk. In some cases, the concentrations exceeded intervention level (IL) for potable water (Figure 167).



a)



b)

Figure 167. Specific activity of ^{3}H in the farm products
(with respect to the distances to the "Atomic" lake (a) and Shagan river (b))

Analysis of obtained results shows that the highest ^{3}H specific activity in the animal farm products was found in the enterprises where the pasturelands include the sites with maximal ^{3}H concentrations in Shagan river. At larger distances to the "Atomic" lake towards Shagan river, specific activity of ^{3}H in meat and milk decreased.

In general, assessment of the radionuclides content in the cattle breeding products from the STS territory shows that the ^{3}H concentrations can reach significant values, while concentrations of ^{241}Am, ^{137}Cs and ^{90}Sr remain very low.

To determine the maximal contaminations in the products, the level of environmental contamination (soil, water, plants), quantitative parameters of the radionuclide transfer from the environment into the products, cattle pasturing range, period of staying at contaminated territories, time of cattle move to non-contaminated sites and etc. should be known and considered. It is useless to carry out individual assessments of cattle breeding products quality for each of the test sites.

Theoretical calculations based on quantitative data on soil contamination levels and the radionuclide transfer factors in "soil-vegetation" and "ration-products" systems obtained for the STS provide optimal solution for this issue.

5.2.2. Theoretical quality assessment of the cattle breeding products produced at the STS

5.2.2.1. Selecting transfer factors

By the present time, quite a lot of scientific works dedicated to study of radionuclides transfer into cattle breeding products have been carried out. Review and generalizing materials on these works can be found in N. Grin [188] and the generalized materials of S. Fesenco et al. [189]. There are some IAEA publications [136], generalizing and structuring all the knowledge about parameters and regularities of radionuclides migration in agrosystems also available nowadays.

In assessment of the level of the radionuclides transfer from the environment into cattle breeding products, transfer factor T_f, calculated as a ratio of the product specific activity (meat, milk, byproducts) (Bq/kg) to the total amount of the radionuclide daily intake (Bq/day) is used:

$$T_f = \frac{A_p}{A_r} \quad , \tag{1}$$

where A_p – is the concentration of radionuclide in the product, Bq/kg;

A_r – summary daily intake of the radionuclide with ration, Bq/day.

It should be noted that the transfer factor is to be calculated when the radionuclide in an animal organism or in a product is in its equilibrium state.

Transfer of Cs, Sr, Am and Pu radionuclides into the cattle breeding products. Table 63 provides the radionuclide transfer factors for some farm products available in the IAEA publication [136].

Table 63.

Radionuclides transfer factors for the cattle breeding products

Product type	T_f from forage per 1 kg (k) of product			
	^{137}Cs	^{90}Sr	^{241}Am	$^{239+240}$Pu
Horse beef	–	–	–	–
Beef	$\underline{3.0\times10^{-2}}$ $4.7\times10^{-3} – 9.6\times10^{-2}$ (58)	$\underline{2.1\times10^{-3}}$ $2.0\times10^{-4} – 9.2\times10^{-3}$ (35)	$\underline{5.0\times10^{-4}}$ – (1)	$\underline{6.0\times10^{-5}}$ $8.8\times10^{-8} – 3.0\times10^{-4}$ (5)
Mutton	$\underline{2.7\times10^{-1}}$ $5.3\times10^{-2} – 1.3$ (41)	$\underline{1.7\times10^{-3}}$ $3.0\times10^{-4} – 4.0\times10^{-3}$ (25)	$\underline{1.1\times10^{-4}}$ – (1)	$\underline{5.3\times10^{-5}}$ $2.0\times10^{-5} – 8.5\times10^{-5}$ (2)
Mare milk	–	–	–	–
Cow milk	$\underline{4.6\times10^{-3}}$ $6.0\times10^{-4} – 6.8\times10^{-2}$ (288)	$\underline{1.5\times10^{-3}}$ $3.4\times10^{-4} – 4.3\times10^{-3}$ (154)	$\underline{4.2\times10^{-7}}$ – (1)	$\underline{1.0\times10^{-5}}$ (1)

Note: the numerator is the mean value, and the denominator is the range of values, in brackets – number of A_f values in the IAEA database; "–"– not available.

The Table above shows that transfer of ^{137}Cs and ^{90}Sr into agroecosystem around the world was studied quite well. However, use of this data can be incorrect in our conditions, since, first of all, the transfer factors vary within the wide range; secondly – most of the data were obtained in laboratory conditions or after radiation accidents in Southern Ural and Chernobyl Accident. They can differ from the situation at the Semipalatinsk Test Site in character of radioactive contamination, biological species of animal breeding and their productivity, feeding type, cattle-management conditions, types of forage plants, soil and many other factors. It should also be noted that in general, the studies have been carried out in "feed – animal product" system, at that the research in the "soil/sod – animal products" system was of secondary priority. This is due to the fact that forage served as the main source of radionuclides intake for animals. At the Semipalatinsk Test Site, however, soil and grass sod can bring significant amount of radionuclides into daily ration of the animas due to the steppe zonality.

Some solitary plutonium and americium studies were carried out, while there is still no data for tritium. These facts prove topicality and necessity of studying this issue at the former STS territory where no study was carried out previously.

Assessing the contamination level of agricultural products, it is therefore necessary to use the radionuclides transfer parameters (transfer factors, elimination half-lives and etc.) obtained under the same conditions where the focus products originate from.

^{3}H transfer into cattle breeding products. ^{3}H in farm products is divided into organically bound tritium (OBT) and tritium in free water of tissues (HTO). In 2010 at the regular session of the IAEA working group in Vienna [190], the exploration degree of transfer of both ^{3}H forms into products was assessed once again. Some of the data is given in the Table 64.

Table 64.

Exploration degree of ^{3}H transfer into agricultural products

Agricultural products	Exploration degree	
	after intake of tritiated water	after intake of organically bound ^{3}H
Cow milk	well	1 experiment
Beef	2 works	no data available
Mutton	no data available	no data available

The Table shows that only the ^{3}H transfer into cow milk was studied well enough. In other cases, there were either few or no studies performed. There is also no data in the Table on the ^{3}H transfer into horse breeding products, which are very popular in Central Asia. We were not able to find any publications on this topic.

Research of ^{137}Cs, ^{90}Sr, ^{241}Am, $^{239+240}Pu$ transfer into animal products at the STS. To obtain the radionuclide transfer coefficients for animal products, full scale experiments have been carried out at the STS territory with farm animals involved. The most popular species typical for this region were used as experimental animals: sheep, black cattle, horses, pigs and laying hens.

The studies were carried out at the "Experimental Field" site of the STS located in a desert-steppe zone characterized by higher content of ^{241}Am and $^{239+240}Pu$ radionuclides [191]. At this site, the parameters of the radionuclide transfer into organs and tissues of sheep (one and half year-old castrates) [192, 193], horses (8-9-yerars old mares, and one-year-old filly foals) [194], black cattle (9-10-years old cows), as well as hens were studied; the radionuclides were introduced with feed, soil and in solution (of soil extractions) [195].

The studies were also performed at the radioactively contaminated "Degelen" site located in a low-mountain massif. Here the parameters of (^{3}H, ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}Pu$) radionuclides transfer into sheep organs and tissues at peroral intake with water, hay and soil [196, 197], as well as the parameters of ^{90}Sr transfer into cow milk at intake with feed and water were studied [198]. Individual studies were carried out to study the transfer of ^{3}H radionuclide into cow milk, as well as into poultry products.

All the works were carried out in summer period with animals kept in stable. Some individual groups of animals (black cattle, small cattle, horses, pigs) were fed with contaminated forage, soil, contaminated water; in some cases, water solution of various radionuclides was delivered orally. Feed, water, and soil was taken from the most contaminated parts of the technical sites at the "Degelen" and "Experimental Field". To control the radionuclides intake during the whole experiment the amount of consumed forage and water was accounted every day, also vegetation, soil and water were sampled according to the scheme of experiment.

The duration of keeping the animals and birds in stable varied from 1 to 120 days. At the end of each period the animals and birds were slaughtered by means of dehematizing. The radionuclides were measured in all the main organs and tissues.

Obtained transfer factors for the radionuclides from forage into animal products produced under the STS conditions are given in the Table 65.

Table 65.

The radionuclide transfer factors for animal products

Transfer factors	^{137}Cs, $\times10^{-2}$	^{90}Sr, $\times10^{-4}$	^{241}Am, $\times10^{-6}$	$^{239+240}$Pu, $\times10^{-5}$
Mutton				
Soil in the epicenters of surface tests	3.1 ± 1.1	–	2.3 ± 1.3	0.06 ± 0.03
Soil in the zones of radioactive streamflows		–		1.5 ± 0.6
Steppe vegetation in the epicenters of surface tests	2.6 ± 0.,4	–	<3,000.0	8.6 ± 3.9
Meadow vegetation from radioactive streamflow zones	7.8 ± 4.8	1,8 ± 0,7		
Water	17.0 ± 0.2	4,1 ± 0,8	–	–
Beef				
Steppe vegetation in the epicenters of surface tests	0.0050	0,14	<88.1	<1.5
Soil in the epicenters of surface tests	0.0082	<0.0068	25.9	0.0025
Chicken meat				
Steppe vegetation in the epicenters of surface tests	200.0	–	–	–
Soil in the epicenters of surface tests	20.0	–	180.0	–
Horse beef (10 years)				
Soil in the epicenters of surface tests	0.0078	–	7.1	–
Water	2.7	6.6	6.5	0.088
Horse beef (1 year)				
Soil in the epicenters of surface tests	0.013	0.63	1.6	0.015
Water	5.0	6.0	3.3	0.071

The Table shows that the transfer factors for various sources differ from one another. The radionuclides are better transferred with water than with feed and worse with soil. Considering the radionuclides transfer into cattle breeding products, contribution of each component should therefore be assessed individually.

The radionuclides distribution in animal organs and tissues was also studied and the results were published [199]. The difference between accumulation in muscular tissue and in main depositing organs can differ by 3 to 5 orders of magnitude from one another. For example, at a long term ^{90}Sr intake by sheep (over 120 days), its concentrations in bone tissue and wool were 2,500 and 60 times higher than in mutton; concentrations of ^{214}Am and $^{239+240}$Pu in liver were higher for 200 and 500 times, respectively.

*Accepted transfer factors.*The character of the radionuclides metabolism in animal bodies revealed in the full-scale experiments at the STS match available data. However, obtained transfer factors (T_f) of ^{90}Sr and ^{137}Cs for beef and mutton turned to be significantly lower than the T_f values in the IAEA database [136]. $^{239+240}$Pu transfer factors resulted from the full-scale experiments at the STS exceeded the mean values given in the IAEA's technical document. These differences in the values come from a lot of factors typical for the STS (natural and climatic conditions, specific peculiarities of animals and their productivity, radionuclide speciation and etc.), which have no analogues in the world. Nowadays it is hard to find which of the factors made the most significant impact on such a difference in the values.

The transfer factors obtained in the full-scale experiments at the STS were used to assess the radionuclide concentration in the cattle breeding products. Transfer factors from the IAEA database (mean values) were used for the products when we lacked the data. Instead of missing transfer factors "soil-into-product", the transfer factors from hay were used. The transfer factors used to calculate the radionuclides content in cattle breeding and poultry products are given in the Table 66.

Table 66.

Transfer factors used in calculation of the radionuclide content in products

Product type	Radionuclides				
	^{137}Cs	^{90}Sr	^{241}Am	$^{239+240}$Pu	^{3}H
T_f from forage per 1 kg (l) of product					
Horse beef	3.0×10^{-2}	2.1×10^{-3}	5.0×10^{-4}	6.0×10^{-5}	–
Beef	3.0×10^{-2}	2.1×10^{-3}	5.0×10^{-4}	6.0×10^{-5}	–
Mutton	7.8×10^{-2}	1.8×10^{-4}	1.1×10^{-4}	8.6×10^{-5}	1.4×10^{-1}
Cow milk	4.6×10^{-3}	1.5×10^{-3}	4.2×10^{-7}	1.0×10^{-5}	–
T_f from soil per 1 kg (l) of product					
Horse beef	2.7×10^{-2}	6.6×10^{-4}	6.5×10^{-6}	8.8×10^{-7}	–
Beef	8.2×10^{-5}	6.8×10^{-7}	2.6×10^{-5}	2.5×10^{-8}	–
Mutton	3.1×10^{-2}	4.5×10^{-5}	2.3×10^{-6}	1.5×10^{-5}	–
T_f from water per 1 kg (l) of product					
Mutton	1.7×10^{-1}	4.1×10^{-4}	-	-	1.1×10^{-1}

Note: ▭ – results of the full-scale experiments at the STS;
▭ – IAEA data;
"–" – not available.

Parameters of ^{3}H transfer into animal products. Due to the lack of information about the parameters of ^{3}H transfer into animal products, full-scale experiments were carried out at the STS territory to study the ^{3}H transfer into cow and mare milk, mutton, eggs and muscular tissue of laying hens [200–202]. It should be noticed that only the parameters of ^{3}H transfer into free water were studied in these experiments. The content of organically bound ^{3}H in products was not considered. The most widespread species of animals typical for this region were used as experimental animals: sheep, cattle, horses and laying hens. The study was performed at the site adjacent to one of the radioactively contaminated tunnels with water seepage, located at the "Degelen" site.

The experimental works with animals and birds were based on the scientific approaches and principles of the pairs-analogues and the period groups. So, the animals and the birds were divided into groups with various sources of radionuclides intake: atmospheric air, water and vegetation. When ^{3}H inhalational intake with atmospheric air was considered, the objects of research were kept on sites with increased concentrations of ^{3}H in air in specially designed cages. Other groups of animals and birds have been receiving ^{3}H with tunnel water. And different groups were fed with vegetation harvested at radioactively contaminated territories.

As the result, the factors of ^{3}H transfer into animal products and half-lifes were obtained. The transfer factor (T_f) was calculated as a ratio between the ^{3}H specific activity in the products (Bq/kg or kBq/l) and the total amount of the radionuclide intaken by an animal during a day (Bq/day). The parameters of ^{3}H transfer into the animal products obtained during the full-scale experiments at the STS are given in Table 67.

