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Original Research

Radionuclide Content in the Soil-Water-Plant-Livestock Product System in East Kazakhstan

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Abstract

In this study the concentration of radionuclides (Cs-137, Am-241, and Pu-239/240) in different types of environmental samples and livestock products were determined. The samples of soil, plants, water, milk, and meat from five stationary control points belonging to the zone of radiation risk situated near Semipalatinsk Test Site in Kazakhstan were collected. The concentrations of radionuclides were determined by alpha- and gamma-spectrometry. Results about the content were discussed. The levels of radionuclides did not exceed the maximum contaminant levels. The most contaminated samples were soil (Cs-137: 2,100.0 and 1,380.0 Bq/m, Am-241: 2,220.037 and 900.015 Bq/m, and Pu-239/240: 567.0 and 372.0 Bq/m) and plants (Cs-137: 0.3 and 2.2 Bq/kg) from the Sarzhal and Kainar regions.

Keywords: radionuclide, Semipalatinsk Test Site, Kazakhstan, zone of radiation risk, environment, livestock products

Introduction

Water and food are essential for life and their quality has great impact on public health and safety [1]. This is especially important in East Kazakhstan because of nuclear tests carried out at the Semipalatinsk Test Site (STS) [2]. The STS is located on the territory of three provinces (oblasts) of Kazakhstan – namely, Vostochno-Kazakhstanskaya, Karagandinskaya and Pavlodarskaya – and occupies an area of 18,500 km^2 with a perimeter of about 600 km. In the territory of the former Semipalatinsk oblast, the area of the test site comprises 10,000 km^2 and represents 54, 39, and 7% of each previously stated oblast, respectively. A reported 498 nuclear tests were conducted by the Soviet Union at the STS between 1949 and 1989 (a 40-year period) [3-7]. The first nuclear test conducted at STS "Opytnoe Pole," on 29 August 1949, was a plutonium bomb that yielded about 22 kT of explosive power. Between 1949 and 1962 the Soviet Union conducted 118 atmospheric nuclear and thermonuclear tests, 26 of them near the ground. The approximate cumulative explosive yield of these tests, 6.4 MT, is about 6 times greater than the explosive yield of the above-ground tests at the Nevada Test Site and represents about 6% of the yield of the tests conducted in the Marshall Islands. In 1965 two additional atmospheric tests, "Balapan" and "Sary Uzen," with deliberate soil excavation were conducted. Although above-ground testing stopped in 1962, vented underground detonations continued up to 1989. The last test took place on 12 February 1989 and resulted in leakage of large amounts of the radioactive noble gases xenon and krypton [3].

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The radionuclides emanating from these tests resulted in atmospheric and environmental contamination. Testing at the site ceased in 1989, and in July 2000 an international team of scientists conducted a controlled detonation of 100 tons of explosives in the last remaining tunnel of the test site, effectively ending Kazakhstan's status as a nation capable of testing and launching nuclear weapons [8]. In addition to nuclear bomb testing, on-range confidential fighting tests involving radioactive substances (either sprayed by means of aerial bombs or artillery shells) were conducted. All of these activities have been damaging to health: experts estimate that 1.2 to 1.6 million inhabitants have been subjected repeatedly to large doses of ionizing radiation. The test site also negatively impacted the health of the population through chronic exposure. The 40 years of nuclear weapon testing on STS caused irreparable damage to the health of humans and the environment (increased diseases and death rates). Nuclear testing even caused detrimental effects to subsequent generations. The whole territory of Semipalatinsk and adjacent to the test site territories of Pavlodar, East-Kazakhstan, and Karaganda regions had been classified as a zone of ecological calamity. Mitigation of these effects are addressed by the State program through a complex set of measures, including health precaution, treatment, rehabilitation, social protection of people, and social-economical improvement of the regions [9]. Since 1989 by the decree of the President of the Republic of Kazachstan (Nursultan A. Nazarbaev), nuclear tests have stopped at the STS, but the test site still affects the environment in Central and East Kazakhstan, and Altai (Russia), and also on the safety of the population living in and near the territory of the test site. Contaminated territories are considered those territories that have effective equivalent radiation doses of population more than 0.1 rem for all periods of nuclear testing. At 2010 cancer diseases per 100,000 people in the Republic of Kazakhstan were 181.2 people, but in East-Kazakhstan 273.3 people; mortality due to cancer per 100,000 people in the Republic of Kazakhstan is 103.9 people, in East-Kazakhstan 158 people. Increasing cancer is observed in the settlements of the East-Kazakhstan region [10].

