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«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

ХАБАРЛАРЫ

ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ
АКАДЕМИИ НАУК РЕСПУБЛИКИ
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ASSESSMENT OF DEFORMATION AND RADIATION STATE OF ADJACENT TERRITORIES OF THE DEPOSIT "KARAZHYRA"

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Abstract. The Semipalatinsk Test Site (STS) has been the site of numerous nuclear tests, resulting in significant environmental contamination by radionuclides. Additionally, the Karazhyra coal deposit is currently being developed within this territory. According to the legislative acts of the Republic of Kazakhstan, the entire STS area is presently classified as reserve land. Ensuring the safety of this territory for economic activities remains a critical challenge, necessitating an assessment of its deformation state and a forecast of radioecological situation. To address this issue, comprehensive monitoring approach-integrating geodetic, satellite, and radioecological methods-is required to evaluate the area and provide recommendations for its potential economic use.

Purpose of the work. This study aims to develop a geodetic monitoring

framework for the Karazhyra coal deposit, located within the Balapan test site, where underground nuclear explosions were conducted. The objective is to assess deformation state of territory and determine cadastral value of contaminated land plots. *Results.* The paper presents results of scientific work conducted by the authors on geodetic monitoring of deformation processes on the earth's surface, as well as zoning of contaminated lands with the establishment of their cadastral value. *Scientific novelty.* Method for creating geodynamic polygon is proposed. This approach enables effective monitoring of land deformation dynamics and allows for adjustment of land assessments based on contamination levels.

Practical significance. Proposed geodynamic monitoring approach for assessing the SNTS territory is applied in master's and PhD dissertations and integrated into the educational processes of the Kazakh National Research Technical University (KazNITU), the Eurasian National University (ENU) and the International Educational Corporation **(**IEC**).**

Keywords: Semipalatinsk Test Nuclear Polygon, radionuclide contamination, land parcel boundaries, «Karazhira» coal deposit.

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«ҚАРАЖЫРА» КЕНОРНЫНА ЖАҚЫН АЙМАҚТЫҢ ДЕФОРМАЦИЯЛЫҚ ЖӘНЕ РАДИАЦИЯЛЫҚ ЖАҒДАЙЫН БАҒАЛАУ

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Аннотация. Семей сынақ полигоны (ССП) аумағында көптеген ядролық сынақтар жүргізілді, бұл қоршаған ортаның радионуклидтермен ластануына әкелді. Сонымен қатар бұл аймақта «Қаражыра» көмір кен орны игерілуде. Қазақстан Республикасының заңнамалық актілеріне сәйкес, қазіргі уақытта ССП-ның барлық аумағы босалқы жерлерге жатқызылған. Қазіргі жағдайда адамның шаруашылық қызметі үшін аумақтың қауіпсіздігін қамтамасыз ету кезек күттірмейтін міндет болып табылады, бұл деформация жағдайын бағалауды және радиоэкологиялық жағдайды болжауды талап етеді. Ол үшін жерді халық шаруашылығына пайдалану бойынша кейінгі ұсыныстармен аумақты бағалау үшін кешенді мониторингтің (геодезиялық, ғарыштық, радиоэкологиялық) мүмкіндіктерін пайдалану қажет.

Жұмыстың мақсаты. Ластанған жер учаскелерінің деформациялық және ластанған жағдайын бағалау үшін жерасты ядролық жарылыстары жүргізілген Балапан полигонының аумағында орналасқан Қаражыра көмір кен орнының аумағына кешенді мониторинг жүргізу сызбасын әзірлеу. *Нәтижелері.* Жұмыста жер бетінің деформация процестеріне геодезиялық мониторинг жүргізу, сондай-ақ ластанған жерлерді анықтау аймақтарға бөлу бойынша авторлар жүргізген ғылыми жұмыстардың нәтижелері берілген. *Ғылыми жаңалығы.* Жерлердің деформациялық жағдайының өзгеруіне және ластану деңгейіне байланысты тиімді бақылауға мүмкіндік беретін геодинамикалық полигон құрудың әдістемесі ұсынылған.

Практикалық маңызы. ССП аумағын бағалаудың геодинамикалық полигонын құрудың ұсынылған әдістемесі Қ.И. Сәтбаев атындағы Қазақ Ұлттық техникалывқ зерттеу университетінің, Гумилев атындағы Еуразия ұлттық университеті (ЕҰУ) және Халықаралық білім беру корпорациясының (ХБК) оқу процесінде магистранттар мен докоранттардың диссертацияларында қолданылады.

