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ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

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RESEARCH OF THE CHARACTERISTICS OF UNDERGROUND AND SURFACE POLLUTION OF LAKE KISHKENSOR ON THE TERRITORY OF THE SEMIPALATINSK TEST SITE

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Abstract. The direct consequences of nuclear explosions at the Semipalatinsk test site have been well studied, however, unique phenomena may appear under special circumstances. One of the unique radiation objects is Lake Kishkensor, the radiation contamination of which was discovered 27 years after the last underground nuclear explosion. According to one version, the source of radioactive contamination of Lake Kishkensor is the nearest "combat" well (1366), according to another version, contaminated groundwater is transferred to the lake through the regional Sosnovy fault, which passes through the Balapan test site, where any of the "combat" wells in the zone of its influence can be a source of radioactive contamination.

The study employed isotope hydrology techniques, laboratory analysis of radionuclides, and monitoring of groundwater, surface waters, and bottom sediments. Systematic sampling was conducted and analyzed using spectrometry and radiochemical preparation. The primary sources of contamination were identified as atmospheric fallout from nuclear tests and the inflow of contaminated

groundwater. The highest concentrations of ^{3}H and ^{90}Sr were observed in the southern part of the lake, with seasonal variations in contamination levels. Radionuclides ^{137}Cs and $^{239+240}Pu$ were confined to bottom sediments without significant migration into surface waters.

Thus, this article presents the results of a study of the nature and mechanism of radionuclide contamination of a lake located on the territory of the Semipalatinsk test site. As a result of the study, a new local area of radiation contamination of the daylight surface on the territory of the test site was discovered. The findings provide a scientific foundation for developing radiation monitoring programs and ecosystem rehabilitation strategies in contaminated areas. The methods and conclusions can also be applied to similar aquatic systems affected by radionuclide contamination.

Keywords: Semipalatinsk Test Site, 'Balapan' site, Lake Kishkensor, contamination, tritium, strontium, plutonium, cesium, ground waters, surface waters, bottom sediments.

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СЕМЕЙ СЫНАҚ АЛАНЫҢДАҒЫ КІШКЕНСОР КӨЛІНІҢ ЖЕР АСТЫ ЖӘНЕ ЖЕР ҮСТІ ЛАСТАНУ ЕРЕКШЕЛІКТЕРІН ЗЕРТТЕУ

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Аннотация. Семей полигонындағы ядролық жарылыстардың тікелей салдары жақсы зерттелген, алайда ерекше жағдайларда ерекше құбылыстар пайда болуы мүмкін. Бірегей радиация ошақтарының бірі – Кішкенсор көлі, оның радиациялық ластануы соңғы жерасты ядролық жарылысынан кейін 27 жылдан кейін анықталған. Бір нұсқа бойынша Кішкенсор көлінің радиоактивті ластану көзі ең жақын орналасқан «жарылыс» ұңғыма 1366

онда оның әсер ету аймағындағы «жауынгерлік» ұңғымалардың кез келген ұңғылары радиоактивті ластану көзі болуы мүмкін.

Зерттеуге изотоптық гидрологиялық әдістер, радионуклидтердің зертханалық талдауы және жер асты суларының, жер үсті суларының және түбі шөгінділерінің мониторингі кірді. Үлгілер жүйелі түрде жиналып, спектрометрия мен радиохимиялық препаратты қолдану арқылы талданды. Көлді ластаудың негізгі көздері ядролық сынақтардың атмосфералық төгінділері және ластанған жер асты суларының ағыны екені анықталды. ^{3}H және ^{90}Sr ең жоғары концентрациясы ластану деңгейінің маусымдық ауытқуы тіркелген көлдің оңтүстік бөлігінде байқалды. Радионуклидтер ^{137}Cs және $^{239+240}$Pu су ортасына айтарлықтай ауыспай-ақ түбіндегі шөгінділерде локализацияланған күйінде қалады.

Осылайша, бұл мақалада Семей полигоны аумағында орналасқан көлдің радионуклидтік ластануының табиғаты мен механизмін зерттеу нәтижелері берілген. Зерттеу нәтижесінде полигон аумағында күндізгі жарық бетінің радиациялық ластануының жаңа жергілікті аймағы анықталды. Зерттеу нәтижелері радиациялық бақылау және радиациялық ластанудан зардап шеккен аймақтардағы экожүйелерді қалпына келтіру бағдарламаларын әзірлеу үшін пайдалы. Әдістер мен нәтижелерді ұқсас проблемалардан зардап шегетін басқа су объектілеріне қолдануға болады.

Түйін сөздер: Семей полигоны, Балапан полигоны, Кішкенсор көлі, ластану, тритий, стронций, плутоний, цезий, жер асты сулары, жер үсті сулары, түп шөгінділері..

