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Environmental aspects of past uranium mining in Central Asia and Mongolia

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Abstract. The aim of the work is to generalize data on the formation and current state of uranium tailings in the countries of Central Asia and Mongolia, as well as to develop recommendations for improving the radioecological situation. The object of study is uranium tailings and adjacent territories in the countries of Central Asia and Mongolia. The study is based on the analysis of previously published research conducted in the specified countries. Radiation monitoring was carried out using modern instruments and equipment manufactured in the Russian Federation (Doza), the Republic of Belarus (Atomtex), the USA (Canberra), and Germany (Thermo). It was established that the negative radiological impact of uranium tailings on the environment and population is driven by similarities in natural and climatic conditions and the specific features of uranium ore processing. In Central Asia, a number of tailings remain unreclaimed, while in Mongolia uranium waste has not yet been subjected to remediation measures. In certain local areas, the gamma dose rate reaches up to 3.5 μSv/h, which is nearly 12 times higher than background levels. The necessity of implementing a comprehensive set of measures is substantiated, including the establishment of systematic radiation monitoring, rehabilitation of contaminated areas, and strengthening of interstate cooperation in the implementation of national and international projects.

Keywords: uranium production, uranium tailings, dose rate, pollution, reclamation

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Экологические аспекты прошлой добычи урана в Центральной Азии и Монголии

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Аннотация. Цель исследования — обобщение данных о формировании и современном состоянии урановых хвостохранилищ в странах Центральной Азии и Монголии, а также разработка рекомендаций по улучшению радиоэкологической обстановки. Объект исследования — урановые хвостохранилища и прилегающие к ним территории в странах Центральной Азии и Монголии. Использованы материалы ранее выполненных исследований. Радиационный мониторинг проводился с применением современных приборов и оборудования производства Российской Федерации («Доза»), Республики Беларусь («Атомтех»), США (Canberra) и Германии (Thermo). Установлено, что негативное радиологическое воздействие хвостохранилищ на окружающую среду и население обусловлено сходством природно-климатических условий и особенностями переработки урановых руд. Выявлено, что в странах Центральной Азии часть хвостохранилищ остается нерекультивированной, тогда как в Монголии урановые отходы до настоящего времени не охвачены рекультивационными мероприятиями. На отдельных участках мощность дозы гамма-излучения достигает 3,5 мкЗв/ч, что превышает фоновые значения почти в 12 раз. Обоснована необходимость реализации комплекса мер, включающего организацию системного радиационного контроля, реабилитацию загрязненных территорий и расширение межгосударственного взаимодействия при реализации национальных и международных проектов.

Ключевые слова: урановое производство, урановые хвостохранилища, мощность дозы, загрязнение, рекультивация

Вклад авторов. *Мирсаидов У.* — руководство исследованием, создание рукописи и ее редактирование. *Назаров Х.М.* — концептуализация, верификация данных, создание черновика рукописи. *Цэрэн Д.* — администрирование проекта, визуализация. *Чимэдбазарын Ж.* — проведение исследования, верификация данных. Все авторы ознакомлены с окончательной версией статьи и одобрили ее.

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Заявление об использовании технологий искусственного интеллекта. При создании настоящей статьи технологии генеративного искусственного интеллекта не использовались.

Заявление о доступности данных. Все данные, полученные в ходе этого исследования, включены в опубликованную статью.

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Introduction

Uranium production and its growing industry require special attention to the risks that may arise from the mining, processing and storage of this radioactive material. Between 1942 and 1996, uranium ore was mined and processed in the countries of Central Asia, resulting in significant amounts of radioactive waste [1].

In a later period, uranium ores from the former Soviet era were also involved with the Mongolian People's Republic [2]. Mongolia has a colorful history of uranium-related activities as a result of over 60 years of cooperation with major companies from Russia, the USA, Canada, China, France and the Czech Republic. The development of uranium production in the Mongolian People's Republic can be divided into three stages:

1) *Formation:* intensive geological exploration, discovery and development of promising deposits (1960–1995);

2) *Stagnation:* Suspension of production, asset restructuring (1994–2016);

3) *Revival:* opening and exploitation of new fields, recovery of activity (from 2016 to present).

Each of the development stages is related to the problems of radiation protection, environmental protection, personnel and population. With the increasing trend of uranium mining activity now in Mongolia, clarification, identification and assessment of possible environmental impacts from mines that have ceased production become a pressing task.