Table 67.

Parameters of the ^{3}H transfer into animal and poultry products

Products	^{3}H T_f into products with various environmental components					
	Air		Water		Feed	
	long-term entry	single entry	long-term entry	single entry	long-term entry	single entry
Chicken meat	2.5	1.2	2.6	1.2	8.3	4.2
Chicken eggs	7.7	1.2	2.7	0.81	83.3	12.5
Mutton	–	–	0.12	0.063	0.34	0.096
Mare milk	–	–	>0.015	0.0070	0.21	0.011
Cow milk	–	0.027	>0.022	0.0038	0.018	0.017

The data given in the Table show that ^{3}H intaken with forage is better transferred than at intake with water. Experimental data allow to assess the ^{3}H content in basic products produced at the STS.

5.2.2.2. Calculation of expected ^{137}Cs, ^{90}Sr, ^{241}Am, $^{239+240}Pu$ and ^{3}H concentrations in animal products

The main radionuclide intake pathways for animals and birds at the STS. When animals are pastured at the STS territory air, water, soil and vegetation can serve as sources of radionuclides. As it was found before [203], the air insignificantly contributes to the radionuclide intake (^{3}H, ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}Pu$) by animals and birds and this way of intake can therefore be neglected.

Increased concentrations of the radionuclides (^{3}H, ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}Pu$) in STS water can be met at the "Degelen" site and in the streamflows running beyond its boundary (the creeks Uzynbulak, Karabulak, Baytles, Toktakushyk and etc.) [203], as well as in the water of Shagan river where increased concentrations of ^{3}H were found. The percentage of water in daily consumption rate of radionuclides, except for ^{3}H, is less than one percent.

Soil can enter the body by two ways: with dust on plants, and soil accidentally swallowed by animals from the ground surface. The main sources of ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}Pu$ intake for farm animals are soil and dust, those of ^{3}H – forage and water (Table 68).

Table 68.

Contribution of soil, water and vegetation into daily intake of radionuclides for animals (as exemplified by small cattle), %

STS territory	^{137}Cs		^{90}Sr		^{241}Am		$^{239+240}$Pu		^{3}H	
	soil	forage	soil	forage	soil	forage	soil	forage	water	forage
epicenters of surface tests	98	2	88	12	99.7	0.3	99	1	–	–
traces of radioactive fallouts	89	11	87	13	96.7	3.3	96	4	–	–
conditionally "background" territories	85	15	40	60	–	–	90	10	–	–
zones of radioactive streamflows	45	55	9	91	–	–	97	3	67	33
WRA	–	–	12	88	–	–	–	–	–	–
Note: Calculated based on obtained accumulation factors of radionuclides for plants at the STS										

When forecasting the concentrations of radionuclides in the cattle breeding products, their concentration in the ration and A_r from the ration into the products are considered. Since the previous calculations show that the environmental components (soil, water, feed) somehow contribute to the radionuclide intake, it can be assumed that the radionuclide content in the cattle breeding products (C_{prod}) would be as follows:

$$C_{prod} = V_{(soil)} \times C_{(soil)} \times K_{п\,(soil)} + V_{(feed)} \times C_{(feed)} \times T_{f\,(feed)} + V_{(water)} \times C_{(water)} \times T_{f\,(water)}, \quad (2)$$

where $V_{(feed)}$ – feed daily consumption rate, kg/day;
$V_{(soil)}$ – amount of accidentally swallowed soil, kg/day;
$V_{(water)}$ – annual consumption of water, l/day;
$C_{(feed)}$ – specific activity of the radionuclide in feed, Bq/kg;
$C_{(soil)}$ – specific activity of the radionuclide in soil, Bq/kg;
$C_{(water)}$ – specific activity of the radionuclide in water, Bq/l;
$T_{f\,(feed)}$ – transfer factor of the radionuclide from feed per 1 kg (l) of product;
$T_{f\,(soil)}$ – transfer factor of the radionuclide from feed per 1 kg (l) of product;
$T_{f\,(water)}$ – transfer factor of the radionuclide from water per 1 kg (l) of product.

The calculations were not considered for ^{241}Am, ^{137}Cs, ^{90}Sr and $^{239+240}$Pu radionuclides intake with water. Also, the ^{3}H entry with soil was not considered.

As was stressed before, migration of radionuclides in the "soil-plant" system is the first stage of a biological cycle, determining the level of radionuclides transfer into animal organism and their products. Concentrations of ^{241}Am, ^{137}Cs, ^{90}Sr and $^{239+240}$Pu in plants can be calculated based on experimentally obtained data on the parameters of radionuclides accumulation by plants at the STS [119], therefore:

$$C_{(feed)} = C_{(soil)} \times A_r, \quad (3)$$

where A_r – is the radionuclide accumulation factor for plants (chapter 3.2.)

Indexes of annual consumption of feed, water and soil are based on literary data [205] (Table 69). Annual intake of the radionuclides with soil swallowed by animals during

grazing was calculated based on the assumption that during the grazing period black cattle and small cattle can consume up to 600 and 70 kg of soil, respectively [162, 182].

Table 69.

Physiological parameters of farm animals used in the calculations

Parameter	Cows	Horses	Sheep
Forage consumption rate, kg/day	15	12	1.2
Water consumption rate, l/day	70	35	2
Amount of accidentally swallowed soil, kg/day	1.6	1.6	0.2

The Table 70 provides accepted mean values for the background territories [181]. The content of radionuclides was calculated using the formula (3).

Table 70.

Average specific activity of radionuclides in soil and plants at the conditionally background territories

Sources	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	^{241}Am, Bq/kg	$^{239+240}$Pu, Bq/kg
Specific activity in soil	18	10.8	0.9	4.7
Specific activity in feed	0.36	2.7	0.032	0.005

Calculated radionuclide intake rates for farm animals when pastured at the conditionally "background" territories are shown in the Table 71.

Table 71.

Annual intake of artificial radionuclides by animals at the conditionally background territories

Farm animals	Living weight, kg	Radionuclides entry into 1 animal organism, Bq							
		daily entry with forage				daily entry with soil			
		^{137}Cs	^{90}Sr	^{241}Am	$^{239+240}$Pu	^{137}Cs	^{90}Sr	^{241}Am	$^{239+240}$Pu
Horse	350-400	4.3	32.4	0.38	0.06	28.8	17.6	1.4	7.5
Cow	400	5.4	40.5	0.48	0.075	28.8	17.6	1.4	7.5
Sheep	50-60	0.43	3.2	0.038	0.006	3.6	2.2	0.18	0.94

Based on the above data, the radionuclide concentrations in cattle breeding products produced at the studied lands can be assessed. Expected concentrations of the radionuclides in the cattle breeding products are given in the Table 72.

Table 72.

Expected concentrations of the radionuclides in cattle breeding products

Products	Forecasted concentration, Bq/kg			
	^{137}Cs	^{90}Sr	^{241}Am	$^{239+240}$Pu
Horse beef	9.1×10^{-1}	8.0×10^{-2}	2.0×10^{-4}	1.0×10^{-5}
Beef	1.6×10^{-1}	8.5×10^{-2}	2.8×10^{-4}	4.7×10^{-6}
Mutton	1.5×10^{-1}	6.8×10^{-4}	4.6×10^{-6}	1.5×10^{-5}
Cow milk	1.6×10^{-1}	8.7×10^{-2}	8.1×10^{-7}	7.6×10^{-5}

Obtained values of the expected radionuclide concentrations in agricultural products for cattle pastured at the conditionally "background" territories are well below the PL given in the Table 61.

Calculation of maximal permissible concentrations of ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}Pu$ in soil for production of cattle breeding products To reveal the lands where the cattle can be pastured and the products meeting health standards can be produced, the maximal permissible levels (MPL) of ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}Pu$ radionuclides in soil can be calculated. Based on the formula (3):

$$MPL_{(soil)} = \frac{C_{(MPLprod.)}}{V_{(soil)} K_{n(soil)} + V_{(feed)} T_{f(feed)} A_f} \quad (4)$$

Permissible levels of the radionuclide contents in the products are given in [i. 5.2.1].

Calculated MPL of the radionuclides in soil at various STS sites allowing to produce animal products (exampled by mutton and cow milk) complying with the health standards are given in Tables 73, 74.

Table 73.

Maximal permissible levels of the radionuclide contents in soil of the STS sites (for mutton), kBq/kg

STS sites	^{137}Cs	^{90}Sr	^{241}Am	$^{239+240}Pu$
epicenters of surface explosions	32	3,300	9,000	1,600
zones of radioactive streamflows	7	100	9,000	1,300
WRA testing venues	–	150	–	–
radioactive fallout traces	30	3,100	3,600	5,000
zones of radioactive streamflows	20	700	–	1,000

Table 74.

Maximal permissible levels of radionuclides content in soil of the STS sites (for cow milk), kBq/kg

STS sites	^{137}Cs	^{90}Sr	^{241}Am	$^{239+240}Pu$
epicenters of surface explosions	28	18	7,900	300
zones of radioactive streamflows	10	1	7,900	300
WRA testing venues	–	2	–	–
radioactive fallout traces	24	17	7,500	300
conditionally "background" territories	22	6	–	300

The tables above show that pasturing cattle at territories with high radionuclide concentrations, especially those with soil contaminated by the transuranium ones, it is possible to get cattle breeding products of acceptable quality. Such concentrations of ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}Pu$ can only be found in epicenters of the surface tests and in the zones of radioactive streamflows; the radionuclide ^{90}Sr – in the WRA testing zones. Therefore, the radionuclides transfer into the cattle breeding products at the conditionally background territories do not impose any danger.

When the cattle is pastured at contaminated territories for a long time, the levels of radionuclide concentrations in the main depositing organs (^{90}Sr – bone tissue, ^{241}Am and $^{239+240}$Pu – liver) would be significantly higher than in the meat of these animals. However, the contaminated spots are small compared with the whole territory. For example, at the WRA testing site with an area of 63 sq. km, the area of the site with soil contaminated with ^{90}Sr (activity of 1.5 kBq/kg and more) is 8.0 sq.km, highly contaminated area (more than 100 kBq/kg) – 0.14 sq.km. The area with soil contaminated with ^{241}Am and $^{239+240}$Pu at the "Experimental Field" site (S=375 sq. km) of above 10 kBq/kg – is 1.5 sq.km in total. If animals stay at these sites for a short period, radionuclides content in products would still be insignificant, and the sites would pose no danger in terms of exposure dose for population.

Expected ^{3}H concentrations in the cattle breeding products. The mentioned equation (3) can also be used to assess the ^{3}H contamination degree of the cattle breeding products at the conditionally background territories.

As an example, let us use the territory of Uzynbulak creek which flows from the "Degelen" site and runs far beyond its borders, where maximal ^{3}H concentrations in the environmental objects are as follows:

60 kBq/l – in water;

50 kBq/kg – in free water of plants (excluding OBT).

Based on the data above and using the daily norms of pasture forage and water consumption by cattle (Table 69), ^{3}H concentrations in daily ration were calculated (Table 75).

Table 75.

Daily ^{3}H intake for the farm animals and birds

Farm animals	^{3}H intake, kBq/day		
	with forage	with water	total
Cow	750	4,200	4,950
Mare	600	2,100	2,700
Sheep	60	120	180

Annual intake of ^{3}H with forage was calculated taking into account the fact that meadow vegetation consists of moisture for 70% and for 30% of dry matter; at that, the amount of hydrogen within the organic substances of plants is ~6% of dry mass [206]. ^{3}H activity in organically bound water of plants can be taken equal to ^{3}H activity in free water of the plants [136].

The ^{3}H transfer factors for the products given in Table 67 were used in the calculations of the radionuclides content in cattle breeding products.

Based on the above data, one can assess the ^{3}H concentrations in animal products produced at the studied territory. Expected ^{3}H concentrations in the animal products are given in the Table 76.

Table 76.

Expected ^{3}H concentrations in the cattle breeding products

Product type	Forecasted concentration, kBq/kg (l)		
	when entering with forage	when entering with water	Total
Cow milk	14	92	106
Mare milk	126	32	158
Mutton	20	14	35

As one can see in the Table, expected concentrations of ^{3}H can exceed the permissible values. This means that the animal products produced near the water objects originating from the Degelen massif and Shagan river can be inedible.

Estimation of maximal permissible concentrations of ^{3}H in the STS water objects. The values were calculated in the way similar to the calculation of maximal permissible concentrations of ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}Pu$ in water. However, unlike other radionuclides, ^{3}H starts its migration from water. Therefore, the equitation would look as follows:

$$MPC_{(water)} = \frac{C_{(PLprod.)}}{V_{(water)}T_{f(water)} + V_{(feed)}T_{f(feed)}A_f}, \quad (5)$$

Using the equitation above, we can calculate that the maximal permissible concentrations of ^{3}H in water is 93 kBq/l for mutton and 47 kBq/l for cow milk.

Based on these empirical data on the quality of products at the STS and the theoretical estimations based on special studies of the animals, the following recommendations can be given:

– when the radionuclide content in soil lies within the range of basic levels for the STS territory neither practical nor theoretical works on animal products assessment make sense;
– when the radionuclide concentrations in soil exceed the accepted basic levels, theoretical assessments can be carried out using the transfer factors provided in Chapter 5.2.3;
– while carrying out studies in vicinity of Shagan river and the water sources running out of the "Degelen" site, theoretical estimates should be made taking into account contaminated territory area and amounts of feed at the contaminated sites. When the value exceeds one tenth of the MPL in water, additional measures should be undertaken to determine the actual ^{3}H content in the products;
– when animals are pastured either at the territory of the "4A" site or in direct proximity to this site, ^{90}Sr content in wool or milk of the animals could be assessed just to determine the amount of the radionuclide intake by the animals.

In further studies of the STS territory aimed at the lands transfer into economic turnover, quality assessment of the cattle breeding products can be limited by just theoretical calculations.

An exception is only Shagan river and water sources, running out the "Degelen" site. Pasturing animals at these sites can lead to increased ^{3}H presence in the products.

