Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 31, issue 1 / 2025, pp. 88-99

ASSESSMENT OF THE IMPACT OF THE URANIUM INDUSTRY ON THE ENVIRONMENT AND POPULATION

Vasyl LYASHENKO[1], Viktor STUS[2],Yuriy KYSELOV[3], Ivan LISOVYI[4]*

[1]Ukrainian Research and Design-Intelligence Institute of Industrial Technology, Zhovti Vody, Ukraine
vilyashenko2017@gmail.com
[2]Dnipro State Medical University 49044, Dnipro, Ukraine, e -mail: viktor.stus@gmail.com
[3]Uman National University of Horticulture, Uman, Ukraine, e -mail: kyseljov@ukr.net
[4]Uman National University of Horticulture, Uman, Ukraine, e -mail: lisov.iv.ol@gmail.com

DOI: 10.2478/minrv-2025-0008

Abstract: *The paper provides an assessment of the impact of the uranium industry on the state of the environment and the population based on the development and implementation of engineering solutions and measures to reduce gamma radiation and radon concentration in the premises, the implementation of environmental and social rehabilitation of the contaminated territory, residential buildings, objects social sphere and the population living in the zone of influence of uranium facilities. The specified measures are aimed at improving the environmental safety of the environment and the population in order to minimize the negative impact of radiation and other factors. Used radiometric methods (measurement of the exposure dose and intensity of γ-radiation, measurement of the radioactivity of γ- and β-radiation, measurement of the power of the exposure dose of γ-radiation, determination of the power of the absorbed dose of γ-radiation in air, analysis of natural radionuclides (PRN); statistical and mathematical research methods using an integrated system approach Radioecological studies included: measurement of the exposure dose rate (PED) of γ-radiation by the network 100 x 10 m (walking survey) in the area of 40 km2, soil sampling for radium and uranium content, determination of radon concentration in residential premises specialists of various bodies of state power and local self-government in solving the above-mentioned tasks, for the regions located in the zone impact of mining and beneficiation plants for mining and primary processing of uranium ores. It was established that exceeding the normative level of the equivalent equilibrium concentration of radon of 50 Bq/m3 in individual rooms is caused by its release from the underground space and input channels of external heat and water supply networks, internal channels of distribution of heat networks. It has been proven that filling the heat network channel from the outside of the building with a layer of clay to a depth of 1 m and sealing it, sealing the entry of heat and water networks through the foundation of the building and concreting the pit reduce the volumetric activity of radon in the room by 5-6 times. The so far rare experience of increasing radiation and social protection of the population of the city of Zhovti Vody, Ukraine, which has been living in the zone of influence of uranium industry facilities for more than 70 years, is presented. It is proposed to continue research and provide funds (at the expense of enterprises, local and central state authorities) for conducting scientific substantiation and developing preventive measures to minimize the negative effects on human health from the action of heavy metals and radiation factors, taking into account the peculiarities of their combined impact on the population and workers of the uranium mining and mining and metallurgical industry.*
Keywords: *radioecology, uranium production, state programs, environmental protection measures, radiation and social protection, population*

1. Introduction

Statement of the problem. A characteristic feature of the Dnieper region of Ukraine is the development and primary processing of uranium ores in the city of Zhovti Vody. The presence of enterprises of the initial stage of the nuclear cycle in the cities of Zhovti Vody, Kamianske, disposal of radioactive waste, led to the formation of a complex radio-ecological situation in the region. The city of Zhovti Vody is the only one in

* Corresponding author: Prof. eng. V.I. Lyashenko, Ph.D., Ukrainian Research and Design-Intelligence Institute of Industrial Technology, Zhovti Vody, Ukraine, vilyashenko2017@gmail.com

Ukraine where, since the 1950s, mining and primary processing of uranium raw materials - the basis of nuclear fuel for atomic energy - has been carried out. The Zhovtorichan deposit of iron-uranium-scandium ores is located on its territory. This field has been developed since 1895. At the beginning of the development, until the mid-40s of the last century, the extraction of enriched iron ores took place, and from 1951, the development of uranium ores began, which was completed at the end of 1989 [1], [2]. The Zhovtovodsky site is home to the Vilkhivska, Severnnaya-Drenazhna, Kapitalna, Nova, Nova-Hlyboka, Pivdenna-Ventilatsyna mines, a plant for the primary processing of uranium raw materials (hereinafter - GMZ), a sulfuric acid plant (hereinafter SKZ) and a number of auxiliary subdivisions, the plant's office is also located here (Fig. 1).

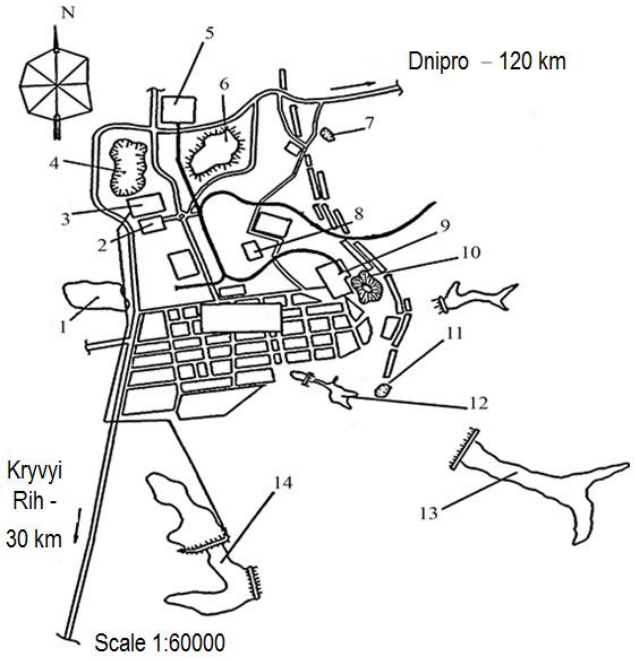

Fig. 1. Zhovtovodsk industrial site (diagram): 1 – thermal power plant (CHP) waste ash dump; 2 – CHP; 3 – hydrometallurgical plant; 4 – tailings depository of brown iron quarry; 5 – sulfuric acid plant; 6 - reclaimed dump; 7 – "Veseloivanivskyi" quarry; 8, 9 – "Olkhovska" and "Nova" mines; 10 - collapse zone (failure); 11 – "Gabaevsky" quarry; 12, 13, 14 - tailings "T", "P" and "Sh"

The main uranium production facilities (mines, mines, industrial sites of mining and metallurgical plants, hydrometallurgical plants, tailings storage facilities, etc.) were located on the specified territories, which were subjected to man-made pollution. Bringing them to an ecologically safe state is an urgent task for such territories. At the same time, the practical solution of these tasks is hindered by the lack of experience in planning and implementation of environmental restoration projects, the lack of financial resources for the implementation of long-term rehabilitation programs [3], [4].