Depending on the rate of equivalent dose, contaminated territories were subdivided on the next zones: zone of extreme radiation risk, zone of maximal radiation risk, zone of high radiation risk, zone of minimal radiation risk, and territory with privilege social-economic status [11-15].

The goal of this study was measuring the possible contaminating isotopes like Cs-137, Am-241, and Pu-239/240 of the environmental and food samples from East Kazakhstan, determining their origin and seeking relations between radionuclide content and other properties of the samples and estimating their hazard to the food chain. Although the major anthropogenic radioactivity of the environment comes from the relatively short-lived isotopes, like Cs-137 (half-life: 30.2 years) nowadays, a potential long-term hazard comes from the long-lived plutonium isotopes, three of them are a-emitters: Pu-238, Pu-239, and Pu-240. The hazard of the last one comes from plutonium itself and, in addition, from the daughter isotope Am-241, which is also a γ-emitter. Plutonium and americium have health hazards even in small concentrations due to their extremely high radiotoxicity [16]. Because of the long-term threat of these radionuclides, there is an increasing need for environmental monitoring of these actinides.

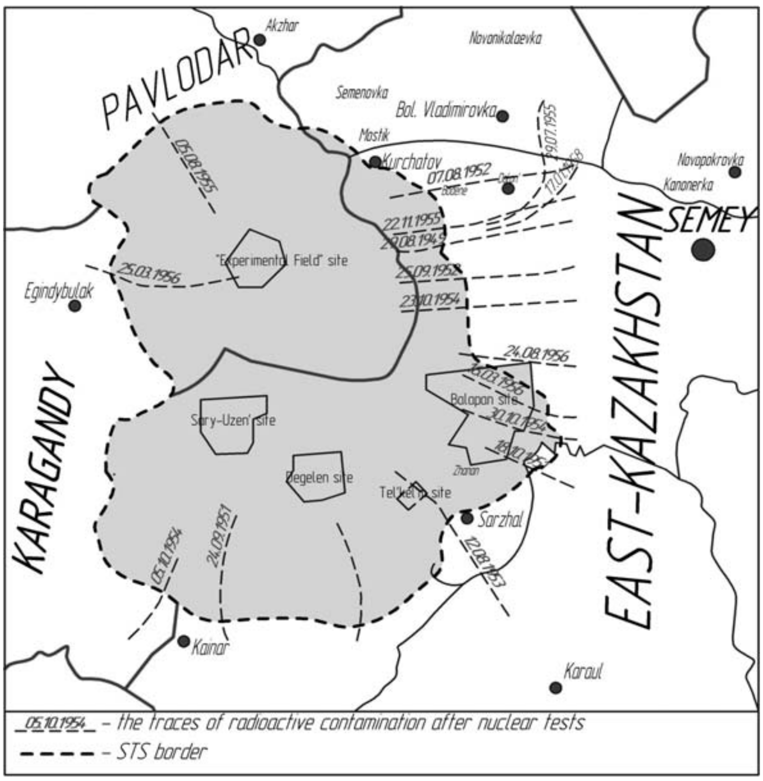

Fig. 1. Map of control points in East Kazakhstan.

Material and Methods

Sampling Areas

For analysis of the radioecological situation on the adjacent territories, five stationary control points where soil, water, livestock products, and vegetation were sampled were chosen (Fig. 1).

1. Sarzhal control point: situated 150 km from Semey city and 25 km from STS, belongs to the zone of extreme radiation risk. The village of Sarzhal is situated on the southeast border of the STS. The village was contaminated by radionuclides during nuclear tests. The most important contamination event was the testing of the first thermonuclear explosion that took place on 23 August 1953. Other potential sources of contamination, for the population of this village, include the sites of explosions – Telkem 1 and Telkem-2, which are situated several dozen kilometers from Sarzhal (the two craters are currently filled with groundwater and animals have been seen drinking from these craters) and the Degelen mountains (where more than 200 underground nuclear explosions were carried out in the tunnels).
2. Kainar control point: situated 275 km from Semey city and 70 km from STS, belongs to the zone of very high radiation risk. Main sources of radioactive contamination of Sarzhal and Kainar settlements caused by the powerful aboveground nuclear test in 12.08.1953, local aboveground nuclear test (24.09.1951, 05.10.1954, 16.03.1956), and Tel'kem nuclear tests [7].
3. Akzhar control point: (Pavlodar region) situated 250 km from Semey city and 80 km from STS, belongs to the zone of very high radiation risk. The village of Akzhar is situated on the northern border of the STS. The main potential source of contamination was the nuclear tests carried out on the "Experimental Field" site. The Experimental Field was the first test site on STS and used for above-ground and air nuclear tests during 1949-62. The first nuclear explosion was tested on August 29, 1949. In total on The Experimental Field were carried out 116 nuclear explosions, including 86 air and 30 above ground explosions. The test site area and adjacent territories were exposed to repeated radioactive contamination where the main sources were atmospheric explosions.
4. Novopokrovka control point: settlement Borodulikha, situated 35 km from Semey city and 165 km from STS, belongs to the zone of high radiation risk.
5. Karkaraly control point: situated 475 km from Semey city, 250 km from Karaghany city, and 120 km from STS, belongs to the zone of minimal radiation risk.