The purpose of this article is to summarize available materials on the formation and current status of uranium tailings in the countries of Central Asia and Mongolia and to develop recommendations for improving the radioenvironmental situation in these countries.

Materials and methods

The uranium tailings and their natural-manmade sites, adjacent territories in the countries of Central Asia and Mongolia were chosen as the objects of study.

Radioactive uranium waste in Tajikistan. As a result of the activities of the State Unitary Enterprise "Tajredmet" (former 6th Plant, Leninabad Mining and Chemical Works) in Tajikistan, radioactive contamination areas have been created, which are technogenic waste materials and deposits of off-balance ore dumps ores. The total amount of waste accumulated during this period is 55 million tons in an area of 170 hectares with a total activity of 6.5–7.7 thousand Curies. Almost all major uranium heritage sites are located in northern Tajikistan in mountainous areas near the settlements: Istikloll, Buston, Khujand, Adrasman [3].

Radioactive uranium waste in Kyrgyzstan. In Kyrgyzstan, there are 33 radioactive tailings and 25 waste rock dumps at 6 sites [4].

Radioactive uranium waste in Uzbekistan. There are 4 closed uranium mines and 29 empty rock dumps near the shaft and mine shafts in the Yangsaibad ore field. The total amount of contaminated material accumulated here is about 500,000 m^3. Mainly off-balance ores from the primary uranium mining sites in the Central Kyzyl-Kum region were transported to the vicinity of Uschkuduk, where they were stored and remain until now [1].

[1] *Technical Reports Series No. 488. The Environmental Behaviour of Uranium.* Vienna: International Atomic Energy Agency; 2023. p. 334–336.

Radioactive uranium waste in Kazakhstan. Uranium was first mined in Kazakhstan in 1948. In 1963, in order to expand mining operations, the former Ministry of Middle Engineering of the USSR on the Mangyshlak peninsula laid the city of Shevchenko (now Aktau) and created a leading urban-forming enterprise — the Caspian Mining and Metallurgical Enterprise, the structure of which included a chemical and hydrometallurgical enrichment plant. The amount of radioactive waste accumulated by uranium mining plants is 61 million tons with a total activity of 6.23 PBq [5].

Radioactive uranium dumps in Mongolia. The approximate estimates of uranium waste generated in Mongolia during 1988–1995 amount to 2 million tons [6], including only dumps, stored and off-balance ores.

In accordance with the agreement between the governments of the USSR and the Mongolian People's Republic of 23 December 1981 "On the development of uranium deposits in the territory of the Mongolian People's Republic" and on the basis of the decision of the Council of Ministers of the USSR of 17 May 1982 543–150ss, Priarangny Mining and Chemical Works began in 1983 to build the Soviet mining enterprise "Erdes", on the territory of Mongolia on the basis of the deposit "Dornod", which is part of the group of uranium deposits of the Dornodsky ore field, located 300 km from Krasnokamensk in the Transbaikal region of the Russian Federation. The deposit "Dornod" with a capacity of 400,000 ore per year was put into operation in 1988. Uranium production at this time was 860 tons of U_3O_8 per year. From 1989 to 1991, about 500,000 tons of ore were shipped, and another 300,000 tons were stored in ore warehouses [2].

Except for an open career, an underground mine 7 was organized at the same deposit. However, due to a changed environment for uranium raw materials, the financing of the construction of the "Erdes" plant was discontinued, as well as the large-scale uranium prospecting. In March 1995, the shipment of ore from Mongolia was stopped, although production continued until the end of 1996.

During radiation monitoring, modern instruments and equipment were used — a set PackEye FHT1377 ("Thermo Scientific", German) and dosimeters DKS-96 ("Doza", Russia), DKS-AT1123 ("Atomtex", Belarus).

Sampling and sample preparation have been carried out in accordance with the GOST 17.4.3.01-83, GOST 17.4.4.02-84 and GOST 17.4.3.01-2017.

Measurements of the total alpha- and beta activity of soil samples were performed on a gamma-ray spectrometer ("Canberra Industries", USA) and alpha-beta radiometer UMF-2000.

Determination of heavy metals using X-ray fluorescent analysis on the "Spectroskan МАКС–GV" and on the atomic absorption spectrophotometer "KVANT-2A" NGO "Cortek" company.

Results and discussion

State of uranium facilities in Tajikistan. Some assessments of the current state of former uranium facilities in Tajikistan are presented in the works [7–10].

