

Поступила в редакцию 28.08.2026
Поступила после доработки 08.09.2026
Принята к публикации 25.09.2026

DOI:
IRSTI: 68.41.31

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RADIOECOLOGICAL EVALUATION OF ENVIRONMENTAL MEDIA AND GOAT MILK IN AREAS AFFECTED BY THE FORMER SEMIPALATINSK NUCLEAR TEST SITE

Abstract: This study aimed to evaluate the radioecological status of environmental media and goat milk obtained from territories characterized by different degrees of radiation hazard in the vicinity of the former Semipalatinsk Nuclear Test Site. Field investigations were carried out in four settlements of the Abai Region—Dolon, Karaul, Borodulikha, and Kokpekty—which were selected as representative locations for extreme, maximum, high, and minimal radiation-risk zones, respectively. Soil, vegetation, water, and goat milk samples were collected to determine the activity concentrations of the principal radionuclides, including ¹³⁷Cs, ⁴⁰K, and ¹³¹I, by gamma-ray spectrometry. The sensory characteristics and physicochemical parameters of the milk were also examined for compliance with the applicable regulatory requirements. The findings demonstrated a consistent spatial variation in radionuclide activity among the investigated locations. The greatest concentrations were observed in samples collected from territories classified as extreme- and maximum-risk zones. The transfer of radionuclides along the trophic chain “soil–plant–animal–milk” was confirmed, demonstrating the influence of residual environmental contamination on agricultural products. Despite the observed differences in radionuclide content, all milk samples met established safety standards, and the activity concentrations remained well below permissible limits. No significant negative effects of radiation on the organoleptic or physicochemical characteristics of goat milk were identified. The results demonstrate that long-term exposure to low-dose radiation does not significantly affect milk quality and poses no substantial radiological threat to consumers. The study expands current knowledge on radionuclide migration in agroecosystems of the former test site and highlights the importance of continuous environmental monitoring to ensure food safety and sustainable agricultural development in affected regions.

Keywords: radioecology; radionuclides; cesium-137; potassium-40; iodine-131; goat milk; radiation safety; Semipalatinsk Nuclear Test Site.

Introduction

The ecological state of the regions located near the former Semipalatinsk Nuclear Test Site (SNTS) continues to attract considerable attention from researchers and public health specialists [1, 2]. From 1949 to 1989, the Semipalatinsk Nuclear Test Site was the location of more than 456 nuclear tests this territory, resulting in large-scale accumulation of long-lived radionuclides, primarily cesium-137, as well as the natural radionuclide potassium-40 and the radionuclides, including short-lived iodine-131, have been detected in various environmental components [3, 4]. Most of these radionuclides can migrate through ecosystems and remain in the biosphere for prolonged periods, whereas iodine-131 decays relatively rapidly leading to persistent contamination of the soil cover, water bodies, vegetation, and, consequently, livestock products [5, 6, 7]. The geographical proximity of the test site to populated areas significantly increases the risk of radiation exposure to humans through trophic chains, particularly via dairy products, which form an important part of the local population's daily diet [8, 9, 10].

Over the past several decades, many researchers have investigated the lasting effects of radioactive contamination on human health and ecosystem integrity. Particular attention is paid to the monitoring of livestock products produced in areas of elevated radiation risk, as they represent one of the main pathways for the entry of radionuclides into the human body [11]. Among the most significant isotopes are cesium-137, potassium-40, and iodine-131, which, when ingested with food,

are capable of causing serious disturbances in thyroid gland function (iodine-131) as well as affecting the overall radiation background of the body (cesium-137 and potassium-40) [12]. Cesium-137 is a product of the nuclear fission of uranium and plutonium, formed during nuclear explosions and other technogenic processes. These radionuclides pose a significant threat to the environment and public health due to their high biological availability and their ability to actively migrate through food chains [13].

Cesium-137 has a half-life of about 30 years and undergoes β -decay accompanied by γ -radiation. Owing to its chemical similarity to potassium, it can readily enter biological systems and participate in metabolic processes. Iodine-131 is characterized by a short half-life (8.02 days), intense β - and γ -radiation, and high tropism to the thyroid gland, which makes it particularly dangerous upon entering the body [14]. Potassium-40, in turn, is a natural radionuclide with a half-life of 1.25 billion years and serves as the main source of internal human irradiation due to its presence in the tissues of living organisms. Its occurrence in environmental objects and food products is an important indicator of the natural radiation background [15]. Due to their similarity to potassium (for ^{137}Cs and ^{40}K) and the ability to concentrate in the thyroid gland (for ^{131}I), these isotopes are actively absorbed by living organisms. This makes the analysis of their content in food products critically important for an objective assessment of the radiation safety of territories [16].