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ИССЛЕДОВАНИЕ ОСОБЕННОСТЕЙ ПОДЗЕМНОГО И ПОВЕРХНОСТНОГО ЗАГРЯЗНЕНИЯ ОЗЕРА КИШКЕНСОР НА ТЕРРИТОРИИ СЕМИПАЛАТИНСКОГО ИСПЫТАТЕЛЬНОГО ПОЛИГОНА

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Аннотация. Прямые последствия ядерных взрывов на Семипалатинском полигоне хорошо изучены, однако, в особых обстоятельствах могут появляться уникальные феномены. Одним из уникальных радиационных объектов является озеро Кишкенсор, радиационное загрязнение которого обнаружено спустя 27 лет после проведения последнего подземного ядерного взрыва. По одной из версий, источником радиоактивного загрязнения озера Кишкенсор является ближайшая «боевая» скважина (1366), по другой версии – загрязненные подземные воды переносятся в озеро через региональный разлом Сосновый, который проходит через испытательную площадку «Балапан», где любая из «боевых» скважин в зоне его влияния может являться источником радиоактивного загрязнения.

Исследование включало изотопно-гидрологические методы, лабораторный анализ радионуклидов и мониторинг грунтовых и поверхностных вод, а также донных отложений. Пробы отбирались системно, анализировались с помощью спектрометрии и радиохимической подготовки. Установлено, что основные источники загрязнения озера — это атмосферные выпадения после ядерных испытаний и приток загрязнённых грунтовых вод. Максимальная концентрация ^{3}H и ^{90}Sr наблюдалась в южной части озера, где зафиксированы сезонные колебания уровней загрязнения. Радионуклиды ^{137}Cs и $^{239+240}Pu$ остаются локализованными в донных отложениях без значительной миграции в водную среду.

Таким образом, в данной статье представлены результаты исследования характера и механизма радионуклидного загрязнения озера, расположенного на территории Семипалатинского испытательного полигона. В результате исследования был обнаружен новый локальный участок радиационного загрязнения дневной поверхности на территории полигона. Результаты исследования полезны для разработки программ радиационного мониторинга и восстановления экосистем в зонах, подвергшихся радиационному загрязнению. Методы и выводы могут быть применены к другим водоёмам, страдающим от аналогичных проблем.

Ключевые слова: Семипалатинский испытательный полигон, площадка «Балапан», озеро Кишкенсор, загрязнение, тритий, стронций, плутоний, цезий, подземные воды, поверхностные воды, донные отложения

Introduction. For the territory of the former Semipalatinsk test site, it is extremely important to promptly identify areas of migration of man-made radionuclides with water flows, since at present the aquatic environment at the test

site serves as a source of secondary pollution of the environment. Various areas with high values of man-made radionuclides in surface waters were identified. Today, the direct consequences of underground nuclear explosions have been well studied, however, unique phenomena may appear under special circumstances. One of such objects is a system of lakes, radioactive contamination of which was discovered 27 years after the last underground nuclear explosion at the Semipalatinsk test site. In particular, unexpected radioactive contamination (^{3}H, ^{90}Sr and $^{239+240}$Pu) of the daylight surface of natural lakes in the western part of the Balapan section of the Semipalatinsk test site was discovered (Lyakhova, et al, 2012; Aktayev, et al, 2023; Aidarkhanov, et al, 2013; Subbotin, et al, 2013; Gorbunova, et al, 2012).

The lakes under study are natural reservoirs of the test site and are located near the western border of the Balapan test site, which was used from 1965 to 1989 to conduct underground nuclear tests in boreholes (vertical mine workings) at a depth of 270 to 1200 m (Fig 1).