CHAPTER 6
ASSESSMENT OF THE RADIOACTIVE CONTAMINATION BOUDARY PARAMETERS AT THE TERRITORIES ASSURING NON-EXCEEDANCE OF THE PERMISSIBLE RADIATION DOSES

The issues related to regulation of current activities at the territory of the former STS and substantiation of the reclamation measures require assessment of the radiation risks resulted from the activities that take place or are planned on these lands. Radioactively contaminated natural objects as well as food products obtained or produced at the radioactively contaminated lands can serve as sources of increased radiation exposure.

At the present time radiation risk assessment is carried out based on the model of the nonthreshold impact of ionizing radiation generally accepted and regulated by the normative documents of RK (Health Standards "Sanitary- Epidemiological Requirements for Provision of Radiation Safety" (HS SERPRS) [46], where effective dose is the measure for radiation risk. Expected annual effective dose of artificial exposure should not exceed 1 mSv per year for population, according to HS SERPRS.

Criteria for assessment of radioecological state of territories have been normatively set by the Decree of the Government of the Republic of Kazakhstan on the 31st of July, 2007 №653 "On approval of criteria for assessment of ecological state of territories" [207]. According to the Decree (i.6. Indexes for radiation safety assessment) "Territories, where average annual values of additional (over natural background) effective exposure dose do not exceed 1 mSv, and average annual values of effective exposure dose from natural sources do not exceed 30 mSv are categorized as territories with relatively favorable ecological situation. Territories, where average annual values of effective exposure dose (additional to natural background) exceed 5 mSv and vary within the dose range up to 10 mSv, should be categorized as territories with emergency ecological situation, and over 10 mSv – as ecological disaster zones".

The Table below (Table 77) provides indexes for assessing radiation safety for various environmental situations based on the parameter of total annual effective dose.

Table 77.

Indexes for assessment of radiation safety [207]

№	Index	Parameter		
		Ecological disaster	Emergency ecological situation	Relatively satisfactory situation
1	Index of contamination with radioactive substances, mSv	Over 50	5-50	1-5

Also the i.7 of the Government Decree №653 (criteria for change of natural environment, s.i.7. Indexes for soils state assessment) says that "choice of the criteria for eco-

logical assessment of soils is determined by specific features of their location, genesis, buffer capacity, as well as variety in their use. Revealing types of activity, leading to soil contamination, allows for complete understanding of the scale and degree of contamination at the studied territory and allows for significant decrease and specification of the number of indexes". Table 78 provides characteristics of territories according to radiological situation.

Table 78.

Characteristics of territories in terms of radiological situation [207]

№	Index	Parameter		
		Ecological disaster	Emergency environmental situation	Relatively satisfactory situation
6	Radioactive contamination, Ci/km^2			
	^{137}Cs	over 40	40-15	up to 15
	^{90}Sr	over 3	3-1	up to 1
	Pu (sum of isotopes)	over 0.1	0.1-0.05	up to 0.05

So, the Governmental Decree provides two criteria for assessment; at that the assessment by effective dose is the principal one and has a priority.

Assessment is made taking into account the intended or planned use of the contaminated territory and the exposure pathways.

At contaminated sites, potential human exposure pathways are the following:

– − External exposure from radionuclides in soil;
– − External exposure from contaminated soil got on skin;
– − Internal exposure from inhalation intake of radionuclides;
– − Internal exposure from radionuclides intake with food products and water;
– − Internal exposure from accidental peroral intake of contaminated soil.

Scientific approach for the protection against radiation impact is still based on establishing of maximal permissible impact on humans, exposed to the highest risks from artificial radiation sources. Therefore, conservative approaches to assess the doses gained by population when living and carrying out activities at the territory of the former STS were developed.

Dose significantly depends on such parameters as artificial radionuclides content in environmental objects, living conditions, dietary habits of population and peculiarities of economic activities.

To consider all the parameters, the most conservative behavior scenario of a person living at contaminated territory – "a farmer involved in subsistence farming" - was considered. It was developed as an addition to the idea "a person subjected to maximum radiation exposure", where it is not clear how generally a person could be exposed to radiation during long time periods [208, 209]. This approach is conservative since it includes several assumptions on people's way of living, where the radiation exposure can be even

higher. It is assumed that the person lives at contaminated territory, cultivates plants and breeds livestock, cultivates and produces products at this territory and consumes them.

If according to a preliminary assessment results the dose and risks for a subsistence farmer are with high probability below the permissible levels, then it can be assumed that the rest of the population would also be protected. Use of such an approach allows to perform the conservative assessment of the population annual exposure dose for living and carrying out activities at the STS territory.

When the radionuclides are present in the environment, the doses should be assessed for representatives of several population groups: adults, 7-12 year old schoolchildren and preschool children of the junior age group, 1-2 year old. The choice of this age groups was because the main components of the 1-2 year old babies are dairy products, 7-12 year old child is considered as a middle tier in respect of volume of air breathing in and products consumption norms. However, previous assessments of radiation exposure on population living at the STS territory [77] show that the main representative of the critical group is a farmer involved in subsistence farming at contaminated territory. Therefore, all further assessments would be carried out for such a farmer.

6.1. General method for dose calculation

Ionizing radiation influences people in several ways: external exposure from radionuclides in natural objects, inner exposure resulted from radionuclide intake with inhaled air, food and water, as well as with radionuclides entry via skin.

Effective dose is the value used as a measure of risk for prolonged consequences from exposure of the whole body and its individual organs and tissues, taking into account their radiosensitivity. It represents a sum of equivalent dose values for organs and tissues multiplied by the respective weighting factors [46]:

$$E = \sum_T W_T \cdot H_T \ ,$$

where H_T – equivalent dose in organ or tissue T;
W_T – weighting factor for organ or tissue T.

So, summing up the products of each of the monofactor exposures by their respective dose factors, the value either equal to or higher than the actual gained dose would be obtained.

Proposed assessment of radiation exposure is carried out by summing the effective exposure doses gained for a calendar year and expected effective internal exposure dose due to intake of artificial radionuclides into organism in the same year.

Expected annual effective dose E_{ef} for a person living at this territory can be expressed as the sum of partial doses for all j-th factors of the radiation impact as follows:

$$E_{ef}=E_{\gamma}+E_{\beta}+E_{skin}+E_{inh}+E_{mg}+E_{ing},$$

where E_{γ} – external gamma radiation exposure dose;
E_{β} – external beta radiation exposure dose;

E_{skin} – external exposure dose from contaminated soil got on hands skin;
E_{inh} – internal exposure dose from inhaled radionuclides;
E_{mg} – internal exposure dose from peroral intake of radionuclides with food;
E_{ing} – internal exposure dose from accidental entry of radionuclides into digestive organs.

Dose from internal beta-, gamma- radiation exposure from soil

Effective dose for population from external beta -, gamma-radiation of radionuclides was determined as follows:

$$E_{\gamma} = \sum E_{\gamma i} \quad (1)$$

$$E_{\beta} = \sum E_{\beta i} \quad (2)$$

$$E_{\gamma} = A_{si} \cdot B_{sgi} \cdot T \cdot K_{tc} \quad (3)$$

$$E_{\beta} = (1/2 \cdot A_{mi} \cdot n_{\beta i}(E_i) \cdot e_i \cdot \exp(-\mu_{si} \cdot 1{,}3 \cdot 10^4)/ \mu_{si} \cdot T \cdot W_t \cdot K_{\beta 0} \quad , (4)$$

where $E_{\gamma i}$ – effective dose of external gamma – radiation from contaminated soil surface for the i–th radionuclide, Sv/year;
$E_{\beta i}$ – effective dose of external beta – radiation from contaminated soil surface for the i–th radionuclide, Sv/year;
T – exposure time, h/year;
B_{sgi} – transfer factor of single surface activity of radionuclide in soil to the yield of absorbed gamma-radiation dose in air 1 m above the soil surface, mGy·m^2/h·kBq, Appendix 7 [210];
K_{tc} = transfer factor from the dose at the altitude of 1 m above the bottoming surface to effective dose for representatives of the j–th group of population, mSv/mGy, (considered to be 0.75 mSv/mGy – for adults, 0.80 mSv/mGy – for school children and 0.90 mSv/mGy – for preschool children) [210];
A_{si} – areal activity of the i-th radionuclide, kBq/m^2 calculated using the following formula:

$$\boldsymbol{A_{si} = A_{mi} \cdot \rho \cdot h \cdot 10^{-3}}, \text{ (kBq/m}^2\text{)}, \quad (5)$$

where A_{mi} – specific activity of the i–th radionuclide in top soil, Bq/kg;
ρ – density of soil cover, $1.3 \cdot 10^3$ kg/m^3;
h – depth of the top soil (0–5 cm).

1/2 – adjustment for 2π geometry, 1/Bq;
$n_{\beta i}(E_i)$ – yield of beta-particles of the i–th energy per nuclear decay, %;
e_i – equivalent dose of beta particles per single fluence for the i–th radionuclide, Sv·cm^2 (HS SERPRS) [46];
$\exp(-\mu_{si} \cdot 1{,}3 \cdot 10^{-4})$ – adjustment for beta particles weaking in 1 m air layer;

μ_{si} – mass coefficient of beta particles weaking in soil and air, approximately equal to $\mu_{\beta i}$ in aluminum,

$\mu_{\beta i}$ = 4,700 cm^2/kg for E=0.9 MeV [211];

W_t = 0.01 – weighting factor for skin;

$K_{\beta 0}$ = 0.5 – coefficient of beta-radiation weaking by clothes.

Internal exposure dose from inhalational intake of radionuclides

Expected annual effective dose from inhalational intake of artificial radionuclides was determined using the formula as follows:

$$E_{inh} = \sum E_{inhi} \tag{6}$$

$$E_{inhi} = V \cdot e_{inhi} \cdot A_v \cdot T, \tag{7}$$

where V – breathing rate of representatives of the j–th group of population, m^3/h.

According to i.7 of HS SERPRS [46], annual volume of inhaled air for different age groups of population is 0.9 m^3/h – for those older than 17, 0.6 m^3/h – for 7-12 year old children, 0.2 m^3/h – for 1-year-old babies. For personnel, the volume of inhaled air is 1.4 m^3/h. At that, the document does not consider increase of breathing rate at hard work.

According to the report of the National Council on Radiation Protection of Great Britain [209], breathing rate for population of different age carrying out light work is 1.4 m^3/h – for those older than 17, 1.1 m^3/h– for 10 year old children, 0.35 m^3/h – for 1-year-old babies. It should be remembered that breathing intensity for people performing hard work gets increased in average for two times and for very hard work it increases up to four-five times.

When assessing the dose of internal exposure from inhalation intake of radionuclides, we take the values of UK National Council on Radiation Protection [209] considering that during work the breathing rate gets increased for 2 times for all considered groups of population.

e_{inhi} – dose factor for the i–th radionuclide when entering by inhalation pathway for population, Sv/Bq [46];

T – exposure time, h/year;

A_v – concentration of the i–th radionuclide in air taking into account resuspension, Bq/m^3.

Concentration of radionuclides in air is calculated as follows:

$$A_v = A_{in} \cdot \rho_{sus} \cdot K_0, \tag{8}$$

where A_{mi} – specific activity of the i–th radionuclide in the top soil, Bq/kg;

K_o – enrichment factor, used to determine average specific activity of radionuclides in the fraction of <8 μm;

p_{sus} – average annual dust content, kg/m^3.

Natural average annual dust content was taken as $1 \cdot 10^{-8}$ kg/m^3, under conditions of increased dust content – $2 \cdot 10^{-7}$kg/m^3. Values of average annual dust content were experimentally obtained at the STS territory.

Internal exposure dose from consumption of food produced at contaminated territory

Effective dose from radionuclides entry with food was determined as follows:

$$E_{mg} = \sum E_{mgi}, \tag{9}$$

$$E_{mgi} = A_{mgi} \cdot q \cdot e_{dti}, \tag{10}$$

where A_{mgi} – specific activity of the i–th radionuclide in food products, Bq/kg;
q – annual consumption rate of the food product, kg/year;
e_{dti} – dose factor for the j–th population group for the i–th radionuclide when it comes with food, Sv/Bq Appendix 9 [210].

Specific activity of the i–th radionuclide in products of vegetable origin was calculated as follows:

$$\mathrm{A_{mgi}} = A_{mi} \times K_{ac} \times \frac{K_{\%}}{100}, \tag{11}$$

where A_{mgi} – forecasted content of radionuclides in vegetation products (Bq/kg);
A_{mi} – average concentration of radionuclides in soil (Bq/kg);
K_{ac} – accumulation factor;
$K_{\%}$ – percent of dry matter content in the total mass of plants.

Specific activity of the i–th radionuclide in animal products was calculated as follows:

$$A_{mgian} = A_{ration} \times K_t, \tag{12}$$

where A_{ration} – activity of radionuclides in daily ration, Bq;
K_t – transfer factor of the radionuclide from ration per 1l (kg) of product.

External exposure dose from contaminated soil got on the open skin area

Open skin area (50% of the total) [209] is exposed to α-, β-particles contained in dust layer (0.01 cm) covering this part of the skin. Effective exposure dose rate from radionuclides in the dust layer equals to:

$$E_{skin} = \sum E_{skini}, \tag{13}$$

$$E_{skini} = W_t \cdot 0{,}5 \cdot \rho \cdot A_{mi} \cdot t \cdot n_i \cdot e_{\alpha,\beta i} \cdot T, \tag{14}$$

where W_t – weighting factor for tissue (skin), 0.01 (Appendix 1, Table 2 [212]);
0.5 – adjustment for the exposed part of skin (50% of skin area is exposed to impact), Appendix A [209];
ρ – density of dust layer on the skin was taken equal to $0.5 \cdot 10^{-3}$ kg/cm^3;
A_{mi} – specific activity of the i–th radionuclide in the top 5–cm layer of soil, Bq/kg;
t – thickness of dust layer on the skin was taken equal to 0.01 cm [209];
n_i – yield of particles per decay for the i–th radionuclide;
$e_{\alpha,\beta i}$ – equivalent dose per single fluence of the i–th radionuclide (Table 14 of HS SERPRS), Sv·sq. cm;
T – exposure time per year, h/year.

Internal exposure dose from accidental peroral intake of contaminated soil

The internal exposure dose for population from accidentally swallowed contaminated soil particles from hands skin is considered.