Methods

One hundred samples (four samples from each kind and from each place, weight/volume 2 kg or 2 L) for radiochemical analysis were collected during the spring and autumn 2012.

Plants

The STS is located in the plains of the dry Eurasian steppe. The harvested plants in terms of frequency of occurrence belong to the group of Natural Phytocenosis: feather grass (*Stipa capillata*, *S. sareptana*, *S. lessingiana*, *S. sareptana*) and fescue (*Fectuca valesiaca*), *Artemesia* species such as *Artemesia terrae-albae* and *Artemesia turanica*. For example *Stipa capillata* is a perennial bunchgrass species in the family *Poaceae* and *Festuca valesiaca*, is a species of flowering plant in the *Poaceae* family. Plants from sites not less 6 m^2 (2m×3m) were cut using scissors, sickle, or knife and collected into plastic bags. The height of cutting plants was not less 3 cm above the ground. The samples were labeled and transported to the laboratory. After that the samples were dried at 35ºC and blended.

Soil

At each locality uncultivated soil was collected using hand tools (three samples from each place, depth 5-10 cm; in the frame of 25 cm×25 cm). Foreign bodies were removed and the soil samples were collected into the plastic bags, labeled and transported to the laboratory. After that the samples were dried in a muffle furnace at 110ºC, passed through 2 mm sieves, weighed, and placed in Marinelli beakers. Meat and meat products: portions of raw meat and meat products samples were cut to small sizes and were oven dried at 110ºC to attain a constant weight. Samples after drying were crushed and homogenized. Milk and milk product samples (1 l) drying and then ashing at 450ºC. Water samples were collected from the rivers of five control points during the summer of 2012. The sample volumes were taken between 1.5 and 2.0 L, the ambient temperature was 25-23ºC, the water temperature was 17-18ºC. The samples were collected into plastic bottles, labeled, and transported to the laboratory. The water samples were filtered and added nitric acid to obtain pH=1, about 3 ml per 1 l of sample, controlled by indicator paper. After concentration, the radionuclides were determined by gamma spectrometer.

Radionuclide Measuring Equipment

Gamma-Spectrometry:
Cs-137 and Am-241 Activity Measurements

A high-purity germanium (HPGe) detector (model GC 2019, relative efficiency 40%, FWHM 1.80 keV at 1.33 MeV, FWHM - 840 eV at 122 keV) was used to collect the gamma-ray spectra. This detector was connected to a Canberra digital multichannel analyzer DSA-1000, which was connected to a computer that used Genie 2000 spectroscopy software. The standard deviation of the net peak area also was given by the Genie software. The system was calibrated using standard mixtures (OMASN #21.13., radionuclides Eu-152, Am-241, Cs-137, Khlopin Radium Institute, St. Petersburg, Russia) of gamma-emitting isotopes in Marinelli beakers. In order to determine the curve at lower energies, Am-241 (59.5 keV) was used. The minimum limit of detection for the determination of radionuclide's by γ-ray spectrometry for the above detection system at 95% confidence level is 0.1 Bq for 0.5 kg of environmental samples.

Alpha-Spectrometry:
Pu-239 + 240 Activity Measurements

A standard alpha-spectrometry procedure was applied according to the Standard method № KZ 07.00.01239-2010 "Determination of artificial radionuclides Pu-239/240, Sr-90 of environment samples: soil, sediments, plants," Almaty, 2010. P.25. For determining Pu-239+240 10 g of the sample were used. Spectrum processing and specific activity of isotopes were calculated by GENIE-2000 software. The method for separation of plutonium is based on ion exchange with Dowex 1×4 anion exchange resin. Radioactive tracer Pu-242 is added and the sample is brought into solution either by wet ashing or microwave digestion. The sample is introduced into an ion exchange column (Dowex 1×4, 50-100 mesh, in NO_3^- form) in 8 M HNO_3, washed with 8 M HNO_3 and 10 M HCl, and the Pu fraction is eluted with concentration 1 M HCl + 1 M NH_4I solution. The plutonium is electrodeposited on a stainless steel disc and counted with an Alpha Analyst (Canberra) alpha spectrometer with two chambers. Counting efficiency is approximately 35-40%. Spectrum processing and specific activity of isotopes were calculated by GENIE-2000 software. Quality control was assured by determining Pu-isotopes in certified reference samples.