Therefore, the assessment of the impact of the uranium industry on the environment and the population, the development and implementation of engineering and technical solutions and measures to reduce gamma radiation and radon concentration in premises, the implementation of ecological and social rehabilitation of the contaminated territory, residential buildings, social sphere objects and the population living in the zone of its influence, aimed at protecting the environment and its protection, is an important scientific, economic and social task [5], [6].

The object of the research is radiation-hazardous objects of the uranium mining and processing industry (industrial sites and sanitary protection zones and strips in the zone of influence of mines, rock dumps and, according to the balance, according to the content of the useful component of ores, mine waters, hydrometallurgical plants , tailings storage facilities and slurry pipelines to them), as well as the locations of uranium heritage objects and adjacent territories on the example of the city of Zhovti Vody, Ukraine.

The purpose of the study is to assess the impact of the uranium industry on the environment and population on the surrounding natural environment and human health from radiation factors and heavy metals. The implementation of these environmental and social measures will allow to raise the standard of living of the population living in the zone of influence of uranium production. To achieve the goal, the following tasks were solved:

1. To carry out a complex of works on the rehabilitation of the polluted territory of the city to reduce dose loads on the environment and the population.

2. Bring the radiation background in residential, administrative buildings and structures to the level determined by the current radiation safety standards.

3. Create and ensure the functioning of a system of permanent ecological and radiation monitoring of the city territory.

4. To strengthen the social protection of the population living in the territories in the zone of influence of uranium production.

2. Materials and methods

The authors used radio methods (measurement of the exposure dose and intensity of γ-radiation, measurement of the radioactivity of γ- and β-radiation, measurement of the power of the exposure dose of γ-radiation, determination of the power of the absorbed dose of γ-radiation in the air, PRN analysis); statistical and mathematical research methods using complex system approaches. Radioecological studies included: measurement of the power of the exposure dose (PED) of γ-radiation along a network of 100x100 m and 20x10 m (pedestrian γ-survey) in an area of 40 km^2; soil analysis for the content of radionuclides; water sampling for radium and uranium content; determination of the total α- and β-activity of the soil; determination of radon concentration in residential premises [7].

Radiation safety - the state of nuclear radiation facilities and the environment, which ensures that dose limits are not exceeded, any unjustified exposure is excluded, and the radiation doses of personnel and the population are reduced below the established dose limits, to the extent that it can be achieved and is economically justified in accordance with the requirements " Radiation safety standards of Ukraine (NRBU-97) [8].

3. Equipment support

The following devices and equipment approved by the state bodies of metrology and standardization of Ukraine were used for the radiation survey of the territory and residential premises of Zhovti Vody: dosimeter DBG-06T, radiometers SRP-88N and IRM, gamma spectrometer SGS (LP-4900B), radon monitor AlphaGUARDPQ2000, a set of measuring equipment КВИР-2010Z, etc., manufactured at Positron GmbH and Tetra (Zhovti Vody) together with Genitron GmbH (Frankfurt am Main, Germany) and others. [9].

4. Discussion and assessment of research results

Uranium ore is mined by the mine method at the Zhovtorichan industrial site, which became the main site of the Eastern Mining and Processing Plant (now the Eastern Mining and Processing Plant, Ukraine). A group of mines is located here ("Vilkhovskaya", "Northern Drainage", "Capital", "New", "New Deep", "Southern Ventilation"). During the period from 1951 to 1989, the balance reserves of uranium ores were completely repaid and their mining was stopped. After the mining of uranium ores, the "Nova" mine was transferred to the joint venture JV "ShidGZK-Ashurst" [10], [11].

Depending on the nature of its formation, this element has a different half-life: radon-222 - 3.8 days, and radon-220 (thoron) -55 s. Radon spreads through the pores (cracks) of the soil, rocks or ores and can penetrate into the air of residential premises or the atmosphere. The main source of radon entering the indoor air is the soil under the building and construction materials extracted from deposits (crushed stone, gravel, sand, rubble and sawn stone, cement and brick raw materials), by-products of industry, as well as production waste used for manufacturing similar products.

During the period of exploitation of the Zhovtorichan deposit, two quarries ("Gabaevskii" and "Veseloivanivskii") and four tailings pits (used brown iron pit (KBZ); "Shcherbakivska" ("Sh") beams were formed (Fig. 2a, b); "Razberi" ("R") and "Ternivska" Tailings storage areas occupy more than 3,505 ha, on which accumulated about 50 million tons of waste with a total activity of 62.1 thousand Ki. For groundwater control, 74 and 70 wells were drilled along the perimeter of the tailings reservoirs of the "Sh" and KBZ, respectively. From the north, at a distance of 2 kilometers, there is a hydrometallurgical plant (HMZ) for the processing of uranium ore and its reserve "tailing storage" KBZ [12], [13].

