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Radiological assessment of the territories of the Turkestan region on zero background and development of a radiation monitoring system in a transboundary context

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ABSTRACT

The study shows the radiation situation on the territory of settlements located beside the impact zone of the nuclear power plant in Uzbekistan at the «zero stage», with definition of dominant species of flora and fauna; on the basis of which, the most suitable bioindicators for further research will be identified. Within frame of this work, the territories of fives settlements in the Republic of Kazakhstan, the nearest to the power plant site of top priority in Uzbekistan were examined. Radiochemical analysis, methods of radio spectrometry, mass spectrometry were used. The objects of study were soil, water, biota, food. In soil samples taken in Zhetysai and Zhyly-su, the specific activity of 232Th was twofold higher than the national average. The total alpha-activity of portable water samples in the village of Zhyly-su exceeded one-and-a-half fold of the allowable level. The concentrations of artificial (137Cs and 90Sr) as well as natural radionuclides (226Ra and 232Th) in the food products of population were within the standard. Dominant species of plants and animals for further use as the bioindicators of quality of environmental objects were proposed. The results obtained would enable to estimate forecasted effective doses for population and develop a monitoring system as well as a list of indicators for monitoring and evaluating the "zero background" of the selected territory. The monitoring model and its components used in this study may be applicable to other countries (in a transboundary context).

Keywords: Soil, Radionuclides, Power plant, Environment, Plants, Animals, Water.
Article type: Research Article.

INTRODUCTION

Nuclear power plants (NPPs) are a possible source of potential pollution by induced radionuclides of the environment causing chronic disease and disorders and contamination of plants, marine and terrestrial organisms in the environment (Ziyaei *et al*. 2014; Talbi *et al*. 2021; Sweaf & Oudah 2024). Carrying out radiation monitoring around the NPP is an international requirement and is determined by the national legislation of many countries [Environmental Impact Assessment (EIA) in accordance with IAEA rules]. However, for many countries, there is a problem of radiation control in a transboundary context. So, for instance, during the construction of a NPP in Uzbekistan, the future NPP should undergo an environmental impact assessment in Kazakhstan. NPPs construction sites are assessed for radiological situation at «zero stage» in different countries, e.g., in the Republic of Belarus under Environmental Monitoring in the Construction Zone of Belarusian Nuclear Power Plant Programme at the NPP construction stage prior to its commissioning, integrated radiation assessment studies were carried out, in particular, water, air and soil baseline surveys (MERB 2013). During the construction of NPP in Belarus, in such countries as Lithuania, Latvia, Poland, which are territorially involved in the construction of these plants, negotiations were held with consideration of the results of the environmental impact assessment. In addition, the Lithuanian side involved independent scientists and applicants to assess the radioecological state of the areas bordering the Belarusian side. In this case, a clear monitoring program for the countries involved has not been developed either. For the countries involved in the development of a program of radiation monitoring on a «zero background» is relevant, taking into account natural and territorial features, the proximity of industrial enterprises, in particular uranium production. Similar studies were carried out in world practice. Field studies on the pre-operational period of a Belarusian NPP have allowed us to determine the "background" level of gamma-emitting radionuclides in individual components of the environment (National report of the Republic of Belarus 2019). In Lithuania, studies were carried out on the impact of the Belarusian NPP. In addition to the main components, attention was paid to the description of the preoperative radioecological state of the pine forest ecosystem (Jefanova *et al*. 2020). In Iraq (Salah Al-Deen Province), a radiological assessment of the potential Al-Mahzam NPP site was carried out. Atmospheric, as well as aquatic, releases of radionuclides during normal operation of the power plant were used to estimate the annual effective dose equivalent to the highest exposed individual living around the site and down river from it (Ries *et al*. 2019). Prior to the commissioning of Akkuyu NPP in Turkey, studies were carried out to assess the impact of the NPP on the environment with forecast of the environment radioactive pollution risk (Durusoy and Yildirim, 2017) The Leningrad NPP in the Russian Federation was also ranked for the areas of possible ^{137}Cs and ^{131}I depositions, as well as forecasting annual ingress of radioactive substances into the environment was calculated (Perevolotskaya & Perevolotskii 2020). When studying the radiation situation in China (Sanmen), the following types of studies were included in the monitoring program: annual effective dose (AED) and excess risk (ER) were estimated based on continuous radioactivity monitoring in drinking water and ambient dose, cancer incidence was further analyzed through authorized health data collection (Hong *et al*. 2023). In India, the following monitoring model was used: the primary objective of the present study is to determine the natural (^{226}Ra, ^{232}Th, and ^{40}K) and anthropogenic (^{137}Cs) radioactivity in soil samples collected around the proposed Mithivirdi Atomic Power Project (MAPP) site and its contribution to dose rate in the surrounding environment (Patra *et al*. 2021). In almost all countries, the following control parameters were chosen before the construction of a NPP: soil, bottom riverbed sediments, surface water, and the atmospheric boundary layer. The main technogenic radionuclides present in discharges, emissions and radioactive waste during the operation of nuclear power plants, as well as natural radionuclides, have been selected as controlled parameters. The problem in the field of NPP impact research is precisely the lack of a clear scheme of monitoring components for neighbouring countries. Also, in the literature data, plants and animals, which can be indicators of changes in the radiation situation, are not included in the monitoring system before the construction of a NPP. In many countries, when studying the radiation situation before building a NPP, the proximity of industrial enterprises is not taken into account. According to Bakhtin *et al.* (2010) the Republic of Kazakhstan has become the world's largest uranium supplier, topping the list of leading producers of natural uranium (Bakhtin *et al*. 2015; Hosseini *et al*. 2023). It is required to focus on the location of uranium-ore-deposits in relation to the territories being studied (Sozak and Otyrar districts of the Turkestan region). This is necessary because uranium mining can have a negative impact on the radiation situation in the region under study. Monitoring of the radiation situation in the zone of influence of a NPP is necessary not only to control the safety of this facility, but also to inform the population in order to reduce social tension and inform the population (Buraeva *et al*. 2023). Also, in the Republic of Kazakhstan, a comprehensive assessment of the territories of the Turkestan region was not carried out. In accordance with the IAEA radiation safety requirements and legislation of the Republic of Kazakhstan, the radiation monitoring which consist of three stages should be carried out around nuclear power facilities. The first stage prior to the commissioning of NPP, include assessment of «zero» radioactive reference level with radionuclides and assessment of radiation doses, morbidity, iodine sufficiency for the population, analysis of demographic and hygienic situation in the region. The second - operation of NPP (under regular condition and in the event of an accident), includes the monitoring of all parameters and indicators necessary for the assessment of environmental pollution, radiation doses and morbidity of the population (Dilip *et al*. 2009). The third stage is monitoring during decommissioning and a few years after decommissioning (ESMPRP 2005). This study presents an original and reflective study that will allow employing a similar monitoring scheme to study the radiation situation and update protective measures in other countries (transboundary context). Thus, this study aimed to assess the radiation situation on the territory of settlements in Turkestan region, falling under the potential influence of NPP being constructed at the level of «zero background», with definition of dominant species of flora and fauna; on the basis of which, the most suitable bioindicators for further research will be identified. Based on the results, the annual effective dose to the population will be determined. In the case of building a NPP in a neighbouring state, it is necessary to establish a clear list of controlled parameters for a particular case. In the case of the construction of a nuclear power plant in Uzbekistan for the adjacent territories of Kazakhstan, we propose to perform the following work tasks:

1.Determining the settlements of the Republic of Kazakhstan that fall under the potential influence of NPP under construction in Uzbekistan.
2.Outlining the components required for radiation monitoring in a transboundary context.
3.Outdoor and indoor studies of ambient dose equivalent rate; Indoor air radon.
4.Soil, water radioactivity sampling and measurement.
5.Specific radionuclide activity in bottom sediment.
6.Some biota and foodstuffs' sampling and measurement.
7.Determining species composition of vegetation and wildlife at the area and applying a micronucleus test of animals to assess the negative impact of environmental factors.
8.Summarizing data on radiation monitoring in the selected area and evaluating the "Zero background" of the Turkestan region.

MATERIALS AND METHODS

Determination of the territory for research and description of the sampling location

In the summer 2022, expedition trips were organised and studies were carried out on the territory of five settlements in Turkestan region, located in the immediate vicinity of NPP being constructed within a radius of up to 100 km. The Shardara village was also selected as an observation point as the priority site of the future NPP in Uzbekistan Tuzkan Lake and Shardara reservoir have a connection with Aidar-Arnasay system of lakes (Fig. 1).

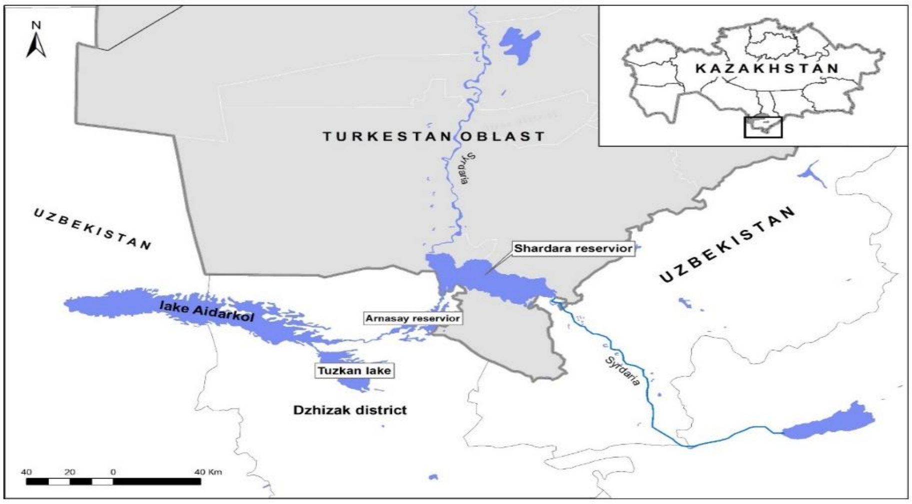

Fig. 1. Characteristics of the location and correlation of Aidar - Arnasay system of lakes (Tuzkan Lake) in Uzbekistan and Shardara reservoir (Kazakhstan).

Thus, the settlements for the study (in accordance with the requirements of the IAEA) were determined by the following settlements (Table 1).

Table 1. Settlements selected for the study.

№	Settlement	Distance from the place for construction of NPP (km)	Population	Number of water samples	Number of soil samples
1	Myrzakent Settlement	85.9	13339	2	10
2	Zhetysay City	84.3	24484	2	10
3	Shardara City	126.1	28443	2	10
4	Zhyly-su Village	84.4	5011	2	10
5	Zh. Kalshoraev Village	73.5	3005	2	10

Radon measurement in indoor air and Gamma fields

Ambient equivalents to outdoor and indoor gamma radiation doses were measured at a distance of one metre from the ground. A gamma walkover survey of the area was conducted on the 500 × 500 m network. The dosimeters DKS-96, DKS-AT-1123 (Republic of Belarus), RCS-01-SOLO (Republic of Kazakhstan) were used to measure gamma-phones on foot. For positioning, GPS Garmin device was used enabling to locate points in the geographical coordinate system. A car-borne gamma survey of the region was carried out with the help of Gamma Sensor mobile radiological laboratory (Russian Federation). By determining the spectrum composition of radionuclides, the coordinates of the study area are automatically marked. Of all standards, the main factor contributing to the annual effective dose is a radioactive gas – radon (Olszewski *et al.* 2018). To assess the natural radiation background of the region, the measurements of equivalent equilibrium volumetric activity (EEVA) of radon and thoron were carried out in residential and administrative premises by radiometers Ramon-02 and Ramon-02A (SOLO LLP, Republic of Kazakhstan). The EEVA of radon and thoron was measured in 15 homes in each location (6 in the central area and 10 in the suburbs).

Soil, water radioactivity sampling and measurement.

Ten soil samples were taken from each locality (five in the centre and two in the outskirts of the village). The sampling was taken under GOST 17.4.3.01-83. General requirements for envelope soil sampling were provided with a sample weight of 600 g. All samples were tagged and numbered in accordance with the list. The sampling depth was between 2 and 10 cm (Fig. 2). The roots, plants and stones were separated from the samples taken.

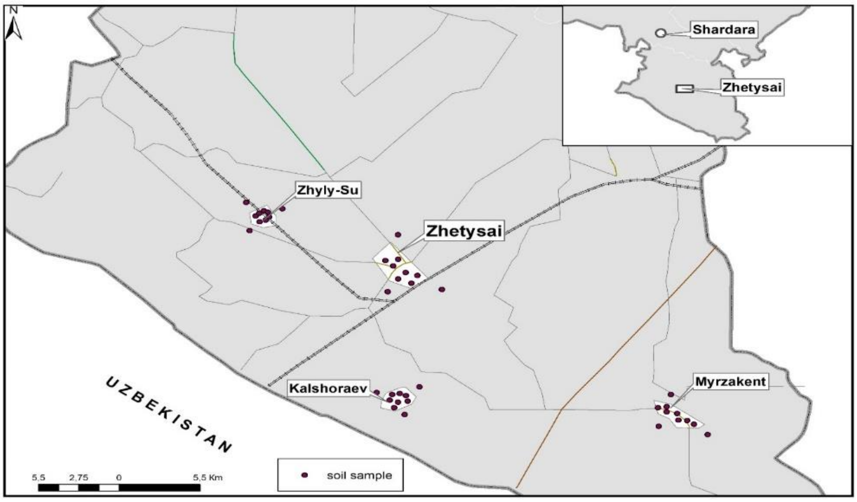

Fig. 2. Soil sampling location.

