Risks and environmental impacts of Kazakhstan's uranium production

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Abstract. The article examines the establishment of uranium production in Kazakhstan and assesses the risks of man-made disasters and their consequences. The authors trace the history of the uranium industry and conduct a statistical analysis of uranium deposits based on their geographical distribution. The Republic of Kazakhstan holds a significant position in the global uranium market due to its substantial uranium reserves. While the country benefits from the presence of three unique industries – tantalum, uranium, and beryllium – these also pose certain risks. The article highlights the industrial disaster caused by a beryllium fire at the Ulba Metallurgical Plant and its environmental and public health consequences. The study further explores the development of Kazakhstan's nuclear industry, its integration into international uranium markets, and the establishment of the International Nuclear Fuel Bank in the country. Additionally, it provides an analysis of the environmental threats and risks associated with uranium production.

1 Introduction

The early 21st century has intensified discussions on environmentally sustainable energy sources. Industrial disasters at nuclear power plants, such as the Chernobyl disaster in the late 20th century and the Fukushima accident in the early 21st century, have contributed to widespread fears regarding nuclear energy. As a result, many countries have suspended nuclear power plant construction programs, citing environmental and public safety concerns. However, states with existing nuclear power plants do not plan to phase them out, as nuclear energy is classified within the framework of the "green economy".

Kazakhstan is among the top ten countries with the richest natural resources, including oil, gas, coal, and non-ferrous and precious metals. Experts suggest that Kazakhstan's subsurface contains nearly the entire periodic table. As the demand for energy resources, particularly nuclear power, continues to rise, Kazakhstan's uranium deposits have gained significant global importance. According to experts, Kazakhstan ranks first in uranium production and second in uranium reserves, supplying approximately 40% of the world's uranium. Currently, there are "443 power reactors operating in 30 countries, with nuclear energy accounting for 16% of global electricity generation" [1].

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Kazakhstan's vast uranium deposits and abundant natural resources have led to the development of industrial facilities for non-ferrous metallurgy and uranium production. The country's industrial history dates back to the Soviet era, specifically the period of the Kazakh SSR. Today, uranium production and the construction of nuclear power plants remain critical issues for Kazakhstan's energy strategy and economic development.

The natural resources of Soviet Kazakhstan played a decisive role in the establishment of industrial facilities for both non-ferrous and ferrous metallurgy. During the pre-war and wartime periods, the relocation of industrial enterprises, based on an assessment of available natural resources, served as a catalyst for the development of uranium production, including the construction of the 10th Postal Plant. The discovery of uranium deposits marked the beginning of large-scale events in Kazakhstan's history, notably the establishment of the Semipalatinsk Test Site, covering over 18,000 square kilometers, where atmospheric and underground nuclear tests were conducted from 1949 to 1989. As a result, the population living in areas affected by uranium production and nuclear testing faced long-term medical and environmental consequences.

Kazakhstan's uranium reserves have raised significant challenges related to environmental safety and the peaceful use of uranium. This study examines the history of uranium production, including an analysis of Kazatomprom and its subsidiaries, as well as an analytical overview of the threats and risks associated with Kazakhstan's transformation into a nuclear fuel storage site. The research focuses on Kazakhstan's nuclear industry, with the Ulba Metallurgical Plant as a case study, while the primary subject of investigation is the threats and risks associated with uranium production

2 Methods

Interdisciplinary research integrates methodological principles from related scientific fields. The philosophy of science provides the foundation for formulating and structuring a research hypothesis. This study employs a methodological approach based on historical analysis and an analytical review of available materials on Kazakhstan's uranium industry. The authors draw on classical concepts of scientific, theoretical, and logical inquiry, evaluating statistical data and physical parameters in the context of industrial and natural resource assessment related to nuclear energy.