Uranium tailings of the city of Istiklol. In 2022–2023, rehabilitation of the uranium site "Taboshar" was carried out. As a result of the levelling of "Factories of poor ores", its area has almost doubled (from 7.9 hectares to 14.5 hectares), the steepness of the waste heap slope has decreased from 60–70^o to 18–22^o, and the height from 60 m to 35 m. The dose rate of gamma-ray radiation at the outage surface reached a background level of 0.30 μSv/h, with a characteristic range of 0.17–0.65 μSv/h. The capacity of the surface coverage of uranium tailings "I–IV stage" with neutral soil was also additionally increased, as a result of which the dose of gamma radiation on their surface reached 0.25 μSv/h, with a characteristic range of 0.18–0.36 μSv/h.

The tailing of Workshop 3. The dose power of gamma radiation in the dewatering environment was determined to be 0.4–0.7 μSv/h and could reach 3.0–4.0 μSv/h at locations where the dewatering is located. Additional remediation work is required.

The Adrasman tailing is located at a conservation site, at the foot of the slope, which has traces of the removal of material from the tailing heath in the lower part of the Saya (mountain river). These sites have elevated gamma radiation dose power levels of 1.2–2.5 μSv/h. We believe it is necessary to reconstruct the existing drainage canal.

State of uranium facilities in Kyrgyzstan. In the area of Min-Kush settlement are located 4 tailings (Tuyuk-Suu, Taldy-Bulak, and Dalnee) with radioactive materials — a volume of 1.15 million m^3, an area of 196,500 m^2, as well as 4 waste rock dumps [11–13] The mean value of the gamma radiation dose at the surface of the tailings is 0.3–0.6 μSv/h, although in some areas a value of 5–12 μSv/h has been observed. Rehabilitation work in the village of Min-Kush is in its final stages.

The "Kaji-Sai" tailing. In 2019, the recultivation of the tailings storage facility was completed. On the surface of the tailings storage facility, the dose rate of gamma radiation is on average 0.3–0.6 μSv/h.

Waste rock dump in the area of Shekaftar settlement. The mean value of the gamma radiation dose to the dewatering surface is 0.6–1.5 μSv/h. The waste rock dump, located on the bank of the river Sumsar, are tensively diffused by the waters of the river.

The "Myluu-Suu" tailing. The dose power value of gamma radiation at the tailpipe surface is within 0.6–1.0 μSv/h. Rehabilitation work is being carried out on the tailings, miners, industrial buildings and shafts of the uranium complex in the city of Mayluu-Suu.

State of uranium facilities in Uzbekistan. In the mine of Charkesar-1, the waste rock dumps are located in randomly selected trenches at the bottom and on the edges of the valley. The average background gamma radiation around the site is 0.6 μSv/h. On the surface of rock cuttings, the dose rate of gamma radiation varies from 0.8 μSv/h to 2.5 μSv/h. The natural background level of gamma radiation of the surface rocks in the vicinity of the Charkesar-2 mine is about 0.3–0.4 μSb/h, the total specific alpha activity of the rock varies in the range of 1.0–1.3 kBq/kg.

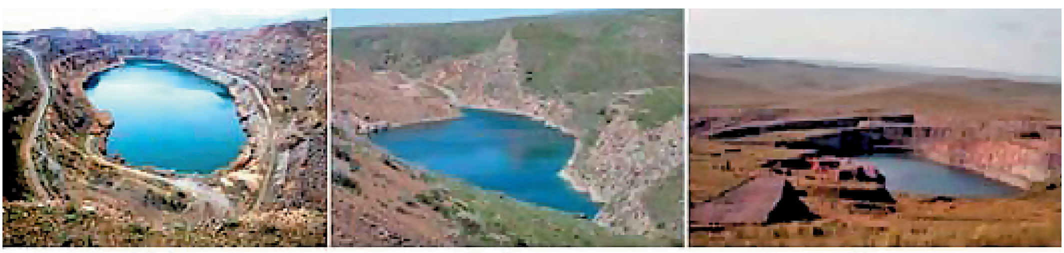
The tailings of the Hydrometallurgical Plant of the Navoi city and in the vicinity of the city of Uchkuduk. The tailings sludges were formed during the processing of the deposits of Sugrala, Sabirsai and Uchkuduk. The dose rate on the surface of the waste varies between 5.0–17.0 μSv/h, total alpha-activity ratio of the tail material 90–100 thousand Bq/kg[2].