Nuclear tests at the Semipalatinsk Test Site have left a profound impact not only on the environment but also on the public health of the region. Numerous scientific studies emphasize the need for a comprehensive approach to investigating the consequences of radiation exposure. This approach should include monitoring of both artificial and natural radionuclides, as well as the development of measures to ensure the sustainable development of the territories for future generations [17]. In this regard, the study of the quality and safety of dairy products obtained from farms located in areas with varying levels of radiation risk from the former SNTS has acquired particular relevance.

The present study is devoted to a comprehensive analysis of the quality characteristics of goat milk produced in districts of the Abai Region representing different levels of radiation risk within on the territory affected by the former Semipalatinsk Nuclear Test Site. Particular attention is paid to the content of radionuclides (primarily ^{137}Cs , ^{40}K , and ^{131}I) and to assessing their possible influence on the physicochemical and organoleptic properties of the product. The obtained data will help expand existing knowledge on the migration of radionuclides along the trophic chain “soil – plant – animal – milk” and provide a scientific basis for recommendations aimed at ensuring the radiation safety of dairy products in radioactively contaminated territories.

Thus, despite the considerable volume of accumulated scientific data on the radioecological consequences of the Semipalatinsk Test Site activities, the issues concerning the impact of residual radioactive contamination on the quality and safety of locally produced goat milk, taking into account the content of cesium-137, potassium-40, and iodine-131, remain insufficiently studied. The solution to these tasks is of both scientific and practical importance for the population of the regions adjacent to the former test site.

Materials and methods

The study encompassed areas differing in the degree of radiation hazard resulting from past activities at the former Semipalatinsk Nuclear Test Site.

The farms were chosen based on three criteria: the radiation hazard category of the area, the availability of dairy goats, and the production of goat milk for household consumption and commercial distribution.

The investigation covered four settlements:

- Dolon, Beskaragai District—extreme radiation-hazard zone;
- Karaul, Abai District—maximum radiation-hazard zone;
- Borodulikha, Borodulikha District—high radiation-hazard zone;
- Kokpekty, Kokpekty District—minimal radiation-hazard zone.

In each settlement, five composite samples of soil, plants, water, and goat milk were collected. The animals were kept under traditional pasture-stall housing conditions typical for the region. During the spring-summer-autumn period, the goats grazed on natural pastures for 8–10 hours per day, with natural grass serving as the main feed. In winter, the animals were housed indoors and received rough and concentrated feeds (hay and compound feed). Watering was carried out from centralized or local water sources. The keeping conditions complied with zoohygienic and veterinary-sanitary

standards. For the study, clinically healthy lactating goats aged 2–5 years were selected, kept under similar feeding and housing conditions.

Sampling procedures were conducted in accordance with the following regulatory documents and guidelines:

- GOST 17.4.3.01-2017, “General Requirements for Sampling”;
- GOST 27262-87, “Plant Feeds. Methods of Sampling”;
- ST RK 1545-2006, “Radiation Control. Sampling of Surface Water and Wastewater. General Requirements”;
- ST RK 1623-2007, “Radiation Control. Food Products. Sampling, Analysis, and Hygienic Assessment”;
- methodological recommendations for the radioecological and agroecological assessment of agricultural lands located within the former Semipalatinsk Nuclear Test Site.

Samples were collected from typical pasture plots for each settlement, located at a distance of at least 20 m from roads and other possible sources of additional contamination. Preference was given to flat, undisturbed areas with dense grass cover and no signs of erosion.

Soil. Soil samples were taken from a depth of 0–5 cm using the “envelope” method (5 points: 4 at the corners of a square and one in the center). The area of each sampling point was approximately 100 cm². The composite sample with a mass of at least 1 kg was packed in polyethylene bags with appropriate labeling.

Plants. Plant samples (not less than 1.5–2.0 kg) were manually harvested with a sickle from 1 × 1 m plots, leaving at least 3 cm above the ground to prevent contamination by soil particles. The plant material was packed in polyethylene bags.