Water samples were taken under GOST 17.1.5.05-85 Protection of Nature Hydrosphere General Requirements for Surface and Seawater, Ice and Sediment Sampling GOST P 51592-2000 (Water; General sampling requirements). Each sample contained at least 5 litres of water. In total, ten water samples from five settlements (open water and portable water) were selected. All shipping and tagging rules were adhered to. Radiochemical and radiospectrometric analyses of samples were conducted at the Radio-spectrometry and Radiochemistry Test

Laboratory, Institute of Radiobiology and Radiological Protection, Astana Medical University NJSC. The laboratory is certified under the accreditation system of the Republic of Kazakhstan GOST ISO/IEC 17025-2019. The spectrometric detection of alpha particles from the counting sample (steel disk with electrolytically applied thorium isotopes) was carried out on the alpha spectrometer Progress-Alpha with software Progress-2000 (Russian Federation). Radiochemical analysis for specific activity of ^{137}Cs and ^{90}Sr in samples of portable water was carried out in accordance with Methodical Recommendations on Sanitary Control of Radioactive Substances in Environmental Samples approved by the Municipal Cultural Institution of the Ministry of Health of the RoK. № 5.05.008.99. The total alpha, total beta activity in the water and soil samples were identified under the Methodical Radiation Hygiene Guidelines and GOST 31864-2012, while portable water under ST RK ISO 9697-2006 Water Quality. After radiochemical preparation, soil and water samples were measured threefold with exposure of 1,000 and 2,000 seconds respectively on the MFF-2000 radiometer, then alpha/beta activity of the samples was calculated based on the formulas from the mean. The specific activity of radionuclides in the soil samples was measured with spectrometric complex Progress-BG (with NaI detector) on the basis of Radionuclide Activity Measurement through Scintillation Gamma-, Beta-Spectrometer Method with software Progress, KZ.07.00.00303-2004.

Sampling and measurement of bottom sediments

During the Shardara reservoir bottom sediments sampling, GOST 17.1.5.01-80 standards were applied. Samples were taken by a special sampler approximately 5 m from shore and 20 to 30 cm deep. In total, three background sediment samples were collected at 30-metre intervals. The combined alpha and beta activity of the bottom sediment samples was measured using the low photon radiometer UMF-2000 (#KZ.07.00.00441-2005. Measurement method of the total alpha and beta activity of water samples using the alpha-beta radiometer MFF-2000). The method is based on the special preparation of soil samples (samples were dried on the open surface for 7 days, then ground and sieved with subsequent radiochemical analysis of sample). The next step was to measure the counting rate of alpha-beta particles from prepared sample, the detection efficiency of which was determined using a certified reference sample containing ^{238}U in equilibrium with daughter products. The measurement was carried out according to the Methodological Recommendations for Radiation Protection approved by the Chairman's Decree dated 8 September 2011, No. 194. The activity concentration of radionuclides in bottom sediment samples was measured using the spectrometric complex Progress-BG gamma with beta-spectrometric pathways.

Some biota and foodstuffs' sampling and measurement

Each home of local residents was surveyed. The questionnaire included the most common products used, age, occupation and etc. Based on the survey results, the food basket of local residents was defined. Research was carried out on the following foodstuffs: lamb, rice, milk, meat, watermelon, melon, fish (*Sander lucioperca* and *Cyprinus carpio*). Prepared product of peripheral blood from the following biological objects: lake frog (*Pelophylax ridibundus*) five species, medial racerunner (*Eremias intermedia*) five species, red-pepper fish (Rudd: Pisces) one species, snakehead fish (*Channa argus*) 2 species, gopher (*Spermophilus* or *Citellus*) two species. From the dominant species of vegetation of the Turkestan region we selected the following species of plants: Algerian sea lavender (*Limonium ramosissimum*), halophytes genus of flowering plants, species of dicotyledon plants of genus of camel's thorn (*Alhagi maurorum*, a family of Fabaceae, named: camelthorn), Soljanka sore, or chicken, a species of weeds from the genus *Solyanka* (*Kali tragus* subsp. *tragus*), Amaranthus (*Amaranthus retroflexus*). In food products and biological objects, specific activities of ^{137}Cs, ^{90}Sr, ^{232}Th and ^{226}Ra were determined through spectrometric complex Progress-BG with gamma- and beta-spectrometric tracts according to the approved method. The uranium contents in the tissues of fish (*Sander lucioperca* and *Cyprinus carpio*), frogs (*Pelophylax ridibundus*) were determined by means of mass spectrometry with inductively coupled plasma on Agilent-7800 device using regulated analysis methods. The species composition of the dominant flora and fauna of the research area was determined. The peripheral blood products of the fauna predominant species were prepared for further analysis to estimate the amount of spontaneous micronuclei after production and colouration of the fixed peripheral blood products for further use of dominant animal species as indicator bio-objects at «zero stage» and after NPP operation. The object of the study was blood preparations of the following biological objects: Desert lacertas (*Eremias intermedia*) 21 slides, ground squirrel (*Spermophilus* or *Citellus*) 27 slides. Peripheral blood preparations of the lake frog were taken for bioindication of aquatic ecosystems (*Pelophylax ridibundus*) 20 slides, dominant fish species in water bodies of selected areas i.e., Redeye (*Rudd pisces*) 3 slides, Shakehead fish (*Channa argus*) 18 slides. Peripheral blood samples taken with a syringe from the tail vein of the dominant species of biological objects in the Turkestan region were fixed on a defatted glass slide. In fish, peripheral blood was taken from the caudal vein by cutting off the caudal peduncle. The resulting preparations in the amount of 65 pieces were dried in air and fixed with 96% ethyl alcohol. The work was carried out in the field. At the laboratory stage, the slides were stained according to Romanovsky-Giemsa. Before staining the smears, the finished liquid dye is diluted at the rate of 1– 2 drops of the dye per 1 mL- distilled water. After rinsing with distilled water, it was dried on filter paper for 30 min. Anomalies of nuclei in blood erythrocytes and morphological analysis of changes in erythrocytes, micronuclei were evaluated on hematological preparations using an EX20-MSC-Company microscope (China) with an oil immersion objective - PLAN 100x/1.25 oil, ∞/0.17 (100-fold increase).

Food products

Food products are an important link in migration of radionuclides, the same as portable water. From the analysis of reference source data, the main source of radionuclides for human body are live-stock products. For instance, 70-80% of ^{131}I come with milk, 70-80% caesium and 60-70% strontium radionuclides can come with bread, meat and dairy products. The inhabitants of fresh reservoirs, as well as forest biogeocenoses are capable of accumulating and supplying radioactive substances in human body (Nazarov 2020). The study of radionuclides content of anthropogenic origin is one of the stages of integrated assessment of the studied area at the level of «zero background». We surveyed 15 houses of local residents in each of the settlements including Zhetysai, Zhyly-su, Myrzakent, Shardara and Kalshoraev.