Effective dose of accidentally swallowed particles of contaminated soil was determined as follows:

$$E_{ing} = \sum E_{ingi} \,, \tag{15}$$

$$E_{ingi} = M_{annual} \cdot A_{mi} \cdot e_{} \tag{16}$$

where M_{annual} – annual accidental swallow of contaminated soil particles, kg/year, ($8.3 \cdot 10^{-3}$ kg/year – for an adult, $18 \cdot 10^{-3}$kg/year – for 7–12 year old children, $44 \cdot 10^{-3}$kg/year – for babies of less than 1-year-old) [209];

A_{mi} – specific activity of the i–th radionuclide in the top 5–cm layer of soil, Bq/kg;

e_{dti} – dose factor for the i–th radionuclide for peroral intake (accepted as equal to the dose factor of radionuclide intake with food, given in Appendix 9 [210]), Sv/Bq.

6.2. Selection of source data for "a farmer involved in subsistence farming" scenario

This scenario considers a farmer's living environment at the STS territory. As the farmer we considered an adult worker (man). The farmer consumes products of both vegetable and animal origin produced at the considered territory. In this scenario we assume that the farmer does not use personal protection equipment. Here we do not consider either reduction in external exposure when the soil is covered with snow (winter period), or seasonal changes of dust content in air, or increased attitudes (up to 1.5–2 meters) over the ground surface and shielding with equipment (for a farmer).

It is assumed that radioactive contamination is uniformly spread over the area, and distribution in the soil layer is of exponential character. Dust content in indoor air is taken as equal to 10^{-8} kg/m^3. Shielding factor (house walls) is taken equal to 0.4 [213].

The farmer cultivates crops and does haymaking at the land plot (farm) located near the place of his residence. It is expected that a farmer spends a part of his working time managing the cropland and taking care of plants, all the rest of his time he spends at the backyard and courtyard, taking care of cattle and home. The dose for a farmer is calculated based on assumption that he spends 8 hours per day outdoors. Generalized data about the time the farmer spends outdoors and indoors and the parameters used in the estimation of his radiation exposure according to the scenario "a farmer involved into subsistence farming" is listed in the Table 79.

Table 79.

Parameters used in the dose assessment

Factor	Unit	Value
Time spent outdoors	h/year	2,920
Time spent indoors	h/year	5,840
Breathing rate outdoors (V)	m^3/h	2.8
Breathing rate indoors (V)	m^3/h	1.4
Average annual dust content outdoors (p_{sus})	kg/m^3	$2 \cdot 10^{-7}$
Average annual dust content indoors (p_{sus})	kg/m^3	10^{-8}

Local population was interviewed to specify the parameters of basic food products consumption at the STS territory. The amount of food products consumed, cultivated and produced at the STS territory, coefficients of transfer into crop and animal products are given in Tables 80 – 83.

Table 80.

Consumption rate for food products cultivated and produced at the STS territory

Food products	Amount of food products consumed, kg/year
	A man
Enriched wheat flour, grade 1	16.6
Bread made of enriched wheat flour, grade 1	91.3*
Oat	2.4
Beans, pea	2.6
Potato	117.9
White cabbage	31.6
Carrot	23
Tomato	6.2
Cucumber	6.2
Beet	6.2
Onion	26
Beef	30*
Horse beef	40*
Mutton	40*
Poultry meat	10*
Milk, liters	200*
Sour cream, 20% of fats	30*
Koumis (horse milk), liters	60*
Semi fat curd	30*
Eggs, pcs	200*
Note: * - changes introduced according to results of an interview	

Table 81.

Accepted transfer factors for crop products for the "contaminated territories" of the STS

Agricultural products	Tf			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Cereals				
Wheat	4.3E-02	2.6E-02	9.5E-06	2.2E-05
Oat	8.7E-03	1.9E-02	9.5E-06	2.2E-05
Leafy vegetables				
Cabbage	8.2E-03	4.3E-01	1.1E-03	7.9E-04
Leguminosae				
Beans, pea	2.4E-03	6.6E-02	6.7E-05	4.8E-04
Fruited vegetables				
Tomato	1.0E-02	1.5E+00	8.5E-05	2.3E-04
Cucumber	9.4E-02	1.5E+00	8.5E-05	7.9E-04
Bulbous vegetables				
Onion	2.6E-02	2.4E-01	7.9E-03	7.0E-03
Tuberous roots				
Potato (bulbs)	6.6E-03	3.4E-02	1.6E-03	1.3E-03
Beet (root crops)	5.3E-02	1.3E+00	1.7E-03	8.6E-04
Carrot (root crops)	7.7E-03	3.8E-01	3.0E-02	3.6E-03

Table 82.

Accepted transfer factors for calculation of radionuclide concentrations in the products

Product	T_f from feed per 1 kg (l) of product				T_f from soil per 1 kg (l) of product			
	^{137}Cs	^{90}Sr	^{241}Am	$^{239+240}$Pu	^{137}Cs	^{90}Sr	^{241}Am	$^{239+240}$Pu
Beef (horse beef)	2.7×10^{-4}	8.8×10^{-6}	8.2×10^{-4}	5.5×10^{-4}	8.0×10^{-5}	5.9×10^{-7}	2.3×10^{-5}	1.4×10^{-8}
Mutton	1.4×10^{-1}	2.7×10^{-4}	$>3.0\times10^{-3}$	1.0×10^{-4}	$1.4\times10^{-1\times}$	$2.7\times10^{-4\times}$	$>3.0\times10^{-3\times}$	$1.0\times10^{-4\times}$
Poultry meat	3	2.3×10^{-2}	$6.6\times10^{-4\times\times}$	$2.3\times10^{-5\times\times}$	2.1×10^{-2}	9.1×10^{-4}	6.6×10^{-4}	2.3×10^{-5}
Cow milk	4.6×10^{-3}	2.0×10^{-4}	4.2×10^{-7}	1.0×10^{-5}	$4.6\times10^{-3\times}$	$2.0\times10^{-4\times}$	$4.2\times10^{-7\times}$	$1.0\times10^{-5\times}$
Sheep milk	7.7×10^{-2}	3.0×10^{-2}	$6.9\times10^{-6\times\times\times}$	1.0×10^{-4}	$7.7\times10^{-2\times}$	$3.0\times10^{-2\times}$	$6.9\times10^{-6\times}$	$1.0\times10^{-4\times}$
Eggs	4.3×10^{-1}	8.8×10^{-1}	3.0×10^{-3}	1.2×10^{-3}	$4.3\times10^{-1\times}$	$8.8\times10^{-1\times}$	$3.0\times10^{-3\times}$	$1.2\times10^{-3\times}$

Note: [ ] – IAEA data, [ ] – data from full-scale experiments at the STS,
"*" – T_f from soil; "**" – T_f from feed; "***" – T_f for goat milk;

Table 83.

Parameters for assessment of possible radionuclides entry into farm animals when pastured at the STS territory [70]

Farm animal	Live weight, kg	Daily norm at pasture forage consumption (per dry weight), kg	Amount of soil swallowed when pastured (including dust on plants), kg
Horse	350-400	18	1.93
Cow	400	16	1.91
Sheep	50-60	2.5	0.24
Birds	4-6	0.15	0.021

6.3. Assessment of boundary parameters for radioactive contamination at the STS territory

6.3.1. Revealing the main exposure pathways for population living at the STS territory

Most of the STS territory is represented by conditionally "clean" territories. These are the territories where the level of artificial radionuclides concentration is comparable with the level of global fallouts background. The main artificial radionuclides at these territories are ^{137}Cs, ^{90}Sr, $^{239+240}$Pu, ^{241}Am.

To determine the significance of exposure pathways, considered in this technique, let us make a pre-estimate of the expected annual effective doses for the following routes of population exposure:

- external exposure from beta emission;
- external exposure from gamma emission;
- external exposure from contaminated soil on skin;
- internal exposure from inhalational intake of radionuclides;
- internal exposure from peroral intake of radionuclides with food;
- internal exposure from accidental entry of radionuclides into digestive tract.

The main parameter for the dose assessment is specific activity. To reveal the main routes of exposure, let us make an assessment for a farmer and take specific activity of the radionuclides in soil as "A_i" Bq/kg. Dose factors for assessment of expected annual dose are given in the Table 84 [46, 210, 214].

Table 84.

Factors used in the radiation exposure assessment

Factor	Factor value					
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am	^{152}Eu	^{154}Eu
B_{sg}, mGy·m^2/h·kBq	2.5×10^{-6}	1.0×10^{-9}	1.3×10^{-9}	9.7×10^{-8}	3.9×10^{-6}	4.2×10^{-6}
$e_{inhc,}$ Sv/Bq	4.6×10^{-9}	5.0×10^{-8}	5.0×10^{-5}	4.20×10^{-5}	4.2×10^{-8}	5.3×10^{-8}
e_{dt} (adult), Sv/Bq	1.3×10^{-8}	$2.8\cdot10^{-8}$	2.5×10^{-7}	2.0×10^{-7}	1.4×10^{-9}	2.0×10^{-9}
$n_{\beta i}$, %	0.95	1	-	-		
$e_{\alpha,\beta i}$, Sv·m^2	5.0×10^{-10}	5.0×10^{-10}	5.0×10^{-6}	5.0×10^{-6}		

The radiation exposure assessment performed for a farmer from considered exposure pathways is shown in the Table 85.

Table 85.

Results of assessment of annual effective exposure dose per unit of the radionuclide specific activity in the top soil layer

Exposure pathways	Effective dose, (mSv/((Bq/kg)×year))			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
External exposure from gamma-radiation	A×6.5E-04	A×2.6E-07	A×3.3E-07	A×2.5E-05
External exposure from beta-radiation	A×1.2E-09	A×1.2E-09	-	-
Internal exposure from inhalation intake of radionuclides	A×7.9E-09	A×8.6E-08	A×8.6E-05	A×7.2E-05
Internal exposure from accidental peroral intake of soil	A×1.1E-07	A×2.3E-07	A×2.1E-06	A×1.7E-06
External exposure from contaminated soil on skin	A×5.0E-11	A×5.0E-11	A×5.5E-07	A×5.5E-07
Internal exposure from consumption of food products (water) cultivated or produced at this territory	A×1.5E-04	A×5.1E-04	A×7.1E-05	A×3.5E-05
Total of all the exposure pathways	**A×8.0E-04**	**A×5.1E-04**	**A×1.6E-04**	**A×1.3E-04**
Note: - the most significant exposure pathways for each radionuclide				

Obtained results show that the values of partial expected annual effective doses from external beta radiation, external exposure from contaminated soil on skin and inner exposure from accidental peroral intake of contaminated soil make less than 0.1% of the total amount for all considered routes of ionizing radiation exposure on humans. Therefore, consideration of the listed above mechanisms makes no sense in further assessment of the radiation exposure.

The Table shows that for the radionuclides $^{239+240}$Pu and ^{241}Am, the main exposure pathway is inhalational intake, for ^{137}Cs – external gamma-radiation, for ^{90}Sr – internal exposure from peroral intake of food products.

The main contributors to expected annual effective exposure dose rate for population of the STS territory would therefore be as follows:

– External exposure from gamma-radiation of artificial radionuclides in the top (5 cm) soil layer
– Internal exposure from inhalation intake of radionuclides;
– Internal exposure from intake of food products produced at the considered territory.

6.3.2. Boundary values of artificial radionuclide specific activities in soil that assure the non-exceedance of the dose of 1 mSv for population

According to HS SERPRS, we take the sum of effective external exposure dose for a calendar year, and expected effective internal exposure dose, determined by radionuclides intake by the organism for the same year as annual effective dose. Expected annual effective dose from artificial exposure should not exceed the value of 1 mSv per year for population in average for any of sequential 5 years.

Using the obtained data (Table 85) let us determine the boundary values of artificial radionuclides specific activity in the top soil for each radionuclide for the main exposure pathways, assuring non-exceedance of annual effective dose of 1 mSv. Let us also determine the limiting values for the radionuclide specific activities for the annual effective dose of 1 mSv with the only one radionuclide in soil from summary exposure from all exposure pathways. For example, the main exposure pathways equation for ^{137}Cs would look as follows:

$$1\ (\text{mSv/year}) = (A\times 6.5\text{E-}04 + A\times 7.9\text{E-}09 + A\times 1.5\text{E-}04)\ (\text{mSv/((Bq/kg)}\times\text{year)})$$

$$A=1.2\text{E+}03\ (\text{Bq/kg}).$$

Calculated boundary values of the specific activities are given in the Table 86.

Table 86.

Boundary specific activity values for artificial radionuclides in the top soil layer for a territory with favorable radiological (radioecological) situation for carrying out economic activities

Exposure pathways	Boundary values of specific activity, Bq/kg			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
External exposure from gamma-radiation	1.5E+03	3.9E+06	3.03E+06	4.0E+04
Internal exposure from inhalation intake of radionuclides	13E+08	1.2E+07	1.2E+04	1.4E+04
Internal exposure from consumption of food products (water) cultivated or produced at this territory	6.8E+03	1.9E+03	1.4E+04	2.9E+04
Total for the main exposure pathways with the dose of 1 mSv	1.2E+03	1.9E+03	6.4E+03	7.6E+03

6.3.3. Assessment of the boundary parameters for the STS territory contamination by the main critical pathways

Expected annual effective dose is determined as a sum of doses from the main radionuclides on the main exposure pathways. Since the sum of exposure from each radionuclide should be ≤1 mSv, then the equation of expected annual effective dose would look as follows:

$$1 = \frac{A_{Cs-137}}{A_{bCs-137}} + \frac{A_{Sr-90}}{A_{bSr-90}} + \frac{A_{Pu-239+240}}{A_{bPu-239+240}} + \frac{A_{Am-241}}{A_{bAm-241}}, \quad (1)$$

where A_{Cs}, A_{Sr}, A_{Pu}, A_{Am} – expected content of radionuclides in soil,
A_{bCs}, A_{bSr}, A_{bPu}, A_{bAm} – boundary values for the radionuclide specific activities in soil at the dose of 1 mSv.