Түйін сөздер: Семипалатинск ядролық сынақ полигоны, радионуклидтік ластану, жер учаскелерінің шекаралары, кен игеру, «Қаражыра» көмір кен орны.

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ОЦЕНКА ДЕФОРМАЦИОННОГО И РАДИАЦИОННОГО СОСТОЯНИЯ ПРИЛЕГАЮЩИХ ТЕРРИТОРИЙ МЕСТОРОЖДЕНИЯ «КАРАЖЫРА»

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Аннотация. На территории Семипалатинского испытательного полигона (СИП) проводились многочисленные ядерные испытания, что привело к значительному загрязнению радионуклидами окружающей среды. К тому же, на данной территории разрабатывается угольное месторождение «Каражыра». В соответствии с законодательными актами РК, в настоящее время вся территория СИП отнесена категории земель запаса. Сложившихся условиях актуальной задачей является обеспечение безопасности территории для хозяйственной деятельности человека, для которой необходимы оценка деформационного состояния и прогноз радиоэкологической ситуации. Для этого необходимо использовать возможности комплексного мониторинга (геодезического, космического, радиоэкологического) для оценки территории с последующей рекомендаций по использованию земель для народного хозяйства.

Цель работы. Разработка схемы геодезического мониторинга территории угольного месторождения «Каражыра», которое расположено на территории испытательной площадки «Балапан», где были проведены подземные ядерные

взрывы, для оценки деформационного состояния и кадастровой стоимости загрязненных земельных участков.

Результаты. В работе приведены результаты научных работ, проведенных авторами по геодезическому мониторингу деформационных процессов земной поверхности, а также зонированию загрязнённых земель с установлением их кадастровой стоимости.

Научная новизна. Предложена методика создания геодинамического полигона, которая позволяет эффективно отслеживать изменения в деформационном состоянии земель и корректировать оценку в зависимости от уровня загрязнения.

Практическая значимость. Предложенная методика создания геодинамического полигона для оценки территории СИЯП, используется диссертационных работах магистрантов, докторантов, в учебных процессах Казахского национального исследовательского технического университета (КазНИТУ) имени К.И. Сатпаева, Евразийского национального университета (ЕНУ) имени Гумилева и Международной образовательной корпорации (МОК).

Ключевые слова: Семипалатинский испытательный ядерный полигон, радионуклидное загрязнение, границы земельных участков, разработка, угольное месторождение «Каражыра».

Introduction. About 75% of its territory (territory of the Aral Sea and Semipalatinsk Test Site), the coast of the Caspian Sea, desert and semi desert pastures of Central and Southern Kazakhstan, etc.) are subject to an increased risk of environmental disruption. STS was one of the main test sites used for nuclear weapons tests for 40 years (Materials, 2012, 150; Space, 2002. 488).

Currently, the Karazhyra coal deposit is being developed within the landfill territory, salt is being extracted from Lake Zhaksytuz, geological surveys and exploration are underway, hay is being harvested, and cattle are being grazed. These activities, first, contribute to the spread of radioactive contamination both within and beyond the landfill's boundaries. Second, they pose additional risks to workers, the regional population, and consumers of the resulting products. Exploiting mineral deposits without considering the radioactive environment and hydrogeological maps of contamination can result in the complete loss of the deposit. The territory, soil, and minerals may remain contaminated for hundreds or even thousands of years (Environmental, 2016).

That is why studying the natural environment—including soil and vegetation, water and air quality, and local fauna—is essential for the region. Contaminated lands and areas near the landfill, affected by radionuclide fallout, require continuous monitoring and assessment to determine their suitability for agriculture, industry, and other sectors. As portions of the STS territory are being transitioned to economic use, a top priority is conducting comprehensive studies and implementing measures to ensure safe economic activities in these areas (Lukashenko, 2010, 343; Subbotin, et al., 2010, 8; Umirbaeva & Omirjanova, 2019:4; Issabekova, et al., 2023:6).