Water. Water samples with a volume of 1.5–2.0 liters were taken from the surface of open water bodies, wells, and springs into plastic containers.

Goat milk samples were obtained directly from the selected farms following the requirements of ST RK 1623–2007. Only clinically healthy animals maintained under comparable feeding and housing conditions were included to minimize the influence of external factors on the results. The collected samples were subjected to organoleptic, physicochemical, radiological, and statistical examinations. Their organoleptic properties were assessed in accordance with GOST 32940–2014, “Raw Goat Milk. Technical specifications”. The following parameters were determined: appearance, color, consistency, odor, and taste in the cooled state. To exclude subjectivity, each sample was assigned a code number. Odor was assessed at 35 °C and, if necessary, after pasteurization (GOST 28283–2015). Taste was evaluated after boiling the sample at (20 ± 2) °C.

The mass fractions of fat, protein, and nonfat milk solids (NMS), as well as density, were determined using the “Klever-2” automatic analyzer. Prior to analysis, the samples were homogenized, degassed, and brought to a temperature of 25 ± 2 °C. The results were compared with the requirements of GOST 32940–2014.

Radiological investigations were carried out using the RKG-AT1320S scintillation gamma-radiometer (NaI(Tl) detector). The specific activity of artificial (¹³⁷Cs, ¹³¹I) and natural (⁴⁰K) radionuclides was determined. Measurements were performed in the standard Marinelli geometry (volume 1 dm³).

Sample preparation for radiometry:

Milk: Samples were homogenized, filtered through multilayer gauze, and poured into Marinelli vessels up to the control level.

Soil. The collected samples were allowed to dry naturally at room temperature, ground into a homogeneous mass, and sieved through a sieve with 1-mm-diameter apertures. The prepared soil was compacted into Marinelli vessels and left for at least one day to reach radioactive equilibrium.

Plants: Plant samples were cleaned of foreign material, rinsed with purified water, and subsequently oven-dried.

The activity concentration of each radionuclide (A, Bq/kg) was determined using the RKG-AT1320S scintillation gamma-radiometer and calculated according to the following equation:

$$A = \frac{N - N_{\phi}}{\varepsilon \cdot P_{\gamma} \cdot m \cdot t}$$

where:

N — number of pulses in the full energy peak;

N_φ — background;

ε — registration efficiency;

Py — quantum yield;
 m — sample mass, kg;
 t — measurement time, s.

All laboratory investigations were conducted at the Shakarim Lab research facility (Laboratory of Veterinary and Sanitary Examination) and the accredited Milk Analysis Laboratory of Shakarim University Non-Profit Joint Stock Company, formerly known as Agrotechnopark. Statistical data analysis. The results are expressed as the arithmetic mean (M) $\pm$ standard deviation ($\pm$ SD). The statistical significance of differences was assessed using methods of variational statistics.

Results

Sensory characteristics of raw goat milk collected from farms located in different radiation-risk zones within the area affected by the former Semipalatinsk Nuclear Test Site (SNTS) were assessed in accordance with GOST 32940–2014, “Raw Goat Milk. Technical Specifications.” The results of this assessment are presented in Table 1.

Table 1 – Results of organoleptic characteristics of goat milk

№	Sample location	Color	Taste and odor	Consistency
1.	Dolon	White, cream	Clear, with a faint grassy note	A homogeneous liquid with slight protein flocculation
2.	Karaul	White, cream	Clear, with no foreign odors or tastes	A homogeneous liquid, free of sediment and protein flakes
3.	Borodulikha	White, cream	Clear, with no foreign odors or tastes	A homogeneous liquid, free of sediment and protein flakes
4.	Kokpekty	White, cream	Clear, with no foreign odors or tastes	A homogeneous liquid, free of sediment and protein flakes

All examined milk samples exhibited a uniform white-to-cream color typical of high-quality goat milk. No deviations in color intensity or the presence of extraneous shades were detected across the studied settlements. The taste and odor of the milk from Karaul, Borodulikha, and Kokpekty were assessed as clean, with no foreign odors or aftertastes, fully complying with the requirements of the regulatory standard. In contrast, the milk from Dolon village (the zone of extreme radiation risk) showed a faint grassy (herbal) note in both taste and odor. This minor variation may reflect differences in the botanical composition of local pastures and the possible transfer of volatile plant-derived compounds into milk in areas characterized by higher levels of residual radioactive contamination.