The tailing pulp from the hydrometallurgical plant with uranium ore enrichment waste flows along the technological route to the main tailings storage facility in the "Sh" beam, which is located from the south at a distance of 1.5 km. Uranium ore mining and processing enterprises are powerful sources of radiation impact on the environment, which requires the implementation of a whole set of special measures aimed at reducing radiation pollution of the environment, as well as radiation and social protection of residents who are forced to live in the zone of man-made radiation exposure [14], [15].

a) ***b)***

Fig. 2. General view of tailings storage facilities for hydrometallurgical ore processing waste storage: a – Shcherbakivska beam; b – mining and technical reclamation of the tailings depository of the former quarry of brown railways

The most dangerous from a radiation point of view are the Zhovtorichan deposit and the radioactive waste disposal area in the Razberi stream (tailing repository "R"), located on the left bank of the river valley. Zhovta, which is used as a storage device for dumping waste from the Nova mine. The average chemical composition of the discharge water in terms of the composition of metals and trace elements was as follows: beryllium < 0.00005 (limit permissible concentration (MPC) – 0.002), mercury < 0.0005 (MPC – 0.0005), barium < 0.001 (MPC – 0. 1), cobalt < 0.002 (HPC – 0.1), molybdenum < 0.002 (COD – 0.25), arsenic < 0.003 (COD – 0.005), nickel < 0.001 (COD – 0.1). Other metals are present in small amounts: lead – 0.011 mg/l (COD – 0.03 mg/l), zinc – 0.08 mg/l (COD – 1.0 mg/l).

The content of cadmium exceeded the COD in two times in one of the 12 selected samples. 11 BPK, zinc – 8 BPK, iron – 5.8 BPK were recorded. Exceedings of COD were noted for aluminum, bromine, iron, and manganese. Sulfates - 545 mg/l; ammonium nitrogen - 1.28 mg/l; petroleum products - 0.04 mg/l. From 1992 to 2002, according to SES No. 9, uranium concentrations close to PCingest were recorded in mine waters. At the same time, the uranium content in Yellow, which flows near the tailings pond, was 0.004-0.039 mg/l and did not exceed the COD.

The "P" tailings reservoir is surrounded by an earthen dam made of compacted loams and clays, the natural screen of the dam is clay and loamy soils. The drained clarified waters of the tailings storage facility are discharged into the river. Yellow in the form of a drainage stream. The Zhovti Vody, which flows in the eastern part of the settlement area of Zhovti Vody from north to south belongs to the rivers of the category of economic and domestic purpose and is not a source of drinking water supply. Mine and drainage waters mix with the waters of the river. Yellow with variable monthly consumption. After that, mine, sludge, and river waters are mixed, including with discharges from city sewage treatment facilities, with additional amounts of river water. Yellow and fall into the river. Ingulets [16], [17]. The radionuclide composition of the waters obtained as a result of mixing at this stage determines the quality of the waters entering the "Karachuny" reservoir located 1 km above (the city of Kryvyi Rih).

It should be noted that the slight excess of mineralization, mainly due to sulfate ions, is due to the natural factor of this region. The natural mineralization of underground waters of the aquifer complex of crystalline rocks, which form the water inflow to the mine and the area of the "P" beam, is from 1500 to 5500 mg/l, with a sulfate-sodium composition and varies in sulfate content from 1200 to 2700 mg/l.(annual receipt of radioactive waste – 467,876.13 tons).

The enterprise does not have technologies and factors that would increase the content of sulfates in circulating water. The high content of sulfates in the Zhovti Vody is explained by the fact that the area of the river flows through a region with high mineralization of underground natural water that feeds the river [18]. The "Sh" tailings repository is a source of radioactive contamination of the atmospheric environment of the southern part of the city in the summer (Fig. 3).

The tailings storage facility is located 1.5 km south of the city. Yellow Waters within Shcherbakivska stream. It covers an area of 256 hectares. The bulk storage is part of the closed water circulation system of the HMZ, with no flow into the open hydrographic network. In accordance with the project, the interception of drainage water by an enclosing dam was organized, as well as the interception and diversion into the river. Yellow rainwater from the catchment area of the stream around the tailings storage facility. During the period of operation, 27.7 million were accumulated. tons of radioactive waste containing uranium, thorium, lead, polonium with a total activity of 282.2x1012 Bq (annual intake of radioactive waste – 467876.13 tons).

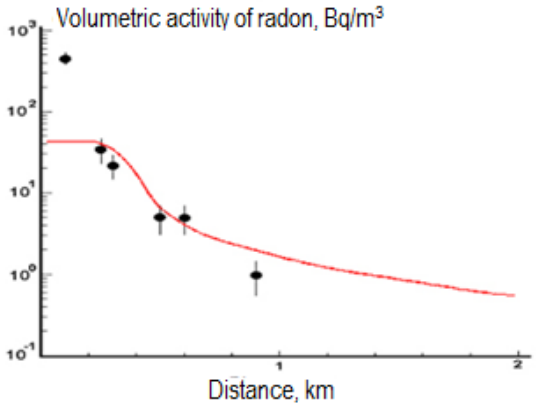

Fig. 3. Dependence of the volumetric activity of radon in the air on the distance to the tailings repository

The radiation situation in the sanitary and protective zone of the "Sh" beam is as follows: the dose rate of gamma radiation was from 0.1 to 4.32 μSv/hour (on average - 0.47784 μSv/hour); the total alpha activity of native soil radionuclides ranged from 21.27 to 1106 Bq/kg; total alpha activity in vegetation was from 2.3 to 170.2 Bq/kg; the specific total alpha activity of natural radionuclides in grain crops ranged from 14.4 to 28.7 Bq/kg [19], [20].

Exfoliation of radon from the surface of the tailings repository is 2–10 Bq/m^2 x s. The content of radionuclides exceeds the temporarily permissible level: natural uranium - by 11%, radium-226 - by 33%, by total alpha activity - by 94.65%. Analyzing the water in this region, we can conclude that the water of the Yellow, which is a tributary of the river Ingulets affects the content of radionuclides in it. A sanitary-protective zone with a design width of 1,000 m is organized, landscaped, and the regime of the zone is observed. The nearest housing is located at a distance of 1500 m from the dam.

