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Radiological safety of animal products

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ABSTRACT

The presence of radionuclides such as caesium-137 and strontium-90 in the food chain remains a critical environmental and public health concern, particularly when humans ingest these substances. Kazakhstan, with its history of nuclear testing, particularly at the Semipalatinsk Test Site, has experienced significant residual contamination from past nuclear explosions. This legacy continues to contribute to the presence of caesium-137 and strontium-90 in the environment, posing potential risks to ecology and human health. The study, conducted in Kazakhstan and involving sampling of soil, plants, water and animal products, is a key step towards understanding the extent of radionuclide contamination in the region. One of the novel aspects of this study is its holistic approach, which goes beyond the traditional focus on direct food contamination. The study uniquely examines the environmental pathways that facilitate the transfer of radionuclides from soil and plants to animals, thereby providing a deeper understanding of how contamination can spread through the food chain. This multi-level analysis integrates different environmental matrices, making it one of the first to examine the interconnected dynamics of radionuclide migration through soil, plants, water, and animal products in Kazakhstan. A particularly encouraging finding of this study was the lack of excess activity in milk and meat samples, suggesting that contamination in these specific regions may be within acceptable limits. However, the study's novelty lies not only in its results, but also in its emphasis on the importance of ongoing monitoring. Despite the lack of immediate health threats from these specific samples, the study highlights the need for ongoing surveillance to ensure that radionuclide levels remain within safe limits.

Keywords: food safety, radioactive contamination, animals, radionuclide, veterinary sanitation.

INTRODUCTION

In recent decades, the issue of radioactive contamination of the environment has become particularly pressing, especially in areas where nuclear tests have been conducted or nuclear accidents have occurred. In such contexts, it is vital to minimize the risks of food contamination and develop effective strategies to protect food systems from radiation exposure in order to prevent adverse health effects throughout the food chain. As radiation contamination is often long-lasting, its monitoring and mitigation remain significant challenges.

Between 1949 and 1989, 456 nuclear tests were conducted in Kazakhstan, 113 of which occurred in the atmosphere and on the ground. These tests led to widespread contamination of large areas with long-lived radionuclides, including Cesium-137 (Cs-137). This contamination has severely impacted the environment and agriculture, with an estimated release of about 9x10^16 Bq of Cesium-137 into the environment, significantly worsening the state of the biosphere **[1]**. The legacy of these tests continues to affect ecological systems and food safety, making Kazakhstan a key example of the long-term consequences of nuclear testing.

Studying the contamination of animal products such as milk and meat is essential to assess potential risks to human health. One of the most effective methods for protecting these products is providing animals with environmentally friendly feed, which reduces the radioactive activity in their milk and meat. However, in cases of mass contamination, where access to clean feed may be limited, alternative protective measures should be employed, such as diluting feed with uncontaminated materials **[2]**.

Gamma spectrometry is commonly used to analyze radioactivity in environmental samples. High-resolution gamma spectrometry is a widely employed technique to monitor product radiation contamination, enabling accurate measurement of radionuclides like Cesium-137. Recent studies conducted in Singapore found that radiation levels in dry milk were low enough not to pose a significant health risk to children **[3]**. This highlights the importance of reliable monitoring techniques in ensuring the safety of food products.

Moreover, advances in radiochemical separation and β-counting techniques have enabled precise analysis of Strontium-90 (90Sr) and Cesium-137 (137Cs) in soil and other ecosystem components. These methods comply with International Atomic Energy Agency (IAEA) standards and have been used in recent studies analyzing 21 soil samples. The results show regional variations in the concentrations of these isotopes, highlighting the uneven distribution of contamination and the need for localized assessments **[4]**.

Understanding how radionuclides behave in ecosystems is another critical aspect of environmental protection. Radionuclides move through ecosystems, from soil and plants to water and animals. Recent research indicates that the transfer coefficient of Strontium-90 from soil to grass is much higher than that of Cesium-137, indicating that plants more readily absorb Strontium-90. This has important implications for agriculture and animal health, as contaminated vegetation can pose a significant risk to animals that graze on it **[5]**.

Climate conditions, such as precipitation and temperature, play a significant role in the spread of radionuclides in the environment. These factors can accelerate the movement of contamination through water and soil, further complicating risk assessments. Studies have shown that rainfall and temperature variations can influence the mobility of radioactive substances, necessitating the inclusion of climate data in environmental risk assessments **[6]**.