Determination of dominant species of flora and fauna of the study area

To study the species composition of vegetation and biota objects, several expedition trips to the territory of the Turkestan region were organized during the summer and autumn 2022.

Thus, we proposed to include and study the following components in radiation monitoring at the «zero stage»:

1.Outdoor and indoor studies of ambient dose equivalent rate;

2.Radon measurement in indoor air and Gamma fields;

3.Determination of specific activity of radionuclides in soil;

4.Determination of specific activity of radionuclides in water and bottom sediments;

5.Determination of the specific activity of radionuclides in products and annual expected effective doses from basic foodstuffs;

6.Determination of dominant species of flora and fauna and using them as bioindicators and micronucleus test of dominant animal species.

For statistical processing of the results, analysis of variance (one-factor, two-factor, analysis of variance without repetitions), Student's t-test were used. The results were statistically processed using the Excel, SPSS, Statistica 6.0 data analysis software.

RESULTS

Outdoor and indoor studies of ambient dose equivalent rate

The average values of ambient dose equivalent rate at the street close to the houses were as follows: in Zhetysai Town 113.3 nSv h^{-1}, in Shardara City 126.6 nSv h^{-1}, in Zhyly-su village 111.1 nSv h^{-1}, in Kalshoraev village 130.2 nSv h^{-1} 119, and in Aksen village 7. This corresponds to the background mean Republic value (IBSE 2015). Statistical processing shows no statistically significant differences ($p < 0.05$). An analysis of variance between groups (localities) was used, where $F = 1.8$, $p = 0.1$ (no statistically significant differences between localities were found). Also, measurements of ambient dose equivalents conducted inside residential buildings showed average values for each settlement equal from 121.3 nSv h^{-1} in Myrzakent and up to 138.2 nSv h^{-1} in Kalshoraev Settlement, which also corresponds to the mean Republic values (IBSE 2015). When performing the variance analysis, statistically significant differences were not observed ($F = 1.4$, $p = 0.2$). Notably, the building materials of the surveyed premises were identical. The EEVA value of radon in the residential of the following towns: Zhetysay, Shardara, Zhyly-su, Myrzakent and Kalshoraev ranged from 5 to 12 Bq m^{-3} at standard values of 200 Bq m^{-3}. The smallest values were found in Kalshoraev village from 2 to 13 Bq m^{-3}. Average value was 3 Bq m^{-3}.

In Zhetysai, 15 measurements were carried out, among which EEVA maximum value was 111 Bq m^{-3} (average 12, median 2). This difference between the median and the average results from a high EEVA of 111 Bq m^{-3}.

Indoor air radon

The EEVA value of radon in the residential and administrative buildings of the following towns: Zhetysai, Shardara, Zhyly-su, Myrzakent and Kalshoraev ranged from 5 to 12 Bq m^{-3} at standard values of 200 Bq m^{-3}. The smallest values were found in Kalshoraev from 2 to 13 Bq m^{-3}. Average value was 3 Bq m^{-3}. In Zhetysai, 15 measurements were carried out, among which EEVA maximum value was 111 Bq m^{-3} (average 12, median 2). This difference between the median and the average results from a high EEVA of 111 Bq m^{-3}.

Specific activity of radionuclides in soil

The observed concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs specific activity in soil, compared to mean Republic values, are shown in Table 2.

Table 2. Specific activity of radionuclides in soil (Bq kg^{-1}).

No	Radionuclides	Mean Republic values	Settlement				
			Zhetysay	Shardara	Zhyly-su	Myrzakent	Kalshoraev
1	^{137}Cs	35	24.3 ± 16.3	10.2 ± 8.8	33.6 ± 13.3	14.3 ± 13.3	18.3 ± 14.6
2	^{226}Ra	35	29.4 ± 22.0	22.7 ± 15.4	21.8 ± 17.7	21.5 ± 18.7	18.9 ± 13.9
3	^{232}Th	60	115.2 ± 33.2	50.5 ± 22.6	114.3 ± 33.5	60,03 ± 27.1	100.46 ± 32.0
4	^{40}K	300	302.1 ± 227.2	310.1 ± 200.0	307.1 ± 227.1	310.1 ± 200.0	302.6 ± 198.6

From the results obtained, increases in the specific concentration of ^{232}Th were observed in the soil of the following towns: Zhetysay, Zhyly-su and Kalshoraev. There is a possibility that uranium mining companies in Sozak and Otyrar regions of Turkestan region may have an influence. The mean worldwide values were also taken into account for better comparison (Fig. 3). When examining soil samples, the result can be influenced not only by uranium-rich territories, but also by other factors. One of the examples is the total organic carbon content that influences the activity of ^{137}Cs. Also, the content of carbonates may contribute to a change in the content of ^{232}Th to a greater or lesser extent.

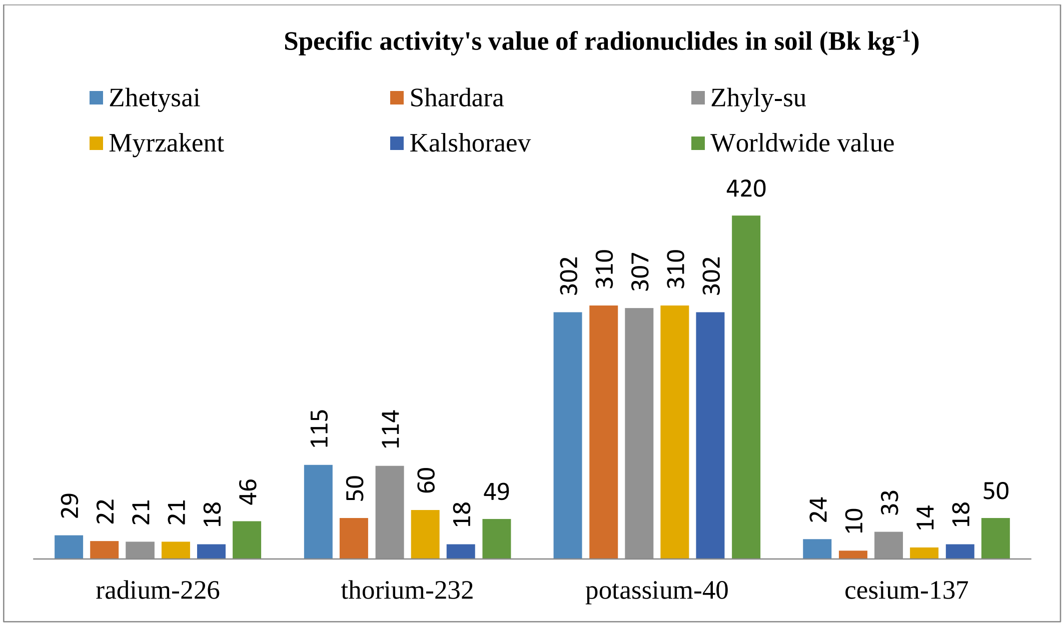

Fig. 3. Specific activity's value of radionuclides in soil.