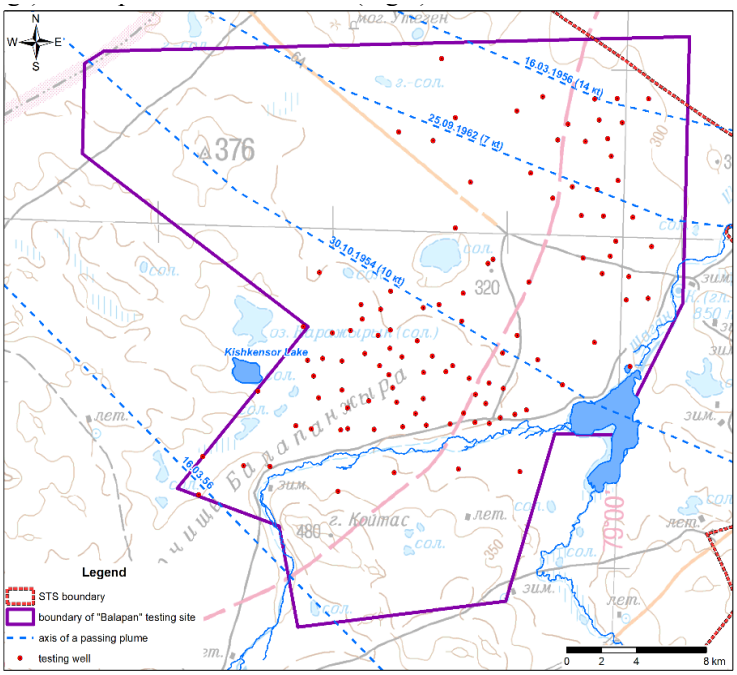


Fig 1. Location of Lake Kishkensor in the vicinity of the 'Balapan' site

Previous in-depth research conducted at the Balapan site revealed the presence of artificial radionuclides in the waters of natural lakes Karazhurek and Kishkensor. The measured specific activity of ^{3}H in Lake Shunkursor's water reached 30 Bq/kg, while in Lake Kishkensor, it was as high as 5000 Bq/kg. The concentration of 90Sr in the water ranged between 1 and 5 Bq/kg (Aktayev, et al, 2023; Aidarkhanova, et al, 2022).

According to one version, the source of radioactive contamination of Lake Kishkensor is the nearest "combat" well; according to another version, contaminated groundwater is transferred to the lake through the regional "Sosnovy" fault, which passes through the Balapan test site, where any of the "combat" wells in its zone of influence can be a source of radioactive contamination (Subbotin, et al, 2010).

Overall, the discovery of radioactive contamination in lakes decades after the explosions suggests that the effects of nuclear testing may be more complex and long-lasting than previously thought at the Semipalatinsk Test Site.

It is necessary to understand how the nuclear explosions affected the formation of lakes and how radionuclides entered the lakes and continue to spread. This will help to assess the long-term effects of the tests and develop measures to protect the environment.

Materials and research techniques

Bottom sediments and soils. For research into man-made radionuclides in bottom sediments and soils, the inundable zone between the rim and the boundary of surface waterflood was outlined on the map. Bottom sediment sampling points were located at nodes of a 150x150 meter rectangular grid. Soil sampling points were located at nodes of a 250x250 m grid. The sampling scheme is depicted in the figure (Fig *2*).

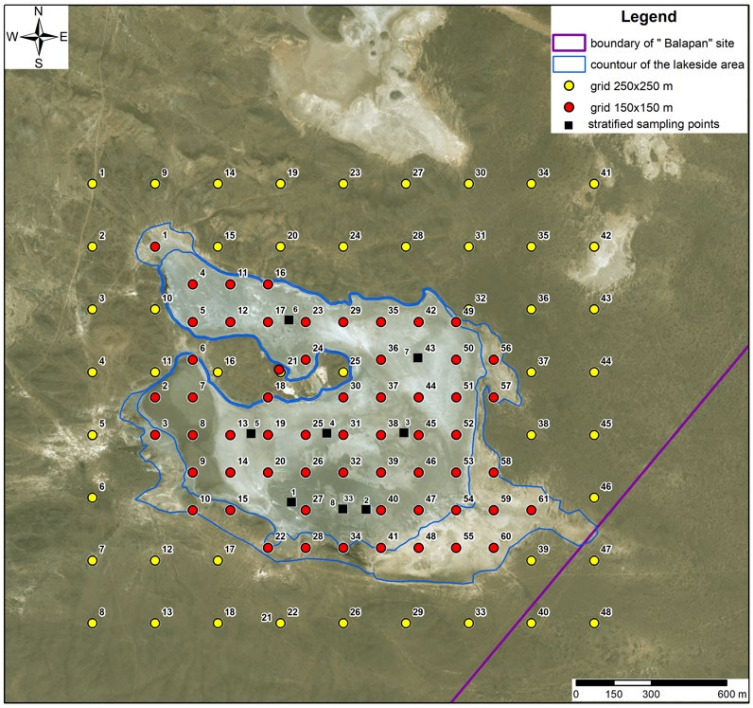


Fig 2. The sampling scheme of bottom sediments and soils at Lake Kishkensor

Bottom sediment samples and soil were obtained from the designated locations. The collection process utilized a specialized metal instrument, allowing samples to be taken from a depth of 0 to 5 cm. To study the vertical distribution of radionuclides in bottom sediments, eight specific sampling locations were designated (Fig 2). Stratified bottom sediment sampling was accomplished down to 60 cm deep at a 20 cm interval.

Surface waters. Surface water samples were collected using a polyethylene container specifically designed for water intake.

Ground waters. Groundwater research was conducted in areas anticipated to be pathways for ground and fracture water movement. For this purpose, exploratory boreholes were drilled, with their locations strategically chosen based on the proximity of existing 'warfare' boreholes in the surrounding area (Fig 3).

