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The impact of nuclear testing on the environment: the case of the Semipalatinsk nuclear test site

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Abstract. This article examines the environmental and public health consequences of nuclear tests conducted at the Semipalatinsk test site. The study addresses radiation emissions, changes in ecosystems, and the impact on biodiversity. The level of radioactive contamination in soil and water bodies is discussed, along with morbidity statistics among the local population, including rising rates of cancer and congenital anomalies. The results of contemporary research evaluating the current state of the environment and proposing rehabilitation measures for affected areas are also analyzed. Furthermore, the article highlights international initiatives and projects aimed at mitigating the effects of nuclear testing and restoring ecosystems. The authors stress the importance of ongoing environmental monitoring and the development of rehabilitation strategies. In conclusion, the significance of an integrated approach to analyzing the consequences of nuclear tests is emphasized, with a focus on ensuring sustainable development and safeguarding the health of future generations.

1 Introduction

The Semipalatinsk nuclear test site operated in Kazakhstan from 1949 to 1989 and became the site of more than 450 nuclear tests. The test site is located in Kazakhstan on the border of Semipalatinsk (now Abai region), Pavlodar and Karaganda regions, 130 kilometers northwest of Semipalatinsk (now Semey), on the left bank of the Irtysh River.

The test site covers 18,500 square kilometers [1]. The previously closed city of Kurchatov, renamed in honor of the Soviet physicist Igor Kurchatov and formerly designated as Moscow-400, Bereg, and Semipalatinsk-21, the Terminal Station is located on this territory.

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Fig. 1. Location of the Semipalatinsk nuclear test site.

On August 29, 1949, the first nuclear test was conducted in the USSR: the first ground-based nuclear explosion with a capacity of more than 20 kilotons was carried out on the territory of the Semipalatinsk nuclear test site. A total of 473 nuclear explosions were carried out at this secret test site in Kazakhstan from 1949 to 1989, including 90 aerial, 26 ground, and 354 underground ones (Fig. 1). In addition to nuclear tests, 175 explosions with the use of chemicals were carried out here, 44 of them with charges of more than ten tons.

The tests were carried out in various ways, including ground, air, underground explosions in tunnels and wells, as well as excavation work. Both nuclear and thermonuclear charges were used, which allowed researchers to study various aspects of nuclear weapons. Nuclear tests at the Semipalatinsk test site were conducted at several sites: "Experimental Field" was used for testing nuclear weapons in the air and on the surface of the earth; "Degelen" served for underground tests in tunnels; "Balapan" and "Sary-Uzen" were designed for underground tests in wells; "Aktan-Berli" was used for experiments with an incomplete chain reaction; "Telkem" served to test the technologies of industrial explosions. A "New" site was created at the Semipalatinsk test site, designed for conducting underground nuclear explosions in wells. However, no nuclear tests were conducted on it. The greatest damage to the environment in terms of radioactive contamination was caused by ground and air nuclear explosions, as well as excavation work, in which explosions in wells at shallow depths led to the release of radioactive soil [2].

The nuclear tests conducted on the territory of Kazakhstan had catastrophic consequences. The total power of the explosions exceeded 50 megatons, radioactive contamination spread over a vast territory of 304 thousand square kilometers, where more than 1.7 million people lived. As a result, the Semipalatinsk region become an environmental disaster zone [3].

Fig. 2. Number of nuclear explosions at the Semipalatinsk nuclear test site in 1949–1989.

2 Methods

The study of the consequences of nuclear tests is becoming increasingly relevant in view of the increasing public interest in nuclear safety and environmental protection. After the closure of the Semipalatinsk test site, Kazakhstani scientists, together with international experts, conducted extensive studies of the radiation situation at the site and nearby territories. As a result, the primary areas affected by radioactive contamination were identified, and the mechanisms and pathways through which radioactive materials spread were examined. Researches shown that part of the test site can be used for agricultural and other purposes, which opens up new opportunities for the development of the region [4].