Based on the data presented, the world specific values of ^{232}Th (Ahmad *et al*. 2019) is 49 Bq kg^{-1}; in our studies the value of ^{232}Th in 5 settlements was on average 71 Bq kg^{-1}. In this case ^{232}Th, in our opinion, has a direct connection with the territorial location of Otyrar district's deposits in Turkestan region. At present, the Otyrar deposit is actively extracting uranium (Zarechnoye JSC). Thorium isotope, in addition, is widely distributed in the natural environment, especially given the fact that uranium is being actively extracted on the areas of the southern Kazakhstan. These areas are characterized by: intrusive and effusion rock outcrops with elevated background U and Th; local near-surface insolation and evaporation clusters of U typical for arid zones; areal development of aquifers and water sources with abnormal concentrations of natural radionuclides (Shishkov & Bakhur 2013). ^{137}Cs was within the mean worldwide values. According to the results of one-way analysis of variance, at $\alpha = 0.05$, statistically significant differences in the specific activity of soil sample radionuclides between settlements selected were not observed (at $F = 2.214$; $p = 0.128$).

Radioactivity in water

The first stage of the water samples' study (potable water, water from open sources) was to determine the total activity in the settlements selected (Table 3).

Table 3. Total specific α, β activity values of water samples (Bq dm^{-3}).

No.	Sampling location, settlement	Geographical coordinates	A- activity (Bq dm^{-3})	β- activity (Bq dm^{-3})
1	Zhyly-su water pump (portable water)	N 40.4134271 E 68. 292789	0.30	0.27
2	Shardara water pump (portable water)	N 40.4134271 E 67. 942733	0.04	0.15
3	Kalshoraev water pump (portable water)	N 40.4134271 E 67. 942733	0.20	0.19
	Intervention level (IL) for portable water (Sambayev 2017).		0.20	1.0
4	Shardara, Shardara reservoir	N 40.4134271 E 68. 017765	0.18	0.27
5	Zhetysai, surface water body	N 40.4741642 E 68.1914007	0.42	0.01
6	Zhetysai, surface water body	N 40.464468 E 68.2012736	0.09	0.04
7	Kalshoraev, surface water body	N 40.4134271 E 68.1738939	0.26	0.05
8	Myrzakent, surface water body	N 40.403223 E 68.35246	0.52	0.07

The results obtained are in line with the intervention permissible level for the territory of the Republic of Kazakhstan, except the water sample from Zhyly-su village. In this case, the infiltration of natural uranium-thorium radionuclides through groundwater appears to have had an impact on the open water of the locality. There is a possibility of a contribution to the total activity of natural radionuclides of the uranium-thorium series because of the active extraction of uranium at the uranium deposit of Zarechnoye JVC (Otyrar region). In the neighbouring Republic of Uzbekistan, the main uranium mining area is the Central Kyzylkum district (Novoii Mining and Chemical Plant; Olovov & Akhmedov 2019). Due to the remote location from the border of Kazakhstan, we can eliminate the impact of industrial enterprises of the Republic of Uzbekistan on increment in the total activity of water samples. Cesium and strontium are sensitive indicators for detecting potential radioactive emissions in open water and portable water samples. This is particularly important when monitoring the NPP pre-commissioning phase. Due to their relatively lengthy half-lives, ^{90}Sr and Cs^{137} may be stored for a long period in terrestrial and marine systems after emission into the environment. Therefore, after determining the total radionuclide activity of water samples, the specific activities of caesium and strontium were identified (Fig. 4). Hygienic standards - Sanitary and Epidemiological Requirements of Radiation Safety approved by order dated 27.02.2015 # 155. Thus, the content of ^{137}Cs and ^{90}Sr in all samples was within the norm, but in portable water samples it exceeded the value of total alpha-activity.

Radioactivity in bottom sediments

The assessment of radionuclide composition of the bottom sediments is important not only for the assessment of open water contamination, but also for the assessment of groundwater contamination and characterization of the functioning of aquatic ecosystems (Benjamin *et al*. 2017), taking into account the fact that the bottom sediments impact on the activity of benthic organisms, as well as on the migration of radionuclides (Trapeznikov & Trapeznikova, 2012). The next step defined the specific activities of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in the samples of the bottom sediments of Shardara water storage reservoir (Table 4).

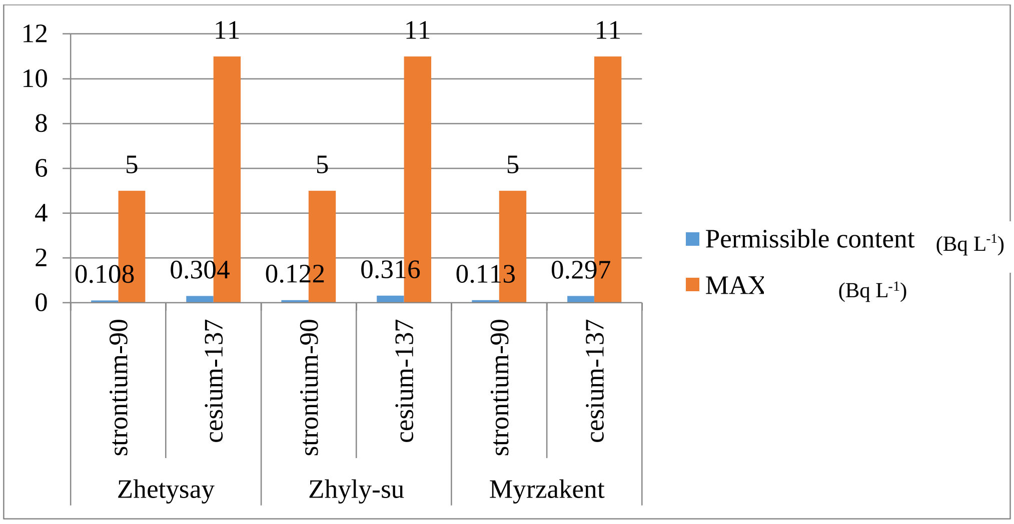

Fig. 4. The results of ^{137}Cs and ^{90}Sr content in water samples (Bq L^{-1}).

Table 4. Specific radionuclide activity in bottom sediment samples of Shardara water storage reservoir (Bq/kg).