Example of such activity is the development of the Karazhyra coal deposit, which is located on the territory of the Balapan test site, where underground nuclear explosions were carried out in 106 combat wells (Fig. 1)

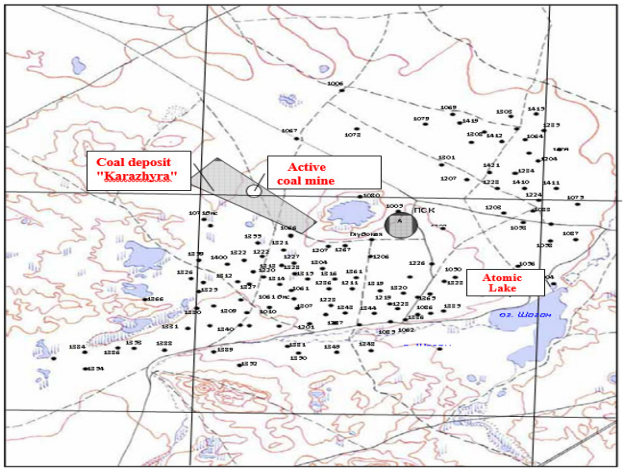

Fig. 1 - Map of the location of test wells at the Balapan site, the «Karazhyra» coal deposit and the « Atomic Lake».

Object and subject of research. *The object of this study* is the territory of the Semipalatinsk Test Site (STS). *The subject of the study were*: 1) geological, tectonic and hydrogeological conditions of adjacent territories; 2) deformations of the earth's surface; 3) waste rock and coal dumps; 4) snow, soil and plants. Samples were collected according to GOSTs and methodological recommendations. Field studies were conducted in the impact zone of the Karazhyra coal deposit, located 130 km southwest of the city of Semey in the Abay region of the Republic of Kazakhstan (Fig. 2).

Fig. 2 - General view of the Karazhyra coal mine

Research methods. To monitor deformations of the STS territory, it is proposed to create geodynamic polygon (GDP) with local networks, which will allow monitoring changes in the earth's surface and minimizing the impact of radiation on environmental components.

Experimental data were processed by variational statistical methods using the Microsoft Excel program. The most effective method in this case is the creation of Geographic Information system (GIS), which allows not only to save the existing data and provide easy access to them, but also to conduct modeling, the results of which can be combined with geographical and space images of the region under study.

Results: Currently, environmentalists and environmental agencies in the Republic of Kazakhstan are paying close attention to the quality and radioactivity levels of coal extracted from the Karazhyra deposit. This coal serves as the primary fuel source for energy and industrial enterprises, as well as for residents of the East Kazakhstan and Abay regions. Therefore, ensuring environmental safety and maintaining coal quality are critical concerns for much of the region's population. The Karazhyra deposit is developed through open-pit mining.

The surrounding area is intersected by the Kalba-Chingiz fault, which includes major fractures such as the Kishkentai, Karazhirek, and Chinrau faults (Subbotin, 2010, 4; Adushkin, 2016,108; Zholtaev, 2018, 9).

Foliation zones along these faults can be tens of meters thick and tilt at an angle of 70–80° to the southwest (for the Karazhirek and Karazhiri faults) and to the northeast (for the Kishkentay fault). Along the Karazhiri fault, thrusts of Paleozoic layers onto Jurassic coal-bearing deposits are observed, the tilt angle of which varies from 20 to 80°. The Chinrau fault zone tilts to the northeast at an angle of 50–80°. Due to the gently sloping bedding of coal-bearing rocks, their outcrops beneath the overlying loose layers in the northwest of the deposit extend for nearly 4 km. In the southeast, where the bedding is steeper, these outcrops measure approximately 750 m in length, with weakly expressed folding. Underturns of coal-bearing rocks are observed only near tectonic faults. In the central part of the deposit, no significant fractures complicate the coal-bearing strata (Fig. 3).

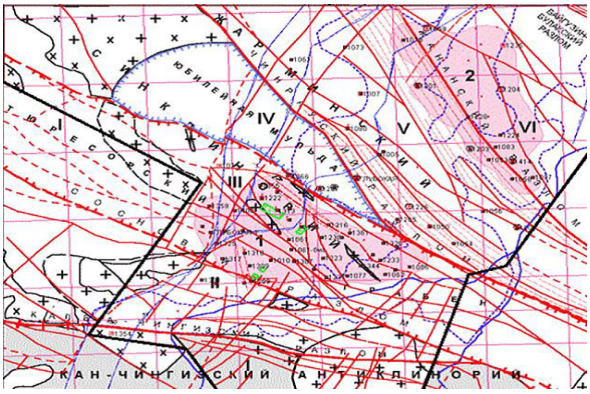

Fig. 3 - Tectonic scheme of the adjacent territory of Karyzhyra

In the northeast, the ridge is bounded by the Chinrau fault upthrust, and in the southwest by the Karazhir fault upthrust, along which there are overthrust structures (Baybatsha, 2013).