Results and Discussion

A number of papers concerning the ground deposition of fission products after the Chernobyl accident have been published [17-25]. However, as a consequence of the difficult and labor-intensive procedures necessary for determining of actinides in the soil, fewer scientific papers have been presented on this topic [26-28]. Only some papers have reported on the occurrence of radionuclides in the whole ecosystem of East Kazakhstan.

Values obtained for the activity concentrations of Am-241, Cs-137, and Pu-239+240 are listed in Table 1 (Am-241 and Cs-137 concentrations were determined by gamma spectrometry and Pu-239+240 by alpha spectrometry).

There is evidence of the existence of hot spots as a consequence of the accident, which can be identified by the high anomalous concentration of Am-241 originating from Pu-241 beta decay.

The early investigation of Yamamoto et al. [29-31] and Priesta et al. [32] has shown the radiological situation in the Sarzhal region as the most contaminated sites in the south-eastern part of the Semipalatinsk test site. Our investigation confirmed that the most contaminated areas by Am-241, Cs-137, and Pu-239/240 were Sarzhal (zone of extreme radiation risk) and Kainar (zone of maximum radiation risk).

The highest concentration of Am-241, Cs-137, and Pu-239/240 were determined in the samples of soil from Sarzhal settlement – 37.0; 35.0, and 9.0 Bq/kg, respectively. In Kainar settlement content of Am-241 was 15.0 Bq/kg, Cs-137 – 23.0 Bq/kg and Pu-239/240 – 6.2 Bq/kg. In other settlements the concentration of these radionuclides was at a low level (0.2-6.1 Bq/kg). Sarzhal belongs to the zone of extreme radiation risk and is near the "Balapan" test site, where 105 underground nuclear explosions were conducted. The Balapan area (780 km^2, site of 105 underground nuclear tests) may be the receptor of much of the STS

Table 1. Radionuclide content in the samples: water, milk (Bq/l) and soil, plants and meat (Bq/kg).

	Am-241	Cs-137	Pu-239/240
Soil			
Sarzhal	37.00±1.0	35.0±4.00	9.60±2.15
Kainar	15.00±1.15	23.0±1.90	6.20±3.55
Novopokrovka	5.00±1.25	1.80±0.25	1.00±0.50
Akzhar	5.52±0.20	3.50±0.65	6.10±3.55
Karkaraly	0.42±0.11	0.50±0.11	0.20±0.09
Plants			
Sarzhal	1.53±0.35	2.22±0.13	0.90±0.05
Kainar	1.00±0.01	0.91±0.12	0.24±0.01
Novopokrovka	0.51±0.01	0.80±0.23	0.12±0.04
Akzhar	0.82±0.01	1.30±0.25	0.32±0.01
Karkaraly	0.33±0.15	0.32±0.07	0.10±0.03
Water			
Sarzhal	0.52±0.01	0.13±0.01	0.12±0.01
Kainar	0.35±0.01	0.14±0.02	0.10±0.03
Novopokrovka	0.22±0.05	0.13±0.04	0.14±0.01
Akzhar	0.25±0.01	0.12±0.04	0.12±0.03
Karkaraly	0.42±0.12	0.15±0.01	0.15±0.01
Milk			
Sarzhal	0.50±0.10	0.15±0.01	0.12±0.03
Kainar	0.45±0.10	0.64±0.21	0.14±0.03
Novopokrovka	0.33±0.15	0.55±0.13	0.13±0.01
Akzhar	0.54±0.21	0.82±0.08	0.14±0.05
Karkaraly	0.25±0.01	0.24±0.01	0.12±0.01
Meat			
Sarzhal	0.34±0.01	0.82±0.20	0.13±0.02
Kainar	0.33±0.01	1.83±0.4	0.13±0.06
Novopokrovka	0.34±0.04	0.62±0.20	0.14±0.02
Akzhar	0.35±0.01	0.23±0.08	0.14±0.05
Karkaraly	0.31±0.07	0.82±0.40	0.12±0.01

radionuclide contamination (including that of the Opytnoe Pole, where 86 nuclear tests were conducted in the air and 30 on the ground) [32]. In fact, the dominant wind direction is from the West (blowing toward the east), the underground water tends to run from the "Experimental Field" region toward the Sarzhal and Kainar settlements. Soils in a radius of 600 m from the epicenter of the explosion were contaminated with the fission products Cs-137 and Sr-90, the activation products Am-241, Co-60, Eu-154, and Eu-152, and the components of nuclear weapons material Pu-239/240. Soil is the upper layer of unsaturated zone of the earth, and very diverse in composition and behavior. The soil phase consists of mineral particles of various sizes, shapes and organic matter in various stages of degradation [33].