Sample code	Geological coordinates	^{232}Th	^{226}Ra	^{40}K	^{137}Cs
		Specific activity value			
LAT.- LONG.-1	N 41° 12' 17" E 67° 55' 52"	62.6 ± 26.3	13.5 ± 11.2	178.5 ± 116.2	12.5 ± 9.7
LAT.-LONG.-2	N 41° 20' 449" E 67° 92' 984"	45.4 ± 16.3	15.3 ± 9.3	145.3 ± 99.2	9.5 ± 6.7
LAT.-LONG.-3	N 41° 20' 365" E 67° 92' 036"	61.9 ± 23.9	18.4 ± 7.2	330.4 ± 178.3	13.4 ± 9.6

Radioactivity in food

According to the survey results, the most popular food products were meat (lamb), pasta, potatoes, rice, fish. In summer season - fruits and melons. We have determined the specific activity of artificial radionuclide ^{137}Cs in food products of selected territories in Turkestan region (Fig. 5). In comparison with the permissible values taken from Hygienic requirements to the safety and nutritional value of foodstuff in the Republic of Kazakhstan dated June 11, 2003, # 447, the specific activity of ^{137}Cs does not exceed the allowed level in foodstuff. Annual expected effective doses of ^{137}Cs from milk and potatoes (most commonly consumed) were calculated using the following equation, on assumption that the daily intake of radionuclides with products was constant throughout the year:

$$E\ k\ (\text{mcSv/man/year}) = D\ k\ (\text{Bq/man/day}) \times A\ k\ (\text{mcSv/Bq}) \times 365\ (\text{days})$$

where: E k is the annual expected effective dose of the radionuclide k, and Ak is the expected effective ratio for the radionuclide k when ingested. The obtained expected effective ratio for adults were 0.7×10^{-2} mcSv/Bq for ^{137}Cs (Nabeshi *et al*. 2020). Based on the data provided, the specific activity of radionuclides in food is included in the reference values. The study of the content of uranium in fish is necessary, due to the presence of uranium deposits at the territory of Turkestan region. According to the survey results, the monthly dietary of the residents in Shardara included fish, mainly Sazan and zander (*Sander lucioperca* and *Cyprinus carpio*), the biosamples of which were analysed for the content of uranium. Based on the reference source, uranium isotopes are unevenly distributed in the body of fish (Gudymenko 2014). The highest concentration was observed in the body and head of the fish, therefore, tissue samples from the body of the fish (*Sander lucioperca*, *Cyprinus carpio*) were analysed for U content and the following results were obtained (Table 6).

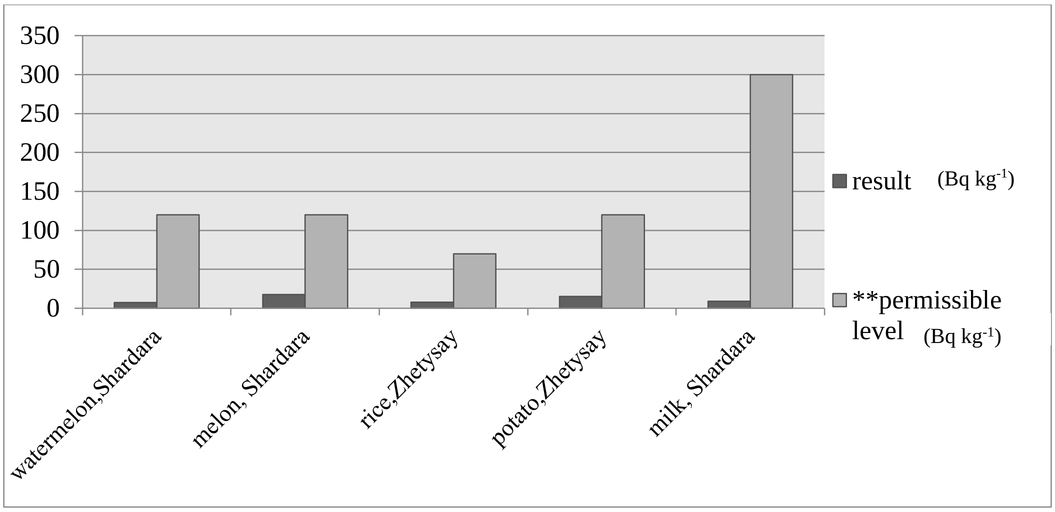

Fig. 5. Activity ^{137}Cs in foodstuff.

Taking into account uranium production in the southern regions of Kazakhstan (Otyrar district, JV Zarechnoye), we determined specific activity of ^{232}Th, ^{226}Ra in food products (Bq kg^{-1}; Table 5).

Table 5. ^{232}Th, ^{226}Ra specific activity in food products, Bq kg^{-1}.

No	Foodstuff/settlement	^{232}Th	^{226}Ra
1	Water melon/ Shardara	76.3 ± 28.8	4.3 ± 16.7
	*UNSCEAR 2000 [23] reference values	500	3000
2	Melon/ Shardara	122.6 ± 31.4	9.9 ± 4.1
	Reference values of * UNSCEAR 2000 [23]	500	3000
3	Rice/Zhetysai	92.6 ± 33.2	4.4 ± 2.5
4	Rice/Uzbekistan	101.2 ± 35.1	10.6 ± 2.3
	Reference values of * UNSCEAR 2000 [23]	300	8000
5	Potatoes, Zhetysai	64.46 ± 17.1	12.43 ± 4.2
	* UNSCEAR 2000 [23] reference values of	500	3000
6	Milk, Shardara	29.6 ± 7.1	3.2 ± 1.9
	*UNSCEAR 2000 [23] reference values	300	5000

* UNSCEAR 2000.

Table 6. Uranium content in fish from Shardara Reservoir.

No.	Settlement	Product type	Uranium concentration (ng L^{-1})	Uranium concentration (mkBq kg^{-1})	Worldwide range* of U, (μBq kg^{-1})
1	Shardara	fish- zander	bones-14.88 meat-1.92	bones-183.76 meat-23.71	100000
2	Shardara	fish- carp	bones-69.01 meat-6.54	bones-852.15 meat-80.769	

*UNSCEAR.

The uranium content in fish samples (bones and soft tissue) from Shardara Reservoir as per *UNSCEAR 2000 corresponds to background values. As for the meat products, the meat of lamb is the most widely consumed (based on local population survey). According to the results of mass spectrometry with inductively coupled plasma, the specific activity of uranium was 36.8 μBq kg^{-1}, not exceeding the worldwide range of U specified in UNSCEAR 2000 (15000 μBq kg^{-1}).