With regard to consistency, all samples were homogeneous liquids. Milk from Karaul, Borodulikha, and Kokpekty was free of visible sediment or protein flakes. The samples from Dolon displayed a slight protein flocculation (graininess), which, however, did not affect the overall homogeneity or technological suitability of the milk. Such minor structural changes are within acceptable limits for raw goat milk and are most likely related to natural variations in protein stability rather than to any significant deterioration in quality.

Overall, the organoleptic evaluation demonstrated that goat milk produced in all four settlements meets the basic sensory requirements of GOST 32940-2014. The observed minor differences in taste, odor, and consistency in the Dolon samples did not constitute defects that would render the product unsuitable for consumption or further processing. These findings indicate that the residual radiation background in the studied areas does not exert a pronounced negative influence on the sensory characteristics of goat milk. The results are consistent with earlier studies showing that organoleptic properties of dairy products remain relatively stable even under moderate radioactive contamination, provided that animal health and feeding conditions are maintained at an adequate level.

The physicochemical parameters of raw goat milk collected in settlements located in various radiation-risk zones within the area affected by the former Semipalatinsk Nuclear Test Site (SNTS) were determined using the “Klever-2” instrument in compliance with GOST 32940–2014, “Raw Goat Milk. Technical Specifications.” The results are presented in Table 2.

Table 2 – Physicochemical characteristics of goat milk

№	Sample location	Fat mass fraction, %	Protein mass fraction, %	Dry skimmed milk residue (DSMR), %	Density, kg/m ³
1.	Dolon	3,44 ± 0,1	3,01 ± 0,1	8,30 ± 0,1	1027,6 ± 0,3
2.	Karaul	3,52 ± 0,05	3,24 ± 0,04	8,58 ± 0,09	1029,6 ± 0,3
3.	Borodulikha	3,35 ± 0,06	3,18 ± 0,05	8,48 ± 0,08	1030,5 ± 0,4
4.	Kokpekty	3,25 ± 0,07	3,05 ± 0,06	8,15 ± 0,10	1031,9 ± 0,5

All milk samples fully complied with the normative requirements of GOST 32940-2014. The mass fraction of fat ranged from 3.25 % to 3.52 %, exceeding the minimum standard value of 3.2 %. The highest fat content was observed in milk from Karaul village (3.52 ± 0.05 %), while the lowest value was recorded in Kokpekty village (3.25 ± 0.07 %). Protein content varied between 3.01 % and 3.24 %, which is also above the regulatory threshold of 2.8 %. The highest protein level was found in the Karaul samples (3.24 ± 0.04 %), and the lowest — in Dolon (3.01 ± 0.1 %).

The content of dry skimmed milk residue (DSMR) ranged from 8.15 % to 8.58 %, meeting the minimum requirement of 8.2 %. A slight tendency toward lower DSMR values was noted in samples from the extreme radiation-risk zone (Dolon) and the minimal radiation-risk zone (Kokpekty). Milk density was within the standard interval of 1027–1030 kg/m³ in all cases, although a minor increasing trend was observed from Dolon (1027.6 ± 0.3 kg/m³) to Kokpekty (1031.9 ± 0.5 kg/m³).

The observed variations in physicochemical parameters across the studied settlements were small and remained within the limits of natural biological variability typical for goat milk under traditional pasture-stall feeding conditions. No statistically significant deterioration in milk quality was associated with the level of residual radiation contamination. These findings indicate that the current radiation background in the examined areas of the former SNTS does not exert a negative influence on the basic technological characteristics of goat milk. The results are consistent with previous studies demonstrating the stability of the main physicochemical indicators of dairy raw materials even under moderate long-term radioactive impact, provided that animal health status and feeding regimes are maintained at an adequate level.

The content of the key radionuclides ¹³⁷Cs, ⁴⁰K, and ¹³¹I in raw goat milk and in the main components of the environment (soil, plants, and water) was determined by gamma-spectrometric analysis using the RKG-AT1320S scintillation gamma-radiometer. The results are presented in Tables 3 and 4.