Determined activities are not so high as can be expected taking into account that the sampling area is a nuclear test site. The current results were compared with investigations of other researchers. Orzeł and Komosa [34] and Piekarz and Komosa [35] reported contamination of Polish soil taken from a deeper layer (5-10 cm deep) with Pu-239/240 ranged from 0.2 to 0.4 Bq/kg.

Soil is the main source of radionuclide contamination of the food chain. As a result of radionuclide fallout to the ground, they accumulate in the soil, are included in the biogeochemical cycle of transfer, and become a new component of the soil. The soil is more important and inertial link and the rate of radionuclide transfer in the chain depends on the transfer in the soil. Radionuclides are transfered from soil to the plants [36, 37], free-living animals [38-40], food [41, 42], and underground and surface waters [43-45].

The STS is located in the plains of the dry Eurasian steppe. It is comprised primarily of steppe grassland dominated by the family *Poacea* (primarily the genus *Stipa*), fescue (*Fectuca valesiaca*), and *Artemesia* species. Vegetation that grows on the fields and meadows are the main sources of radionuclide contamination of the animals' bodies and of course meat and milk. The cattle chew the vegetation up to 160 m^2 from the area (per cow), and therefore the radionuclides contaminate the animals' bodies intensively. Carlsen et al. described that 1% of Cs and Sr incoming during the day are removed from the body through milk [8]. Our results of vegetation analysis showed the presence of radionuclides in samples, but in a low quantity. So Cs-137 maintenance was more in the samples from Sarzhal – 2.2 Bq/kq and Akzhar – 1.3 Bq/kg; Am-241 – in Sarzhal – 1.5 Bq/kg and Kainar – 1.0 Bq/kg; Pu-239/240 concentration was more in vegetation of Sarzhal – 0.9 Bq/kg and less concentration – in Karkaraly settlement – 0.1 Bq/kg: in other regions its varied from 0.1 to 0.3 Bq/kg.

Contamination of food products derived from both farmed and wild animals can represent major sources of radiation exposure to humans from routine and accidental releases of radioactivity to the environment [33, 46, 47]. Zharykbasova [48] have reported the occurrence of heavy metals (Cd, Pb, Zn, Cu) in milk samples from the districts of Semey. The concentration of Cd in 4 regions among 30 regions were higher than the maximum allowable concentration (MAC) from 3.6 to 4.7 times, Pb concentration – in 8 regions from 1.7 to 7 times of MAC, Zn concentration – in 11 regions from 1.8 to 3.8 times of MAC, Cu concentration – 6 times higher in 1 region. In our investigations, radionuclides detected in samples of livestock products did not exceed allowable levels. The most contaminated milk samples in comparison with other settlements were from Sarzhal: Am-241 – 0.5 Bq/kg; Cs-137 – 1.8 Bq/kg and Pu-239/240 – 0.1 Bq/kg; less contaminated in Karkaraly: Am-241 – 0.2 Bq/kg; Cs-137 – 0.2 Bq/kg and Pu-239/240 – 0.1 Bq/kg, but still it was a very low level of radionuclides. In the highest concentration were noted for meat samples from Kainar: Pu-239/240 – 0.1 Bq/kg; Cs-137 – 1.8 Bq/kg, and Am-241 – 0.3 Bq/kg.

Water is essential for life and its quality has great impact on public health and safety [1]. Two rivers occur near the borders of the STS, the Irtysh north of the site, which runs