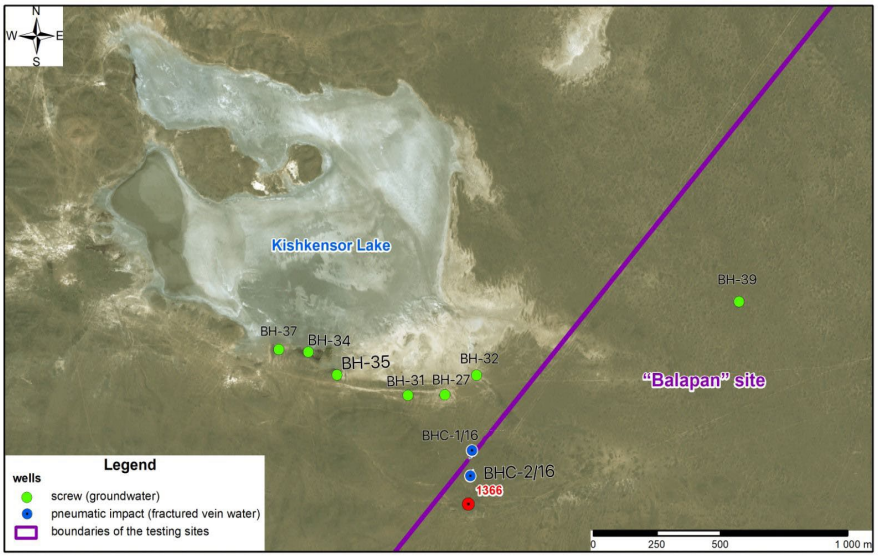


Fig 3. Research areas of ground waters

The groundwater study was conducted for ground and fracture waters in the wells shown in the figure. The study depth was from 1.5 to 17 m.

Study of water exchange processes. The utilization of an isotope hydrology technique is currently one of direct methods to obtain information on conditions under which various types of waters are produced. Research into the ratio of stable hydrogen (^{2}H) and oxygen (^{18}O) undelay the technique (For, 1989; Vasilchuk, et al, 2000; Craig, 1961). A laboratory analysis to determine the ratios of stable isotopes 2H/18Oin samples was carried out in order to study water exchange processes. For the comparative analysis, values derived were overlaid onto the local line of meteoric water with data on these isotopes in the regional precipitation (Toktaganov, et al, 2018).

Laboratory analysis. The measurement of the ratio of stable isotopes $^{2}H/^{1}H$ and $^{18}O/^{16}O$ in the measured sample and in the standard was carried out on a highly sensitive laser spectrometer LGR 912-0008. Water samples calibrated against the International Standard VSMOW (IAEA) were used as internal standards. Gamma-spectrometric studies of the prepared samples were carried out in accordance with the measurement procedure on the MI 2143-91 RK gamma-spectrometer. The measurement time for each sample was determined experimentally depending on the activity of the radionuclide being studied. In cases where the specific activity of the man-made radionuclide was less than 100 Bq/kg, the sample measurement time was 2 hours. Beta-spectrometric studies of environmental samples were carried out in accordance with the international standard ISO 9698:1989 (E). The measurement time of the prepared counting sample was about 120-180 minutes. The quenching correction in the sample was determined using the external standard 133Ba. The liquid scintillation spectrometer used was TRI-CARB 2900. The analysis of the prepared samples for the content of $^{239+240}Pu$, ^{238}Pu was carried out in accordance with the methodology, and in accordance with the passport for the spectrometer and the GENIE2000 software.

Results

The study of man-made radionuclides in bottom sediments and soils focused on their content and distribution

The results, illustrating the spatial patterns of ^{3}H and ^{137}Cs concentrations in these sediments and soils, are presented in the accompanying figure (Fig 4).

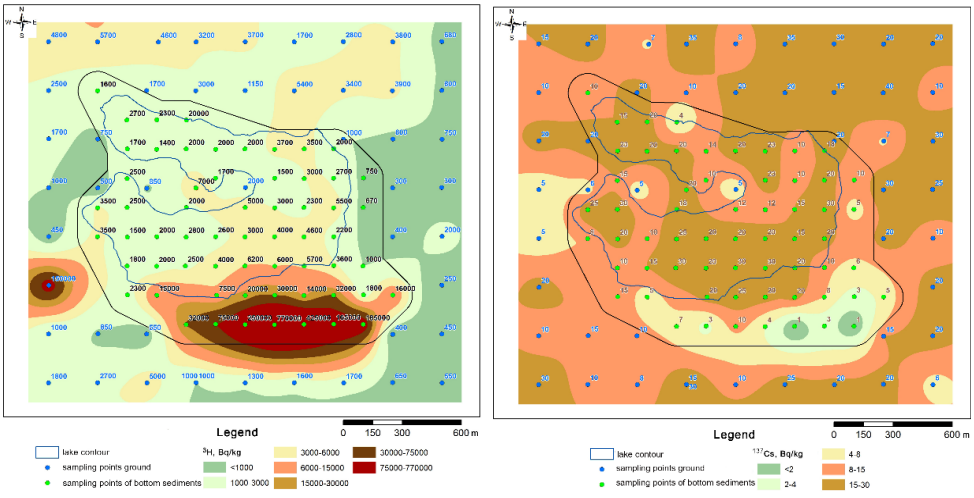


Fig 4. ^{3}H and ^{137}Cs distribution in bottom sediments and soils

According to findings, ^{3}H concentration in bottom sediment samples ranges widely – 670 to 770,000 Bq/kg of activity concentration. The primary contamination

