UDC 502.55 (477)

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EXPERIENCE OF REHABILITATION OF FORMER URANIUM PRODUCTIONS AND ITS IMPORTANCE FOR UKRAINE

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Abstract. *In the article is given a short description of world uranium deposits. Shown the main countries where during the Soviet era was intensive extraction, processing and enrichment of uranium ore. Described the economical expenses on remediation measures and environmental situation in the mining areas of former uranium production.*

Keywords: international cooperation; operator; regulatory body; uranium production; uranium storage tails.

1. Introduction

Uranium – a chemical element, designated by the symbol *U*, is a heavy steel-gray color metal, which was first isolated in 1840 by English chemist Eugène Peligot. Opening of the French physicist Becquerel in the late nineteenth century, the phenomenon of radioactivity manifested the spontaneous decay of atomic nuclei of uranium predetermined energy value of this unique item. Further studies have shown that natural uranium -238 with a slight enrichment of uranium -235 can create conditions for continuous nuclear fission that attaches to the chain reaction [15]. This discovery was the source of both civilian and military use of nuclear energy and promotes active geological study of uranium raw material resource base and development of the nuclear industry. Practically, it was shown that several kilograms of uranium can develop the same electrical and thermal energy as a ton of coal and oil or thousands of cubic meters of gas [8].

The average content of uranium in the earth's crust (clarke) $2{,}5\times10^{-4}$ % by weight (2-4 ppm depending on the region), in acidic igneous rocks $3{,}5\times10^{-4}$ %, in clays and shales 3.2×10^{-4} %, in basic rocks 5×10^{-5} %, ultramafic mantle rocks 3×10^{-7} %. The amount of uranium in the layer of the lithosphere thickness of 20 km is estimated at 1.3×10^{14} m [3].

With the development of uranium deposits in the lower boundary of the uranium take 0.06-0.10 %, with concomitant extraction of uranium mine at its profitable content in the ores is 0.01-0.03 % [2].

First Uranium has been detected in the Czech Republic in the form of mineral pitchblende, and later in Africa and north-western Canada. In these countries until 1940 was focused its main extraction. Currently opened more than 200 uranium deposits, which are concentrated in 40 countries [14].

According to the World Nuclear Association (WNA) the main reserves of uranium (96.5 %) are concentrated in 15 countries, among them – in Australia proven reserves (466 tonnes, about 20 % of world reserves), Kazakhstan (18 %.), Canada (12 %), Uzbekistan (7.5 %), Brazil (7 %), Nigeria (7 %), South Africa (6.5 %), United States (5 %), Namibia (3 %), Ukraine (3 %), India (2 %) [16].

In Ukraine, domestic production of its own natural uranium is 500-800 tons per year, which meets the needs of the domestic nuclear industry only for 30 %. The rest Ukraine buys from Russia, but by 2020 intends to provide 100 % of its own uranium production.

In the Soviet Union (USSR) uranium mining history began in Tajikistan in 1926, when it was discovered Tabosharsk deposit. After this to the uranium mining map joined: Uzbekistan, Kyrgyzstan, Kazakhstan, Ukraine (Eastern possessing plant mined uranium at the deposit of town Zhovti Vody (v. Terny, Dnipropetrovsk region, development and processing of uranium- iron ores), Russia and Bulgaria. A significant amount of these deposits to date are abandoned fields, but they are still remaining as dangerous environmental problems associated with uranium mining. This is due to the fact that the territory on which were located the main uranium production objects (mines, industrial sites of mining and chemical plants and hydrometallurgical plants, tailings, etc.) due to imperfect process and the lack of environmental safety standards, have undergone anthropogenic pollution. Therefore remain relevant problem of reduction of such areas into the environmentally safe condition [13].

In the former USSR, where uranium was mined, there is no experience in project planning and implementation of environmental remediation of territories of the former uranium production, as well as lack of financial resources for the implementation of long-term remediation programs.

At the same time on the uranium mining and processing industries of the EU in recent years, developed a program of international technical cooperation: IAEA (projects and RER/0986 RER/3010), UNDP, and other EurAsEC aimed at helping in the implementation of rehabilitation projects. Simultaneously carried out or planned activities in the programs of the World Bank (Maili -Suu, Kyrgyzstan), ISTC (Kaji-Say, Kyrgyzstan), the OSCE (Taboshar, Tajikistan), TACIS (Lermontov, Russia). Analysis shows that the effectiveness of their performance largely depends on the availability of appropriate national strategies of environmental safety, regulatory compliance and regulatory mechanisms, as well as experience in managing similar projects in accordance with international standards [10].