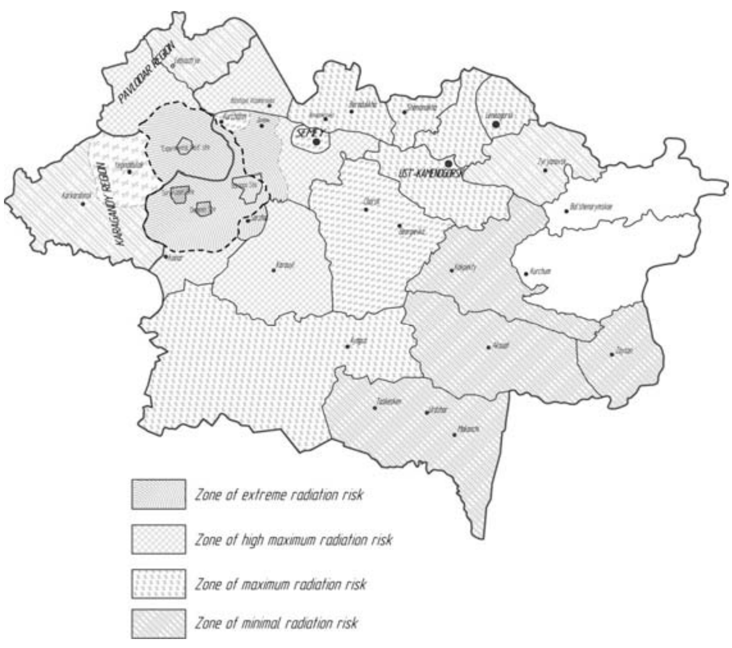

Fig. 2. Zones of radiation risk in East Kazakhstan.

Table 2. Comparison of effective weighted dose size obtained from the radionuclide Am-241 after consumption of 1kg of product by people of different age groups.

Name of sample	Size of effective weighted dose e (g) [x10^{-7} Sv]					
Age (g)	g≤1	g=1-2	g=2-7	g=7-12	g=12-17	g>17
e (g) [x10^{-7} Sv]	37.0	3.7	3.7	2.2	2.0	2.0
Plants						
Sarzhal	56.61	5.66	5.66	3.37	3.06	3.06
Kainar	37.00	3.70	3.70	2.20	2.00	2.00
Novopokrovka	18.87	1.89	1.89	1.12	1.02	1.02
Akzhar	30.34	3.03	3.03	1.80	1.64	1.64
Karkaraly	12.21	1.22	1.22	0.73	0.66	0.66
Mean	31.01	3.10	3.10	1.84	1.68	1.68
Water						
Sarzhal	19.24	1.92	1.92	1.14	1.04	1.04
Kainar	12.95	1.30	1.30	0.77	0.70	0.70
Novopokrovka	8.14	0.81	0.81	0.48	0.44	0.44
Akzhar	9.25	0.93	0.93	0.55	0.50	0.50
Karkaraly	15.54	1.55	1.55	0.92	0.84	0.84
Mean	13.02	1.30	1.30	0.77	0.70	0.70
Milk						
Sarzhal	18.50	1.85	1.85	1.10	1.00	1.00
Kainar	16.65	1.67	1.67	0.99	0.90	0.90
Novopokrovka	12.21	1.22	1.22	0.73	0.66	0.66
Akzhar	19.98	2.00	2.00	1.19	1.08	1.08
Karkaraly	9.25	0.93	0.93	0.55	0.50	0.50
Mean	15.32	1.53	1.53	0.91	0.83	0.83
Meat						
Sarzhal	12.58	1.26	1.26	0.75	0.68	0.68
Kainar	12.21	1.22	1.22	0.73	0.66	0.66
Novopokrovka	12.58	1.26	1.26	0.75	0.68	0.68
Akzhar	12.95	1.30	1.30	0.77	0.70	0.70
Karkaraly	11.47	1.15	1.15	0.68	0.62	0.62
Mean	12.36	1.24	1.24	0.73	0.67	0.67

through Kurchatov, Shaghan and Semey, and the Shagan River on the eastern border of the site, running south from Shagan to Sarzhal, including 50 km along the "Balapan Site" (Fig. 2). Water analysis shows the high concentration of Am-241 in Sarzhal – 0.5 Bq/kg, Karkaraly – 0.4 Bq/kg, which is close to the maximum allowable concentration (0.69 Bq/kg). In Akzhar and Novopokrovka Am-241 concentration was about 0.2 Bq/kg. Cs-137 data did not exceed MAC (11 Bq/kg) and were varied at a very low level – 0.1 Bq/kg. Monitoring of water quality is especially important in these places because of the introduction of contaminants by nuclear tests that were carried out at the Semipalatinsk Test Site.

Radionuclide contamination from the nuclear tests led to an increase of cancers, cardiovascular disease, leucosis, and central nervous system disorders among the population of the Semipalatinsk region [49, 50]. The rate disease of population of East-Kazakhstan, Karaghandy, and Pavlodar regions for 2002-03 was higher on 1.1 times due to republic rates for the same period. Hence for 2002-03 disease per 100,000 people in East Kazakhstan was 71,825.7 and 69,638.0, Karaghandy region 59,414.1 and 58,935.1,

Table 3. Comparison of effective weighted dose sizes obtained from the radionuclide Cs-137 after consumption of 1kg of product by people of different age groups.