Table 3 – Results of the physicochemical characteristics of goat milk

№	Sample location	¹³⁷ Cs, Bq/l	⁴⁰ K, Bq/l	¹³¹ I, Bq/l
1	Dolon	4,7 ± 0,3	29,8 ± 2,4	3,0 ± 0,2
2	Karaul	3,8 ± 0,3	27,5 ± 1,9	2,9 ± 0,2
3	Borodulikha	3,1 ± 0,2	24,5 ± 1,6	2,2 ± 0,2
4	Kokpekty	1,1 ± 0,1	21,8 ± 1,4	1,0 ± 0,1

Table 4 – Results of radionuclide content in soil, plant, and water samples

№	Sample location	Object	¹³⁷ Cs, Bq/kg (l)	⁴⁰ K, Bq/kg (l)	¹³¹ I, Bq/kg (l)
1	Dolon	Soil	131,5 ± 0,5	715 ± 24	0,46 ± 0,04
		Plants	57,2 ± 2,8	245 ± 16	1,3 ± 0,3
		Water	2,4 ± 0,2	10,8 ± 3,5	0,07 ± 0,02
2	Karaul	Soil	41,2 ± 1,4	640 ± 19	0,44 ± 0,07
		Plants	35,8 ± 1,1	155 ± 14	1,35 ± 0,05
		Water	1,7 ± 0,2	9,2 ± 2,8	0,06 ± 0,02
3	Borodulikha	Soil	6,8 ± 0,4	350 ± 21	0,51 ± 0,04

№	Sample location	Object	^{137}Cs , Bq/kg (I)	^{40}K , Bq/kg (I)	^{131}I , Bq/kg (I)
4	Kokpekty	Plants	$3,5 \pm 0,2$	147 ± 8	$0,36 \pm 0,03$
		Water	$0,95 \pm 0,08$	$7,3 \pm 1,1$	$0,05 \pm 0,01$
		Soil	$4,0 \pm 0,3$	292 ± 14	$0,43 \pm 0,05$
		Plants	$1,6 \pm 0,2$	180 ± 9	$0,10 \pm 0,02$
		Water	$0,58 \pm 0,07$	$6,6 \pm 1,0$	$0,03 \pm 0,01$

A clear gradient in radionuclide levels was observed across the studied settlements, corresponding to the decreasing order of radiation risk: Dolon (extreme risk) > Karaul (maximum risk) > Borodulikha (high risk) > Kokpekty (minimal risk). In goat milk (Table 3), Samples collected from Dolon village (^{137}Cs – 4.7 ± 0.3 Bq/l, ^{40}K – 29.8 ± 2.4 Bq/l, ^{131}I – 3.0 ± 0.2 Bq/l) exhibited the highest activity concentrations of all three radionuclides. The lowest values were found in Kokpekty village, where activity concentrations were 4.3 times lower for ^{137}Cs , 1.4 times lower for ^{40}K , and 3.0 times lower for ^{131}I compared with Dolon.

The same spatial pattern was evident in environmental samples (Table 4). Soil from Dolon showed the highest ^{137}Cs activity (131.5 ± 0.5 Bq/kg), which was more than 32 times higher than in Kokpekty soil. Plant material from Dolon also exhibited elevated levels of ^{137}Cs (57.2 ± 2.8 Bq/kg) and ^{131}I (1.3 ± 0.3 Bq/kg). Water exhibited the lowest radionuclide activity concentrations among the environmental components analyzed in all four settlements, although the values showed a similar decline from higher- to lower-risk areas.

Discussion of Results

The gradual decrease in radionuclide activity concentrations across different radiation risk zones indicates a correlation between residual contamination in the territory of the former Semipalatinsk Nuclear Test Site and the migration of radionuclides through the local soil–plant–animal–milk food chain. The relatively higher transfer of ^{137}Cs and ^{131}I into plants and subsequently into milk is consistent with the known high bioavailability and mobility of these isotopes. At the same time, the natural radionuclide ^{40}K showed less pronounced variation, which is expected given its ubiquitous presence in the environment.

Notably, the activity concentrations of all radionuclides detected in goat milk remained well below the intervention limits specified for dairy products by national and international radiation-safety regulations.

It follows that, under current conditions, goat milk produced in the study areas does not pose a significant radiological threat to the population. Our results are consistent with previous studies conducted in the area affected by the Semipalatinsk Test Site, which also confirmed a clear correlation between the transport of radionuclides and the degree of soil contamination [4, 6, 7]. At the same time, the present work provides new data specifically on goat milk — a product that has been less studied compared to cow milk or meat in the radioecological literature of the region. The absence of significant changes in organoleptic and physicochemical properties despite the existing radiation gradient suggests high adaptive capacity of the local goat population and stability of milk quality under chronic low-level exposure.