Atmospheric precipitation, which passes into surface runoff, is almost completely intercepted by the surface drainage system on the territory of the GMZ. Discharge of intercepted surface water is carried out in the tailings storage facility of the GMZ in the "Sh" beam. At a distance of 2 km to the north of the residential buildings of the city, on the watershed plateau of the river Zhovta and Zelena, where the spent tailings repository of radioactive waste "KBZ" is located. The area of the tailings storage facility is 54.8 hectares, the volume of solid waste is 12.4 million. m^3. The nearest settlements: 2 km in the southern direction - m. Zhovti Vody, in the south-west - the village. Green Grove, 1.7 km in the eastern direction in the valley of the river Yellow - p. Veselo-Ivanivka.

KBZ is used for the tailings storage, which consists of a small bowl with a depth of 10–15 m and a large bowl with a depth of 60–65 m. The quarry was used for waste storage without special anti-filtration measures. Storage of the tailings material, which is waste from the processing of uranium ores, was systematically carried out in the period from 1964 to 1982 by means of hydro pouring. 15.944 million was placed in his cup. tons of tails. The total activity is 93.3x1012 Bk.

The project sanitary protection zone with a width of 500 m is organized, the regime of the zone is observed. A large part of the surface of the tailings storage facility is covered with an insulating layer (70 cm thick alumina layer and fixed with a 20 cm thick quartzite layer) in order to prevent a negative impact on the surrounding natural environment, and the remaining part has a pond used as a reserve tank. Given that in the industrial zone of the city, in its northern part, the GMZ is located, surrounded on all sides by radiation-hazardous objects.

The operation and location of these facilities cause (emissions into the atmosphere, solid waste dumps, discharge of wastewater) a harmful effect of a number of production factors on the surrounding natural environment and the population of the city of Zhovti Vody, Ukraine [21].

The extraction and primary enrichment of uranium ores became a specific feature of the formation of the radiation situation in the city of Zhovti Vody [22] and the first source of radio-ecological pollution of the Dnieper region. This led to the formation of 550,000 m^3 of empty rock dumps and out-of-balance ores and disturbance of 968 hectares of fertile land. The state of radio-ecological pollution of the Dnieper region (contamination of the region with radionuclides ^{137}Cs, ^{90}Sr) was negatively affected by the Chernobyl disaster (1986), as the third source of radio-ecological pollution of the Dnieper region. As a result, natural and artificial radionuclides accumulated in the region.

Historically, a situation arose when the population within the city of Zhovti Vody. was forced to live permanently in the zone of radiation pollution, which exceeds the norms established by the NRBU-97 [8].

According to the results of air research on radiation indicators, it was established that, relative to background values and established standards, the concentration of radionuclides significantly decreases with increasing distance from the tailings dam and the fence of the HMZ. At the border of the SZZ and in the monitoring zones, the concentration of radionuclides is mainly at the lower limit of measurement.

The formation of the radiation situation in the city was influenced by the contamination of roads, sidewalks, residential buildings, schools and kindergartens, other buildings and premises with mining rocks that contained radioactive materials, which negatively affects the environment and the inhabitants of the city. As a result, Zhovti Vody formed on the territory of the city separate local (up to 450 sites) with a radiation background of 40–500 μr/h (the natural background is 15–22 mkr/h). According to the data of the departmental laboratory, the radioactive contamination of the soil around the city. Zhovti Vody (at a distance of 10 to 40 km) does not exceed background values in terms of total alpha activity and amounts to: m. Pyatikhatki - 1776 Bk/kg, Komisarivka village - 1443 Bk/kg, village Erastivka, weather station - 2220 Bk/kg, village. Yellow – 2553 Bq/kg.

Soil contamination with natural radionuclides exceeding the background values is recorded within the SZZ in the areas directly adjacent to the dam storage facilities or the HMZ fence along the pulp pipeline. At the border of the SZZ, the maximum activity of natural radionuclides in the soil is 146.5 Bq/kg, and the maximum result of atmospheric precipitation is 1.243 Bq (m^2 x day), which does not exceed the control level of 7.4 Bq (m^2 x day). According to the results of groundwater research in the monitoring network of wells, the increase in the concentration of natural radionuclides does not go beyond the limits of the SZZ and is registered on the border of the tailings dams and on the territory of the SZZ. Vegetation pollution is: potassium–40 – 308–412 Bq/kg; thorium-232 – 3.0 – 3.7 Bq/kg; uranium-238 – 1.5 – 3.4 Bq/kg; exposure dose rate (EDR) – 13.0 μR/hour [22].

In the conditions of Zhovti Vody employees of the main production and the population of the city receive an additional dose of radiation exposure, and are also subject to the combined effect of waste - uranium ore dust, radon and its decay products (Fig. 4) [8].

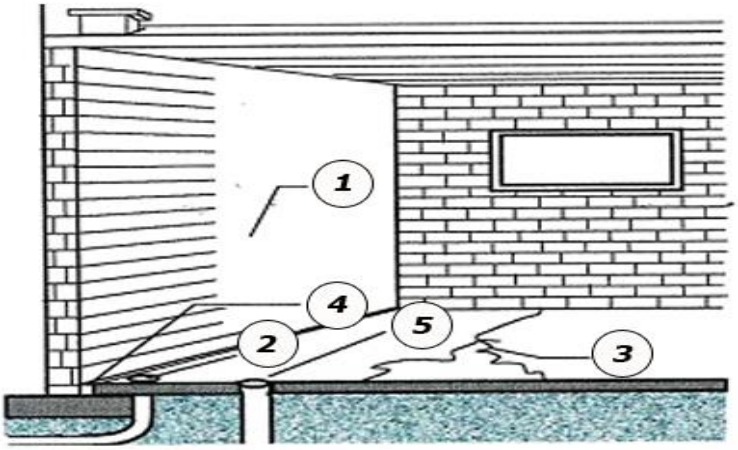

Fig. 4. Scheme of ways of radon penetration into the premises: 1–block walls; 2-sewer pipe; 3-cracks in the floor; 4 – the place where the walls meet the floor; 5 - sewage well

In particular, contamination of soil, water and atmospheric air with such radionuclides as uranium-238, radium-236, lead-210 and polonium-210 was detected. In the surface layer of the soil, the concentration of uranium-238 exceeds the background concentration by 2-7 times, radium-226 by 2-9, lead-210 by 2-25, and polonium-210 by 2-17 times. About 50 million have been accumulated in the city. tons of waste, including 1.4 million tons of toxic I-IV hazard classes. Exceeding the two-fold norm of radon concentration in residential premises is 9 percent, and in the private sector - more than 21 percent, which is several times higher than the norms of NRBU-97.