The ratio values for the artificial radionuclides at the conditionally "clean" STS territories are as follows: $^{137}Cs/^{90}Sr = 1.6$; $^{239+240}Pu/^{241}Am = 5.3$; $^{137}Cs/^{241}Am = 22.5$.

When all the main dose forming radionuclides (equation 1) are involved and their ratio values for the conditionally "clean" STS territories are known, one can find the specific activity boundary parameters for the main dose forming radionuclides based on the main critical exposure pathways.

Calculated boundary parameters of specific activity from the net impact of the main dose forming radionuclides within the main exposure pathways for the annual effective dose of 1 mSv are given in the Table 87.

Table 87.

Specific activity values of the main radionuclides from the main exposure pathways for the boundary dose value of 1 mSv

Parameter	Specific activity, Bq/kg			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Dose of 1 mSv	859	537	202	38,1

Let us check the obtained results as follows: we put the obtained specific activity values (Table 84) into the Table 77. The obtained results are given in the Table 88.

Table 88.

Expected annual effective dose for a farmer scenario from the main dose-forming radionuclides and the main exposure pathways

Exposure pathways	Effective annual dose, mSv				
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am	Total
External exposure from contaminated soil surface	5.6E-01	1.4E-04	6.7E-05	9.5E-04	5.6E-01
Internal exposure from inhalation intake of radionuclides	6.8E-06	4.6E-05	1.7E-02	2.8E-03	2.0E-02
Internal exposure from consumption of food products cultivated and produced at this territory	1.3E-01	2.8E-01	1.4E-02	1.3E-03	4.2E-01
Total	**6.9E-01**	**2.8E-01**	**3.2E-02**	**5.0E-03**	**1.0E+00**

Therefore, with calculated specific activity values (Table 87) and accepted source data ("Farmer involved into subsistence farming" scenario), the annual effective dose for a farmer would not exceed 1 mSv.

Using the proposed technique, one can assess the content of radionuclides from the main exposure pathways for other parts of the STS territory, as well as for different behavior scenarios.

6.4. Assessment of the radioactive contamination boundary parameters by the main critical ways for the "Experimental Field" and the "4A" sites of STS

6.4.1. Sites "Experimental Field" and "4 A"

At the territory of the "Experimental Field" site, surface and atmospheric nuclear explosions were carried out. "Experimental Field" includes technical grounds (P-1, P-3, P-5) where the surface nuclear tests were actually carried out. The "P-1" testing ground is located in the center of the "Experimental Field". At "4" and "4A" sites, warfare radioactive agents (WRA) were tested.

To assess the boundary parameters of specific activity, let us consider the object IK-2 located at the "P-1" ground of the "Experimental Field", and the site "4A". At these sites, such artificial radionuclides as ^{137}Cs, ^{241}Am, ^{152}Eu, ^{154}Eu, ^{90}Sr, $^{239+240}$Pu were found. These sites differ from other sites of the STS by presence of ^{152}Eu and ^{154}Eu radionuclides in the top soil, as well as by increased specific activities of other radionuclides and absolutely different radionuclides ratio values when compared with the conditionally "clean" areas of the STS.

The ratios of the radionuclides calculated for the site "4A" and the object "IK-2" (of the "P-1" testing ground), are given in the Table 89.

Table 89.

Calculated ratio values for the radionuclides at the "4A" site and object "IK-2" (P-1)

Site	Radionuclides ratio				
	^{137}Cs/^{90}Sr	$^{239+240}$Pu/^{241}Am	^{137}Cs/^{241}Am	^{137}Cs/^{154}Eu	^{154}Eu /^{152}Eu
4A	0.011	20.7	2.2	1.8	2.7
"IK-2" object ("P-1")	0.29	6.9	14.3	13.9	0.026

6.4.2. Assessment of the boundary parameters of radioactive contamination at the sites "4A" and "P-1" (object "IK-2") of the STS territory by the main critical routes

The maximal specific activities were determined in the i.6.3 for the radionuclides ^{137}Cs, ^{90}Sr, $^{239+240}$Pu, ^{241}Am for the annual effective dose of 1 mSv when only one radionuclide from the main exposure pathways is present in soil (Table 87). Similarly, let us determine the specific activity values for the radionuclides ^{152}Eu, ^{154}Eu from the main exposure pathways for the maximal dose value of 1 mSv.

The dose factors for internal exposure dose from peroral intake of ^{152}Eu, ^{154}Eu radionuclides with food for adults is for 2 orders of magnitude lower than that of the $^{239+240}$Pu, ^{241}Am radionuclides and for an order of magnitude lower than that for ^{137}Cs, ^{90}Sr. The levels of contamination with ^{152}Eu, ^{154}Eu at the considered area are for 2 orders of magnitude lower than the level of contamination with $^{239+240}$Pu, ^{241}Am at the "Experimental Field" site and for 4 orders of magnitude lower than the level of contamination with ^{90}Sr at the "4A" site. Therefore, it makes no sense to consider the dose from internal exposure due to peroral intake of the radionuclides ^{152}Eu, ^{154}Eu with food products.

The assessed dose loads for a human under the scenario "a farmer involved in subsistence farming" and specific activities in soil from the main exposure pathways "A_i" are given in the Table 90 below.

Table 90.

The assessed annual effective exposure doses per unit of the radionuclide specific activity in the top soil layer

Exposure pathways	Effective dose, (mSv/((Bq/kg)×year))	
	^{152}Eu	^{154}Eu
External gamma-radiation exposure	A×1.0E-03	A×1.1E-03
Internal exposure from inhalation intake of radionuclides	A×7.2E-08	A×9.1E-08

Employing the obtained data (Table 85) one can determine the boundary values for specific activity of artificial radionuclides in the top soil for the territory not classified as radioactively contaminated zone (annual effective dose is less than 1 mSv).

Table 91 provides calculated specific activities that assure non-exceedance of the annual effective dose of 1 mSv when only one radionuclide is present in soil.

Table 91.

Specific activities of each radionuclide from the main exposure pathways at the boundary dose value of 1 mSv

Parameter	Specific activity, Bq/kg					
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am	^{152}Eu	^{154}Eu
Dose of 1 mSv	1.2E+03×	1.9E+03×	6.4E+03×	7.6E+03×	1.0E+03	9.3E+02
× - specific activity values were taken from the Table 78						

Similar to i.6.3.3, let us determine for the "Experimental Field" and the "4A" test sites the boundary values for specific activity from the impact in the sum of the dose-forming radionuclides from the main exposure pathways for the annual effective dose of 1 mSv.

Table 89 provides the radionuclide ratios calculated for the sites "4A" (spot 1) and the ground "P-1" (object IK-2).

Considering the radionuclides ^{137}Cs, ^{90}Sr, $^{239+240}$Pu, ^{241}Am, ^{152}Eu, ^{154}Eu, the equation 1 would take to form:

$$1 = \frac{A_{Cs-137}}{A_{bCs-137}} + \frac{A_{Sr-90}}{A_{bSr-90}} + \frac{A_{Pu-239+240}}{A_{bPu-239+240}} + \frac{A_{Am-241}}{A_{bAm-241}} + \frac{A_{Eu-152}}{A_{bEu-152}} + \frac{A_{Eu-154}}{A_{bEu-154}}, \quad (2)$$

where A_{Cs-137}, A_{Sr-90}, $A_{Pu-239+240}$, A_{Am-241}, A_{Eu-152}, A_{Eu-154} – radionuclide contents in soil,
$A_{bCs-137}$, A_{bSr-90}, $A_{bPu239+240}$, $A_{bAm-241}$, A_{Eu-152}, A_{Eu-154} – boundary values for specific activities of the radionuclides in soil that assure the non-exceedance of the dose of 1 mSv.

Let us put into the equation 2 the calculated boundary values of specific activity for each radionuclide (Table 91) and the ratios of these radionuclides at sites "P-1" and "4A" (Table 89) and determine the boundary values for the radionuclide specific activities for the main critical exposure pathways.

The resulted boundary parameters of the specific activity from the impact in a sum of the main dose-forming radionuclides from the main exposure pathways for the annual effective dose of 1mSv are provided in Table 92.

Table 92.

Specific activities of the main radionuclides from the main exposure pathways at the dose boundary value of 1 mSv

Parameter	Specific activity , Bq/kg					
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am	^{152}Eu	^{154}Eu
Dose of 1 mSv	**"4 A" site**					
	20.1	1,830	189	9.1	4.13	11.2
	"P-1" ground					
	182	627	87.8	12.7	503	13.1

Let us verify the obtained results substituting the obtained specific activity values (Table 92) into the Table 85. The obtained results for the "P-1" ground (object "IK-2") are given in the Table below (Table 93).

Table 93.

Expected annual effective dose for the agricultural behavior scenario (a farmer) from the main dose forming radionuclides and the main exposure pathways

Exposure pathways	Effective annual dose, mSv						
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am	^{152}Eu	^{154}Eu	Total
External exposure from contaminated soil surface	1.2E-01	1.6E-04	2.9E-05	3.2E-04	5.03E-01	1.41E-02	6.4E-01
Internal exposure from inhaled radionuclides	1.4E-06	5.4E-05	7.5E-03	9.2E-04	3.63E-05	1.19E-06	8.5E-03
Internal exposure from consumption of food products cultivated or produced at this territory	2.7E-02	3.2E-01	6.2E-03	4.4E-04			3.6E-01
Total	**1.5E-01**	**3.2E-01**	**1.4E-02**	**1.7E-03**	**5.03E-01**	**1.41E-02**	**1.0E+00**

There are no economic activities carried out and no food cultivated or produced at the "Experimental Field" (P-1) and the "4A" sites. Let us therefore perform similar assessment of the boundary values of the artificial radionuclide specific activities from external gamma-radiation and internal exposure due to inhaled radionuclides for the sites "P-1" and "4A".

The boundary values of the radionuclide specific activities that assure the non-exceedance of the annual effective dose of 1 mSv at presence in soil of only one radionuclide from the sum of external gamma-radiation and internal exposure from inhaled radionuclides are given in the Table 94.

Table 94.

Specific activity values for each radionuclide from the main exposure pathways for the dose boundary value of 1 mSv

Parameter	Specific activity, Bq/kg					
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am	^{152}Eu	^{154}Eu
Dose of 1 mSv	1.5E+03	2.9E+06	1.2E+04	1.0E+04	1.0E+03	9.3E+02

Using the previous method, the Table 95 demonstrates the boundary values of specific activity from the total effect of the main dose forming radionuclides from considered exposure pathways at the boundary annual effective dose value of 1 mSv.

Table 95.

The radionuclide specific activities for external gamma radiation and internal exposure from inhalational intake of the radionuclides at the dose boundary value of 1 mSv

Parameter	Specific activity, Bq/kg					
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am	^{152}Eu	^{154}Eu
Dose of 1 mSv	**"4 A" site**					
	427	3.9×10^{4}	4,020	194	87.8	237
	"P-1" ground					
	282	973	136	19.7	780	20.3

Verifying these results, one can put the obtained specific activity values (Table 95) into Table 85. The results obtained for the testing ground P-1 (object IK-2) are given in the Table 96 below.

Table 96.

Expected annual effective dose for agricultural behavior scenario from the main dose forming radionuclides and the main exposure pathways

Exposure pathways	Effective annual dose, mSv						
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am	^{152}Eu	^{154}Eu	Total
External exposure from contaminated soil surface	2.7E-02	9.6E-06	1.0E-03	1.0E-02	6.31E-01	3.40E-02	**7.0E-01**
Internal exposure from inhaled radionuclides	3.2E-07	3.2E-06	2.7E-01	3.0E-02	4.33E-05	2.73E-06	**3.0E-01**
Total	**2.7E-02**	**1.3E-05**	**2.7E-01**	**4.0E-02**	**6.3E-01**	**3.4E-02**	**1.0E+00**

Obtained boundary values of the radionuclide specific activities that assure non-exceedance of the annual effective dose of 1 mSv/year for economic activities at the STS territory exceed the value of the radionuclide specific activities due to global fallouts

for ~30 – 40 times. Therefore, with radionuclides specific activity values at the level of global fallouts, expected annual dose would be low allowing to avoid radiation exposure assessment.

It is therefore reasonable to optimize the works at the STS territory aimed towards the lands transfer into economic turnover determining the specific activities of the artificial radionuclides and their ratios in order to assess the radiological situation at the STS territories.

This technique for assessing the specific activity boundary parameters also allows to estimate other sites with different ratio values and human behavior scenarios.

CONCLUSION

General assessment of the surface radioactive contamination at the radiation-hazardous objects in the STS allows to state that in the majority of cases the radioactively contaminated spots are quite small in size (in most cases the area is < 1 sq. km.), except for the radioactive fallout traces resulted from the excavation and surface tests of high yield (> 10 kt), the area of which is up to $n\times10^1 - n\times10^3$ sq.km; however, there are only 3 sites of this kind beyond the test sites. Isotopic composition and special distribution of the radionuclides at each of the sites significantly depends on both the character of the performed test, and the main migration mechanisms typical for this site.

Comparison of the total STS area (18,300 sq.km.) with typical dimensions of the contaminated sites allowed to assume that a considerable part of the STS was either not contaminated at all due to the tests or the contamination level is negligible. This assumption has been verified in a detailed survey of the so-called "background" territories beyond the test sites, evident and known fallout traces. The level of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu, ^{241}Am concentration in soil of these territories was almost equal to or comparable with the concentrations of these radionuclides in global fallouts. Statistical processing of the data on concentrations of these radionuclides in soils at the conditionally "background" territories along with considering the nuclear-physical mechanisms of their formation have revealed that the isotopic ratios for these territories lie within quite a short range of values: that allows to assess concentrations of certain radionuclides based on the known concentrations of their "generic" radionuclides. The average $^{239+240}$Pu / ^{241}Am ratio value was found to be 5.2, ^{90}Sr / ^{137}Cs – 0.6. At that, the applicability conditions for these ratios are the average concentrations of ^{137}Cs (18 ± 2 Bq/kg) and ^{241}Am (< 0.8 Bq/kg) to remain in the top 5cm soil within the range 18 ± 2 Bq/kg and < 0.8 Bq/kg, respectively.