Water resources contaminated with radionuclides, such as Cesium-137, seriously threaten ecosystems and human health. Both natural and anthropogenic sources can contribute to water contamination. Once radionuclides enter water systems, they can impact food chains for years to come. Developing efficient water purification methods is critical to mitigating the long-term effects of radioactive contamination **[7]**.

Japan's experience after the Fukushima Daiichi nuclear accident underscores the urgent need for effective management of radiocesium contamination in food products. In Japan, comprehensive measures were implemented to clean products and animals from radionuclides, and strict standards were set for the levels of Cesium-137 in food products. These efforts highlight the importance of establishing robust protection, decontamination strategies, and monitoring systems to prevent food contamination after a nuclear accident **[8]**.

Recent studies focus on improving risk assessment techniques, radiation detection methods, and protective measures. For instance, advances in isotopic analysis, contamination modeling, and ecosystem behavior studies provide new insights into how radionuclides affect food systems and human health. Furthermore, international efforts to harmonize safety standards and develop better decontamination techniques are pivotal in preventing and managing food contamination in regions affected by nuclear testing or accidents **[9]**.

Scientific Hypothesis

“In the regions of Kazakhstan (Kyzylorda, Turkestan, Almaty, and Abay), the levels of radioactive contamination of soil, plants, water, and livestock products depend largely on geographic, climatic, and soil conditions, with areas closer to historical nuclear test sites showing higher levels of radionuclides such as Cesium-137 (Cs-137) and strontium-90 (Sr-90) in environmental samples and food products".

1. Proximity to nuclear test sites: Areas such as Kyzylorda, Turkestan, and Abay, which are geographically close to a nuclear test site, are expected to have higher contamination levels. This suggests that contamination will be uneven across regions, with some areas experiencing higher levels of radionuclides.

2. Geographic differences: Differences in soil composition and land use across regions (e.g., differences in agricultural practices or vegetation types) can affect the uptake and retention of radionuclides, resulting in different contamination levels of plants, soil, and water.

3. Climate conditions: Climate factors such as precipitation, temperature, and wind play an important role in the dispersion and deposition of radioactive materials. Regions with higher rainfall may experience more significant leaching of contaminants into water resources, while areas with drier climates may have more localized contamination affecting local soil and plants.

4. Soil characteristics: Soil texture and organic content affect how radionuclides are uptaken and retained. Sandy soils may allow more significant infiltration of contaminants, while clay or loamy soils may bind them more tightly. The study suggests that areas with soil types conducive to radionuclide retention may have higher plant and water contamination levels.

5. Environmental Impacts on Livestock and Agriculture: Given the direct interactions between contaminated soil, plants, water, and livestock, the hypothesis suggests that areas with higher levels of contamination will show elevated levels of radioactive isotopes in meat, milk, and other agricultural products, which will impact food safety.

Objectives

1. Measurement of radioactive contamination of soil, plants, water, and livestock products in the Kyzylorda, Turkestan, Almaty, and Abay regions.
2. Assess food safety by assessing contamination levels in livestock products.

MATERIAL AND METHODS

Samples

Samples description:

Soil samples: Soil samples were collected from various agricultural fields at 0–50 cm depth to analyze the concentration of radionuclides in the soil.

Plant samples: Plant samples were taken from grass growing in a semi-natural habitat. These samples represent the vegetation found in the region to assess the uptake of radionuclides.

Water samples: Water samples were collected from a nearby river, representative of the region's surface waters, and tested for radionuclide contamination.

Milk samples: Milk samples were collected from dairy cows raised in the region to assess the transfer of radionuclides from feed to milk.

Meat samples: Meat samples were obtained from local cattle and used to study the bioaccumulation of radionuclides through the food chain.

Samples collection:

1. Soil Samples: Soil samples were collected from the designated agricultural fields and temporarily stored at 4°C until further processing.
2. Plant Samples: Plant samples were carefully harvested from the selected semi-natural habitat and stored at room temperature for transport to the laboratory.
3. Water Samples: Water samples were collected in clean containers from the river and refrigerated at 4 °C to preserve their integrity.
4. Milk Samples: Milk samples were obtained from dairy cows, stored at 4 °C, and transported to the laboratory within 24 hours for analysis.
5. Meat Samples: Meat samples were collected from local cattle, stored at -20 °C for short-term preservation, and then transferred to the laboratory for examination.