zone is concentrated in the southern region, where the highest ^{3}H levels were recorded. Additionally, a localized area in the southwestern part showed an elevated ^{3}H concentration of 150,000 Bq/kg in the soil. The concentration of ^{137}Cs in bottom sediments ranges from less than 2 Bq/kg to 30 Bq/kg. Unlike ^{3}H, the distribution of ^{137}Cs does not show any distinct local or zonal patterns.

The distribution patterns of ^{90}Sr and $^{239+240}Pu$ in sediments are illustrated in the accompanying figure (Fig 5).

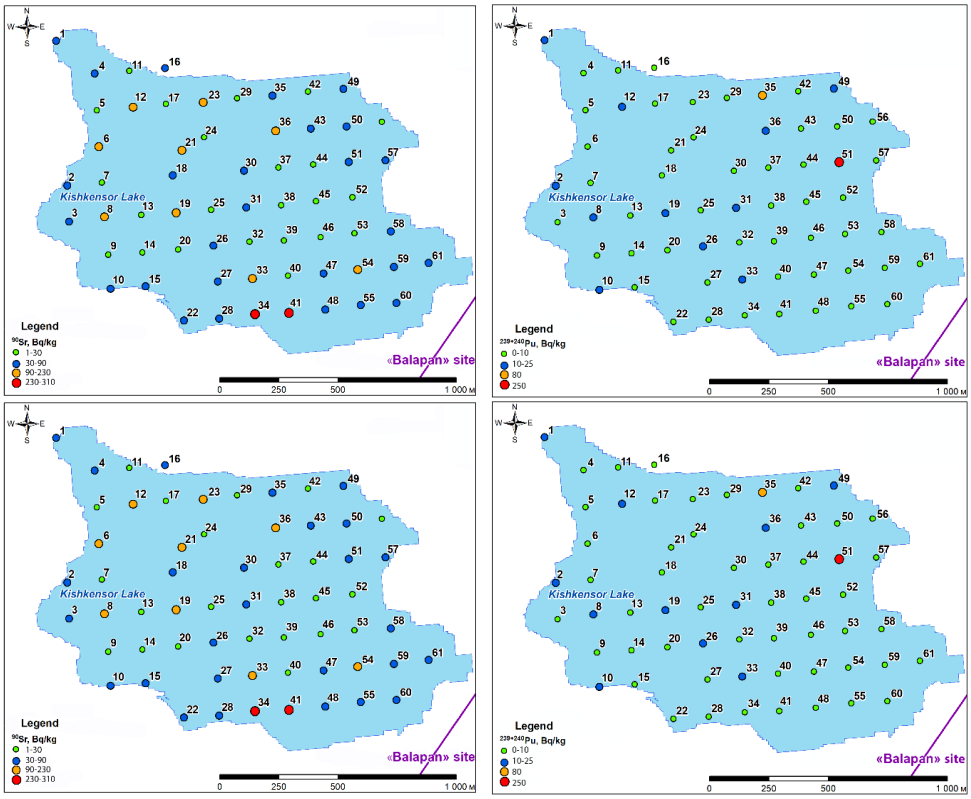


Fig 5. ^{90}Sr and $^{239+240}Pu$ distributions in bottom sediments

The activity concentration of ^{90}Sr ranges between 1 and 310 Bq/kg, with most measurements falling within the 1 to 90 Bq/kg range. Notably, peak concentrations of 230 and 310 Bq/kg were identified at observation points 34 and 41, located in the southern area. The levels of $^{239+240}Pu$ generally range from 1 to 25 Bq/kg, except at two locations, where elevated concentrations of 80 and 250 Bq/kg were detected.

The investigation into the presence of man-made radionuclides at various depths in bottom sediments revealed their distribution patterns

Detailed findings on these distributions are presented in the accompanying table (Table 1).

Table 1. The vertical distribution of man-made radionuclides was examined to assess their concentration levels at varying depths