3 Discussion and results

The Semipalatinsk test site was located in an area with a high population density. The territories of neighboring villages were repeatedly contaminated with nuclear decay products [5]. Reservoirs and traditional pastures for grazing livestock, both state farm and personal, were also affected by pollution. Significant levels of radionuclides accumulated in milk, animal meat, as well as in vegetables and fruits.

People received additional doses of radiation through water and food. As a result, the number of cases of cancer and cardiovascular diseases, leukemia, disorders of the central nervous system increased among the population living near the test site during this period, as well as mortality increased [6, 7].

The study of the consequences of nuclear tests began in 1991 after the closure of the test site, but the data obtained in different years on the level of radioactive contamination differed significantly from each other. Therefore, it became necessary to conduct a comprehensive study of the consequences of nuclear tests. To investigate the consequences of nuclear weapons tests in Kazakhstan, as well as to monitor and mitigate environmental pollution, the National Nuclear Center was established. Since 2008 the Center carried out work on a comprehensive environmental survey of the test site, which was completed in 2021 [8].

The first studies were conducted at the site of nuclear explosions at the test site, where the contamination levels were found to be the highest. It was necessary to determine the level of radioactive contamination in the territories adjacent to the test site and territories remote from the test site. For this purpose, the territory of the Semipalatinsk test site was surveyed for a long time (13 years), during this period more than 25 thousand environmental samples were taken.

First of all, the environmental survey of the Semipalatinsk test site was supposed to help divide the territory into two zones: radioactively contaminated (“dirty”) and conditionally background, where the levels of radionuclides in the natural environment correspond to background values. In addition, it was planned to determine the level of radioactive pollution of the environment

A comprehensive environmental survey of the Semipalatinsk test site was aimed at determining the level of the main technogenic radionuclides in the soil; assessing the radiation state of surface and groundwater with forecasting the dynamics of changes. An important objective was to study atmospheric air pollution, the radiation levels in vegetation within the surveyed area, and the potential concentrations of radionuclides in crops cultivated in this region. An analysis of the fauna and the content of radionuclides in the organisms of wild and domestic animals was carried out. In addition, it was planned to prepare recommendations on eliminating the consequences of nuclear tests, identify areas with radiation hazards where it is necessary to carry out measures to eliminate the consequences of nuclear tests, and areas that do not pose such a danger.

One of the key outcomes of the project was the evaluation of the radiation risk posed by the test site to the population in the event that a portion of its land is integrated into economic use. It was found that in the territory occupying more than 80% of the total area of the Semipalatinsk test site, the average annual effective dose for the population will not exceed 0.3 mSv/year. For comparison, in the Republic of Kazakhstan, the average annual effective dose should not exceed 1 mSv per year. This means that in most of the territory of the Semipalatinsk test site, the expected levels of radiation exposure to the population are significantly lower than the established norms. However, it is important to keep in mind that radioactive contamination is not localized: contaminated sites are not concentrated in one place, but are distributed throughout the test site, and conditionally clean sites may be located between them.

The second significant result of the project was the realization of the need to revise the official boundaries of the test site and update them. This involves establishing clear boundaries between the currently radioactively contaminated areas and those that can be allocated for economic use, with the mandatory creation of a buffer zone between them. Thus, the program provided key information about the current radiation status of the former Semipalatinsk test site.

In the period from 2008 to 2015, a comprehensive environmental survey of 42% of the territory (7,860 square kilometers) was conducted at the Semipalatinsk test site. During the survey, 2,459 measurements of the radiation background were performed using various instruments. In order to accurately interpret the data obtained, values that were below the detection limits of the devices used were excluded from the analysis. The analysis of the data obtained during the environmental survey showed that the level of background radiation in the studied area varies from 0.05 to 0.23 mSv/h. The average value of the background radiation was 0.12 mSv/h. Statistical analysis confirmed that the distribution of radiation parameters in the study area is close to natural, which indicates a normal radiation background.