Radioactivity of biota objects

Amphibians have thin skin that absorbs water well, thus exposing them to radionuclides impact from the environment both inside and outside (Baranovskaya *et al*. 2010). The lake frog (*Pelophylax ridibundus*) is one of the dominant species of the amphibian of Shardara Reservoir area. This type was further proposed as a bioindicator for pollution control at different stages of nuclear power plant operation. Given the proximity of uranium mining facilities, it is advisable to identify whether the uranium content in the bones and soft tissues of the lake frog (*P. ridibundus*) is confirmed. The values obtained are included in the imputed reference values for natural concentrations of uranium in animals and humans (recalculated to mg L^{-1} -0.00033 for bones and 00001 to 0.0002 mg L^{-1} of tissue). Thus, the results obtained can be used in this particular case for comparison with the indicators obtained after the operation of the NPP. Changes in the ranges of the obtained values will reveal changes in the radioecological situation in the region. For studies in other countries, in a similar context (before the construction of a nuclear power plant), the described model of radioecological monitoring can be used.

Determining species composition of vegetation and wildlife at the area of Turkestan region under the potential impact of the NPP in Uzbek Republic being constructed

Within the area of Turkestan, dominant plant species have been identified*:* *Comber multicolour* (*Tamarix ramosissima* Ledeb), Asian shrub plant (Advent flora 2004). Also, Juzgun (*Calligonum*) a genus of perennial deciduous branched shrubs with a wide root system and an openwork crown fixed on the slopes of beams and gullies, sandy beaches. *Wormwood* (*Artemisia cina*) is an herb of the genus Wormwood (*Artemisia*) of the Asteraceae family (Asteraceae), which is an endemic plant, grown in large massifs along the river valleys in the desert plains and foothills. Of the identified species, there are the largest families of mares (Chenopodiaceae Vent.) 18%, composite (Asteraceae Dumort.) 16%, Poaceae family (*Poace* Barnhart) 12%, Fabaceae family (Fabaceae Lind.) 6%, Crucifers family (Brassicaceae Burnett) - 4%, Buckwheat family (Polygonaceae Juss.) 3%. The following dominant animal species have been identified among wild animals within Turkestan region: from mouse-shaped rodents' Common vole [*Allactage elater* (Lichtenstein, 1825)], Eastern Blindness [*Ellobiustancrei* (Blasius, 1884)], house mouse [*Musmusculus* (Linnaeus, 1758)], Turkestan rat [*Tusturk estanicu*s (Satunin, 1903)]. Of the genus of rodents, yellow gopher (*Spermophilus fulvus*), the genus of rodents, squirrel family (Sciuridae) live in open habitats such as meadows, grasslands and semi-deserts, have yellow, light orange, light brown or greyish colouration. Of the amphibians (Amphibia): lake frog (*Pelophylax ridibundus*); of the reptilia (Reptilia): grey gecko; Mediodactylus (formerly Cyrlopodion) Russowii; desert lidless skink, *Abgepha deserti* and desert lacerta: *Eremiasvelox*. Snakes (Ophidia, or Serpentes) are represented by the following species: Pallas' coluber, *Elaphe dione*; mountain runner, Hemorrhois (*Coluber ravergieri*); water snake (*Natrix tessellata*). Given the fact that artificial radionuclides are in the compounds available for uptake by plants (NPP operation time), the following dominant plant species can be included in the Turkestan Area Monitoring and Control Programme: Algerian sea lavender (*Limonium ramosissimum*); halophytes genus of flowering plants, species of dicotyledon plants of genus of camel's thorn (*Alhagi maurorum*, a family of Fabaceae, names: camelthorn); Soljanka sore, or chicken, a species of weeds from the genus Solyanka (*Kali tragus* subsp. *tragus*), Amaranthus (*Amaranthus retroflexus*); multiflorous tamarisk (*Tamarix ramosissima* Ledeb); Comb zhytnyak (*Agropyron cristatum*); Calligonum (*Calligonum*); Common nettle (*Urticadioica* L.) with determination of the transition coefficient through soil-plant system. While researching the dominant species of fauna in this region, the following animal species may be considered as the bioindicators of environmental quality: Middle desert lacerta (*Eremias intermedia*); Yellow Gopher (*Spermopus* or *Citellus*); Common Field (*Allactage elater*). For bioindication of aquatic ecosystems, it is advisable to use lake frog (*Pelophylax ridibundus*); dominant fish species of water bodies of selected areas, such as Red-eye fish (*Rudd pisces*); Snakehead fish (*Channa argus*), Sazan (*Cyprinus carpio*), Zander (*Sander lucioperca*).

Micronucleus test

Our studies have shown that under the given environmental conditions of the Turkestan region (Zhetysay, Shardara and Maktaaral regions), 5.88 ± 2.8% of the cells of the studied biota objects had pathologies associated with erythrocytes and micronuclei. Erythrocytes with any one type of pathology were found in 2.5 ± 2.3% of marsh frogs. In the blood of 11.82 ± 2.7% of animals (out of the total number) there are two different types of disorders in the morphology of erythrocytes. Three types of pathologies of red blood cells were noted in 7.94 ±

5.4% of Desert lacertas, and 4.76 ± 3.9% of amphibians had four different types of pathologies of erythrocytes. Regarding the formation of micronuclei, the following distribution was observed: among lizards, 0.41 ‰ of abnormal erythrocytes with micronuclei were found; among frogs, 0.32 ‰ of cells with micronuclei were found. The formation of micronuclei is a consequence of the pathology of mitotic cell division, during which some chromosomes lag behind in metaphase and anaphase. During apoptosis, micronuclei of various sizes can occur, which is associated with fragmentation of the nucleus of the cell subject to this process. At this stage of research, a number of disorders of the nucleus and erythrocytes have been identified, which may indicate a possible adverse effect of environmental factors in their habitat. A differentiated count of micronuclei shows the need for comprehensive studies using the cytogenetic features of living organisms to obtain information about the ecological and genetic state of populations of organisms and their habitat at the zero stage.