Samples preparation:

1. Soil samples: Soil samples were air dried and sieved through a 2 mm sieve to remove debris, and 650 g of the homogenized sample was taken for analysis.
2. Plant samples: Plant samples were washed to remove surface contaminants, dried at 50 °C, ground to a fine powder, and 150 g of the homogenized material was prepared for radionuclide analysis.
3. Water samples: Water samples were filtered to remove solids, and 1000 ml of the filtered water was prepared for radionuclide analysis.
4. Milk samples: Milk samples were homogenized, and 1000 ml were aliquoted for analysis to ensure uniformity and accuracy of radionuclide measurement.
5. Meat samples: Meat samples were defrosted, ground, and homogenized, and 500 g of each sample was taken for radionuclide concentration analysis.

Number of samples analysed: 60

Chemicals -

Animals, Plants and Biological Materials

Plants: *Artemisia tridentata, Agropyron, Elymus, Mentha, Artemisia absinthium, Sisymbrium officinale, Urtica.*

Animals: Cow - *bovis.*

Peasant farm “Azat” Almaty region
Peasant farm “Kurganbai-Bulak” Turkestan region
Peasant farm “Bereke” Abai region
Peasant farm “Duman” Kyzylorda region

Instruments

Gamma-beta spectrometer MKS-AT1315, Republic of Belarus — was used to measure the level of radiation activity and spectral analysis of gamma and beta radiation in samples.

Electronic scales SPX1202, China, were used to precisely weigh samples, which required high accuracy for analysis in laboratory conditions.

Vacuum drying ovens, Stegler VAC-24, China, were used for drying various materials in air and in a vacuum, and they could heat up to 250 ^{0}C.

HL 340 POSIS laboratory refrigerator, Russia — designed for storage at temperatures from 2 to 15 °C in the fridge and at temperatures from -10 to -25 °C in the freezer.

Laboratory Methods

The research was carried out with grant funding from the Ministry of Higher Education and Science of the Republic of Kazakhstan [AP19577014 "Develop ways to reduce radioactivity in the body of animals and livestock products"]. The study was conducted at Kazakh National Agrarian Research University within the Department of Veterinary Sanitation, in collaboration with the TOO NPP "Antigen" laboratory. Research was carried out in four main regions of Kazakhstan: Kyzylorda, Turkestan, Almaty, and Abay. These regions were selected based on their distinct soil, climate, and geographical features. The sampling locations are shown in Figure 1.

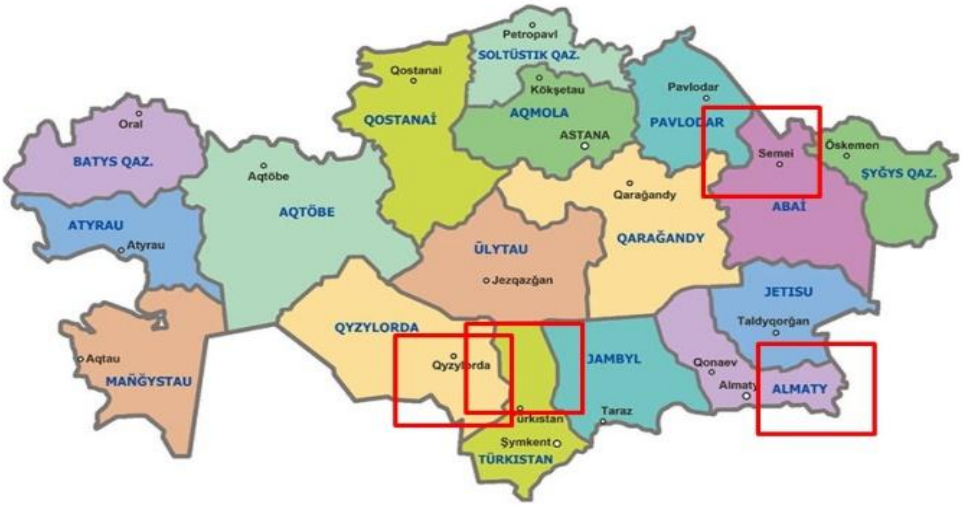

Figure 1 Sampling location.

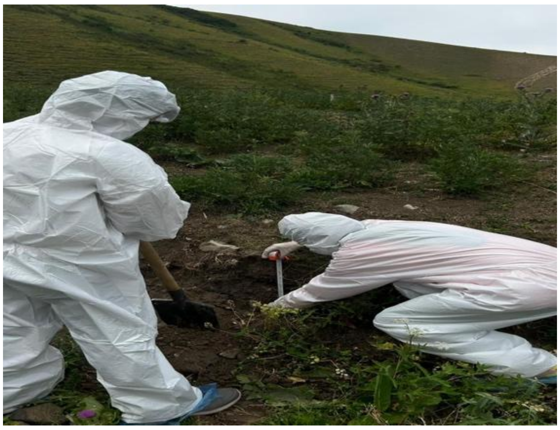

Figure 2 Taking a soil sample.