Name of sample	Size of effective weighted dose e (g) [x10^{-7} Sv]					
Age (g)	g≤1	g=1-2	g=2-7	g=7-12	g=12-17	g>17
e (g) [x10^{-7} Sv]	0.21	0.12	0.096	0.10	0.13	0.1
Plants						
Sarzhal	0.47	0.27	0.21	0.22	0.29	0.29
Kainar	0.19	0.11	0.09	0.09	0.12	0.12
Novopokrovka	0.17	0.10	0.08	0.08	0.10	0.10
Akzhar	0.27	0.16	0.12	0.13	0.17	0.17
Karkaraly	0.07	0.04	0.03	0.03	0.04	0.04
Mean	0.23	0.13	0.11	0.11	0.14	0.14
Water						
Sarzhal	0.03	0.02	0.01	0.01	0.02	0.02
Kainar	0.03	0.02	0.01	0.01	0.02	0.02
Novopokrovka	0.03	0.02	0.01	0.01	0.02	0.02
Akzhar	0.03	0.01	0.01	0.01	0.02	0.02
Karkaraly	0.03	0.02	0.01	0.02	0.02	0.02
Mean	0.03	0.02	0.01	0.01	0.02	0.02
Milk						
Sarzhal	0.03	0.02	0.01	0.02	0.02	0.02
Kainar	0.13	0.08	0.06	0.06	0.08	0.08
Novopokrovka	0.12	0.07	0.05	0.06	0.07	0.07
Akzhar	0.17	0.10	0.08	0.08	0.11	0.11
Karkaraly	0.05	0.03	0.02	0.02	0.03	0.03
Mean	0.10	0.06	0.05	0.05	0.06	0.06
Meat						
Sarzhal	0.17	0.10	0.08	0.08	0.11	0.11
Kainar	0.38	0.22	0.18	0.18	0.24	0.24
Novopokrovka	0.13	0.07	0.06	0.06	0.08	0.08
Akzhar	0.05	0.03	0.02	0.02	0.03	0.03
Karkaraly	0.17	0.10	0.08	0.08	0.11	0.11
Mean	0.18	0.10	0.08	0.09	0.11	0.11

Pavlodar region 50,551.6 and 50,678.9 versus the republic rate 57,517.8 and 56,413.9, respectively. At 2010 cancer diseases per 100,000 people in the Republic of Kazakhstan were 181.2 people, but in East-Kazakhstan 273.3 people; mortality due to cancer per 100,000 people in the Republic of Kazakhstan was 103.9 people, in East-Kazakhstan 158 people. Rakhypbekov [10] has reported on increasing cancer rates in the settlements of East-Kazakhstan.

The estimation of exposures of Kazakh populations from the various sources of radiation is an important task. Based on the obtained results there were calculated effective weighted doses [nSv] from consumption of 1 kg of a product for different age groups (6 groups). The effective weighted dose for a given time is calculated as the sum of the dose effective against extrinsic hazard (radiation) and the weighted dose from the radionuclide captured by the alimentary or respiratory tract [42]. The sizes of doses resulting from the capture of a given radionuclide including their radiotoxicity and age of a person are given by the Polish Ministry Council Decree of 18 January 2005 about limiting doses against ionizing radiation. Tables 2-4 show distribution of radiation doses taken up by people in the

Table 4. Comparison of effective weighted dose sizes obtained from the radionuclide Pu-239/240 after consumption of 1kg of product by people of different age groups.