Only according to the sample data of the Ukrainian Scientific Center of Radiation Medicine (Kyiv) in 42% of the surveyed buildings in the city. Zhovti Vody's equivalent equilibrium volumetric radon activity exceeded the regulation (100 Bq/m^3) for buildings in use. A significant problem not only of the city, but also of the entire region is the utilization and disposal of sources of ionizing radiation at OJSC "Electron-Gas", where 17,996 units of sources of ionizing and neutron radiation with a total activity of 14,675 Ki are stored, most of which were placed back in the 1990s century [23].

Even in small doses, the influence of ionizing radiation causes mutagenic, immunosuppressive and cytotoxic effects, premature aging, dysfunction of all organs, including the testicles. Sources of ionizing radiation, which have a harmful effect on germ cells, suppress the activity of steroid hormones and the synthesis of receptor proteins, causing a general inhibition of gonadotropic activity and disruption of spermatogenesis. There is an increase in immunodeficiency states, autoimmune diseases, oncology, unfavorable course of pregnancy and childbirth, and an increase in urological pathologies.

In the structure of the distribution of diseases, the first place is occupied by diseases of the respiratory system and blood circulation, the second is the digestive system, and the third is diseases of the genitourinary organs. Morbidity of the population has a steady upward trend. In particular, the incidence rate of myocardial infarction and chronic bronchitis in the city exceeds the regional average by 2 times. The population of the city is decreasing at a rate 2.1 times higher than the average for Ukraine (almost by one thousand people annually).

The rate of oncological diseases increased almost 2 times in men (mainly due to lung, stomach and intestinal cancer) and 1.3 times in women (mainly due to breast cancer). and cancer morbidity and mortality in Zhovti Vody is the highest in the Dnipropetrovsk region and exceeds the average indicators for Ukraine. The incidence of tuberculosis is almost 2 times higher than the regional average. A high level of congenital anomalies in children is also noted.

Research conducted by the Association of Surgeons, the American Agency for Radiation Protection, the Ukrainian Scientific Center for Radiation Protection and Radiation, and the Ukrainian Scientific Center for Radiation Medicine (UNCRM) clearly established a link between the risk of cancer and radon inhalation. Radon forms daughter radioactive products that can accumulate in the lungs when inhaled. In the further radioactive decay of these products, surrounding tissues are damaged, which, in turn, leads to the formation of cancer cells. According to the ERA, from 5 to 20 thousand of annual lung cancer deaths are the result of human inhalation of radon. According to the authors, the main danger of radon lies in the fact that a person is constantly in the radiation zone (at school, at home, at the workplace, on vacation).

Therefore, carrying out a complex of works on the rehabilitation of contaminated territories, reclamation (deactivation) of homesteads and implementation of anti-radon measures in residential premises is the first step to improving the health of the population in the zone of increased radioactivity. The Environmental Protection Agency (USA) confirms that approximately 14,000 lung cancer deaths in the United States per year are the result of radon exposure

The main total dose load on a person from sources of ionizing radiation on the territory of Ukraine is considered to be radon and its decay products in the air of residential premises and reaches 75% (Fig. 5).

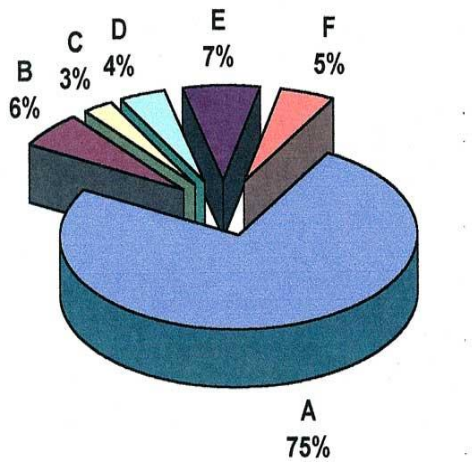

Fig. 5. Total dose load: A – radon in the air; B – radioactivity of building materials; C – natural gamma background; D – Uranium-238, Radium-226, Radon-222 in water; E – cosmic radiation; F – external beta pollution

To reduce the concentration of radon in the air, rooms are developed for each residential building, based on its volume-planning and structural solutions and radon concentration, and are carried out after removing abnormal inclusions from their structural elements. These works are divided into three types: ventilation, insulation, combined (Fig. 6).

Ventilation measures include ventilation of premises, sex space and basement if they are available. The type of ventilation, the frequency of air exchange and air ducts is determined by calculation. Insulation measures include the formation of a layer between the base soil and the floor structure, without reducing the construction volume of the residential building.

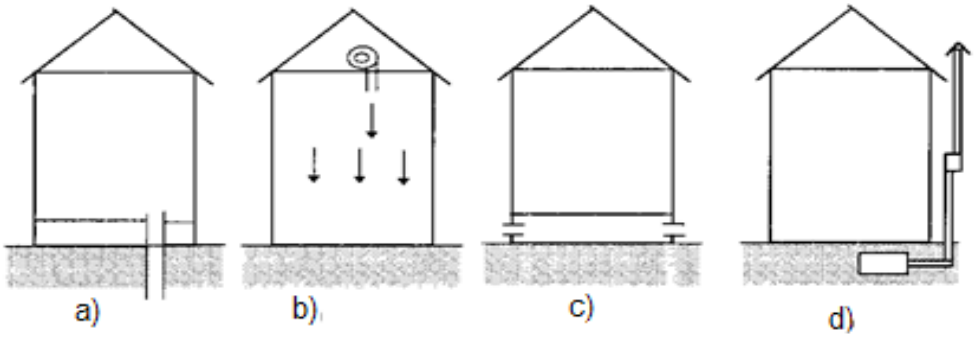

Fig. 6. Schemes for reducing radon in the air of residential premises:
a - sealing of underground floors (insulation); b – creation of increased pressure inside the room;
c – underground ventilation; d - underground pressure reduction

These works are performed with the mandatory evacuation of the residents of the premises or the building as a whole. The insulating layer in the floors of residential buildings is carried out with the removal of the existing floor, the deepening of the floor space, the formation of a sealing layer with its installation in the body of the foundation, the restoration of the floor structures and the arrangement of the premises.