Figure 3 Water sampling.

Sampling and radiation control were performed in accordance with the ST 1623-2007 standard of the Republic of Kazakhstan, which is aligned with the international recommendations of ISO 11929 (International Organization for Standardization, 2010), governing the methodology for measuring environmental radiation levels. These standards ensure consistency and accuracy in radiation measurements, guaranteeing that the results are comparable with international protocols for assessing environmental radiation. The soil sampling scheme is presented in Figure 2.

Figure 4 Taking a grass sample.

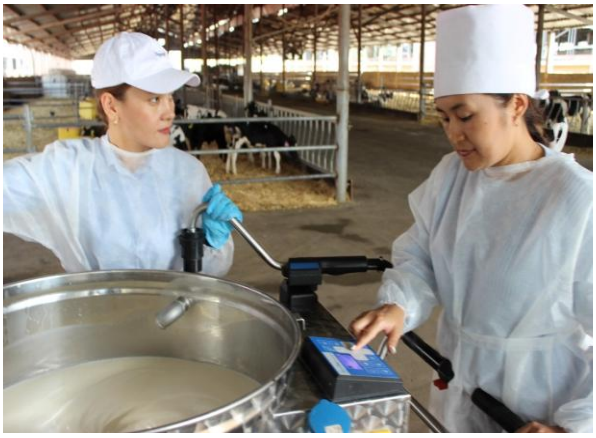

Figure 5 Milk sampling.

For plant samples, collections were made at a height of 5-10 cm above the soil surface for large animals and 1-5 cm for small animals. The sampling of plants is shown in Figure 4.

Water samples were collected from both the surface and various depths, following the international guidelines for water sampling (ISO 5667-3, 2012). The collection process is illustrated in Figure 3.

Milk and meat samples were collected from various anatomical sites: the 4th-5th cervical vertebrae, shoulder blade, thigh, and thicker parts of the back muscles. A total sample weight of at least 200 g was obtained from spot samples, which were combined to form a composite sample. The mass of the composite sample was determined based on the specific activity of the individual samples and the research method. To prepare an average sample, approximately 0.2-0.3 kg of meat was cut into small pieces and mixed thoroughly. Milk sampling is depicted in Figure 5.

The methods used for these sample collections were based on modified home laboratory protocols that follow general environmental sampling procedures as outlined in ISO 17025 (International Organization for Standardization, 2017).

Gamma-Beta Spectrometry: The samples' radiation levels were measured using an MKS-AT1315 gamma-beta spectrometer, a device commonly employed for radiation detection in environmental and food product samples. The spectrometer detected gamma radiation from Cesium-137 and beta radiation from Strontium-90.

This technique is internationally recognized for its sensitivity and accuracy in detecting Cesium-137 and Strontium-90 in various environmental matrices, including soil, water, and food products. The spectrometer has been validated in the State System of Measurement Units of the Republic of Kazakhstan under registration number KZ.02.03.00471-2020.

Sensory Evaluation of Food:

Although sensory analysis was not the primary focus of this study, any evaluations of sensory attributes of foods (such as taste, odor, texture, and appearance) would follow established guidelines (ISO 8586-1, 2012). These evaluations would involve trained raters who would subjectively rate the sensory attributes of food samples. However, sensory analysis was not a central component of the current study.

The gamma-beta spectrometry method used in this study adheres to international protocols for detecting Cesium-137 and Strontium-90 in environmental samples and food products, ensuring that the results are comparable to global standards. The equipment used is calibrated and validated following the standards set by the State System of Measurement Units of the Republic of Kazakhstan, guaranteeing the reliability and accuracy of the radiation measurements.

Description of the Experiment

In the first stage of the experiment, we collected samples from individual farms. We then processed the samples to ensure accurate analysis of radionuclides such as cesium-137 (Cs-137) and Strontium-90 (Sr-90) in various environmental and biological samples. The sample preparation process involved several steps depending on the sample type.

Soil samples: They were dried in a dryer at 40°C to 50°C to ensure uniform drying and removal of excess moisture. Drying took 8-12 hours. During drying, the soil was periodically stirred to ensure uniform moisture removal.