No.	Sampling points	Sampling depth	^{3}H - Bq/kg	^{90}Sr - Bq/kg	^{137}Cs - Bq/kg	$^{239+240}$Pu - Bq/kg
	plot 1	0-20 cm	9 700 ± 9700	45 ± 4	10 ± 1	3 ± 0,3
		20-40 cm	13 000 ± 1 300	3 ± 0,3	< 1	< 0,2
		40-60 cm	25 000 ± 2 500	4 ± 0,4	< 1	< 0,1
	plot 2	0-20 cm	50 000 ± 5 000	30 ± 3	15 ± 1	7 ± 0,7
		20-40 cm	56 000 ± 5 600	< 0,8	< 1	< 0,2
		40-60 cm	80 000 ± 8 000	< 0,8	< 1	< 0,2
	plot 3	0-20 cm	6 500 ± 650	< 0,7	7 ± 0,7	3 ± 0,3
		20-40 cm	6 700 ± 670	< 0,7	< 1	< 0,1
		40-60 cm	6 000 ± 600	< 0,8	< 1	< 0,2
	plot 4	0-20 cm	5 300 ± 530	35 ± 3	10 ± 1	3 ± 0,3
		20-40 cm	6 200 ± 620	< 0,8	< 1	< 0,1
		40-60 cm	6 000 ± 600	< 0,7	< 1	< 0,1
	plot 5	0-20 cm	4 000 ± 400	< 0,7	7 ± 0,7	9 ± 0,9
		20-40 cm	4 000 ± 400	7 ± 0,7	< 1	< 0,1
		40-60 cm	5 700 ± 570	< 0,6	< 1	< 0,2
	plot 6	0-20 cm	3 200 ± 320	10 ± 1	15 ± 1,5	9 ± 0,9
		20-40 cm	4 000 ± 400	< 0,8	< 1	< 0,1
		40-60 cm	3 300 ± 330	< 0,9	< 1	< 0,2
	plot 7	0-20cm	3 800 ± 380	7 ± 0,7	10 ± 1	7 ± 0,7
		20-40 cm	4 800 ± 480	< 0,8	< 1	< 0,2
		40-60 cm	4 000 ± 400	< 0,7	< 1	< 0,1
	plot 8	0-20 cm	320 000 ± 32 000	150 ± 15	6 ± 0,6	3 ± 0,3
		20-40 cm	435 000 ± 43 500	< 0,8	< 1	< 0,1
		40-60 cm	440 000 ± 44 000	< 0,7	< 1	< 0,1

In all test pits, ^{3}H concentrations either remain consistent or increase with depth. Conversely, the concentrations of ^{137}Cs, ^{90}Sr, and $^{239+240}$Pu are most pronounced at the surface and diminish with depth, frequently dropping below detectable levels in deeper layers.

The study focused on analyzing the presence and levels of man-made radionuclides in groundwater

Groundwater is commonly located above the weathering crust of the underlying rocks at depths between 1.2 and 2.5 meters. Fracture waters were encountered in localized areas with exogenous fracturing zones, with depths ranging from 5.5 to 6.0 meters.

The results of the analysis on the presence of man-made radionuclides in both ground and fracture waters are summarized in the accompanying table (Table 2).

Table 2. The concentration of man-made radionuclides in groundwater near Lake Kishkensor was analyzed and documented

#	Borehole number	^{3}H, Bq/kg	^{90}Sr - Bq/kg	$^{239+240}$Pu - Bq/kg	^{137}Cs - Bq/kg	Ground water level - m	Water type
	BH-27	150 000 ± 15 000	0,5 ± 0,05	< 0,0002	< 0,01	2,42	Ground waters
	BH -31	320 000 ± 32 000	2 ± 0,2	< 0,0002	< 0,01	1,86	
	BH -34	160 000 ± 16 000	4 ± 0,4	< 0,0002	< 0,01	1,20	
	BH -35	77 000 ± 7 700	2 ± 0,2	< 0,0002	< 0,01	1,63	
	BH -32	54 000 ± 5 400	0,5 ± 0,05	< 0,0002	< 0,01	1,35	
	BH -37	6 200 ± 620	< 0,01	< 0,0002	< 0,01	1,50	
	BH -39	30 ± 3	< 0,01	< 0,0002	< 0,01	2,50	
	BHC -1/16	14 200 ± 1420	0,2 ± 0,02	< 0,0002	< 0,01	5,50	Fracture waters
	BHC -2/16	530 ± 53	0,2 ± 0,02	< 0,0002	< 0,01	6,00	

Groundwater shows a wide range of 3H concentrations, varying from 30 to 320 000 Bq/kg across all sampled areas. In the southern region, ^{90}Sr concentrations reach up to 4 Bq/kg. The highest levels of both ^{3}H and ^{90}Sr were recorded in boreholes located in the southern part of the study area. The activity concentration of ^{3}H in fracture water samples from boreholes BCH-1/16 and BCH-2/16, situated near the 'warfare' borehole 1366, was significantly lower compared to that in groundwater. The ^{90}Sr concentration in fracture waters was measured at 0.2 Bq/kg. The concentrations of $^{239+240}$Pu and ^{137}Cs in all water samples were below the detection limits of the employed methodological instruments, measuring less than 0.0002 Bq/kg and 0.01 Bq/kg, respectively.

The investigation focused on understanding the processes of water exchange, aiming to determine the dynamics and interactions between various water sources

To identify the characteristics of how contaminated waters in Lake Kishkensor are formed, the ratio of stable isotopes (^{2}H/^{18}O) in the collected water samples was analyzed. The results were compared with the local meteoric water line and isotope values from regional precipitation. Results are given in the figure (Fig 6).