A significant result of the project was the awareness of the need to revise the official boundaries of the test site and update them. This includes defining the boundaries between the radioactively contaminated territories at the moment and the sites that can be allocated for economic use, with the mandatory creation of a buffer zone between them. Thus, the program provided valuable information about the current radiation status on the territory of the former Semipalatinsk test site.

The radioactivity of soil depends on several factors, such as the activity of the parent rocks, as well as the intensity of the processes of exchange of radionuclides between soils and groundwater, the content of water in soil, organic substances and other factors.

Volcanic rocks, such as granites, have higher radioactivity than sedimentary rocks (with the exception of shales). Among the various soil types, gray soil has the highest radioactivity, and peatlands have the least (Fig. 3.) [9].

The natural radioactive background caused by radioactive isotopes of radium, thorium and potassium present in rocks and soil ranges from 0.07 to 0.20 mSv/h, averaging 0.08–0.10 mSv/h. The annual effective dose of external radiation from all-natural radionuclides ranges from 3.2 to 8.1 mSv.

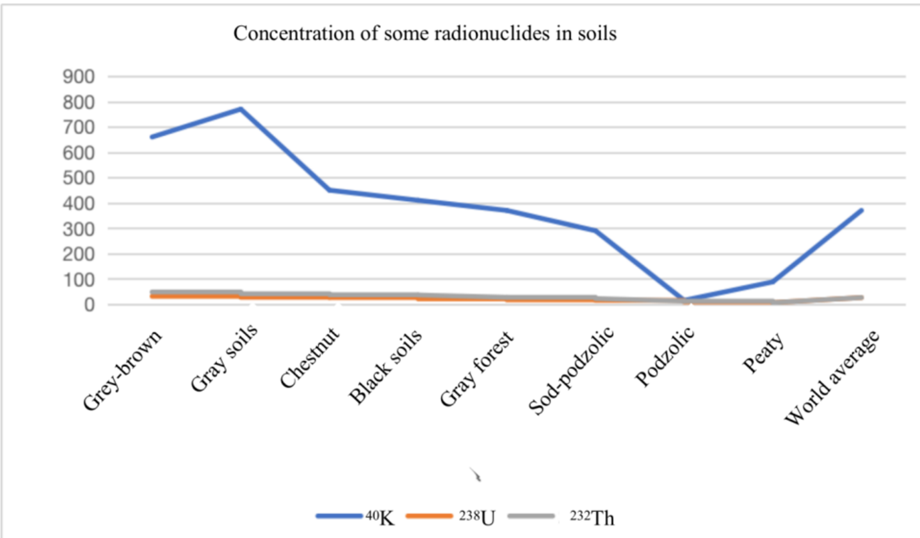

Fig. 3. Concentration of some radionuclides in soils.

The impact of the test site on the ecology of the region and the health of the local population was significant. Nuclear tests in the atmosphere caused widespread environmental pollution: radioactive substances and toxic compounds entered the air, soil and reservoirs [10]. According to various studies, the radiation level in some areas near the test site exceeded the norm by 100–200 times. Radioactive fallout spread over long distances, polluting land and water sources [9]. Studies show that in the soils around the test site, the level of caesium-137 and strontium-90 was 10–20 times higher than permissible standards, which led to contamination of groundwater. This affected changes in the ecosystem: biodiversity decreased, as many species of animals and plants were killed in infected areas, high mortality among wild fauna was observed, which led to a decrease in the population of some species of birds and animals by 50–70%.