2. Characteristics of storage tails in Ukraine

Mining and processing of uranium ore in Ukraine started in the late 1940s. These works were carried out in secrecy without complying the requirements of environmental safety. While the processing of uranium ore carried State Enterprise "Eastern Mining and Processing Plant" (SE "VostGOK") and Production Association "Pridneprovsky Chemical Plant" (PA "PChP"). Currently complete cycle of mining and processing of uranium ore carries only one company – SE "VostGOK." The composition of the SE "VostGOK" includes two operating mines – Smolinsk and Ingul and which, by their energy equivalent to 60 coal mines (almost one-third of Donbass). Processing of uranium ores and obtaining of uranium concentrate (U_3O_8) is carried out on Hydrometallurgical Plant (HMP) in Zhovti Vody. During the processing of uranium ores in HMP generate waste (tails) with high content of radionuclides of natural origin, which by means of pipeline placed in a specially equipped tailing "Balka" Shcherbakovskaya ", which is 5 km away from town Zhovti Vody. By the end of 2013 in the pond "Balka Shcherbakovskaya" accumulated about 40 million tons of uranium waste. The tailing that was mentioned above represents a significant environmental hazard to the population of the city and leads to the contamination of aquifers used for water supply.

One of the first Soviet enterprises of uranium ore processing was PA "PChP" commissioned in 1947 in Dniprodzerzhinsk, Dnipropetrovsk region. In 1991, the PA "PChP" stopped all activities on uranium production, after what were left the tailings of uranium waste on the territory of the plant ("Zhakhidne", "Centralnyj Yar" and "Pivdenno – Skhidne") and outside its territory ("Dnipro", "Sukhachivske" sections 1 and 2, the repository "Base C").

The plant itself is split into a number of specialized companies of different profiles. Totally there are 5 different enterprises now but none of them was not engaged in the treatment with uranium wastes. Upon liquidation of a number of dangerous plant facilities, contaminated with radiation, and the tailings were not presented in an environmentally safe condition in accordance with applicable regulatory and legal requirements for redirecting former uranium production [8]. This led to the creation of centers of radioactive contamination within Dniprodzerzhinsk industrial urban agglomeration, as is evidenced by the data presented in Tables 1-2.

Table 1. Characteristics of the main uranium storage tails of the former uranium production facility PA "PChP" [6]

Name of the object	Period of exploatation	Territory, in ha	Mass of wastes, Mt	Volume of wastes, 10^6 m^3	Total activity, TBq
"Zhakhidne"	1949-1954	6,0	0,77	0,35	180
"Centralnyj Yar"	1951-1954	2,4	0,22	0,10	104
"Pivdenno – Skhidne"	1956 1980	3,6	0,33	0,15	67
"Dniprovske" (D)	1954-1968	73,0	12,0	5,9	1400
"Lantanova fraction"	1965-1988	0,06	0,0066	0,0033	130
Blast furnace№ 6	1978-1982	0,2	0,04	0,02	330
Base "C" (former storage for urainium ore)	1960-1991	25,0	0,3	0,15	440
"Sukhachivske" section - 1	1968-1983	90,0	19,0	8,6	710
section - 2	1983-1992	70,0	9,6	4,4	270

Table 2. Characteristics of emission sources of the former uranium production facilities of PA “PChP” [4]

Name of the object	The area of spreading, thou. m^2	The average specific activity of radionuclide in dust, Bq/kg						Flux density of ^{226}Rn From surface, Bq/(m^2·s)
		^{226}Rn	**^{238}U**	**^{226}Ra**	**^{230}Th**	**^{210}Po**	**^{210}Pb**	
“Zhakhidne”	-	40,2	–	–	–	–	–	0,003–3,075
“Centralnyj Yar”	-	24,0	–	–	–	–	–	0,24–2,57
“Pivdenno - Skhidne”	36	58	2594	733	3560	1190	866	0,673
“Dniprovske” (D)	730	730	–	–	–	–	–	0,001–2,58
“Lantanova fraction”	0,06							
Blast furnace№ 6	-	6,0	–	–	–	–	–	0,017–0,05
Base “C” (former storage for urainium ore)	128,5	330	358–57022	201–3590	760–221652	493–129952	44977–493256	1,25–21,2
“Sukhachivske” section - 1	346	906,8	2500	6200	5980	11120	11140	0,03–1,475
section - 2	185	698,8	–	–	–	–	–	0,005–0,046

In tailings accumulated to 42 million tons of uranium ore processing waste with total activity of 3.2×1015 Bq (average specific activity – 76 kBq / kg). In the storage of uranium waste "DP-6" and "Base C" accumulated to 0.2 million tons of uranium waste with total activity of 4.4 x 1014 Bq (average specific activity – 2.3 MBq/kg). The total area of tailings – 2.77 million m^2. Exposure dose is in the range of from 10 to 35,000 mR/hr.

Data that are shown in Table 2. should be considered as preliminary estimates that require further refinement to identify ways of rehabilitation of contaminated areas.

Irresponsibility of state supervisory bodies and the economic crisis in the first decade of independence of Ukraine led to the fact, that most contaminated sites (former uranium production buildings, slurry pipelines, storage and other facilities), as well as tailings waste from hydrometallurgical processing of uranium, which were formed from 1948 to 1980, in fact for many years were left without appropriate supervision and control. Only in 2000 from the contingency fund of the Cabinet of Ministers of Ukraine were donated money for initial emergency measures to repair and strengthen structures enclosing protection engineering at tailings "Zhakhidne" and "Dniprovske", thereby significantly was reduced the risk of landslides and erosion of levees [6].