The combined tool involves the combination of ventilation measures with the equipment of the insulating layer. Anti-radon measures were carried out in separate premises of the Zhovtovodsk Industrial Technical School, the Scientific and Technical Center for Decontamination and Integrated Management of Radioactive Waste and Sources of Ionizing Radiation (NTC "KORO"), reconstructed building at 18 Parkova Street for housing and separate children's preschool institutions of the city.

Taking into account the mentioned circumstances, the Government of Ukraine adopted a special resolution, according to which the State program of measures for radiation and social protection of the population of the city was approved. Yellow waters of the Dnipropetrovsk region (Resolution of the Cabinet of Ministers of Ukraine dated June 8, 1995 No. 400) [24].

The main tasks of the Program were:

- creating and ensuring the functioning of a system of constant monitoring and control of the state of the natural environment, including the radiation and medical and biological state;
- carrying out works related to the improvement of the natural environment on the territory of the city;
- ensuring radiation safety and preventing man-made emergencies;
- bringing the radiation background in residential and public premises, buildings, structures to the level determined by the norms of NRBU-97, providing the population whose housing cannot be brought up to the norms of NRBU-97, new housing;
- provision of additional nutrition and rehabilitation of children and provision of material assistance to residents living in territories with an unsatisfactory environmental condition and increased radiation background;
- provision of additional medical assistance to children, pregnant women and women giving birth, citizens with benefits defined by legislation;
- development of a network of medical and preventive facilities and ensuring their functioning.

Further measures regarding radiation and social protection of the population of Zhovti Vody is regulated by:

– Resolution of the Cabinet of Ministers of Ukraine dated May 5, 2003 #656. About the approval of the Program of radiation and social protection of the population of Zhovti Vody for 2003-2012.

– Resolution of the Cabinet of Ministers of Ukraine dated June 25, 2012 #579. About the approval of the Program of radiation and social protection of the population of Zhovti Vody for 2013-2022.

5. Engineering and technical measures to reduce gamma radiation pollution and reduce radon concentration

*Radiation pollution by gamma radiation***.** According to the current "Sanitary rules for the liquidation, conservation and repurposing of enterprises for the extraction and processing of radioactive ores" (SPLKP-91), the dose rate of external gamma radiation at a height of 1 m above the surface of the reclamation (deactivation) site should not exceed 20 μR/h above the level background. Implementation of measures for radiation and social protection of the population in the first years is given implementation of the specified Program in the table 1.

Table 1. Implementation of measures for radiation and social protection of the population in the first years

Event names	Financing by year, thousand UAH							
	1	2	3	4	5	6	7	Total
Measures for radiation protection of the population								
1. Implementation of the technical and economic substantiation of measures for radiation protection of the population of Zhovti Vody (the measure is financed and implemented in full)	0.0	159.4	0.0	6.6	0.0	0.0	0.0	166.0
2. The project and working documentation of the complex of works on the rehabilitation of the polluted territory of the city, its reclamation and the implementation of anti-radon measures in the premises of buildings and structures	0.0	0.0	10.0	5.1	18.3	30.0	19.0	82.4
3. Carrying out research work on the development and implementation of anti-radon measures in the premises of buildings and structures	0.0	0.0	3.4	6.0	15.2	8.9	7.0	40.5
4. Creation and operation of a territorial diagnostic and rehabilitation center for the rehabilitation of city residents, including on the basis of a medical institution	31.4 0.0	145.8 0.0	328.0 0.0	246.5 0.0	237.3 0.0	349.0 100.0	200.9 55.0	1538.9 155.0
5. Purchase of medical equipment and medicines to provide the special medical and sanitary part of the city	54.5	1024.9	247.4	99.1	25.8	142.1	126.8	1720.6
6. Implementation of anti-radiation measures on the territory of the city	100.0	345.7	51.7	75.2	4.7	50.9	0.5	628.7
7.Construction of housing for immigrants from radiation-contaminated areas of the city	0.0	481.0	217.5	355.9	0.0	0.0	0.0	1054.4
8. Landscaping of the city territory	60.0	29.2	23.0	0.0	0.0	23.5	0.0	135.7
9. Clearing the channel of the Zhovta River within the city limits	0.0	0.0	0.0	4.8	5.7	0.0	0.0	40.5
10. Carrying out work on the assessment of the impact of environmental pollution on the health of residents, taking into account the long-term consequences	0.0	0.0	0.0	23.0	23.0	0.0	0.0	46.0
11. Creation and implementation of a system of environmental, including radiation monitoring (the measure is not implemented)	0.0	0.0	2.0	0.0	0.0	0.0	0.0	2.0
Total: regarding radiation protection of the population, hryvnias;	245.9 6.2	2186.0 38.4	913.0 16.0	822.2 14.4	330.0 5.8	604.4 10.6	354.2 6.2	5455.7 14.3
Measures for social protection of the population								
1. Monthly additional payments in the amount of 30% of the minimum wage to all residents of the city, including children; monthly supplement in the amount of 25% of the minimum pension by age to pensioners who have more than 10 years of work experience at uranium mining and processing enterprises	0.0	408.2	180.0	172.1	36.9	140.2	156.3	1143.7
2. Reimbursement of part of the cost of meals for preschool children and students in grades 5-11; reimbursement of part of the cost of health care for preschool children and students in grades 1-11	353.3	280.9	823.9	420.5	383.5	645.9	647.8	3565.8
3. Reimbursement of a part of the cost of purchased medicines according to doctors' prescriptions for preschool children, students of grades 1-11, pregnant women, women giving birth and pensioners	6.0	227.2	460.1	261.5	150.0	249.6	250.0	1604.4
4. Free dentures, with the exception of dentures made of precious metals, for persons with more than 10 years of work experience at uranium mining and processing enterprises	0.0	17.1	48.4	47.5	28.4	57.4	44.6	243.4