Despite the work carried out, there are still areas with an increased level of radioactive contamination in the territory adjacent to radiation-hazardous facilities. One of these sites is the territory adjacent to the Degelen site. The main source of radioactive contamination in this area is the watercourses that come out of the tunnels at the Degelen site and carry radioactive substances with them. About 12 tunnel watercourses were found in the area of the Degelen test site, along the banks and floodplains of which there is an increased content of artificial radionuclides in water, soil and vegetation. These watercourses are connected to streams that extend far beyond the test site, which increases the risk of radioactive contamination spreading to wider areas. The Uzynbulak, Toktakushyk, Baitles, Aktybai streams, and other unnamed seasonal watercourses extending beyond the Degelen site pose a potential risk to the local population, as they may be used for watering livestock, drinking, and other household needs. Radioactive contamination of the floodplain of these streams makes it necessary to urgently conduct a radiation survey in order to assess the level of danger and take appropriate measures to protect the population [11].

Radioactive contamination and the effects of testing remain relevant even decades later, since many radioactive isotopes have a long half-life. The population living within the range of the test site experiences a high prevalence of oncological diseases, thyroid disorders, and other chronic illnesses According to the World Health Organization, thyroid cancer in the region increased by 40% compared to other regions of Kazakhstan. Studies show that among the population living within a radius of 100 kilometers from the test site, the incidence of congenital anomalies increased by 20–30% compared with the general indicators for the country [12, 13].

According to scientists, the main ways of exposure of radioactive substances to the local population are:

– external irradiation: contact with radioactive elements remaining in the upper layer of the soil, which emit gamma radiation.

– internal irradiation: the ingress of radioactive substances into the human body through breathing (inhalation route) or with food and water (oral route).

The consumption of foods grown on the territory of the Semipalatinsk test site is particularly dangerous, as they may contain radioactive substances [14, 15].

Livestock products, primarily milk and meat, can significantly increase the dose of internal human radiation. Therefore, the production of clean livestock products in farms located in the area of the Semipalatinsk test site and in territories exposed to radioactive fallout is possible only with strict observance of scientifically sound agricultural methods and comprehensive measures to ensure product quality according to radiation parameters [16].

Currently, the priority is to minimize the effects of nuclear tests and restore ecosystems. International cooperation is a key factor in achieving positive results. International organizations such as the International Atomic Energy Agency, the United Nations Environment Programme (UNEP), WHO and others are working together with Kazakhstan to solve many environmental problems, including the rehabilitation of the test site, including cleaning up contaminated sites, restoring vegetation, developing a radiation monitoring system, and implementing a program to protect public health from radiation exposure.

4 Conclusion

The Semipalatinsk test site become an example of the devastating impact of military tests on the environment and human health, which underlines the importance of responsibility in nuclear safety issues. The impact of the Semipalatinsk nuclear test site on the environment and public health is multifaceted and destructive. Nuclear tests conducted over 40 years had led to significant radiation pollution of the environment, which affected the state of the soil, reservoirs and ecosystem of the region. The level of radioactive isotopes, such as caesium-137 and strontium-90, in some places exceeds permissible norms by tens of times, which poses a threat to biological diversity and ecosystem sustainability.

Kazakhstani researchers have pointed out that past tests of radioactive warfare agents (RWA) at Site 4 of the Semipalatinsk test site have left behind dangerous levels of radioactive contamination, which still poses a serious health risk to the local population, particularly those involved in agriculture. The migration of radioactive substances contributes to the spread of contamination, which threatens not only the test sites themselves but also adjacent areas, making rehabilitation efforts an urgent priority [17].

Radiation-related diseases, especially among the local population, remain a significant concern. The observed increase in cases of cancer and congenital anomalies underscores the need for ongoing health monitoring, as well as the development of medical and rehabilitation programs for affected residents.

The enduring consequences of the Semipalatinsk test site underscore the importance of acknowledging the risks associated with nuclear testing. It serves as a reminder of the necessity to implement measures for environmental protection and the health of future generations, including the rehabilitation of contaminated areas and active participation of the local population in restoration efforts. The experience of the Semipalatinsk test site should be taken into account when developing international standards and norms in the field of nuclear safety and ecology [18, 19].

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