The research methodology incorporates systemic, general scientific frameworks and approaches designed to identify objectively reliable knowledge. This includes statistical parameter analysis, cognitive and analytical reviews of relevant materials, and the synthesis and structuring of data into a visual format for comparison across chronological and numerical dynamics. The study employs a systems approach, integrating perspectives from economics, ecology, and history to provide a comprehensive understanding of the problem. This interdisciplinary framework facilitated the use of methodologies from related fields, enhancing both the analytical process and the overall research workflow.

3 Discussion and results

3.1 Discussion

The topic proposed by the authors has a long history and is subject to various controversial perspectives. Kazakhstan's natural resources have been extensively studied by scientists from multiple disciplines. This research is grounded in the expertise of specialists in nuclear energy, the uranium industry, and the history of industrial facilities, as well as practitioners capable of assessing the environmental and public health impacts of man-made disasters.

Analytical reviews and reports from relevant institutions provide valuable insights into the construction of industrial facilities associated with the development of Kazakhstan's natural reserves. Publicly available documentation on the activities of Kazatomprom and the Ulba Metallurgical Plant, along with scientific reviews and articles on Kazakhstan's nuclear industry [1], and studies on the priorities of the nuclear sector [2], serve as key sources for this study.

Particularly relevant are scientific publications in journals and conference proceedings that directly or indirectly address the issues under investigation. Additionally, media articles highlighting the problems and consequences of man-made disasters, including potential scenarios, provide important context. A notable example is the 1990 beryllium explosion, which was reported in national and regional newspapers in Kazakhstan.

Of special significance to this research are published scientific and analytical articles by scholars specializing in the uranium industry, as well as archival sources. The production activities of the Ulba Metallurgical Plant have been analyzed in the context of potential industrial disaster scenarios, with an emphasis on assessing the possible severe consequences of "potentially hazardous emergencies or systemic incidents, their negative impacts (damage), and associated risks" [3].

Research on uranium production in Kazakhstan and its assessment has been presented in articles published in the proceedings of an international conference. The collection covers a wide range of topics, including analytical studies on the evaluation of mineral resources, experiments in the development of high-tech uranium products, and challenges facing the uranium industry. Of particular interest is the authors' forecast, which, based on the baseline scenario of the World Nuclear Association (WNA), predicts that global uranium demand will rise to 97.5 thousand tons per year by 2030. The authors argue that global demand for natural uranium is directly linked to the volume of electricity generated by nuclear power plants [4]. Additionally, studies assessing the impact of man-made disasters on the population of Kazakhstan highlight severe long-term consequences, with cancer being one of the most serious and burdensome outcomes [5]. A brief review of existing scientific literature on related topics suggests that the specific research questions addressed in this study have not yet been the subject of detailed investigation

3.2 Construction history

The Republic of Kazakhstan is home to one of the largest nuclear fuel cycle enterprises, a plant that produces highly enriched uranium fuel, with its fuel pellets used in nuclear reactors. The Ulba Metallurgical Plant, formerly known as "10 Lead", began its operations following an analytical report on the discovery of significant polymetallic deposits in Altai, which accounted for 60% of the USSR's total lead reserves and 55% of its copper reserves. The Altai ores were particularly valuable due to their high concentration of polymetals, rare, and precious metals. For comparison, if the value of the Kounrad ores is taken as 100%, then the ores of Dzhezkazgan were valued at 184%, while those of Altai and the Leninogorskoye deposit reached 1,251%.

Recognizing the strategic importance of mining in Altai, as well as the efficiency and speed of its development, the Council of People's Commissars of the USSR and the Central Committee of the CPSU (b) issued a special resolution in October 1938 to define the pace of the Altai polymetallic industry's expansion. The pre-war situation necessitated the rapid industrialization of Kazakhstan. The planned initiatives were highly ambitious, particularly in the construction and reconstruction of polymetallic enterprises in Altai. According to the decree, these enterprises were to be reconstructed by 1944, with an expansion of production capacity in the following quantities (fig.1) :