Then the soil samples were ground using a mortar and pestle to reduce the particle size. After grinding, the samples were sieved through a 3 mm sieve to remove large particles or debris. After sieving, the sample was thoroughly mixed to obtain a homogeneous mixture, and the average sample was collected for further analysis. The plant samples were dried in a dryer at a lower temperature range of 30°C to 40°C to prevent loss of volatile components or degradation of the samples. Drying times of 6-8 hours were sufficient. Afterward, they were ground in a blender. This step ensured that all the plant material was uniformly mixed for radionuclide analysis. A portion of the ground plant material was weighed and prepared for radiation measurements. The water samples were refrigerated at 4°C to prevent any biological activity or further changes in the radionuclide concentration. The samples were first filtered through a white belt filter to remove any particulate matter that could interfere with the measurement. After filtration, the water samples were preserved with nitric acid to ensure the stability of the radionuclides during transport and analysis. The standard acid addition rate was 2 ml nitric acid per 1000 militer of water sample. The pH of the water samples was checked with pH paper to ensure that the acidity was appropriate for the sample preservation conditions. Animal Products (Milk and Meat)

Milk samples were stored at or below 4°C to maintain quality and prevent deterioration. Samples were filtered to remove any particulate matter. After filtration, milk was centrifuged to separate fat from the liquid portion, which was then analyzed for radionuclides. After preparation, milk samples were placed in Marinelli bottles for gamma-beta spectrometric analysis. Meat samples were stored at or below 4°C (refrigerated) to slow down microbial activity and maintain sample integrity. Samples were first cut into small pieces to facilitate the grinding process. The meat was ground into a fine paste using an electric miner. The mince was mixed to create a homogeneous sample, which was then placed in a Marinelli jar for radiation measurement.

General procedures for all samples:

After sample preparation, they were placed in appropriate containers (e.g., Marinelli jars for liquid samples such as milk or graduated containers for solid samples such as soil and meat). Then, the samples were subjected to gamma-beta spectrometry using an MKS-AT1315 spectrometer.

Quality Assurance

Number of repeated analyses: 3

Number of experiment replication: 3

Reference materials: GAMMA-BETA SPECTROMETER MKS-AT1315 Operating Manual TIAYA.412151.004 RE

Calibration: Calibration of the MKS-AT-1315 (gamma-beta spectrometer) usually includes several stages that ensure the accuracy and reliability of measurements.

Preparing the equipment, installing and connecting the device. It is not recommended to install the spectrometer near equipment that creates significant network interference. To calibrate the spectrometer, it is necessary to keep the device in normal conditions for 2 hours.

Checking the serviceability of all components of the device (detectors, radiation sources).

Checking the scale setting and the range of measuring gamma and beta activity.

Using radiation sources. Standard sources of radioactive materials with known activity are used for calibration: Cesium-137, Strontium-90. According to GOST 25926-90, GOST R 52241-2004, ISO /12/C35242, the source corresponds to strength classes. Certificate of Conformity N-OIAE.RU.112 (OC). 00106

Sensitivity check. We perform a series of measurements using standard sources and record the readings. We calculate the device's sensitivity using known source activity data and the measured values obtained.

We check the gamma and beta radiation spectra to ensure that the device is correctly registering the peaks and energy levels for each radioactive isotope line. If necessary, we adjust the calibration parameters. If the calibration data shows deviations, we adjust the calibration coefficients for accurate measurements. We repeat the calibration several times to check the stability of the results.

Once the calibration is complete, the MKS-AT-1315 spectrometer will be ready to accurately measure gamma and beta radiation in various samples and environments.

Calibration is performed before and after measurements in studies. To avoid erroneous results, calibration should be performed before each important study and, if possible, after it.

Laboratory accreditation: The experiments were carried out in a laboratory accredited following the international standard ISO/IEC 17025-2019.

Data Access

"The data are available upon request from the corresponding author due to confidentiality.

Statistical Analysis

The SPTR progra (English SPTR - Software for Processing of Terrestrial Radionuclides) is specialized software used for processing and analyzing data related to radionuclides, including for assessing the impact of radiation on ecological systems. In the context of radiation ecology, SPTR can be used to analyze the distribution of radionuclides in various components of ecosystems (soil, water, plants, animals) and to model the migration of radionuclides in natural conditions.