State of uranium facilities in Kazakhstan. The waste rock dumps and the tailings near the village of Zaozerny and the Stepanogorsk city cover approximately 734 hectares and contain about 46 million tons of uranium waste produced with an activity of 5.92 PBq [14]. The surface of ore tailings at mine 9 is covered with a 1 m layer of clay, the dose rate of gamma radiation is 0.2 μSv/h.

State of uranium facilities in Mongolia. Underground mining sub-grade ore dumps determine the increase in radioactivity at local areas within a range of 3.5–15.0 μSv/h against 0.22–0.32 μSv/h.

As for liquid waste, *“Western Prospector”* had been pumped out of a mothballed mine at the *“Gurvanbulag”* field and dumped into a filtration lake near the mine. The identified maximum dose rate at the *“Gurvanbulag”* field reaches 1860 μSv/h, which is 29.2 times higher than the world average radiation level [2; 15].

Uranium quarries in Tajikistan, Kazakhstan and Mongolia. Following the cessation of open-pit uranium mining in these countries, quarries were filled with groundwater, while concentrations ^{238}U and ^{234}U are in the range 20–30 Bq/L (Figure).



a *b* *c*

General view of former uranium mines:
a — Taboshar mine, Tajikistan; *b* — Kurdai mine, Kazakhstan; *c* — Gurvanbulag mine, Mongolia

Source: photo was taken by Kh.M. Nazarov, J. Chimedbazaryn.

[2] *Technical Reports Series No. 488. The Environmental Behaviour of Uranium*. Vienna: International Atomic Energy Agency; 2023. p. 334–336.

Relatively high concentrations of 1,200–1,400 μg/L have been found in a flooded quarry in Kurdai, Kazakhstan. The measurement of Mongolian and Japanese scientists in 2013 near the quarry of the Gurvanbulag field (Mongolia) showed a high effective equivalent dose of 250 μSv/h, which is 5 times higher than the world average radiation level. For more detailed data on the water of the uranium quarry in Isticlol see Table 1.

Table 1. **Uranium activity concentrations in waters from the Taboshar mine site Tajikistan**

Location	Activity concentrations				
	U, μg/L	^{238}U, Bq/L	^{234}U, Bq/L	^{234}U / ^{238}U	^{226}Ra, Bq/L
Mine	1660	20.5	20.9	1.02	1.13
Outlet from adit No. 2	1430	17.6	17.9	1.02	0.87
Syr-Darya river	35.3	0.44	0.73	1.66	0.006

Source: compiled by Kh.M. Nazarov, J. Chimedbazaryn.

The erosion of uranium tailings in Central Asia. Heavy atmospheric precipitation often leads to the erosion of water flows on the surface of the region's tailings in central Asia[3].

Ecological and geochemical assessment of the contamination of the territory around the tailings. The ecological condition of uranium deposits and adjacent areas after so many years of cessation in Central Asian countries and Mongolia should be examined in detail to determine the possible consequences and feasibility of remediation if necessary.

Situation in Tajikistan. The radiological risk remains relatively high at the Digmaia tailing depot, as it is considered active and its surface remains open to date. The vegetation in the area around the specified tailgate is represented by ephemeral-ephemeromeroid and sagebrush communities, also participates petrophytic shrub Atraphaxis, herbaceous perennials: bluegrass, tulip, onion, and sea kale and ephemeral grass. The results of the biogeochemical test are presented in Table 2.

Comparative analysis of the table data. 2 showed that biochemical processes in plant and soil layers affected the number of moving forms of individual elements. During this period, the lead content in soils increased by about 2.6 times, while the content of vanadium remained unchanged. There was a high increase in pollution in 2015. This is due to the drying out of the tail pond, increased dusting surface and volume of material being released. In the period 2016–2017, at the initiative of the Executive Body of the state power in the Sogd region, a partial recultivation

[3] *Technical Reports Series No. 488. The Environmental Behaviour of Uranium.* Vienna: International Atomic Energy Agency; 2023. p. 334–336.

(200,000 m^2) of the surface of the tailing repository was carried out. This contributed to some improvement of the radioecological situation in the surrounding areas around the tailing tank. This is confirmed by the 2020 data.