The detailed investigations of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am speciation in soil demonstrated similarity of the speciation at all the "background" territories irrespective of the distances to the main sources of radioactive contamination; from one hand, this proves the conclusion about their origin (global fallouts), and from another hand, allows to propose several methods for identification of radioactive contamination at studied territories. So, significant decrease in percentage of ^{90}Sr exchangeable forms and presence of particle-size fractions enriched with ^{137}Cs, ^{90}Sr, $^{239+240}$Pu, ^{241}Am is a good indication for the presence of "introduced" contamination, as a rule, from a surface test.

Analysis of the character of air basin contamination with artificial radionuclides both at the territory of the main STS objects and on the adjacent territories shows that inhalational intake of artificial radionuclides can significantly contribute to the radiation exposure only when a human is staying immediately at the territory of a radiation hazardous object. Concentrations of ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}$Pu in air basin at the conditionally "background" STS territories are approximately for 3-6 orders of magnitude lower than the maximal permissible concentrations for population. Since their experimental measurements in air with acceptable precision are quite difficult, it is reasonable to perform a primary assessment of the artificial radionuclides concentration based on the data on the dust content in air, their mean average concentrations in soil and coefficients of aerosol fractions enrichment with artificial radionuclides.

Obtained extensive data on the coefficients of $^{239+240}$Pu, ^{241}Am, ^{90}Sr and ^{137}Cs transfer from soil into both wild and cultivated plants, as well as the radionuclides transfer from soil/feed/water into animal bodies allows to state that farm crop and animal products produced at the conditionally "background" territories would meet the accepted radiation safety standards. Moreover, farm products of acceptable quality can also be produced at some contaminated STS territories; at that, the most critical isotope would be ^{90}Sr, but not the previously poorly studied transuranium elements.

Investigations of water environment have shown that the concentrations of ^{137}Cs, ^{90}Sr, ^{241}Am, $^{239+240}$Pu and ^{3}H in water objects and in the water use objects located at the conditionally "background" territories of the STS and those not hydrogeologically associated with the radiation hazardous STS objects are approximately for 100-1,000 and more times below the maximal permissible concentrations for population. It is reasonable to estimate the ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}$Pu concentrations based on their concentrations in bottom sediments and respective redistribution factors during a preliminary assessment of water use objects contamination.

In the cases when a water use object is hydrogeologically associated or can be associated with the venues of underground nuclear tests, a special increased attention should be paid to such an object. Tritium should be the main radionuclide under control. Therefore, when studying the territories adjacent to the sites "Balapan", "Sary-Uzen", and especially "Degelen", special attention is to be paid to investigation of tritium migration underground.

In general, the performed studies have shown similarity of radioactive contamination character at the conditionally "background" lands on the whole STS territory according to the following important parameters: concentration ratios of the main artificial radionuclides $^{239+240}$Pu, ^{241}Am, ^{90}Sr, ^{137}Cs, their vertical distribution in brown soil, distribution within the soil particle-size fractions, speciation and the coefficients of their transfer into plants. These characteristics, as a rule, are necessary for assessment of radioecological state of objects or territories. This allows to omit works of this kind in further investigations and to use the results already obtained for the radioecological assessment of the STS lands.

Summing up, the amount and the quality of the obtained data, the degree of understanding of radioecological situation at the Semipalatinsk Test Site allow to rely on the conclusions and recommendations, and the STS lands recommended for release into economic turnover are absolutely safe in radiological respect.

APPENDIX

Division No	RGB color ratio			Content
				Low-hill terrain ecosystem
1	234	234	234	*Individual plants and groups with domination of Parmelia vagans, P.cetrata, Diploschistes scropsus, Caloplaca elegans, Orostachys spinosa, Lybanotis buchtormensis, Euphorbia humilis, Pairinia intermedia, Onosma simplicissimum, Diantus* ***acicularis***, Silene *suffrutescens, Hieracium echioides on granite slabs of the summits;* *Individual plants and free-growing groups with domination of Solanum dulcamara, Urtica urens, Setaria viridis, Carex pediformis, Festuca valesiaca in the spalling areas on the tops and man-made rock slides on the ridge crests; combined with grass-motley grass-shrubs (Rosa spinosissima, Lonicera microphylla, Spiraea hypericifolia, Caragana frutex, Artemisia scoparia, Thalictrum simplex, Veronica spuria, Chamaerodos erecta, Festuca valesiaca Agropyron cristatum) communities on the rockslide edges.*
2	192	0	0	Community series: *Perthophytic-motley grass* (Orostachyys spinosa, Sedum hybridum, Patrinia intermedia, Gypsophila palrinii, Veronica pinnata, Potenlilla acaulis, Aretemisia oblusiloba, A. latifolia) *in fractures with fine earth; petrophytic and shrubs* (Rosa spinosissima, Spiraea trilobata, Lonicera microphylla, Cotoneaster melanocarpa, Pentaphylloides parvifolia, Berberis sibirica) *on gravelly parts of granite slabs; juniper* (Juniperus sabina) *on the large rocky man-made talus on the ridge of crest slopes.*
3	208	0	69	Systems of community series: *motley grass-sedge gramineous* (Helictotrichon desertorum, Slipa kirghisorum, Festuca valesiaca, Carex pediformis, Thalictrum foetidium, Bupleurum aureum, Chamaerodos erecta, Pulsatilla patens) *on underdeveloped heavily gravely mountain brown soils of the northern slopes; grass-motley grass* (Fragaria viridis, Onosma simplicissimum, Diantus acicularis, Silene suffretescens, Hieracium echioides, Papaver tenellum, Veronica spuria, Artemisia latifolia, A. rupestris, Festuca valesiaca, Stipa capillata, Agropyron cristatum*) with shrubs* (Spiraea trilobata, S. hypericifolia, Caragana pumila, Lonicera micorhylla) *on underdeveloped heavily gravely brown soils of the southern slopes; combined with the series of: petrophyte-motley grass-shrubs* (Penlaphylloides floribunda, Rosa spinosissima, Spiraea trilobala, Cotoneaster oliganthus, Berberis sibirica, Artemisia obtusiloba, Orostachys spinosa, Ziziphora clinopodioides. Thymus serpyllum, Gypsophila patrinii) *and juniper* (Juniperus sabina), *communities at outputs of granite slabs;* *Groups with domination of* Festuca valesiaca, Stipa kirghisorum, Cleistogenes squarrosa, Carex pediformis, Artemisia frigida, Artemisia latifolia. Thymus serpyllum, Ztiphora clinopodioides, Veronica incana, Ephedra distachya *at disturbed lands.*

Division No	RGB color ratio			Content
4	255	79	167	Community series: *shrub-wormwood- petrophytic motley grass* (Potentilla acaulis, Patrinia intermedia, Orostachys spinosa, Sedum hybridum, Gypsophila patrinii, Artemisia frigida, A. obtusiloba, Caragana pumila. Spiraea hypericifolia*) on stony outcrops;* *sedgy-pea-cold wormwood-sage bunch gramineous* (Festuca valesiaca, Helictotrichon desertorum, Cleistogenes squarrosa, Artemisia frigida, Caragana pumila, Carex pediformis*) at gravelly area; wormwood-sheep fescue-feather grass* (Stipa capillata, S. kirghisorum, Festuca valesiaca, Artemisia marshalliana, A. frigida) *with shrubs* (Caragana pumila, Spiraea hypericifolia) *and motley grass* (Galium verum, Phlomis tuberosa, Leonurus glaucescens, Dianthus leptopetalis) *on underdeveloped gravelly brown soils on the slopes of ridges.*
5	255	163	163	Community series: *petrophytes* (Patrinia intermedia, Orostachys spinosa, Carex supina, Potentilla acaulis, Thymus marschalianus) *on stony outcrops of tops and slopes;* sheep fescue -sandy needle-grasses *(Stipa lessingiana, Festuca valersiaca)* and cold wormwood - sheep fescue-sandy needle-grass *(Stipa lissingiana, Festuca valesiaca, Artemisia frigida)* with caragana *(Caragana pumila)* on slopes; motley grass-sheep fescue-fatuoid*s (Helictotricon schellianum, Festuca valesiaca, Gypsophda patrinii)* with spirea *(Spiraea hypericifolia)* on caved-in parts of slopes and shallows on mountain light-brown soils of the low-hill terrain
6	255	193	171	Community series: *petrophyte-motley grass (Carex* pediphormis, Thymus marschalliana, Ephedra distachya, Patrinia intermedia, Potentilla acaulis) *on rocky outcrops; juniper* (Juniperus sabina) *on stony and derbis slopes; motley grass-cold wormwood-sod grass* (Stipa kirgisorum, Helictotrichon desertorum, Festuca valesiaca, Artemisia frigida, Centhaurea sibtrica, Hieracium echioides) *with shrubs* (Caragana pumila, Spiraea hypericifolia) *in the upper part of slopes; cold wormwood-sheep fescue-stipa* (Stipa sareptana, Stipa capillata, Festuca valesiaca, Koeleria cristata, Artemisia frigida. Iris scariosa), *along the slopes and* interhummock lowlands.

Division No	RGB color ratio			Content
				Ecosystems of high hummocks
7	122	61	0	Community series: *Petrophyte-motley grass - shrubby plants* Caragana pumila. C.frutex, Spiraea hypericifolia, Atraphaxis frutescens, Orostachys spinosa, Sedum hybridum, Ephedra distachya, Ajania frutiiculosa *along the rocky outcrops, grass-petrophytic motley grass* (Gypsophila patrinii, Goniolimon speciosum, Onosma tincthorum, Veronica incana, Hyssopus macranthus, Festuca valesiaca, Stipa capillata, Koeleria cristata) *on gravelly sites, pea shrub-sheep fescue –cold wormwood* (Artemisia frigida, Festuca valesiaca, Caragana pumila) *at intensively channery parts of the peaks and slopes of the flat steeply-sloping hummocks,* *Single plants and thinned groups with domination of* Festuca valesiaca, Koeleria cristata, Stipa capillata, Caragana pumila, C. Frutex, Hyssopus macranthus, Thymus serphyllum, Onosma tincthorum, Veronica incana, Goniolimon speciosum, Ephedra distachya, Artemisia scoparia, A. dracunculus, Berteroa incana *at disturbed lands.*
8	172	81	0	A group of communities on abandoned brown soils of slopes and trains of *steeply-sloping hummocks:* *wormwood-sheep fescue-stipa* (Stipa capillata, Festuca valesiaca, Artemisia frigida, A. marschalliana) *with* Caragana pumila, Spiraea hypericifolia; *shrub-wormwood-sod* (Stipa capillata, Festuca valesiaca, Atemisia frigida, A. marschalliana. Caragana pumila,. Spiraea hypericifolia) with Phlomis tuberosa, Galium ruthenicum, Gypsophalia paniculata; *wormwood-sheep fescue-stipa* (Stipa capillata, Festuca valesiaca. Artemisia frigida, A. marschalliana), *sometimes with* Ceratoides papposa*; groups with* Aremisia austriaca. Eringium planum. Gypsophila paniculata, Acroptylon repens, Chenopodium urbicum, Psathyrostachis juncea, Ceratocarpus arenarius *at disturbed lands.*
9	204	102	0	Combination of the community series: *Various motley grass-sedgy-grass* (Helictotrichon desertorum, Festuca valesiaca, Stipa kirghisorum, Carex pediformis, Thalictrum simplex, Salvia stepposa, Sedum purpurea, Dracocephalum nutans, Veronica spuria. Delphinium dictyocarpum) *on brown soils and grass-motley grass* (Potentilla bifurca, Medicago falcata, Galatella biflora, Iris sibirica, Poa angustifolia, Leymus angustus, Elytrigia repens), *sometimes together with* Rosa spinosissima, R. majalis, Lonicera tatarica. Padus avium, Betula pendula, Popuius tremula *on meadow-brown soils on the slopes.* *Groups with domination of* Artemisia sieversiana, A. dracunculus, Medicago falcata, Euphorbia humilis, Berteroa incana, Alyssum tortuosum, Thlaspi arvense, Tanacetum vulgaris *at disturbed lands.*

Division No	RGB color ratio			Content
10	255	182	109	Community series: *Petrophyte motley grass-spirea-caragana* (Caragana pumila. Spiraea hypericifolia, Patrinia intermedia, Sedum hybridum, Orostachys spinosa, Veronica pinnata) *on tops;* *sod grass-shrub* (Caragana pumila, Spiraea hypercifolia, Festuca valesiaca, Stipa lessingiana), cold wormwood- sheep fescue -feather grass *(Stipa capillata, S. sareptana, S. lessingiana, Festuca valesiaca, Artemisia frigida. Carex supina, Galim ruthenicum);* pea shrub-cold wormwoods *(Artemisia frigida, Caragana pumila*) on the slopes of bald peaks on light-brown gravelly soils.
11	255	199	143	Community series: *Petrophyte motley grass–spirea–caragana species* (Caragana ptimila. Spiraea hypericifolia, Patrinia intermedia, Sedum hybridum, Orostachys spinosa, Veronica pinnata) *on the tops;* *sandy needle-grass-sheep fescue-stipa* (Stipa sareptana, Festuca valesiaca, Stipa lessingiana, Artemisia frigida, Carex supina, Galim ruthenicum), *on the slopes* combined with a comlex of communities: black wormwoods *(*Artemisia pauciflora*)* with c kokpek communities *(*Atriplex cana*)* on the inter-hummocky alkaline, sometimes tasbiyurgun lowlands *(*Nanophyton erinaceimt*)* along the eroded dipressions.
12	255	213	173	Community series: *Petrophyte motley grass-spirea-caragana (Caragana pumila, Spiraea hypericifolia, Patrinia intermedia, Sedum hybridum, Onostachys spinosa. Vetronica pinnata) on the top;* *sandy needle-grass-sheep fescue-stipa (Stipa sareptana, Festuca valesiaca, Slipa lessingiana, Artemisia frigida. Carer supina, Galim ruthenicum) along the slopes combined with the micro zonal range of communities as follows:* *a) reeds (Phragmites australis),* *b) reed grass (Calamagrostis epigeios),* *c) licorice-wild rye (Leymus aitguslus, Glycyrrhiza uralensis),* d) alfalfa- saline bluegrass *(Poa trivialis, Medicagofalcate, Galatella biflora)* in interhummock meadow lowlands.