The sites of the Semipalatinsk test site are robust rocks of granite origin. Granites have low absorption properties of elastic seismic vibrations. Therefore, underground explosions are accompanied by significant tremors. Totally 343 underground explosions were conducted, each of them lead to earth movement. Rock destructions during nuclear underground explosions as formation of new open fissures and ancient tectonic structure are taken place, which caused depression of earth surface (Zejlik, 2013). Fig.4 shows structure section of one of the fields of underground tunnel, where nuclear object is located in the last box.

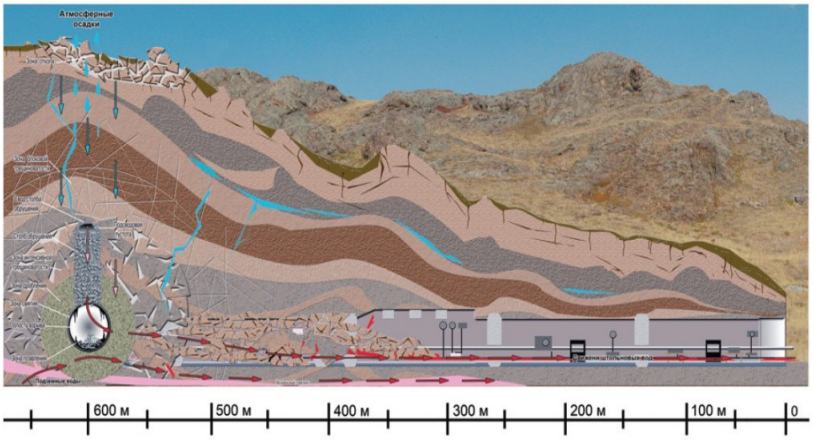

Fig.4 - Location of nuclear object in the test site

At many sites, underground nuclear tests have led to deformation of the day surface in their epicentral zones. This indicates that various geodynamic processes occur above focal cavities after several decades as a result of previously conducted underground nuclear explosions.

Geodetic monitoring. To monitor deformations of the STS territory, common geodynamic polygon (GDP) with local networks was created, consisting of a network of benchmarks, which will allow monitoring changes in the earth's surface.

Local networks «Balapan», «Atomic Lake», «Karazhyra» of the geodynamic polygon were created. Electronic and satellite GPS devices were used to determine the coordinates of the planned altitude network of the GDP, which provided a unique opportunity to quickly and accurately determine the parameters of the rock mass displacement and conduct regular, continuous observations of the change in these parameters over time. Various leveling methods were used to accurately determine subsidence of the earth's surface:

Geometric leveling is used for areas with minimal radiation contamination and allows changes to be recorded with high accuracy.

Trigonometric leveling is used in conditions of increased background radiation, where it is necessary to minimize presence of workers in hazardous areas. In such cases, fan-shaped trigonometric leveling with short beams is used.

Leveling was performed in the forward and reverse directions with a change in the height of the instrument at the station. The height of the sighting beam above the underlying surface was not less than 0,5 m, the length of the sighting beam did not exceed 20 m, and the difference in arms was 0,5 m.

Over the next two periods (2017-2018 and 2020-2023), steady decrease in the marks of all benchmarks is observed, which indicates subsidence of daylight surface in vicinity of combat wells. At many sites, underground nuclear tests led to deformation of daylight surface in their epicentral zones.

Such a phenomenon poses danger to enterprises developing minerals in the immediate vicinity of these sites.

In 2020 and 2023, topographic survey was carried out at the Atomic Lake site. To install geodetic and environmental instruments and speed up measurement operations, we have developed permanent benchmark installed at the control point during monitoring, where the upper part of the center is equipped with a forced centering table (Patent №. 4700, 2020; Aitkazinova, et al., 2020, 8; Nurpeisova et al., 2021, 10). The nature of the earth's surface deformations (subsidence and uplift) noted on the profile lines indicates ongoing geomechanical processes after the explosion and requires further monitoring to establish causes of processes occurring.

Radioecological monitoring. Results of radioecological researches conducted in STS territory in 2014 and 2015 have revealed areas of significant radioactive contamination with nuclear materials. The bulk of the radionuclides formed during the explosions fell directly at the «Balapan» and «Atomic Lake» test sites. To identify technogenic objects on the territory of «Balapan» space images were studied, which allowed identifying a number of objects, including large epicenters. Then field visits were conducted to inventory technogenic objects and assess the degree of technogenic disruption of natural landscape.