From a practical perspective, the results indicate that locally produced goat milk may be considered suitable for consumption under the conditions examined in this study. At the same time, the correlation between environmental pollution and the levels of radionuclides in milk underscores the need for continuous monitoring, particularly in areas classified as zones of extreme and maximum radiation risk. Systematic radioecological surveillance, appropriate pasture management, and the preferential use of less contaminated grazing sites may help reduce potential exposure and support the sustainable development of livestock farming in the Abai Region..

The results demonstrate a clear correlation between the degree of environmental radioactive contamination and the radionuclide burden in goat milk. The findings provide further insight into the movement of anthropogenic and naturally occurring radionuclides through agroecosystems affected by the former SNTS. They also suggest that natural attenuation processes may limit the transfer of radionuclides into livestock-derived products.

Conclusion

This study presents a comprehensive assessment of the environmental radiation situation and its possible relationship to the quality of goat milk in areas with varying levels of radiation risk in the

vicinity of the former Semipalatinsk Nuclear Test Site. The findings reveal a consistent relationship between the extent of environmental contamination and radionuclide activity throughout the soil–plant–animal–milk trophic pathway. A pronounced gradient in radionuclide concentrations (^{137}Cs , ^{40}K , and ^{131}I) was identified, with the highest levels recorded in the zones of extreme and maximum radiation risk (Dolon and Karaul), and the lowest in the minimal risk zone (Kokpekty). This confirms the long-term persistence and migration ability of radionuclides in agroecosystems affected by nuclear testing. Despite the detected differences in radionuclide content, all analyzed goat milk samples met established safety standards. The activity concentrations of radionuclides were significantly below permissible levels, indicating the absence of a significant radiological risk for human consumption under current conditions.

Furthermore, no significant negative impact of residual radioactive contamination on the organoleptic and physicochemical properties of goat milk was detected. All samples met regulatory requirements, and the minor differences observed fell within the range of natural biological variability. This indicates the animals' high adaptability and the stability of milk quality even under prolonged exposure to low-level background radiation. The study confirms that natural attenuation processes and existing agricultural practices contribute to limiting radionuclide transfer into animal products. Nevertheless, the identified correlation between environmental pollution and radionuclide levels in milk underscores the need for ongoing radioecological monitoring, especially in areas classified as high-radiation-risk zones. Overall, the findings expand current knowledge on radionuclide migration in agroecosystems of the former Semipalatinsk Test Site and support the safe use of locally produced goat milk. At the same time, they underline the importance of sustainable land use, controlled grazing, and regular radiological assessment to ensure long-term environmental and food safety.

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БҰРЫНҒЫ СЕМЕЙ ЯДРОЛЫҚ СЫНАҚ ПОЛИГОНЫНЫҢ ӘСЕР ЕТУШІ АЙМАҒЫНДАҒЫ ҚОРШАҒАН ОРТА КОМПОНЕНТТЕРІ МЕН ЕШКІ СҮТІН РАДИОЭКОЛОГИЯЛЫҚ БАҒАЛАУ.

Бұл зерттеуде бұрынғы Семей ядролық сынақ полигоны аумағындағы әртүрлі радиациялық қауіп деңгейі аймақтардың қоршаған орта компоненттері мен өндірілетін ешкі сүтіне кешенді радиологиялық-экологиялық бағалау жүргізілді. Зерттеу Абай облысының төтенше, ең жоғары, жоғары және ең төмен радиациялық қауіп аймақтарын сипаттайтын төрт елді мекенінде — Долон, Қарауыл, Бородулиха және Көкпектіде жүргізілді. Топырақ, өсімдік, су және ешкі сүтінің сынамалары алынып, гамма-спектрометриялық әдістер арқылы, негізгі радионуклидтердің (^{137}Cs , ^{40}K және ^{131}I) мөлшері анықталды. Қосымша нормативтік талаптарға сәйкес ешкі сүтінің органолептикалық және физика-химиялық қасиеттеріне бағалау жүргізілді.