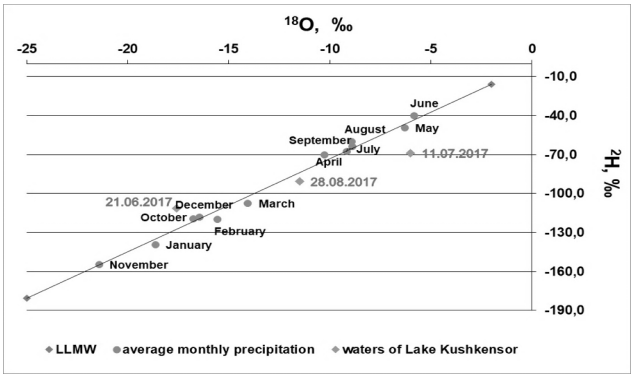


Fig 6. The analysis of the stable isotope ratio

Between late June and mid-July, isotope concentrations significantly increased, ranging from -111.4 to -68.8‰ for ^{2}H and from -17.6 to -6.0‰ for ^{18}O. By late August, the isotope concentrations decreased, reaching -90.7‰ for ^{2}H and -11.5‰ for ^{18}O. These variations suggest that the water sampled in June originated primarily from residual snowmelt, as the isotope ratios align with atmospheric deposition during the winter season. The higher isotope concentrations observed in June are attributed to evaporation, during which the remaining water retained heavier isotopes.

In August, the isotope ratios shifted again, reflecting lighter concentrations, likely due to the influx of groundwater into surface waters. This indicates that winter precipitation plays a key role in recharging groundwater, infiltrating through the cavities of 'warfare' boreholes and raising groundwater levels during spring snowmelt. As a result, contaminated groundwater is subsequently released onto the surface of the lake.

The monitoring focused on tracking changes in surface water contamination levels over time to understand the dynamics and factors influencing pollutant concentrations

Recognizing that radionuclide contamination in Lake Kishkensor could be influenced by water inflow levels, monitoring efforts were conducted. These observations focused on the area with the highest contamination, located in the southern part of the lake. Water samples were collected during spring, summer, and winter across the years 2018 to 2020.

Monitoring observation data is listed in the table (Table 3)

Table 3. Variation in concentrations of man-made radionuclides in surface waters over 2018-2020.

#	Activity concentration, Bq/kg	2018д			2019			2020		
		05	*09*	*11*	*04*	*08*	*10*	*04*	*08*	*09*
1.	^{3}H	180 000 ± 18 000	110 000 ± 11000	430 000 ± 43 000	200 000 ± 20 000	100 000 ± 10 000	175 000 ± 17 000	290 000 ± 29 000	120 000 ± 12 000	190 000 ± 19 000
2.	^{90}Sr	15 ± 1,5	8 ± 0,8	100 ± 10	10 ± 1	17 ± 1,7	10 ±1	14 ± 1,4	17 ± 1,7	3 ± 0,3
3.	$^{239-240}Pu$	< 0,0002	< 0,0002	< 0,0002	< 0,0002	< 0,0002	< 0,0002	<0,0002	<0,0002	<0,0002
4.	^{137}Cs	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01
The determination uncertainty of ^{3}H and ^{90}Sr activity concentration is ±10%										

The activity concentrations of ^{3}H and ^{90}Sr showed significant seasonal variations. In 2018, ^{3}H levels ranged from 110,000 to 430,000 Bq/kg, while in 2019, they were between 100,000 and 200,000 Bq/kg, and in 2020, they ranged from 175,000 to 190,000 Bq/kg. The highest concentrations of 3H were typically recorded during spring and autumn. For ^{90}Sr, the concentration ranged from 8 to 100 Bq/kg in 2018, 10 to 17 Bq/kg in 2019, and 3 to 14 Bq/kg in 2020. No measurable amounts of ^{137}Cs or $^{239+240}Pu$ were detected during the monitoring period.

Discussion

Tritium (^{3}H) Content. Elevated levels of ^{3}H in the surface layer of bottom sediments were predominantly concentrated in the southern region of the lake, indicating this area as the primary entry point for contaminated groundwater. This conclusion is supported by the vertical distribution of ^{3}H, which tends to increase with depth at sites exhibiting the highest concentrations.

Groundwater studies revealed that ^{3}H activity concentrations in fracture waters were lower than those in surface and other groundwater samples. This suggests that ^{3}H does not migrate to Lake Kishkensor through geological fault channels from 'warfare' borehole No. 1366. Instead, the relatively shallow groundwater (1–2.5 m deep) with high ^{3}H levels points to its entry being associated with groundwater level rises.