Table 2. **Average element content in Artemisia plant and soil in the area around the Digmay tailings storage facility, Tajikistan**

Element	Years of measurements								
	2001			2015			2020		
	plant, %	soil, %	K_{ba}	plant, %	soil, %	K_{ba}	plant, %	soil, %	K_{ba}
Mn	0.011	0.04	0.3	0.001	0.001	1.0	0.065	0.0088	0.8
Ni	0.001	0.0018	0.6	0.0025	0.003	0.8	0.0025	0.0031	0.8
V	0.0024	0.002	1.2	0.005	0.002	2.5	0.0054	0.002	2.8
Cr	0.0018	0.0022	0.8	0.0022	0.0011	2.0	0.006	0.0087	0.8
Pb	0.0056	0.0006	9.5	0.002	0.001	2.0	0.007	0.0025	2.3
Zn	0.0086	0.001	8.6	0.0066	0.001	6.6	0.0085	0.0015	5.2
U	0.001	0.0007	1.3	0.001	0.0008	1.2	0.002	0.0011	2.0

Source: compiled by Kh.M. Nazarov, J. Chimedbazaryn.

Situation in Kyrgyzstan. The content of trace elements in the soil cover in the uranium natural-technogenic province of Ming Kush is within permissible concentrations, with the exception of the “Tuyuk-Suu” and “Dalnee” tailings on residential sites 17 and 21, where the concentrations of microelements are increased: Mn, Co, Ni, Ti, Cr, Pb compared to the limit-permissible concentrations and biogeochemical criteria [16]. It has been established that in the soils of individual natural-man-made areas of this tail repository, the specific activity of natural radionuclides exceeds the Clarke values: ^{238}U in 10-15 times, ^{226}Ra in 15–20 times, ^{232}Th and ^{40}K in 1.0–1.5 times.

Situation in Mongolia. Natural radioactive elements Th, U, Rn are associated with the mining production of copper, molybdenum, iron and tungsten. Regular explosive work releases a significant amount of radon from the subsurface, forming a marigold that can be carried by wind to the nearby city of Erdenet.

Also, tail material consisting of particles <80 μm, almost 76%, and 24% of particles <10 μm, at wind speeds above 5.4 m/s, are easily carried away as dust into the atmosphere. When weighed, this dust has a harmful effect on the health of humans and animals by affecting their respiratory organs. And after deposition on the ground, contaminates soil cover as a secondary source of pollution[4].

[4] Bjambasuren B. *Geoecological problems of the Erdenet tailings and their manifestation in biogeochemical fields (Mongolia): master's thesis*. Tomsk; 2019. 126 p.

Biogeochemical maps — schemes of spatial distribution of elements on the territory of the “Erdenatin-Ovoo” enterprise, is a support to the above mentioned. Element contents — Cs, Tb, Ta, Th are explained by natural factors, and the contents of Ta, Th may be explained by geological factors. The resulting data can be used to develop and implement a uranium waste rehabilitation programme in Erdenat, Mongolia.

Conclusion

Analysis of the state of radioactive tailings — uranium heritage of the Soviet period in the countries of Central Asia and Mongolia, shows the identity of formation of a significant amount of radioactive tail material. Because uranium mining and processing sites in these Central Asian countries are located on the mountainous terrain above the transboundary valley of the Syrdarya River, contamination by radionuclides from such heritage tends to be widespread. In the process of dusting tailings, a large amount of particulate matter enters the atmosphere, affecting both public health and the environment.

As a result, to ensure radiation safety in the countries of Central Asia and Mongolia, it is necessary to consider taking the following urgent measures:

– systemic radiological monitoring throughout the mining industry;

– identification of specific sources of radiation exposure;

– development and implementation of a uranium waste rehabilitation program.

We consider it appropriate to ensure a common approach among the countries of Central Asia and Mongolia in order to solve existing problems concerning the rehabilitation of areas exposed to radiation, strengthening of coordination and interaction in this direction for the implementation of large national and international projects with the participation of international organizations.

Recommendations:

For Tajikistan. To further develop and implement projects for the safe management of the uranium heritage of northern Tajikistan:

– to cover the surfaces of the Digmay tailings with local soil from the adjacent hills;

– to move the tails from the Adrasman tailing to a safe place or strengthen the dam and build a drainage canal;

– to carry out reclamation works on the surface of the tailgate of Workshop 3 of the hydrometallurgical plant in Isticlol.

For Kyrgyzstan. To consider the possibility of securing five major tailings, three in Sumsar village, two in Kan village and the waste rock dump in Too-Mojun and Kyzyl-Jhar villages.

For Mongolia. To develop and implement a strategy for the recovery of radioactive tailings of uranium production in the next 5 years (2026–2030).

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