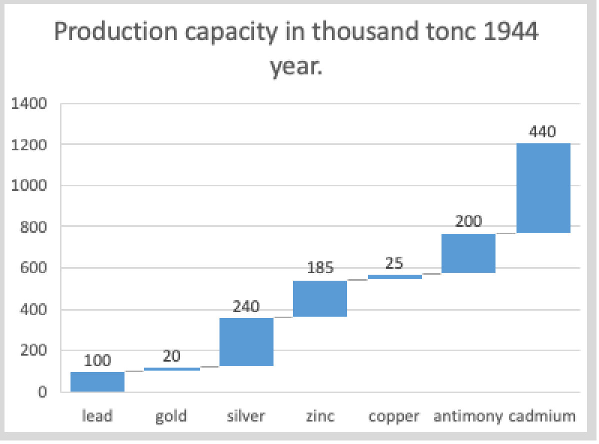

Fig. 1. An expansion of production capacity in the following quantities. Calculated by author

During World War II, the construction of Zinc Plant No. 10 began, based on the evacuated Ordzhonikidze Zinc Electrolyte Plant (Electrozink). Even during peacetime, the plant remained classified as a secret facility and was referred to as 10th Postal. At the time, its construction was overseen by the People's Commissariat of Non-Ferrous Metallurgy of the USSR. A resolution by the State Defense Committee outlined the construction timeline for key facilities, specifying that the first stage of the plant – designed to produce 14,000 tons of zinc per year – was to be commissioned in 1943. The completion date was set for August 1, 1943, but the deadline, along with subsequent targets, was not met due to wartime challenges and labor shortages. As a result, prisoners of war from the German and Japanese armies were enlisted in the construction of this secret facility. The 10th Postal Plant in Soviet Kazakhstan played a pivotal role in the development of thorium, uranium, beryllium, and tantalum production. Although the precise sequence of decisions remains unclear, what is certain is that eastern Kazakhstan became an experimental site for atomic bomb testing at the Semipalatinsk Test Site while also emerging as a key production hub for uranium. Within a span of just a few years, major industrial milestones were reached: tantalum production was established in 1952, uranium production in 1954, and beryllium production in 1956. According to experts, these industries involve some of the most technically complex and hazardous production processes in the world, with severe risks in the event of a man-made disaster.

3.3 Man-made disaster

The Ulba Metallurgical Plant held a key position in the nuclear industry of the USSR. While the late 1980s were marked by perestroika, they were overshadowed by the Chernobyl disaster on April 26, 1986, the largest nuclear accident in history. Four years later, Kazakhstan experienced what became known as a "Small Chernobyl". On September 12, 1990, the press service of the Ulba Metallurgical Plant issued a brief statement, reporting that: "...during smelting at the beryllium-copper ligature site of the Ulba Metallurgical Plant in Ust-Kamenogorsk, at 7:45 a.m., the crucible collapsed, resulting in the partial release of molten material beyond the designated melting unit. There were no casualties or emissions of harmful substances" [6]. Due to the classified nature of the facility, details of the industrial accident remained largely concealed. The residents of Ust-Kamenogorsk, where the plant was located, were reassured that the fire was a routine event and posed no health risks.

In reality, the incident involved "five explosions at the beryllium plant – three minor local explosions in Building 662 and two powerful ones in Building 615. As a result, dozens of tons of fine beryllium dust, measuring 65 microns, were released into the air. Reports indicate that beryllium concentrations exceeded the maximum permissible limit by 14,000 times". Experts emphasize that: "beryllium is an extremely dangerous substance, with a maximum permissible concentration in the air of 0.001 milligrams per cubic meter. Volatile and soluble beryllium compounds, including dust, are highly toxic and have pronounced allergenic and carcinogenic effects. Inhalation of beryllium-contaminated air can lead to a severe disease known as berylliosis" [7].