DISCUSSION

Actions taken for a comprehensive study of the territories in Turkestan region enabled to assess the radiation situation in the pre-operational period of the Uzbek NPP. These results are well comparable to mean republic and world recommended values. In studies conducted by E.I. Nazarov & A.A. Ekidin (Belarusian NPP- pre-operational stage) found the following concentrations of radionuclides in soil: activity concentrations of ^{40}K (natural radionuclide) from 530 to 700 Bq kg^{-1}; those of ^{226}Ra (natural radionuclide) from 30 to 55 Bq kg^{-1}; those of ^{232}Th (natural radionuclide) from 17 to 35 Bq kg^{-1}; those of ^{137}Cs (technogenic radionuclide) at all measured points were significantly lower than 50.0 Bq kg^{-1} (Nazarov *et al*. 2020). In our study: those of ^{40}K (natural radionuclide) from 302 to 310 Bq kg^{-1}; those of ^{226}Ra (natural radionuclide) from 18 to 29 Bq kg^{-1}; those of ^{232}Th (natural radionuclide) from 18 to 115 Bq kg^{-1}; those of ^{137}Cs from 10 to 33 Bq kg^{-1}. When comparing the obtained results with the studies of the pre-operational period of the Belarusian NPP, the concentrations of radionuclides in the surface layer of the soil were at similar levels. Thorium-232 in our study was much higher (up to 115 Bq kg^{-1}). We attributed the excess of thorium-232 in the soil with the work of uranium -mining enterprises. For comparative estimation of the specific activity of ^{232}Th, ^{40}K and ^{226}Ra, literary sources on the content of radionuclides in bottom sediments from reservoirs located in the UAE and Ukraine were studied. The first reservoir is located in the background of Barakah Nuclear Power Plant (Gulf Coast, UAE). The specific activity results of the bottom sediment samples were as follows: ^{226}Ra 4.73 ± 3.1, ^{232}Th 18.3 ± 1.6 and ^{40}K 130.1 ± 105.2. According to the comparison with UNSCEAR values estimated activity concentrations in this study were lower than the world average and lower than the levels recorded in neighboring countries (Ries *et al*. 2019). It was then considered information on the Sofiyevsk reservoir located at the area of Inhul River in the Nikolaev region (Ukraine). In this case, the authors did not exclude the influence of the Chernobyl nuclear power plant, but the results indicate the specific activity of radionuclides in the conditional reference interval: ^{226}Ra 20.3, ^{232}Th 49.2, ^{40}K 420.1 Bqkg^{-1} (Alokhina & Gudzenko 2021). When compared with literary sources, the specific contents of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in our studies were within tolerable values compared to the world values, which are as follows: for ^{226}Ra 4.9 - 60 Bq kg^{-1}; for ^{232}Th 11 - 64 Bq kg^{-1}; for ^{40}K 140 - 1,700 Bq kg^{-1}; for ^{137}Cs 5 - 30 Bq kg^{-1} (Rashid *et al*. 2021). Based on the reference source, one can conclude that the results of the specific radionuclide content in the bottom sediments of Shardara Reservoir indicate activity comparable to the above-mentioned similar studies. The total specific α, β activity values of drinking water samples in our study were within the normal range. The exception was one sample of drinking water from Zhyly-su village. The total alpha-activity of portable water samples in Zhyly-su exceeded one-and-a-half fold of the allowable level. In a study of the radioactivity of drinking water in the area of NPP in China, Miao *et al.* (2021) established the following values for the total specific α activity: 0.022–0.106 Bq L^{-1} and the total β activity: 0.066–0.213 Bq L^{-1}. Research was conducted in 7 provinces of China. The measured gross α and gross β activities in all water samples were below the WHO recommended maximum contamination values (0.5 Bq L^{-1} for gross α, 1.0 Bq L^{-1} for gross β; Miao *et al*. 2021). In our study, in water samples from open sources, the established values correspond to the WHO recommendations. In general, the results obtained are consistent with global studies.

CONCLUSION

According to the results of our study, it was generally established that the radiation situation of the territory and settlements in Turkestan region is stable, not exceeding the mean republic and world values. Exceptions are only the soil samples taken from Zhetysai and Zhyly-su settlements, where ^{232}Th specific activity exceeded two-fold the mean republic value. The total alpha-activity of portable water samples Zhyly-su village exceeded one-and-a-half-fold of the allowable level. Concentrations of artificial and natural radionuclides in foodstuff were within the standard. Based on the studies conducted, water samples in Shardara reservoir, soils from selected areas for the content of artificial and natural (pre-commissioning period of the NPP) and radionuclides during NPP operation should be measured twice a year. Food products proposed for yearly monitoring should include fish, cereals (rice, millet), roots and melons (summer). Meat and dairy products should be checked more often for the content of radionuclides (2-3 times a year). Biological objects from the dominant species of flora and fauna in Turkestan region can be used as indicators of radioactive contamination at 'zero stage' and during NPP operation. Thus, it is recommended to include the following components in the monitoring system in a transboundary context (before NPP construction): Outdoor and indoor studies of ambient dose equivalent rate, indoor air radon measurement of a specific radionuclide activity in soil, water, bottom sediment, some biota and foodstuff. In the course of the study, dominant species of flora and fauna were identified, which are recommended to be used as bioindicator. The proposed monitoring model and its components can be used for other countries in a transboundary context. Any changes in the results of the study in the future can serve as an indicator of changes in the radiation situation of the territory at various stages of construction or operation of the NPP. Given the transboundary context, the characteristics of the study area, and the presence of uranium mining enterprises at the "zero stage", we propose the following model of radiation monitoring:

1.Outdoor and indoor studies of ambient dose equivalent rate;
2.Radon measurement in indoor air and Gamma fields;
3.Determination of specific activity of radionuclides in soil;
4.Determination of specific activity of radionuclides in water and bottom sediments;
5.Determination of the specific activity of radionuclides in products and annual expected effective doses from basic foodstuffs;
6. Determination of dominant species of flora and fauna using them as bioindicators and micronucleus test of dominant animal species; The definition of these indicators in our study was fully achieved. The result achieved gives a complete picture of the radiation situation in the study area at the "zero stage".

Conflict of interest statement

The authors whose names are listed immediately below have NO affiliation with any organization with a direct or indirect financial interest in the subject matter or materials discussed in the manuscript. Anastassiya Ganina, Meirat Bakhtin, Yerlan Kashkinbayev, Polat Kazymbet, Olivier Lourent, Nursulu Altaeva. This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors. All authors have read, understood, and have complied as applicable with the statement on «Ethical responsibilities of Authors» as found in the Instructions for Authors and are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted.

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Author contributions statement

Anastassiya Ganina: wrote the main text of the manuscript, laboratory and field stages of research. Aigul Ismailova: designed the computational framework and analysed the data. Lyazat Orakbay: analyze and search data for comparison with similar studies. Aiman Musina: performing the experiments of micronucleus test, or data/evidence collection. Meirat Bakhtin: guidance and verification of the main stages of the study, text check Polat Kazymbet: section of the purpose and objectives of the study, management and organization of field trips to the territory of the Turkestan region, data collection. Olivier Lourent: commented on previous versions of the manuscript, data collection and analysis. Nursulu Altaeva: prepared figures 1-3, recommendations in the stylistic processing of the text in English. Yerlan Kashkinbayev: guidance and verification of the main stages of the study at the field stage, data collection. All authors read and approved the final manuscript.

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials. This is the first pilot study. The results have not been published anywhere.

Consent statement

The study contained data on people's food preferences. Verbal informed consent was obtained prior to the interview. Identifying details of the participants that were studied should not be published in written descriptions. Permission was obtained from the local authorities before conducting radioecological monitoring of the selected areas. Authors are responsible for correctness of the statements provided in the manuscript.

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