RESULTS AND DISCUSSION

The study aimed to assess the specific activity of radioactive isotopes Cesium-137 (Cs-137) and Strontium-90 (Sr-90) in various environmental samples (milk, meat, vegetation, soil, and water) across different regions of Kazakhstan. The results revealed significant differences in the contamination levels of these radionuclides, as summarized below:

Milk Samples (Table 1): Cesium-137 (Cs-137): Detected at low levels across all regions. The highest concentration was observed in the Almaty region (0.31 Bq/kg), followed by the Turkestan and Kyzylorda regions, with slightly lower levels (0.29 Bq/kg and 0.26 Bq/kg, respectively). The Abay region had the lowest detection (0.17 Bq/kg).

Strontium-90 (Sr-90): It was found only in the Kyzylorda region at a relatively high concentration of 10.36 Bq/kg and was not detected in the other areas.

Table 1 Specific activity of milk studied at various control points (Bq/kg, ml).

№	Name of indicator, units. Change	Weight	Number of samples	Actual result
	Abay region			
1	Specific activity of cesium – 137, Bq/kg (l)	1000 ml	3	0.17± 0.01
2	Specific activity of strontium – 90, Bq/kg (l)	1000 ml	3	0 ± 0
	Almaty region			
1	Specific activity of cesium – 137, Bq/kg (l)	1000 ml	3	0.31± 0.02
2	Specific activity of strontium – 90, Bq/kg (l)	1000 ml	3	0 ± 0
	Kyzylorda region			
1	Specific activity of cesium – 137, Bq/kg (l)	1000 ml	3	0.26± 0.02
2	Specific activity of strontium – 90, Bq/kg (l)	1000 ml	3	10.36± 0.01
	Turkestan region			
1	Specific activity of cesium – 137, Bq/kg (l)	1000 ml	3	0.29± 0.01
2	Specific activity of strontium – 90, Bq/kg (l)	1000 ml	3	0 ± 0

Meat Samples (Table 2): Cesium-137 (Cs-137): Found in varying concentrations, with the highest activity in the Turkestan region (1.9 Bq/kg), followed by Abay (1.70 Bq/kg), Kyzylorda (1.44 Bq/kg), and Almaty (0.50 Bq/kg). Strontium-90 (Sr-90): No significant activity was detected in the meat samples across all regions.

Table 2 Specific activity of meat studied at various control points (Bq/kg, ml).

№	Name of indicator, units. Change	Weight	Number of samples	Actual result
	Abay region			
1	Specific activity of cesium – 137, Bq/kg (ml)	500 g	3	1.70± 0.02
2	Specific activity of strontium – 90, Bq/kg (ml)	500 g	3	0 ± 0
	Almaty region			
1	Specific activity of cesium – 137, Bq/kg (ml)	500 g	3	0.50± 0.03
2	Specific activity of strontium – 90, Bq/kg (ml)	500 g	3	0 ± 0
	Kyzylorda region			
1	Specific activity of cesium – 137, Bq/kg (ml)	500 g	3	1.44± 0.02
2	Specific activity of strontium – 90, Bq/kg (ml)	500 g	3	0 ± 0
	Turkestan region			
1	Specific activity of cesium – 137, Bq/kg (ml)	500 g	3	1.9± 0.01
2	Specific activity of strontium – 90, Bq/kg (ml)	500 g	3	0 ± 0

Grass Samples (Table 3): Cesium-137 (Cs-137): No significant levels of Cs-137 were detected in vegetation across all regions. Strontium-90 (Sr-90): The highest concentration of Sr-90 was found in the Abay region (14.3 Bq/kg), followed by Kyzylorda (8.7 Bq/kg), Turkestan (6.4 Bq/kg), and Almaty (4.8 Bq/kg).

Table 3 Specific activity of the studied grass at different control points (Bq/kg, l).

№	Name of indicator, units. Change	Weight	Number of samples	Actual result
	Abay region			
1	Specific activity of cesium – 137, Bq/kg (ml)	150 g	3	0 ± 0
2	Specific activity of strontium – 90, Bq/kg (ml)	150 g	3	14.3± 0.03
	Almaty region			
1	Specific activity of cesium – 137, Bq/kg (ml)	150 g	3	0 ± 0
2	Specific activity of strontium – 90, Bq/kg (ml)	150 g	3	4.8± 0.02
	Kyzylorda region			
1	Specific activity of cesium – 137, Bq/kg (ml)	150 g	3	0 ± 0
2	Specific activity of strontium – 90, Bq/kg (ml)	150 g	3	8.7± 0.02
	Turkestan region			
1	Specific activity of cesium – 137, Bq/kg (ml)	150 g	3	0 ± 0
2	Specific activity of strontium – 90, Bq/kg (ml)	150 g	3	6.4± 0.01

Soil Samples (Table 4): Cesium-137 (Cs-137): The highest activity of Cs-137 was found in the Abay region (13.94 Bq/kg), followed by Turkestan (10.94 Bq/kg), Kyzylorda (10.35 Bq/kg), and Almaty (10.09 Bq/kg). Strontium-90 (Sr-90): No significant Sr-90 activity was detected in the soil samples from all regions.