An official assessment of the man-made disaster has yet to be conducted, given that there are only three beryllium plants in the world – in the United States, Switzerland, and Kazakhstan – and no similar incident has ever been reported elsewhere. The effects of airborne beryllium exposure on the surrounding environment and the city's population were never systematically examined. In the early 1990s, as the Soviet Union stood on the verge of collapse, Gorbachev's policies of democracy and pluralism of opinions mobilized the local population, leading to a public rally attended by deputies of the Supreme Council in its final convocation. In response, an ineffectual special government commission was formed, headed by biogeochemist Anatoly Nazarov, a former chair of the Chernobyl Commission. Following a random medical examination, the commission concluded that Ust-Kamenogorsk should be officially recognized as an ecological disaster zone, as environmental indicators – including air and water quality – exceeded permissible limits multiple times.

After the collapse of the USSR, the disaster was largely forgotten, but the residents of Ust-Kamenogorsk continued to suffer its consequences. The emissions of harmful substances were further exacerbated by the presence of multiple industrial complexes in the city, including the Lead-Zinc Plant, the Titanium-Magnesium Plant, and the Ulba Metallurgical Plant. These emissions have had, and continue to have, a severe impact on public health. The concentration of hazardous substances such as lead, chlorine, and formaldehyde consistently exceeds maximum permissible levels. Due to unfavorable meteorological conditions (UMC) – as the city is located in a lowland – and the added effects of the beryllium fire, the overall negative impact on public health has worsened, contributing to a rise in cancer cases. Additionally, the Semipalatinsk Nuclear Test Site, located near Ust-Kamenogorsk, has compounded environmental and health risks. Considering that, between 1980 and 1990, the incidence of all forms of tumors in Ust-Kamenogorsk exceeded national averages [5], it is reasonable to assume that cancer rates increased even further following the "Small Chernobyl".

3.4 Uranium production in the Republic of Kazakhstan

In sovereign Kazakhstan, Ulba Metallurgical Plant JSC became the parent company of NAC Kazatomprom, which was established in 1997 and specializes in the production of uranium fuel pellets, as well as alloys and products made from beryllium bronze and tantalum. The Ulba Metallurgical Plant has gained international recognition, achieving global standards in the production of high-tech uranium, beryllium, and tantalum products

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for applications in nuclear energy, electronics, aerospace, and other industries. Uranium production holds a particularly significant position in Kazakhstan's economy, given the increasing global demand for nuclear energy. As nuclear power becomes a dominant trend in the global energy market, Kazakhstan has solidified its role as one of the world's leading uranium producers. Since 2010, the country has consistently held "the top position in global uranium mining. In 2019, Kazakhstan produced 22.7 thousand tons of uranium ore, far surpassing Canada, the second-largest producer, which averages only 9 thousand tons annually" [8].

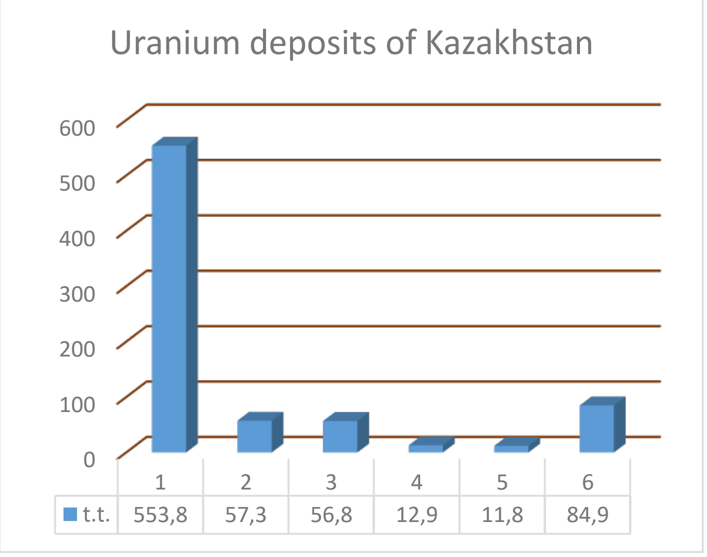

Fig. 2. Uranium deposits of Kazakhstan [9]

All necessary conditions for uranium production have been established in Kazakhstan, including the presence of extensive uranium deposits (fig.2). Visual information on uranium reserves and their distribution indicate that the largest reserves are located in the South Kazakhstan region, which holds 553.8 thousand tons. Other significant deposits include North Kazakhstan (57.3 thousand tons), Almaty (56.8 thousand tons), Mangistau (12.9 thousand tons), Akmola (11.8 thousand tons), and Kyzylorda (84.9 thousand tons). According to experts, the majority of Kazakhstan's uranium reserves (73%) are concentrated in reservoir-infiltration deposits within the Chu-Sarysui and Syrdarya regions.