5. Provision of sanatorium-resort vouchers and partial payment of medical services that can be provided outside the city to persons who are registered in the medical and sanitary part of the city according to the directions of medical institutions	0.0	0.0	125.6	142.8	51.7	65.4	68.9	454.4
Total:								
regarding social protection of the population	359.3	1333.4	1638.0	1044.4	700.5	1157.7	1167.6	7400.9
execution to plan	11.9	31.0	38.1	24.3	16.3	26.9	27.2	25.7
EVERYTHING: according to the program	605.2	3519.4	2551.0	1866.6	1030.5	1762.1	1521.8	12856.6
Implementation to plan, %	8.6	35.2	25.5	18.7	10.3	17.6	15.2	19.2

Due to insufficient budget funding, the above-mentioned Program was extended by the Government of Ukraine by two relevant resolutions of the CMU dated May 5, 2003 No. 656– for the years 2003–2012 and dated June 25, 2012. No. 579 - for 2013-2022. The complex of works on the rehabilitation of the polluted territory of the city involves the solution of tasks with the general budget financing of Ukraine, more than 200 million. UAH., including carrying out a complex of works on the rehabilitation of the polluted territory of the city to reduce the dose loads on the population and strengthen the social protection of the population living in the territories with an increased radiation background [25].

Prospects for further research. The analysis shows that nuclear industry enterprises influence the radioecological state of the natural environment and population. To prevent the harmful effects of radiation pollution on humans, it is necessary to systematically monitor the content of PRN and heavy metals in environmental objects and food products.

With the help of IAEA projects, bilateral cooperation with Norway, Sweden and the USA in Ukraine, Central Asian countries are developing measures to harmonize and improve requirements and criteria aimed at supporting the planning and implementation of rehabilitation programs. The effectiveness of implementation of rehabilitation measures significantly depends on the availability of appropriate national environmental safety strategies, regulatory requirements and regulatory mechanisms, as well as experience in managing similar projects in accordance with the requirements of international standards.

6. Conclusions

Radiation contamination of the territories and buildings of the city of Zhovti Vody was established, 5368 anomalies with exposure dose power above 50 μR/hour were detected, including 71% of anomalies located on the territory of private sector homeowners, in the foundations of residential buildings - 1174 anomalies; in 70.5% of private sector houses, the equivalent equilibrium concentration (ERC) of radon and its daughter decay products is more than 100 Bq / m^3; among the 2,625 surveyed residential buildings, the average ERK of radon is 633 Bq/m^3 (with a norm of 50 Bq/m^3).

It was noted that the main total dose load on a person from sources of ionizing radiation in the territory of Ukraine is considered to be radon and its decay products in the air of residential premises and reaches 75%. The КСИРА-2010Z kit, РГА-09М radiometer and professional radon monitor AlphaGUARD PQ 2000, additional equipment to it are effectively used as exemplary and working means for measuring radon concentration in all environments. The radon monitor is successfully operated at 45 uranium facilities in Ukraine.

It is shown that exceeding the regulatory level of the equivalent equilibrium volumetric activity of radon of 50 Bq/m^3 in individual premises is due to its release from the underground space and the input channel of the external heat and water supply network, and the internal distribution channels of the heat network.

Measures are proposed to reduce the activity of radon in the indoor air by filling the channel of the heat network from the outside of the building with a layer of clay to a depth of 1 m and sealing it, sealing the introduction of the heat and water network through the foundation of the building and concreting the channels, which reduces the volumetric activity of radon in the room by 5 - 6 times. Complete sealing of fields with polyethylene film or other materials, isolation of individual places of communication and the surface of the ground with a concrete coating together with polyethylene reduces the activity of radon in the air up to two times.

The recommended system of radiation monitoring of uranium objects based on devices and automated systems of the new generation. The radiation monitoring system includes four observation posts on the Zhovta and Zelena rivers, observation wells on the territory of the GMZ, which makes it possible to specify the area of contamination of aquifers.

It is proposed to continue promising research and provide funds (at the expense of enterprises, local and central state authorities) for conducting scientific substantiation and developing preventive measures to minimize negative consequences on human health from the action of heavy metals and radiation factors, taking into account the peculiarities of their combined impact on population and workers of the uranium mining and mining and metallurgical industries.

Acknowledgments

The authors express great gratitude for the valuable and constructive advice and recommendations to the specialists: SE UkrNDPI industrial technology (Y.Y. Koshyk, K.V. Kozlov), KPRV Scientific and Technical Center (L.V. Shirokov), State Geological Enterprise Kirovgeology (Makivchuk O.F., G.P. Korniychuk, B.V. Malivanchuk, M.O. Moseichuk), Kharkiv Institute for the Advancement of Doctors (V.M. Sannikov), Ukrainian Scientific Center of Radiation Medicine (I.P. Los), Ukrainian scientific and hygienic center (Serdyuk A.M., Svatkov V.I.), Ukrainian scientific research institute of ecological problems (Kovalenko G.D., Vitko V.I., Kartashov V.V.) and reviewers of the article.

References

[1] **Aben E., Markenbayev Zh., Khairullaev N., et al.,** 2019
Study of Change in the Leaching Solution Activity after Treatment with a Cavitator. Mining of Mineral Deposits, 13(4), pp. 114-120, https://doi.org/10.33271/ mining13.04.114.

[2] **Antonelli C., Feder C.,** 2020
The New Direction of Technological Change in the Global Economy. Structural Change and Economic Dynamics, No. 52, pp. 1–12.