Division No	RGB color ratio			Content
13	255	222	189	Community series: *Ajania-sod grass-cold wormwood* (Artemisia frigida. Stipa lessingiana, Festuca valesiaca. Ajania fniculosa. Ephedra distachya. Veron pinnata, Patrinia intermedia) *on the top,* *Sublessing wormwood-sheep fescue species* (Festuca valesiaca, Artemisia sublessingiana) *with* Spiraea hypericifolia, *Sublessing wormwood kyrgyz feather grass* (Stipa kirghisorum, Arlet sublessingiana) *with* Caragana ptimila *and* Spiraea hypericifolia *with* Verot pinnata, PotentiHa acattlis, Dianthus rigidus *on the slopes and inter-hummock steppe lowlands.*
14	255	234	213	Community series: *Petrophytes* (Patrinia intermedia, Potentilla acaulis, Orostachys spinosa) *on the outputs of parent rocks,* Cold wormwood-sheep fescue-feather grass *(Stipa capillata, S. sareptana, Festuca valesiaca, Artemisia frigida)* on light-brown gravelly soils of flat area, spiraea (*Spiraea hypericifolia)* on meadow-brown soils of microdepressions, combined with a complex of thin-wormwood-stipa-type species *(Stipa capillata, Artemisia gracilescens)* on light- brown alkalinized soils of microelevations and juncea *(Psathyrostachys juncea)* on light-brown alkalinized soils of microdepressions. Ecosystems of low hummocky topography.
				Ecosystems of low hummoscks
15	202	110	108	Community series: *shrub-petrophyte-motley grass* (Orostachys spinosa, Sedum hybridum, Ephedra distachya, Ajania fniticulosa, Caragana pumila, Atraphasis fnitescens*) on underdeveloped gravelly light-brown soils, marshall - wormwood-sheep fescue-stipa* (Stipa capillata, Festuca valesiaca, Artemisia marschalliana), *sometimes with* Spiraea hypericifolia, Caragana pumila, C. frutex *on the light chestnut rubbly soils; shrub-grass-motley grass (*Medicago falcata, Phlomis tuberosa, Potentilla bifurca, Leonurus glaucescens, Poa angustifolia, Leymus ramosus. Spiraea hypericifolia, Halimodendron halodendron) *on meadow-brown soils of* interhummock lowlands*, procenoses with domination of* Artemisia sieversiana, A. austriaca, A. scoparia, Leymus angustus, Achillea asiatica, Potentiila bifurca. Melilotus dentatus, Verbascum phoenicum, Chenopodium acuminatum. Dodartia orientalis *at disturbed lands.*

Division No	RGB color ratio			Content
16	216	150	148	Combinations of the community series: *Petrophytes* (Orostachys spinosa, Patrinia intermedia, Agropyron cristatum. Veronica pinnata, Potentilla acaulis) *at the outputs of parent rocks; shrub-petrophyte-motley grass species* (Orostachys spinosa, Sedum hybridum, Ephedra distachya, Ajania fruticulosa, Caragana pumila, Atraphaxis frutescens *on light brown gravelly underdeveloped soils of the tops of bald peaks; caragana-cold wormwood-sheep fescue-stipa-sandy needle-grass* (Stipa lesingiana, Stipa capillata, Festtuca valesiaca, Artemisia frigida, Caragana pumila) *at the light brown gravelly underdeveloped, sometimes gravelly soils of bald peak slopes;* *shrub-motley grass-grass* (Festuca valesiaca, Poa stepposa. Leymus angustus, Achillea asiatica, Medicago rumanica, Galium ruhenicum, Artemisia pontica, Spiraea hypericifolia, Caragana pumila) *at meadow-chestnut soils in interhummocky valleys and procenoses with domination of* Artemisia austriaca, Chondrilla laticoronata, Thlaspi arvense, Isatis costata, Lactuca serriola, Chorispora sibirica *on disturbed lands.*
17	230	176	176	Community series: *petrophytes* (Omstachvs spinosa, Patrinia intermedia, Potentilla acaulus, Veronica pinnata) *at the outputs of parent rocks, compact wormwood-sheep fescue-sandy needle-grass-stipa species* (Stipa capillata, S. lessingiana, Festuca valesiaca, Artemisia compacia) *at the light brown gravelly underdeveloped soils,* wormwood-sheep fescue-sandy needle-grass *(Stipa sareptana, Festuca valesiaca. Arten gracilescens, A. compacia)* on light brown gravelly soils as a whole: *tasburgun*-anabasis-salsa-*wormwoods* (Artemisia gracilescens. A. pauciora) Anabasis salsa, Nanophyton erinaceum) *with* Limonium suffruticosum *on the light brown alkalinized soils procenoses with domination of* Artemisia albida, A. nitrosa, Bassia sedoides, Axyris hvbrida, Salsola collina, Halogeton glomeratus *at disturbed lands.*
18	219	155	153	Combinations of the community series: *shrub-petrophyte-motley grass (*Orostachys spinosa, Sedum hybridum, Ephedra distachya, Ajania fruticulosa, Caragana pumila, Atraphaxis frvtescens), *pea shrub-coldwormwood-stipa* (Stipa capillata, Caragana pumila, Artemisia frigida), *spirea*-marshall *wormwood-sheep fescue-stipa (*Stipa capillata, Festuca valesiaca, Artemisia marschalliana), cold wormwood (*Artemisia frigida)* along the tops, slops and steppe interhummock lowlands combined with a comlex of the communities: thin wormwood-psathyrostachys juncea *(Psathyrostachys junces, Artemisia gracilescens),* thin wormwood *(Artemisia gracilescens),* black wormwood *(Artemisia pauciflora),* camphor *(Camphorosma monspeliaca),* kokpek *(Alriplex cana)* on interhummocky shallows at alkalinized- alkaline soils.

Division No	RGB color ratio			Content
19	239	240	209	Community series: *Petrophytes* (Ephedra distachya, Veronica pinnata, Orostachys spinosa) *on outputs of parent rocks;* Sublessingian wormwood-stipa-sandy needle-grass *(Stipa lessingiana, Stipa capillata, Artemisia sublessingiana)* on light-brown underdeveloped gravelly soils among the tops and slopes of bald peaks; shrub-sublessingian wormwood-sandy needle-grass-stipa *(Stipa capillata, S. lessingiana, Artemisia sublessingiana, Spiraea hypericifoha, Caragana pumila)* on light-brown gravelly soils along the slopes and tails of bald peaks; *Estragon-wormwood-motley grass-* psathyrostachys-*sheep fescue (Festuca valesiaca, Psathyrostachys juncea, Phlomis tuberosa, Potentilla bifurca, Artemisia dracunculus) with spirea (Spiraea hypericifoha) on meadow-brown soils of interhummocky shallows*.
20	231	188	187	Community series: *ephedroid–cold wormwood-sod grass* (Stipa sareptana, Stipa lessingiana, Festuca valesiaca, Artemisia frigida, Ephedra distachya) *at the rocky outcrops;* sedgy-sod-grass-shrubs (*Spiraea hypericifolia. Caragana pumila, Ephedra distachya, Fesstuca valesiaca, Koeleria cristata, Carex supine)* at the top and slopes of bald peaks with outputs of parent rocks and derbis spots; cold wormwood-sheep fescue-sandy needle-grass-stipa (*Stipa sareptana, Stipa lessingiana, Festuca valesiaca, Artemisia frigida, Kochia prostrata, Carex supina)* at the light brown heavily rubbly soils at the slopes of bald peaks; stipa-sheep fescue-sandy needle-grass –subblessing–wormwood species *(Artemisia sublessingiana, Stipa lessingiana, Festuca valesiaca. S. sareptana)* at the light-brown rubbly soils at the slopes.
21	240	208	208	Combinations of the communities: *petrophytes (*Inula aspera, Patrinia intermedia, Omstachys spinosa, Sedum hybridum, Parmeha vagans) *on outputs of parent rocks on the top and slopes of bald peaks;* *shrubs* (Ephedra distachya, Ajania fruticulosa, Caragana pumila, Atraphaxis frutescens) *at gravelly underdeveloped soils of pald peaks; pea shrub-wormwood-stipa communities (*Stipa capillata, Caragana pumila, Artemisia frigida), spirea-hetero wormwood-sheep fescue-stip-sandy needle-grass *(Stipa lessingiana, S. sareptana, Festuca valesiaca, Artemisia marschalliana, A. frigida, Spiraea hypericifolia)* at the light brown gravelly soils on the slopes and tails of bald peaks on the top, slopes and steppe interhummock lowlands sometimes combined with ecological range of the following communities: shrub-motley grass-grass *(Poa stepposa, Festuca valesiaca, Leymus angustus, Achillea asiatica, Medicago falcata, Spiraea hypericifolia, Caragana pumila)* at the meadow-brown soils of meadow interhummock lowlands.

Division No	RGB color ratio			Content
22	250	240	240	Combinations of the community series: *petrophytes (*Stipa orientalis, Carex supina, Goniolimon speciosum, Artemisia obtusiloba*) at the outputs of parent rocks,* *shrub-petrophyte-motley grass* (Orostachys spinosa, Sedum hybridum, Ephedra distachya, Ajania fruticulosa, Caragana pumila, Atraphaxis frutescens) *at the gravelly underdeveloped soils,* *caragana-wormwood*-sandy needle-grass (Stipa capillata, Caragana pumila, Artemisia frigida), *wormwood- sheep fescue-stipa* (Stipa capillata, Festuca valesiaca, Artemisia marschal*liana),* cold-wormwood (*Artemisia frigida*) on the slopes and steppe interhummock lowlands, spirea-bunchgrass- sublessing wormwoods *(Artemisia sublessingiana, Festuca valesiaca, Stipa lessingiana, S. sareptana, Spiraea hypericifolia)* at the light brown gravelly soils on the slopes and tails of bald peaks; motley grass-marshall-wormwood-sheep fescue- sandy needle-grass-spirea *(Spirea hypericifolia, Festuca valesiaca, Stipa sareptana, Artemisia marchalliana, Galim reuthenicum)* at the meadow-brown soils of interhummock lowland sometimes combined with ecological series of the following communities: cheegrass *(Achnatherun splendens),* salt tree *(Halimodendron halodendron),* wormwood-wild rye (Leymus angustus, Artemisia nitrosa) *in interhummock halophyte meadow lowlands*.
				Ecosystems of deluvial-proluvial plains
23	255	192	0	Groups of communities: *Cold wormwood-sheep fescue-stipa* (Stipa capillata, Festuca valesiaca, Artemisia frigida, Galatella tatarica. Ephedra distachya) *steppes, sometimes with caragana* (Caragana pumila) *and spiraea* (Spiraea hypericifolia), *cold wormwood-sheep fescue*-sandy needle-grass (Stipa sareptana, Festuca valesiaca, Artemisia frigida) *at the light brown gravelly soils of extensive interhummock lowlands*.
23a	255	210	50	Groups of communities: cold wormwood-sheep fescue-stipa *(Stipa capillata, Festuca valesiaca, Artemisia frigida, Galatella tatarica, Ephedra distachya)* steppes, sometimes with caragana *(Caragana pumila)* and spirea *(Spiraea hypericifolia*) on brown gravelly soils of extensive interhummock valleys.

Division No	RGB color ratio			Content
24	255	227	137	Groups of communities: *Marshall-wormwood-sheep fescue-stipa* (Stipa capillata, Festuca valesiaca, Artemisia marschalliana); *sandy needle-grass-sheep fescue-marshall wormwood* (Artemisia marschalliana, A. austriaca, Festuca valesiaca, Stipa lessingiana, S. capillata, Koeleria cristata, Hultemia persica) *at the light loamy light-brown soils together with thin wormwood-sheep fescue-stipa* (Stipa capillata, Festuca valesiaca, Artemisia gracilescens) *with* Anabasis salsa, Nanophyton erinaceum *at light brown alkalinized soils of extensive* interhummock lowlands *and procenoses with domination of* Leymus paboanus, Artemisia t austriaca, Psathyrostachis jtmcea, Thlaspi arvense, Lepidium ruderale, Polygonum aviculare, Kochia scoparia, Chenopodium acuminatum. Ch. album *at disturbed lands*.
25	223	218	0	Groups of communities: Compact wormwood-sheep fescue-stipa *(Stipa sareptana, Festuca valesiaca, Artemisia compacta*) on granite derbis of elevated sites, cold wormwood-sheep fescue-stipa *(Stipa capillata, Festuca valesiaca Artemisia frigida, Galatella tatarica, Ephedra distachya*) on light-brown intensively gravelly soils; Cold wormwood-stipa-sheep fescue (*Festuca valesiaca, Stipa sareptana, Artemisia frigida*) at the light brow normal soils in combination with motley grass-sheep fescue-spirea-caragana *(Caragana pumila, Spiraea hypericifola, Festuca valesiaca, Galium ruthenicum, Potentilla bifurca)* at meadow-brown soils of microdepressions of extensive interhummock lowlands combined with a comlex of communities: thin wormwood (*Artemisia gracilescens);* kokpek *(Atriplex cana)* at interhummock lowlands on depressions at alkalinized soils.
26	255	255	0	Groups of communities: *Various wormwood-sheep fescue-sheep fescue* (Stipa capillata, S. korshinshyi, Festuca valesiaca, Artemisia frigida, A. sublessingiana, Galatella talarica, Ephedra distachya); *spirea-sandy needle-grass-sheep fescue-sublessing wormwood* (Artemisia sublessingiana, Festuca valesiavca, Stipa lessingina, S. sareplana, Spiraea hypericifolia, Ephedra distachya, Koeleria cristata) *on light brown gravelly soils;* *Psathyrostachys juncea-thin wormwood cenoses with black absinth* (Artemisia gracilescens, Psathyrostachys juncea, A. pauciflora, Leymus paboanus, Koeleria cristata) *combined with:* *a) lucerne-sheep fescue* (Festuca valesiaca, Medicago bifurca), *b) motley grass-wheat grass* (Agropyroni cristsatum, Potentilla impollila, Galium ruthenicum), *c) licoric-wild rye* (Leymus angustus, Glycyrrhiza uralensis) *on interhummocky meadow-steppe lowlands and procenoses with domination of* Artemisia sublessingiana, Festuca valesiaca, Kochia prostrata, Bassia sedoides, Gypsophila perfoliata *at disturbed lands*