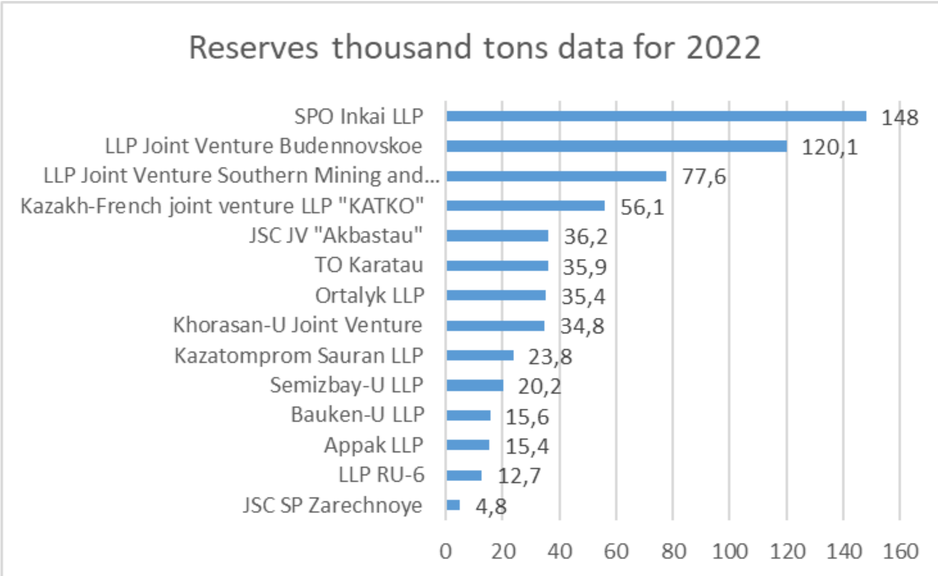

Fig. 3. The total volume of reserves of developed fields (From open sources. https://rus.azattyq.org/a/32767436.html)

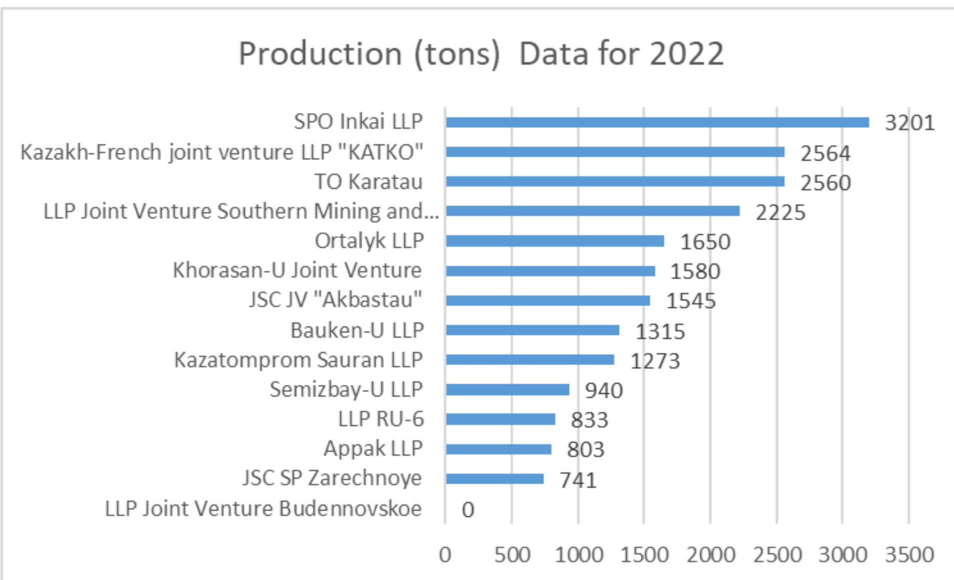

Fig. 4. Rating of uranium production campaigns (From open sources https://rus.azattyq.org/a/32767436.html)