Table 4 Specific activity of the studied soil at different control points (Bq/kg, l).

№	Name of indicator, units. Change	Weight	Number of samples	Actual result
	Abay region			
1	Specific activity of cesium – 137, Bq/kg (ml)	650 g	3	13.94± 0.03
2	Specific activity of strontium – 90, Bq/kg (ml)	650 g	3	0 ± 0
	Almaty region			
1	Specific activity of cesium – 137, Bq/kg (ml)	650 g	3	10.09± 0.01
2	Specific activity of strontium – 90, Bq/kg (ml)	650 g	3	0 ± 0
	Kyzylorda region			
1	Specific activity of cesium – 137, Bq/kg (ml)	650 g	3	10.35± 0.02
2	Specific activity of strontium – 90, Bq/kg (ml)	650 g	3	0 ± 0
	Turkestan region			
1	Specific activity of cesium – 137, Bq/kg (ml)	650 g	3	10.94± 0.01
2	Specific activity of strontium – 90, Bq/kg (ml)	650 g	3	0 ± 0

Water Samples (Table 5): Cesium-137 (Cs-137): Detected at low levels in the Abay region (0.06 Bq/kg), Kyzylorda (0.29 Bq/kg), and Turkestan (0.91 Bq/kg). No Cs-137 activity was detected in the Almaty region. Strontium-90 (Sr-90): It was found at low levels only in the Kyzylorda region (1.33 Bq/kg) and was not detected in other regions.

Cesium-137: Overall, Cs-137 activity was relatively low in all regions, with the highest concentrations found in soil samples, particularly in the Abay region. Its presence in meat and milk samples was limited, indicating that its transfer to higher food chains (e.g. cattle) may be negligible in these regions.

- Strontium-90: Sr-90 contamination levels were notably higher in the Kyzylorda region, particularly in milk, vegetation, and water. This indicates a localized source of contamination, possibly related to historical nuclear activities or environmental pollution in the region.

Geographic variability: The Abay region recorded the highest soil contamination, while the Kyzylorda region stood out for Strontium-90 contamination in milk and vegetation. Contamination levels in all samples were relatively low in the other areas.

Analysis of Cesium-137 (Cs-137) and Strontium-90 (Sr-90) activity in environmental samples across Kazakhstan provides insight into radiological contamination across regions, revealing significant regional variations in contamination levels. These results contribute to understanding how radionuclides from nuclear activities, including atmospheric testing and reactor accidents, impact the environment decades later.

Table 5 Specific activity of the water being studied at different control points (Bq/kg, l).

№	Name of indicator, units. Change	Weight	Number of samples	Actual result
	Abay region			
1	Specific activity of cesium – 137, Bq/kg (ml)	1000 ml	3	0.06± 0.01
2	Specific activity of strontium – 90, Bq/kg (ml)	1000 ml	3	0 ± 0
	Almaty region			
1	Specific activity of cesium – 137, Bq/kg (ml)	1000 ml	3	0 ± 0
2	Specific activity of strontium – 90, Bq/kg (ml)	1000 ml	3	0 ± 0
	Kyzylorda region			
1	Specific activity of cesium – 137, Bq/kg (ml)	1000 ml	3	0.29± 0.03
2	Specific activity of strontium – 90, Bq/kg (ml)	1000 ml	3	1.33± 0.02
	Turkestan region			
1	Specific activity of cesium – 137, Bq/kg (ml)	1000 ml	3	0.91± 0.02
2	Specific activity of strontium – 90, Bq/kg (ml)	1000 ml	3	0 ± 0

Cesium-137 (Cs-137) in the Environment

Cesium-137 is one of the most studied environmental contaminants due to its long half-life of approximately 30 years and its ability to move through the environment **[10]**. In Kazakhstan, environmental samples show relatively low levels of Cs-137 contamination, with the highest concentration recorded in soil from the Abay district (13.94 Bq/kg). These results are consistent with similar studies globally where Cs-137 accumulates primarily in soil due to its relatively low solubility in water **[11]**. The presence of Cs-137 in milk and meat suggests minimal bioaccumulation in higher trophic levels, supporting findings from other contaminated regions, such as Chornobyl and Fukushima, where Cs-137 remained primarily in soil and plants with limited transfer to animals **[12]**, and **[13]**. The relatively low mobility of Cs-137 in water limits its uptake by livestock, reducing its transmission to humans **[14]**.