The first stage included identifying radioactively contaminated areas, drawing up survey maps with different pitches: 200x200; 100x100 and 40x40 meters. Then a pedestrian gamma survey was conducted, including measuring the EDR at nodal points using Radiagem 2000 dosimeter-radiometer.

The second stage included study of the vertical distribution of radiation in the epicentral zones of the sites. It consisted of collecting soil and water samples at different distances from the epicente (Nikonov, et al., 20131, 10; Nurpeisova, et al., 2019, 11; Sanitary, 2009, 80).

As a result of nuclear tests at the SNS, valley of Shagan river has been exposed to radioactive contamination to one degree or another. Basically, radioactive components contamination of the river's ecosystem is concentrated near «Atomic» lake, where excavation nuclear explosion was carried out in well № 1004, and pollution was caused by underground nuclear tests in «combat» wells of «Balapan»

site. Lake Chagan is included by the government of Kazakhstan in the list of areas especially badly affected by nuclear tests. Some species of fish still live in the lake, but eating them is highly discouraged. Water in the lake is not suitable for drinking and irrigation of agricultural land. Level of radioactive substances contained in it, especially tritium *(^3H)* is hundreds of times higher than the permissible levels.

The main danger to humans is only the zone of soil heap around the Atomic Lake, with a radius of 3-4 km, which should be considered as a serious potential source of secondary pollution of environmental objects (water, vegetation, air). As a result of studies in 2018-2020, the presence of high concentrations of ^3H in the waters of the Shagan River at a distance of 5 km downstream from the Atomic Lake was identified and repeatedly confirmed (Fig. 5).

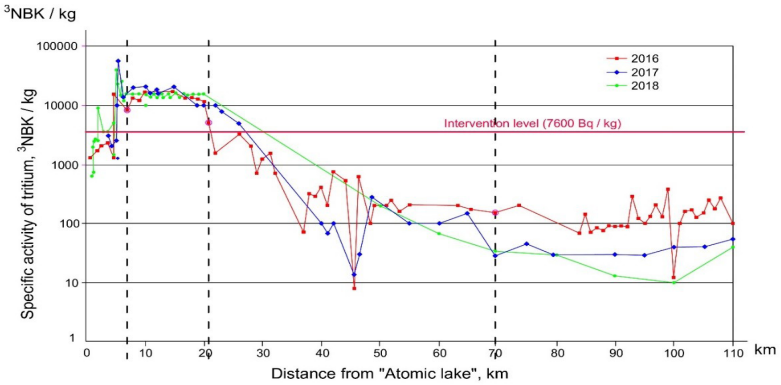

Fig. 5 – Concentration of tritium (^3H) in the waters of the Shagan River depending on the distance from the «Atomic Lake»

In order to understand the process of tritium transfer, we divided graph (Fig. 10) into four sections and for each of them we deduced dependencies:

1) tritium concentration increases according to the formula

$$n = 1000 \cdot 10^{0,242 \cdot L} \text{ (Bq /m}^3\text{), over } 0 < L \leq 5 \text{ km;} \quad (1)$$

where n – specific activity of tritium Bк/m^3;

L- distance from, «Atomic Lake », km.

2) tritium concentration practically does not change and is equal to

n =16200 (Bq /m^3), over 5< L ≤ 20 km; (2)

3) in the third section, tritium concentration decreases according to the formula

$$n = 16200 \cdot 10^{0,054 \cdot (L-20)} \text{ (Bq /m}^3\text{), over } 20 < L \leq 70 \text{ km;} \quad (3)$$

4) tritium concentration slowly increases according to the formula

$$n = 31,6 \cdot 10^{0,005 \cdot (L-70)} \text{ (Bq /m}^3\text{), over distance } > 70\text{km;} \quad (4)$$

It should be noted that, in theory, migration of tritium should stabilize in the fourth section, but research data (2016 - 2018) shows slow increase in concentration.

Perhaps this is the transfer of technogenic radionuclides by the wind, as well as washing away by atmospheric precipitation both on the surrounding area and into Shagan river channel with further transfer of radionuclides by surface water flow. In any case, this is topic for further research (Zejlik, 2013, Ustavich, et al, 2015).