Strontium-90 (^{90}Sr) Content. The ^{90}Sr concentration on the surface of bottom sediments generally ranges from 1 to 90 Bq/kg, showing widespread distribution. Vertically, higher concentrations are found in the top layers, with lower levels (40–60 cm depth) suggesting a surface-origin source of ^{90}Sr. Additionally, peaks of 230 and 310 Bq/kg were recorded at two points in the southern lake area, which supports the hypothesis that groundwater entry is a significant source of ^{90}Sr contamination.

It is likely that ^{90}Sr contamination in Lake Kishkensor arises from two primary sources:

Groundwater entry: Supported by the detection of ^{90}Sr in southern groundwater (up to 4 Bq/kg) and in surface water (up to 100 Bq/kg).

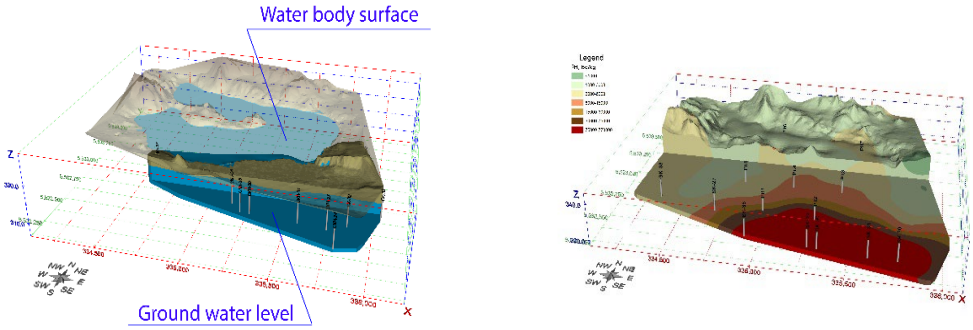
Atmospheric fallout: Confirmed by ^{90}Sr levels ranging from 9 to 200 Bq/kg in the region.

Seasonal Variations in Contamination

Monitoring observations demonstrated substantial seasonal variability in the concentrations of ^{3}H and ^{90}Sr in surface waters. For example, maximum ^{3}H concentrations reached 430,000 Bq/kg, while ^{90}Sr peaked at 100 Bq/kg. These findings suggest that contamination levels in the lake are significantly influenced by the season and the amount of contaminated groundwater inflow.

Stable isotope ratio analysis revealed that winter precipitation plays a critical role in recharging groundwater. Meltwater from snow penetrates the cavities of 'warfare' boreholes, elevating groundwater levels during the spring thaw. This process results in the discharge of contaminated groundwater onto the lake's surface, contributing to radionuclide contamination.

The figure to the left shows paths of contaminated water discharge into Lake Kishkensor, the one to the right presents ^{3}H distribution when ground waters are discharged (Fig 7).



entry of ground waters *b) lake contamiantion with ^{3}H*

Fig 7. Contamination processes at Lake Kishkensor

The contamination of groundwater can be explained by the following process: the depths at which nuclear charges were placed during underground testing, ranging from 270 to 1,200 meters, are significantly deeper than the regional groundwater aquifer. Post-testing, deformation zones formed in the rock mass, comprising voids and fractured rock. Radioactive debris became concentrated on fissure surfaces and rock fragments.

Groundwater infiltrates these artificial fissures, reaching the deformation zones. Upon contact with radioactive debris, the water dissolves radionuclides and transports them back to the phreatic aquifer. These radionuclides subsequently migrate through groundwater flow and eventually discharge onto the surface.

The distribution of ^{137}Cs and $^{239+240}Pu$ in bottom sediments is widespread, without a specific localized concentration. Vertical distribution studies indicate that measurable amounts of these radionuclides are restricted to the 0–20 cm surface layer of bottom sediments. No detectable levels of ^{137}Cs or $^{239+240}Pu$ were found in either groundwater or surface water samples.

The presence of ^{137}Cs and $^{239+240}Pu$ on the surface of Lake Kishkensor is attributed to atmospheric deposition resulting from nuclear tests conducted within the STS region.

Conclusion

The study revealed that the primary sources of contamination in Lake Kishkensor are man-made radionuclides migrating through groundwater, as evidenced by the presence of tritium and strontium in bottom sediments and surface waters.

The spatial and vertical localization of radionuclides in the sediments demonstrates a seasonal dependence of contamination levels, driven by periodic increases in inflows of contaminated groundwater.

The absence of cesium and plutonium radionuclide migration from sediments to surface waters indicates their localized accumulation, influenced by sedimentary processes.

Practical Application. The results of this study can be used to develop ecological programs for radiation monitoring and rehabilitation of the Semipalatinsk Test Site territory. The isotopic ratio analysis methods can be applied to other studies related to contamination of aquatic ecosystems.

Prospects for Further Research. To gain a deeper understanding of contamination dynamics, it is recommended to conduct long-term monitoring studies, considering changes in hydrological conditions and exploring the potential for bioremediation of contaminated areas.

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