The primary uranium products in demand by global consumers include natural uranium oxide derived from uranium concentrates from Kazakhstani deposits, as well as ceramic-grade uranium dioxide powders and fuel pellets (fig.3 , 4). These products are exported to European Union countries, Asian markets including China, India, and South Korea, as well as to North America, specifically the United States and Canada. "China and India are also increasing investments in nuclear energy to reduce carbon emissions. According to available data, China currently operates 19 nuclear reactors, with an additional 41 reactors planned for construction" [10].

Fig. 5. Uranium tablets (Taken from open sources. https://tengrinews.kz/kazakhstan_news/kazahstan-lider-po-dobyiche-urana-v-mire-opasno-li-eto-418141/)

The development of uranium production (fig.5) and nuclear energy is driven by the increasing shortage of energy resources and the global transition toward a "green economy", which includes programs to limit CO_2 emissions. Alongside energy shortages, the growing global population has intensified the demand for environmentally sustainable products and water resources. Given expert assessments of nuclear energy's near-term prospects, concerns over a potential uranium shortage and rising prices appear well-founded.

According to Kazatomprom, uranium production has decreased by 20% annually since 2018, a trend attributed to the uranium market's recovery following the COVID-19 pandemic. However, starting in 2023, the uranium market rebounded, leading to a 25% increase in Kazatomprom's profits compared to 2022. Net profit grew by one-third year-on-year, reaching 222 billion tenge [11].

In addition to uranium production, the Ulba Metallurgical Plant has continued its operations in tantalum and beryllium production. Notably, it remains the only tantalum producer in the CIS, while globally, there are only three beryllium production facilities. Beryllium products are distributed in Western Europe, Russia, China, and Southeast Asia through subsidiaries such as BerylliUM LLC (Moscow, Russian Federation) and Ulba-China Co. Additionally, the Chinese-Kazakh Joint Venture Yingtan Ulba Shine Metal Materials Co., Ltd. was established in Yingtan Industrial Park, China, to manufacture and distribute flat-rolled beryllium bronze products.

3.5 Threats and risks

For the most part, the population of Ust-Kamenogorsk has grown accustomed to living in proximity to the Ulba Metallurgical Plant, although the events of 1990, related to the beryllium incident, remain a significant memory. This coexistence is particularly beneficial for those employed in the plant's operations.

Kazatomprom systematically implements its security policy to ensure compliance with international safety standards. Since 1995, the IAEA safeguards regime has been in place at the Ulba Metallurgical Plant. In accordance with the requirements of the International

Atomic Energy Agency (IAEA) and the national system for accounting and control of nuclear materials, the company has established a comprehensive nuclear materials accounting system at the plant.

To uphold IAEA safeguards, two installations, "KAT-" and "KAG-", have been designated at the facility. Currently, two types of nuclear materials – uranium and thorium – are under IAEA safeguards at Ulba Metallurgical Plant JSC.

The idea of establishing an International Nuclear Fuel Bank, specifically a reserve of low-enriched uranium, was announced in 2006, sparking serious concerns among local residents. The key motivation behind the bank's creation was to provide access to nuclear fuel for countries that chose not to develop their own uranium production.

Kazakhstan's compliance with IAEA requirements, including the renunciation of nuclear weapons, its abundant uranium deposits, and the transparency of its uranium production cycle, played a significant role in the decision to place the low-enriched uranium bank at the Ulba Metallurgical Plant. This initiative, backed by Kazakhstan's first president, N. Nazarbayev, was considered alongside an alternative location at the Semipalatinsk Test Site. The idea of storing low-enriched uranium in Kazakhstan was first proposed in 2001 by M. Dzhakishev, the former head of Kazatomprom, who estimated that the project would generate over one billion dollars in waste disposal fees.