[3] **Basarir H., Binv H., Fourie A., et al.,** 2018
An Adaptive Neuro Fuzzy Inference System to Model the Uniaxial Compressive Strength of Cemented Hydraulic Backfill. Mining of Mineral Deposits, No. 12(2), pp. 1–12, https://doi.org/10.15407/mining12.02.001

[4] **Multi-authored monograph**, 2001
Mining and Processing of Uranium Ores in Ukraine. 2001. Under the general editorship of A.P. Chernova, K.: Adef – Ukraine, 238 p. (in Ukrainian)

[5] **Chetveryk M., Bubnova O., Babiy K.,** 2017
The Rate of Deformation Development in the Rock Massif on the Basis of Surveying Monitoring on the Earth Surface. Mining of Mineral Deposits, 11(1), pp. 57-64, https://doi.org/10.15407/ mining11.01.057

[6] **Dereviahina N., Malanchuk L.,** 2019
Analysis of Operation Parameters of Partial Backfilling in the Context of Selective Coal Mining. Mining of Mineral Deposits, No. 13(4), pp. 129–138, https:// doi.org/10.33271/mining13.04.129

[7] **Dudar T.V.,** 2023
Uranium Mining and Milling Sites as Sources of Technologically-Enhanced Naturally Occurring Radioactive Materials, ISSN 1562-6016, Problems of Atomic Science and Technology, Issue 3 (145), pp. 127-132, DOI 10.46813/2023-145-127 (in Ukrainian).

[8] *** * *,** 1997
Radiation Safety Standards of Ukraine (NRBU-97). 121 p. (in Ukrainian)

[9] **Ghorbani Y., Franzidis J.P., Petersen J.,** 2016
Heap Leaching Technology–Current State, Innovations, and Future Directions: A Review. Mineral Processing and Extractive Metallurgy Review, 37, (2), pp. 73–119.

[10] **Kovalenko G.D.,** 2013
Radioecology of Ukraine / G. D. Kovalenko. – Kh.: INZHEK, 344 p., (in Ukrainian)

[11] **Kovalchuk I., Tobilko V., Kholodko Yu., et al.,** 2020
Purification of Mineralized Waters from U (VI) Compounds Using Bentonite / Iron Oxide Composites. Technology Audit and Production Reserves, T. 3, No. 3 (53), C. 12-18, (in Ukrainian).

[12] **Zelinsky S.E.,** 2022
Radiation Safety and Environmental Impact of Uranium Production in Ukraine. Kropyvnytskyi, 60 p., (in Ukrainian)

[13] **Lyashenko V., Khomenko O., Chekushina T., et al.,** 2021
Substantiation of Efficiency and Environmental Safety of Leaching Metals from Ore: Ways of Development and Prospects. Technology Audit and Production Reserves, 3 (3 (59)), pp. 19–26, doi: http://doi.org/10.15587/2706-5448.2021.235288.

[14] **Lyashenko V., Andree, B., Dudar T.,** 2022
Substantiation of Mining-Technical and Environmental Safety of Underground Mining of Complex-Structure Ore Deposits. Mining of Mineral Deposits, 16(1), pp. 43-51, https://doi.org/10.33271/mining16.01.043.

[15] **Lysychenko G.V., Kovach V.E.,** 2011
The World Experience of Rehabilitation of Uranium Production. Collection. Articles "Technogenic and Ecological Safety and Civil Protection". – Kremenchuk, Vol. 6, pp. 4–12, (in Ukrainian).

[16] **Onika S.G., Rysbekov K.B., Aben E.K., et al.,** 2020
Leaching Rate Dependence on Productive Solution Temperature, *Vestnik KazNRTU*, 142(6), pp. 700-705, https://doi.org/10.51301/vest.su.2020.v142.i6.122**.**

[17] *** * ***, 2015
Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, Vienna: IAEA, 484 p.

[18] **Reiter K., Heidbach O.,** 2014
3–D Geomechanical–Numerical Model of the Contemporary Crustal Stress State in the Alberta Basin (Canada). Solid Earth, No. 5, pp. 1123– 1149.

[19] **Rysbekov K., Huayang D., Kalybekov E., et al.,** 2019
Application Features of the Surface Laser Scanning Technology when Solving the Main Tasks of Surveying Support for Reclamation. Mining of Mineral Deposits, No. 13 (3), pp. 40-48, https://doi.org/10.33271/ mining13.03.040.

[20] **Sotskov V., Dereviahina N., Malanchuk L.,** 2019
Analysis of Operation Parameters of Partial Backfilling in the Context of Selective Coal Mining. Mining of Mineral Deposits, No. 13(4), pp. 129–138.

[21] **Dudar T., Saienko T., Radomska M., et al.,** 2024
Innovation and Digitalization in Environmental Education: The Case Study of Climate Change Adaptation and Analysis of Land Surface Temperature. Journal of Geology, Geography and Geoecology, 32(4), pp. 724-733, https://geology-dnu.dp.ua/index.php/GG/article/view/1066

[22] **Stupnik M., Kalinichenko V, Fedko M., et al.,** 2022
Methodology Enhancement for Determining Parameters of Room Systems when Mining Uranium Ore in the SE "SkhidGZK" Underground Mines, Ukraine. Mining of Mineral Deposits, No. 16 (2), pp. 33–41, https://doi.org/10.33271/mining16.02.

[23] **Serdyuk A.M. Stus V.P., Lyashenko V.I.,** 2011
Ecology and Livelihoods of the Population in the Industrial Regions of Ukraine, Dnipropetrovsk, Vidavnitstvo "Thresholds", 486 p., (in Ukrainian).

[24] **Lyashenko V.I.,** 2014
Ekologitcheskaj bezopasnost'uranovogo proisvodstva v Ukraine. Gornyj zhurnal, No. 4, pp. 113-116, (in Russian).

[25] **Dvoretsky A.I., Lyashenko V.I., Topolniy F.P., et al.,** 2018
Influence of Uranium Industry on the State of Environment and Population. Metallurgical and Mining Industry, No.8, C. 99-109, (in Ukrainian).