Name of sample	Size of effective weighted dose e (g) [x10^{-7} Sv]					
Age (g)	g≤1	g=1-2	g=2-7	g=7-12	g=12-17	g>17
e (g) [x10^{-7} Sv]	42.0	4.2	3.30	2.7	2.4	2.5
Plants						
Sarzhal	37.80	3.78	2.97	2.43	2.16	2.25
Kainar	10.08	1.01	0.79	0.65	0.58	0.60
Novopokrovka	5.04	0.50	0.40	0.32	0.29	0.30
Akzhar	13.44	1.34	1.06	0.86	0.77	0.80
Karkaraly	4.20	0.42	0.33	0.27	0.24	0.25
Mean	14.11	1.41	1.11	0.91	0.81	0.84
Water						
Sarzhal	5.04	0.50	0.40	0.32	0.29	0.30
Kainar	4.20	0.42	0.33	0.27	0.24	0.25
Novopokrovka	5.88	0.59	0.46	0.38	0.34	0.35
Akzhar	5.04	0.50	0.40	0.32	0.29	0.30
Karkaraly	6.30	0.63	0.50	0.41	0.36	0.38
Mean	5.29	0.53	0.42	0.34	0.30	0.32
Milk						
Sarzhal	5.04	0.50	0.40	0.32	0.29	0.30
Kainar	5.88	0.59	0.46	0.38	0.34	0.35
Novopokrovka	5.46	0.55	0.43	0.35	0.31	0.33
Akzhar	5.88	0.59	0.46	0.38	0.34	0.35
Karkaraly	5.04	0.50	0.40	0.32	0.29	0.30
Mean	5.46	0.55	0.43	0.35	0.31	0.33
Meat						
Sarzhal	5.46	0.55	0.43	0.35	0.31	0.33
Kainar	5.46	0.55	0.43	0.35	0.31	0.33
Novopokrovka	5.88	0.59	0.46	0.38	0.34	0.35
Akzhar	5.88	0.59	0.46	0.38	0.34	0.35
Karkaraly	5.04	0.50	0.40	0.32	0.29	0.30
Mean	5.54	0.55	0.44	0.36	0.32	0.33

consumption of the studied products. The dependences in Tables 2-4 are the function of the size of the dose obtained after consumption of 1 kg products and the age of a person. As follows from Tables 2-4, the dose which is the function of radionuclide radiotoxicity and its radioactive concentration is differentiated with age. The weighted doses calculated based on the above after consumption of 1 kg of a chosen product show that Am-241 is a much more threatening anthropogeneous isotope for the organism than Cs-137. The most exposed to Am-241 present in food products were children younger than one year.

Food analysis is of great value in estimating the daily intake of radionuclides. The consumption data for Kazakh people were taken from The GEMS/Food Consumption Areas and GEMS/Food Cluster Diets [51]. They are based on geographic proximity between countries and on similarities between dietary patterns. Kazakhstan belongs to Cluster B and sub cluster B2. The details of consumption are given in Table 5. The highest annual intake of Am-241 and Pu-239/240 is from water (mean 253.4 Bq, 90.7 Bq respectively), intake of Cs-137 from meat (mean 75.4 Bq).

Table 5. Estimated annual intake and annual effective doses of Am-241, Cs-137, and Pu-239/240 by Kazakh adults.

Radionuclide	Am-241		Cs-137		Pu-239/240	
Name of sample	Annual intake [Bq]	Annual effective dose [x10^{-7} Sv]	Annual intake [Bq]	Annual effective dose [x10^{-7} Sv]	Annual intake [Bq]	Annual effective dose [x10^{-7} Sv]
Milk (consumption per annum – 157.1 kg)						
Sarzhal	78.6	157.1	93.6	12.2	18.9	47.1
Kainar	70.7	141.4	100.8	13.1	22.0	55.0
Novopokrovka	51.8	103.7	93.6	12.2	20.4	51.1
Akzhar	84.8	169.7	86.4	11.2	22.0	55.0
Karkaraly	39.3	78.6	108.0	14.0	18.9	47.1
Mean	65.0	130.1	96.5	12.5	20.4	51.1
Meat (consumption per annum – 39.4 kg)						
Sarzhal	13.4	26.8	23.6	3.1	5.1	12.8
Kainar	13.0	26.0	100.5	13.1	5.1	12.8
Novopokrovka	13.4	26.8	86.4	11.2	5.5	13.8
Akzhar	13.8	27.6	128.8	16.7	5.5	13.8
Karkaraly	12.2	24.4	37.7	4.9	4.7	11.8
Mean	13.2	26.3	75.4	9.8	5.2	13.0
Water (consumption per annum – 730 L)						
Sarzhal	374.4	748.8	32.3	4.2	86.4	216.0
Kainar	252.0	504.0	72.1	9.4	72.0	180.0
Novopokrovka	158.4	316.8	24.4	3.2	100.8	252.0
Akzhar	180.0	360.0	9.1	1.2	86.4	216.0
Karkaraly	302.4	604.8	32.3	4.2	108.0	270.0
Mean	253.4	506.9	34.0	4.4	90.7	226.8

Conclusion

Our investigation confirmed that it is still a risk to human and animal health by radionuclides as determined in various types of environment and food samples in East Kazakhstan. Presented results showed that systematic radiological monitoring in East Kazakhstan of various environmental elements and food products is necessary and should be conducted, particularly in Sarhzal.

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