Зерттеу нәтижелері зерттелген аумақтардағы радионуклидтер концентрациясының айқын градиентін көрсетті: олардың ең жоғары деңгейлері төтенше және ең жоғары радиациялық қауіп аймақтарында тіркелді. «Топырақ–өсімдік–жануар–сүт» трофикалық тізбегі бойымен радионуклидтердің миграциясы расталып, бұл қоршаған ортадағы қалдық радиоактивті ластаушылардың ауылшаруашылығы өнімдеріне әсерін айқындады.

Радионуклидтердің мөлшерінде белгілі бір айырмашылықтар анықталғанына қарамастан, зерттелген ешкі сүтінің сынамаларының барлығы белгіленген қауіпсіздік стандарттарына сәйкес келді, ал олардың үлестік белсенділігі рұқсат етілген шекті деңгейлерден едәуір төмен болды. Радиацияның ешкі сүтінің органолептикалық және физика-химиялық сипаттамаларына елеулі теріс әсері анықталған жоқ.

Алынған нәтижелер төмен деңгейдегі созылмалы радиациялық әсер жағдайында ешкі сүтінің сапасының тұрақты сақталатынын көрсетеді және тұтынушылар үшін елеулі радиологиялық қауіптің жоқтығын растайды. Зерттеу нәтижелері бұрынғы ядролық сынақ полигоны аумағындағы агроэкожүйелерде радионуклидтердің миграциясы жөніндегі қазіргі ғылыми түсініктерді толықтырады және зардап шеккен аумақтарда азық-түлік қауіпсіздігін қамтамасыз ету мен ауыл шаруашылығын орнықты дамыту мақсатында қоршаған ортаға тұрақты радиациялық мониторинг жүргізудің маңыздылығын айқындайды.

Түйін сөздер: радиоэкология; радионуклидтер; цезий-137; калий-40; йод-131; ешкі сүті; радиациялық қауіпсіздік; Семей ядролық сынақ полигоны.

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РАДИОЭКОЛОГИЧЕСКАЯ ОЦЕНКА КОМПОНЕНТОВ ОКРУЖАЮЩЕЙ СРЕДЫ И КОЗЬЕГО МОЛОКА В ЗОНЕ ВЛИЯНИЯ БЫВШЕГО СЕМИПАЛАТИНСКОГО ЯДЕРНОГО ПОЛИГОНА

В данном исследовании представлена комплексная радиоэкологическая оценка компонентов окружающей среды и козьего молока, производимого в районах с различной степенью радиационного риска в зоне влияния бывшего Семипалатинского ядерного полигона. Работа проводилась в четырех населенных пунктах Абайской области (Долон, Караул, Бородулиха и Кокпекты), представляющих зоны чрезвычайного, максимального, повышенного и минимального радиационного риска. Образцы почвы, растений, воды и козьего молока были собраны и проанализированы на содержание ключевых радионуклидов (^{137}Cs , ^{40}K и ^{131}I) с использованием гамма-спектрометрических методов. Дополнительно были оценены органолептические и физико-химические свойства козьего молока в соответствии с нормативными требованиями.

Результаты выявили четкий градиент концентраций радионуклидов по исследованным территориям: наибольшие уровни зафиксированы в зонах чрезвычайного и максимального радиационного риска. Было подтверждено перемещение радионуклидов по трофической цепи «почва – растение – животное – молоко», что демонстрирует влияние остаточного загрязнения окружающей среды на сельскохозяйственную продукцию.

Несмотря на выявленные различия в содержании радионуклидов, все образцы молока соответствовали установленным стандартам безопасности, а удельная активность оставалась значительно ниже допустимых пределов. Каких-либо значительных негативных эффектов радиации на органолептические или физико-химические характеристики козьего молока обнаружено не было.

Полученные данные свидетельствуют об устойчивости качества молока в условиях хронического радиационного воздействия низкого уровня и подтверждают отсутствие значимого радиологического риска для потребителей. Исследование расширяет имеющиеся знания о миграции радионуклидов в агроэкосистемах бывшего полигона и подчеркивает важность непрерывного экологического мониторинга для обеспечения безопасности пищевых продуктов и устойчивого развития сельского хозяйства в пострадавших регионах.

Ключевые слова: радиоэкология; радионуклиды; цезий-137; калий-40; йод-131; козье молоко; радиационная безопасность; Семипалатинский ядерный испытательный полигон.

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Поступила в редакцию 01.09.2026
Поступила после доработки 22.09.2026
Принята к публикации 28.08.2026