Discussion. Thus, only at distance of 40 km from the «Atomic» lake along river bed, limited residence zone of population ends and zone of relatively satisfactory radiation situation begins, where concentration of ^{3}H in air is <140 Bq/ m^3 It is worth noting that limited stay zones of population and dangerous radiation situation are small in width - several tens of meters. So, already at distance of 50 m from channel, content of ^{3}H in the air is safe for humans throughout Shagan River.

Results of radioecological studies conducted on the territory of the SNT in 2010-2023 revealed areas of significant radioactive contamination with nuclear materials (Fig. 6).

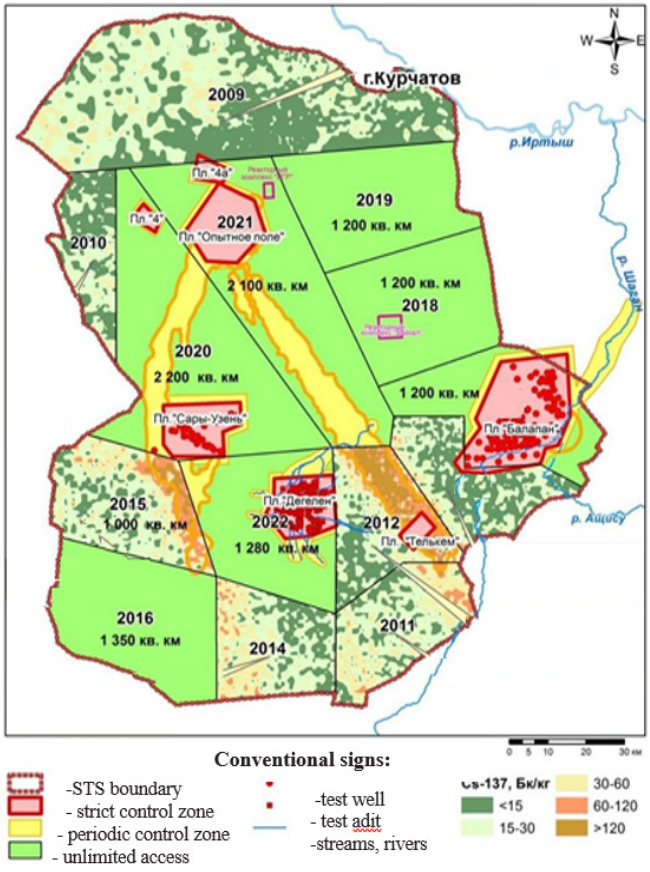

Fig. 6 - Zoning of the STS territory by radiation pollution (based on the results of monitoring in 2010-2023

Nuclear explosions contain several hundred different radionuclides. Among them, the most “persistent”, long-lived are cesium-137, strontium-90. The bulk of the radionuclides formed during the explosions fell directly in the test sites («Balapan», «Atomic» lake).

Since 2023, comprehensive monitoring of the so-called «combat» wells has been carried out on the territory of the Balapan and Sary-Uzen test sites. As a result, the nature of the change in the daytime surface was established - uplift and subsidence, which may indicate various processes occurring above the focal cavities of underground nuclear explosions (UNE). This can lead to dangerous phenomena both at the sites themselves and at a distance from them.

Conclusions

1. The study of the consequences of long-term nuclear tests on territory of the former Semipalatinsk Test Site (STS) and assessment of radioecological state of the soil cover of the lands are among the most pressing problems of the region. For objective assessment of consequences of nuclear explosions on natural environment of polygon, considering study of general radiation situation on it, methodology for conducting comprehensive (space, geodetic, radioecological) monitoring has been developed, determining main deformation and environmental consequences of the STS activities.

2. Based on developed methodology for conducting comprehensive monitoring of state of natural environment, geodynamic polygon has been created to monitor lands adjacent to the territory of the Karazhyra coal deposit, which is important step in management of radiation-contaminated territories. This system allows not only to track changes in deformation of the earth’s surface, but also to adjust the cadastral valuation of lands, which contributes to the safe and rational use of territories.

3. Based on the use of GIS technologies, assessment maps have been created that characterize the geodetic, radiological and ecological information of the STS territories and allow making decisions on the safe use of the lands of the test site. Results obtained from geodetic observations allow substantiating recommendations for improving the operation of local networks and creating regional network on their basis for entire STS. This will allow further study of geodynamic processes and construction of maps of modern movements of the earth’s crust for the entire territory of the STS.

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