Division No	RGB color ratio			Content
27	255	251	105	Groups of communities: *Cold wormwood-sheep fescue-stipa* (Stipa sareptana, Festuca valesiaca, Artemisia frigida); *sublessing wormwood-sheep fescue-stipa community* (Stipa sareptana, Festuca valesiaca, Artemisia sublessingiana), *sheep fescue-sandy needle-grass-stipa-wormwood* (Artemisia marschalliana, A. sublessingiana, Stipa saraplana, S. lessingiana, Festuca valesiaca *at the light brown abandoned soils of uplands), among the micro zonal ecological range of communities as follows: reed* (Phragmites australis), *salt grass* (Puccinellia distans), *licorice-wild rye* (Leymus muiticaulis, Glycyrrhiza uralensis), *cheegrass* (Achnatherum splendens), *halmione* (Halimione verrucifera), *camphorosma* (Camphorosma monspeliaca), *kokpek* (Atriplex cana), *black wormwood* (Artemisia pauciflora) *in kettles and procenoses with domination of* Artemisia scoparia, A. sieversiana, Petrosimonia sibirica, Dodartia orientalis, Ceratocarpus arenarius *at disturbed lands*.
28	255	253	185	Complexes of communities: Thin wormwood-bunchgrass cenoses (*Festuca valesiaca, Stipa capillata, S. sareptana, Koeleria cristata, Artemisia gracilescens)* along the even sites of weakly billowy flat area and micro zonal ranges of communities as follows: *a) meadow-salt shor* (Salicornia europaea, Suaeda acuminata), *b) alpine sawwort -kermek* (Saussurea amara, Limonium coralloides), c) azhrek (*Aeluropus littoralis*), *d) alkaligrass* (Pucinnellia dolicholepis), e) wild rye *(Leymus angustus),* *f) wormwood (*Artemisia schrenkiana), *g) halmine-camphorous–kokpek communities* (Halimione verrucifera. Camphorosma monspeliaca, Atriplex cana), *h) wormwood (*Artemisia gracilescens. A. pauciflora) *on the slopes and bottoms of inter-hummock lowlands and procenoses with domination of* Arlemisia.vulgaris, A.schrenkiana, Kochia sieversiana, Kochia prostrate, Aeluropus littoralis, Halimione verrucifera, Lepidium ruderale *at disturbed lands*.
				Ecosystems of alluvial plains
				Ecosystems of old alluvial plains
29	74	172	66	Group of communities: *Marshall-wormwood-sheep fescue-stipa* (Stipa sareptana, Festuca valesiaca. Artemisia marschalliana); Kochia-marshall wormwood-sod grass *(Stipa sareptana, Festuca valesiaca, Koeleria cristata, Artemisia marschalliana, Kochia laniflora);* subblessing wormwood-spirea-bunchgrass *(Festuca valesiaca, Stipa sareptana, Koeleria cristata, Artemisia sublessingiana, Spiraea hypercifolia)* at the light brown sandy loams and light clay loam gravelly soils combined with *shrub-motley grass grass* (*Leymus ramosus, Poa stepposa, Potentilla bifurca, Medicago falcata, Spiraea hypericifolia, Caragana) at the* meadow-brown soils.

Division No	RGB color ratio			Content
30	138	171	71	Group of communities: Cold wormwood-sod grass *(Stipa capillata, Stipa sareptana, Festuca valesiaca, Cleistogenes squarrosa, Artemisia frigida)* steppes on crushed stonny light-brown soils, sometimes combined with a comlex of communities: wormwood-sod grass *(Stipa capillata, Festuca valesiaca, Artemisia compacta, A. frigida)* steppes at normal brown soils and wormwood-kokpek communities *(Atriplex cana, Artemisia nitrosa*) at brown alkalinized soils.
31	204	204	0	Sublessing wormwood-sheep fescue-feather grass (*Stipa lessingiana, Festuca valesiaca, Artemisia sublessingiana)* steppes on carbonate light brown soils, sometimes among the juncea - thin wormwood species *(Artemisia gracilescens, Psathyrostachys juntcea*) on alkalinized light-brown soils of the old alluvial plain.
32	155	188	88	Group of communities: thin wormwood-*sheep fescue-stipa* (Stipa sareptana, Festuca valesiaca, Artemisia gracilescens), *sod-kochia-thin wormwood* (Artemisia gracilescens, Kochia pmstrata, Festuca valesiaca, Stipa sareptana, Koeleria cristala) *at the light brown gravelly soils of uplands combined with shrub-motley grass-grass species* (Leymus paboanus, Aclnatherum splendens, Giycyrrhiza aspera, Iris balophila, Halimodendron halodendron, Caragana pumila) *at the meadow-brown soils of lowlands*.
33	235	230	0	Complex of communities: *Thin wormwood-sheep fescue-stipa* (Stipa sareptana, Festuca valesiaca, Artemisia gracilescens); kokpek *(Alriplex cana),* black wormwood (*Artemisia paciflora)* species on light-brown alkalinized soils; *aeluropus* (Aeluropus littoralis), *motley grass-grass* (Puccinellia dolicholepis, L. angustus, Leymus paboanus, Saussurea amara, Limonium gmelinii), *schrenk wormwood* (Artemisia schrenkiana), *kermec* (Limonium smelinii) *on meadow alkalinized soils*.
34	209	224	178	Community series: *sparganium (*Spaganium microcarpum) → *cattail family* (Typlta laxmannii) →*reeds* (Phragmites australis) →*motley grass-sedgy communities (Carex* stenophylloides, Epilobium parviflorum, Chamerion angustifolium, Rumex confertits, Mentha aquatica) →*motley grass-cereals* (Alopecurus arundinaceus, Elytrigia repens, Discbampsia cespitosa, Sanguisorba officinalis, Bidens tripartita, Filipendula ulmaria) →*grass-motley grass* (Thalictrum flavum, Glycyrrhiza uralensis, Potentilla virgata, Calamagrostis epigeios, Bromopsis inermis) →*motley grass - shrubs* (Salix cinerea, S. rosmarinifolia, Rosa glabrifolia, R. laxa, Lonicera tatarica, Padus avium, Galium boreale, Angelica deccurens), *sometimes with* Populus nigra, Betula pendula, Populus tremula, Crataegus clorocarpa →*tall cereals* (Achnatherum splendens, Leymus angustus, Halimodendron halodendron) →*wormwood-sod grass* (Festuca valesiaca, Stipa capillata, Poa stepposa, Artemisia nitrosa, A. pontica, A. dracunculus, A. marschalliana).

Division No	RGB color ratio			Content
35	230	238	214	Motley grass-sod grass *(Stipa capillata, Festuca valesiaca, Gatalella tatarica, Medicago bifurca)* steppes on normal brown soils, sometimes with motley grass-grass-shrub *(Spiraea hypericifolia, Rosa acicularis, Festuca valesiaca, Bromus inermis, Galium ruthenicum, Medicago romanica*) cenoses at meadow-brown salted soils of terrace above flood-plain of Irtysh river.
				Ecosystems of modern alluvial plains
36	138	226	138	Community series: *Hydrophytic motley grass* (Jincus gerardii, Heleocharis acicularis, Butomus umbellatus, Crypsis aculeata) → *motley grass-alkali grass - barley* (Hordeum brevisubulatum, Puccinellia dolicholepis, Lactuca tatarica. Inula britannica), → *motley grass-leys-reed grass* (Calamagrostis epigeios, Bromopsis inermis, Sanguisorba officinalis, Thalictrum flavum*) grass-motley grass* (Gatalella biflora, Achillea asiatica. Iris sibirica, Elytrigia repens, Leymus ramosus*) →licoric-grass* (Leymus angustus, Poa angustifolia, Glycyrrhizauralensis) →*cheegrass* (Acbnalherum splendens →*salt tree* (Halimodendron halodendron) *at the soils of meadow type - motley grass-wormwood-sod grass (*Festuca valesiaca, Stipa sareptana, Artemisia poitlica, Medicago falcate, Polenlilla bifutva) *at the meadow soils steppizated in the valley of temporary streamflows.*
37	0	255	0	Community series: *cattail-tuberous reeds* (Bolboschoenus planiculmis, Typha laxmannii → *cyperus-arundinaceous (*Cyperus fuscus, Scirpus lacustris) →*reed motley grass* (Phragmites australis, Lactuca tatarica, Glaux maritima*)* →*hydrophyte motley grass* (Crypsis aculeata, Juncus gerardii, Eleocharis acicularis, Brachyaclis ciliata, Chenopodium rubrum) → *plantain—single year* salsolaceaes (Salicornia europaea, Suaeda prostrata, Chenopoium botrys, Plattlago temiflora, P. maritima) → *motley grass- reeds* (Phragmites australis, Lactuca tatarica, Saussurea amara) → *halophytic-motley grass-cereals* (Aeluropus littoralis, Puccinellia dolicholepis, Limonium gmelinii, Erigeron canadensis*)* → *motley grass-grass* (Hordeum brevisubulatum, Leymus angustus. Inula caspica, Glycyrrhiza uralensis) → *salt tree-cheegrass* (Achnalherum splendens, Halimodendron halodendron) → *camphora-kokpek* (Atriplex cana, Camphorosma monspeliaca).
38	0	254	206	Community series: *reed communities* (Phragmites australis) *on meadow-marsh soils* → *glasswort- plantains* (Plantago tenuiflora, Salicornia europaea) → *motley grass-cereals* (Aelumpus littoralis, Puccinellia teinusssima, Saussurea robusta, Limonium coralloides) → *cereals-motley grass* (Inula caspica, Plantago maritima, Cirsium selosum, Leymus paboanus, Hordeum bogdanii) *at salted sandy channel alluvion → motley grass* (Hyssopus macranthus, Cynanchum sibiricum, Lagohilus pungens, Veronica incana*)* → Atraphaxis frutescens *on sandy pebble soils of channels of temporary streamflows.*

Division No	RGB color ratio			Content
39	213	255	234	Community series*: single year saline* (Salicornia europaea, Suaeda prostrata, Suaeda heterophylla) → *sea coast rib grass (*Plantago maritima) → *halophyte-motley grass (*Plantago salsa, Saussurea salsa, Rumex marschallianus, Glayx maritime, Limonium gmelinii) → *halophyte-grass* (Aeluropus liloralis, Puccinellia dolicholepis, Leymus paboanus*)* → *halophyte-wormwood (*Artemisia schrenkiana, A. nitrosa*)* → *halophyte- semishrub* (Halimione verrucifera, Camphorosma monspeliaca, Limonium suffruticosum) → *halophyte-shrubby communities (*Atriplex cana, Suaeda physophora, Nitraria sibirica, Tamarix hispida) *on saline soils of meadow range; wormwood-sod grass* (Stipa sareptana, Festuca valesiaca, Psathyrostachys junceum, Artemisia gracilescens, A. frigida) *at the steppificated meadow soils combined with a complex of black wormwood-biyung–tasenbiyung species* (Nanophyton erinaceum, Anabasis salsa, Artemisia pauciflora) *on eroded alkalinized soils of lake terraces*.
40	216	199	249	Complex of communities: *Sarzasanic* (Hatocnemum strobilaceum), *potash* (Kalidium shrenkianum), *sorang* (Suaeda physophora), *saltpetrous* (Nitraria sibirica), *biyurgun-obion* (Anabasis salsa, Halimione verrucifera) *on sor alkalinized soils;* *shrenk wormwood-azhrek* (Aeluropus littoralis, Artemisia schrenkiana), *alkali grass- gentle thistle-kermek* (Limonium suffruticosum, L. gmelinii, Saussurea amara, Puccinellia dolicholepis), *wild rye - cheegrass* (Achnatrherum splendens, Leymus angustus) *on meadow-type salt marshes; camphor-kokpek* (Atriplex cana, Camphorosma monspeliaca), *black wormwood* (Artemisia pauciflora), *kochia-grass-thin wormwood* (Artemisia gracilescens, Kochia prostrata), *grass-thin wormwood* (Artemisia gracilescens, Stipa sareptana, Festuca valesiaca, Psathyrostachys juncea) *at solonetzic soils of lake terraces*.
				Ecosystems of sors
41	102	0	255	Sarzasan (*Halocnemum strobilaceum)* and the sites with no vegetation.
				Anthropogenic-industrial ecosystems
42	255	204	255	*Demutation series of communities (recovery): groups of short-lived weeds* (Avena fatua, Lactuca altaica, Artemisia sieversiana, Barbarea stricta, Ceratocarpus arenarius) → *groups of weed plants; creeping-rooted and rhizogenous plurannuals (*Cirsium arvense. Convolvulus arvensis, Artemisia procera, Artemisia austriaca*)* → *sod grass - wormwood* (Artemisia marschalliana, A. dracunculus, Agropyron cristatum, Festuca valesiaca) → *communnities of motley grass-wormwood-sod grass* (Agropyron cristata, Festuca valesiaca, Stipa lessingiana, Artemisia sublessingiana, A. marschalliana, Medicago romanica *at the lands used for agricultural activities.*

Division No	RGB color ratio			Content
43	255	0	0	*Groups and communities including* Elaeagnus oxycarpa, Rosa majalis, Vexibia alopecuroides, Ciclochena xantifolia, Chenopodium album, Leymus angustus) *around urbanized terrain.* *Groups including: wormwood and Austrian wormwood* (Artemisia austriaca), oriental *wormwood* (Artemisia scoparia), Vexibia alopecuroides, *broom kochia* (Kochia scoparia), Kochia siversiana, *wild spin* (Chenopodium album), *Climacoptera* (Climacoptera brachic) *Ebelek* (Ceratocarpus arenarius) *near the winterings.*

LITERATURE

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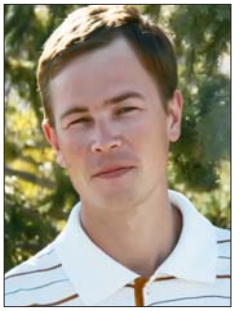

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Issue 5

Optimization of study of the Semipalatinsk Test Site lands for the purpose of their transfer into economic turnover

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