Information about the International Nuclear Fuel Bank's location at the Ulba Metallurgical Plant was later published in the media. Upon learning that their city could be turned into a nuclear waste storage site, the residents of Ust-Kamenogorsk strongly opposed the plan, initiating a letter to the President of the United States. In the letter, they highlighted the existing consequences of proximity to the uranium industry, including adverse health effects, high mortality rates, and environmental degradation. Additionally, they raised concerns about the seismic activity in the region, which could pose risks to the storage of low-enriched uranium. Still reeling from the effects of the beryllium explosion, the city now faced yet another environmental crisis with potentially severe consequences.

In an interview with M. Shibutov, a well-known Kazakhstani expert, an attempt was made to clarify the situation and dispel uranium-related fears regarding the International Nuclear Fuel Bank being established in Kazakhstan. The Ulba Metallurgical Plant is evolving into a logistics hub for the production of uranium hexafluoride, which is then used to manufacture uranium fuel pellets. The entire process operates under the strict supervision of the IAEA, which authorizes the sale of uranium hexafluoride and uranium pellets for use in nuclear reactors. Shibutov highlighted the potential designation of Kazakhstan as a "Uranium Switzerland", emphasizing the international safeguards placed on uranium production as a significant advantage. He also noted the financial benefits associated with the project [12].

In compliance with IAEA regulations, a 600-square-meter warehouse was constructed for the storage of low-enriched uranium (LEU). This facility was designed to accommodate a specific number of transport and packaging kits required for the shipment of uranium hexafluoride, including empty 30B cylinders and other essential equipment necessary for the operation of the LEU Bank [13].

A. Umirbayeva identified two groups of hazardous radiation sources in Kazakhstan:

1) natural radioactive sources;

2) sources resulting from negligent or criminal human activity.

The first group, which poses a background threat to the environment and public health, consists primarily of uranium mines, which directly and indirectly contribute to environmental degradation and health risks for the population. The proposed map highlights the locations of uranium mines in Kazakhstan in blue.

The first group represents naturally occurring radiation, while the second group consists of man-made radiation caused by human activity. These areas constitute high-risk zones that adversely affect public health. Within these spatial and territorial boundaries, continuous and systematic efforts should be made to promote environmental education, disseminate radiation level data, and implement health-preserving technologies. Developing a government program, with adequate funding, should address the resettlement of residents from radioactively hazardous areas to safer locations.

According to experts, real-time data can provide insights into the most polluted countries and regions based on average annual PM2.5 concentration (mcg/m³). The contributing factors to pollution in Kazakhstan include uranium deposits, radioactive waste and its disposal, the legacy of the Semipalatinsk Test Site, man-made disasters involving heptyl at the Baikonur Cosmodrome, and industrial activities related to unique mineral deposits. Given these factors, it is highly unlikely that Kazakhstan will achieve a pollution assessment threshold of 0 to 15 mcg/m³ within the next fifty years.

In April 2022, environmental violations were reported at the Baiken-U, Kyzylkum, and Khorasan-U uranium plants in the Kyzylorda region following a sulfuric acid spill, which caused damage to wildlife and the surrounding land (fig.6).

0-5 Meets WHO requirements	5.1-10 Exceeds 1-2 times	10.1-15 Exceeds 2-3 times	15.1-25 Exceeds 3-5 times	25.1-35 Exceeds 5-7 times	35.1-50 Exceeds 7-10 times	Exceeds more than 10 times

Rating	Country/region	2023	2022	2021	2020	2019	2018	Population
40	 Kazakhstan	22.2	23	31.1	21.9	23.6	29.8	19,000,958

(Data taken from open source // https://www.iqair.com/ru/world-most-polluted-countries)

Fig.6. Among the 134 most polluted countries, Kazakhstan ranks 40th

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 .

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.

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