Strontium-90 (Sr-90) Contamination

Strontium-90, a radioactive fission product, presents a more significant health risk than Cs-137 due to its chemical similarity to calcium and its ability to accumulate in bone tissue **[15]**, and **[16]**. Sr-90 is also more mobile in both soil and water, contributing to its higher bioavailability in the food chain **[17]**. This mobility was evidenced by elevated Sr-90 concentrations found in Kyzylorda environmental samples **[18]**. The detection of Sr-90 in milk (10.36 Bq/kg) and vegetation highlights localized contamination, likely due to historical nuclear tests or waste disposal in the region **[19]**. This pattern of contamination is consistent with other areas affected by nuclear activity, such as the Chornobyl Exclusion Zone **[20]**, and **[21]**. Sr-90's capacity to concentrate in plant tissues and then accumulate in herbivores further indicates the potential exposure risks for livestock. It is crucial to assess the potential consequences for both human health and wildlife **[22]**.

Geographical Variability and Contamination Sources

The differences in contamination levels across regions suggest the presence of localized contamination sources **[23]**. For instance, high Cs-137 contamination in Abay soils and higher Sr-90 concentrations in Kyzylorda may stem from past nuclear testing or reactor accidents **[24]**. These localized patterns are common in areas affected by Soviet-era nuclear activities, where radioactive fallout remains a long-term environmental issue **[25]**. The high concentrations of Cs-137 and Sr-90 in regions with nuclear histories, such as Kazakhstan, highlight the need for continued monitoring of radionuclide concentrations and their long-term environmental effects **[26]**, and **[27]**. The presence of these radionuclides in soil, water, and vegetation indicates the persistent nature of contamination, with fallout from nuclear explosions occurring between the 1940s and 1980s likely contributing to long-lasting environmental effects **[28]**, and **[29]**.

Ecological and Health Implications

Despite relatively low contamination levels in this study, the persistence of Sr-90 and Cs-137 in the environment poses long-term ecological and health risks **[30]**. Sr-90, in particular, is known to accumulate in bones, making it a significant concern for human and wildlife health **[31]**. Prolonged exposure to Sr-90 can lead to increased risks of cancers and other radiation-related diseases, especially in regions with high concentrations of vegetation and livestock products **[32]**. This is a particular concern in areas like Kyzylorda, where the presence of Sr-90 in milk and vegetation could have long-term impacts on agricultural practices and public health **[33]**. The potential for bioaccumulation and biomagnification of these radionuclides in the food chain raises significant concerns for biodiversity and ecological stability, particularly in agricultural regions where livestock forms an essential part of the economy **[34]**. The uptake of Sr-90 and Cs-137 by plants, followed by consumption by herbivores and carnivores, could disrupt local ecosystems and food webs, affecting both human and wildlife populations **[35]**.

CONCLUSION

During a nuclear emergency, an evacuation zone is established to prevent people from being exposed to levels of radiation that pose an immediate health threat. However, the release of radioactivity into the environment can contaminate the food chain, potentially affecting food supplies outside the critical zone. Radionuclides can migrate from soil to crops or animals via feed, even at contamination levels below those that pose an immediate health threat. This study assessed the specific activity of cesium-137 (Cs-137) and strontium-90 (Sr-90) in environmental samples from regions of Kazakhstan. Cesium-137 (Cs-137): generally low in milk and meat, suggesting minimal transfer through the food chain. Higher concentrations were found in soil samples, particularly in Abay. Strontium-90 (Sr-90): showed localized contamination, particularly in Kyzylorda, with higher levels in milk and vegetation, likely related to past nuclear activities or environmental contamination. Abay district had the highest Cs-137 soil contamination, and Kyzylorda region had the highest Sr-90 contamination of milk, vegetation, and water. Overall contamination levels were low, but localized hotspots indicate lingering effects of past nuclear activities or accidents.

Continued monitoring is needed to track long-term contamination trends. This study provides insight into patterns of radiological contamination in Kazakhstan and the migration of radionuclides through the soil-plant-water-animal-food chain system.

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