However, it should be stated that the condition of the protective coating of the majority of tailings and civil engineering infrastructure of the former uranium production plant "PChP" largely remains poor and getting worse every year due to natural factors and because of the lack of preventive measures.

For the implementation of remediation and restoration work in the contaminated areas and radioactive waste management of the former uranium production plant PA "PChP" according to the order of the Ministry of Energy of Ukraine № 562 from 13.12.2000 was created State Enterprise "Barrier" (SE "Barrier"). To this enterprise were given to the balance all potentially dangerous objects of the former PA "PChP".

In order to eliminate the existing range of radio ecological problems associated with man-made pollution in the former PA "PChP", has been developed and approved by the Resolution of the Cabinet of Ministers of Ukraine dated from 26.11.2003 № 1846 State program on bringing dangerous objects of "Pridneprovskyj Chemical Plant" to environmentally safe state, providing protect to the public from harmful effects of ionizing radiation [5]. However, lack of funding made it impossible to fulfill the program. Even already developed projects are not realized, they do not comply with the requirements of applicable law, which implies that the growth of environmental risks to public health of the city and surrounding areas. However, Ukraine's efforts were insufficient and there is a need to turn to the international community [16].

3. Practice that is used by EU member states

In international practice, under the rehabilitation of the environment in areas where former uranium production facilities were, it is considered not only cleaning of the former industrial areas, but the creation of primers depleted ore dumps or tailings, contaminated buildings demolition, decontamination equipment, or simply fencing of such areas. Rehabilitation (recovery), as well as remediation (risk reduction and dose) – a long process of social acquitted return polluted areas and socially beneficial use of acceptable aesthetic condition.

In the EU, all rehabilitation projects suggested at least partial restoration of landscapes of the former uranium production to socially acceptable level of comfort of living of the population in the surrounding areas. For example, if remediation of enterprise "Bismuth" in Germany there was a problem not only lead to a safe state storage sites of uranium waste, closure of old mines and cleaning areas, but almost complete recovery of all technologically disturbed landscapes. Today this program, launched in 1990, is almost completed. It was invested, according to various estimates, € 3-5 billion, with a significant proportion of funds spent on social benefits and aesthetic restoration of environmental indicators, fit harmoniously into the landscape of the surrounding areas.

There are a lot of mentioned above examples. Almost in all cases planning of the recovery strategies began with a political solution and dialogue with the public. Always define clear criteria for the final result and the ultimate goals of rehabilitation, which legislate by local and state authorities. Then make decisions that ensure sustainable financing programs installed regulators and operators responsible for their implementation. Then begins the process of finding ways to achieve the goal.

In the preparatory phase was carried out detailed safety assessment, developed the criteria and requirements for implementing procedures and operations. Optimal variants of engineering solutions were chosen on the basis of priorities based on analysis of monitoring data and safety assessments, including elements of the feasibility studies (FS) for each chosen option of the strategy and the environmental impact assessment (EIA). Projects subjected to public debate, multistage agreement and approval – and only then begins the engineering measures implementing. Parallel functioning of environmental monitoring services, technical and regulatory oversight, developed procedures and mechanisms of institutional control and public awareness.

All this helped to avoid strategic and technical errors in the design and construction of protective structures. This plan required a lot of time and expenses, but will save millions of dollars in the construction phase and in the implementation of institutional controls for a long warranty period functionality of protective measures for hundreds and even thousands of years, based on the specific activity of the prolonged existence of ^{226}Ra, ^{238}U, ^{232}Th and other radio nuclides forming the basis of "remnants" of uranium production.

Other, less ambitious projects of rehabilitation of former uranium production in the EU were also relatively of a high cost. Given the social events in the return of land they use effective amount estimated at several tens to hundreds of millions of dollars. Another striking example of the elimination of negative effects of uranium companies is in the Czech Republic, which was the second country of the Soviet bloc, where the USSR after 1945 fully translated into its charge all sources of natural uranium. Total costs during the 60 years of the Czech nuclear industry exceeded 60 billion of kroner (approximately $3.077 billion). It is important to emphasize that the significant differences in the cost of programs determined only planned end state and the level of social acceptability of the expected result of rehabilitation. Therefore, to the preparatory phase and to the planning work should be given much more attention [8].

4. The role of participants of the rehabilitation process

Based on the analysis of international experience Figure 1 shows the typical sequence of actions of the operator and the regulatory body for the planning and implementation of rehabilitation programs for former uranium industries.

The targets set in a rehabilitation program, only under the condition that initially had been clearly established dose and environmental criteria of the final state territories and objects after the events. However, in most of the CIS countries, where started or planned rehabilitation projects, this problem is not solved yet.

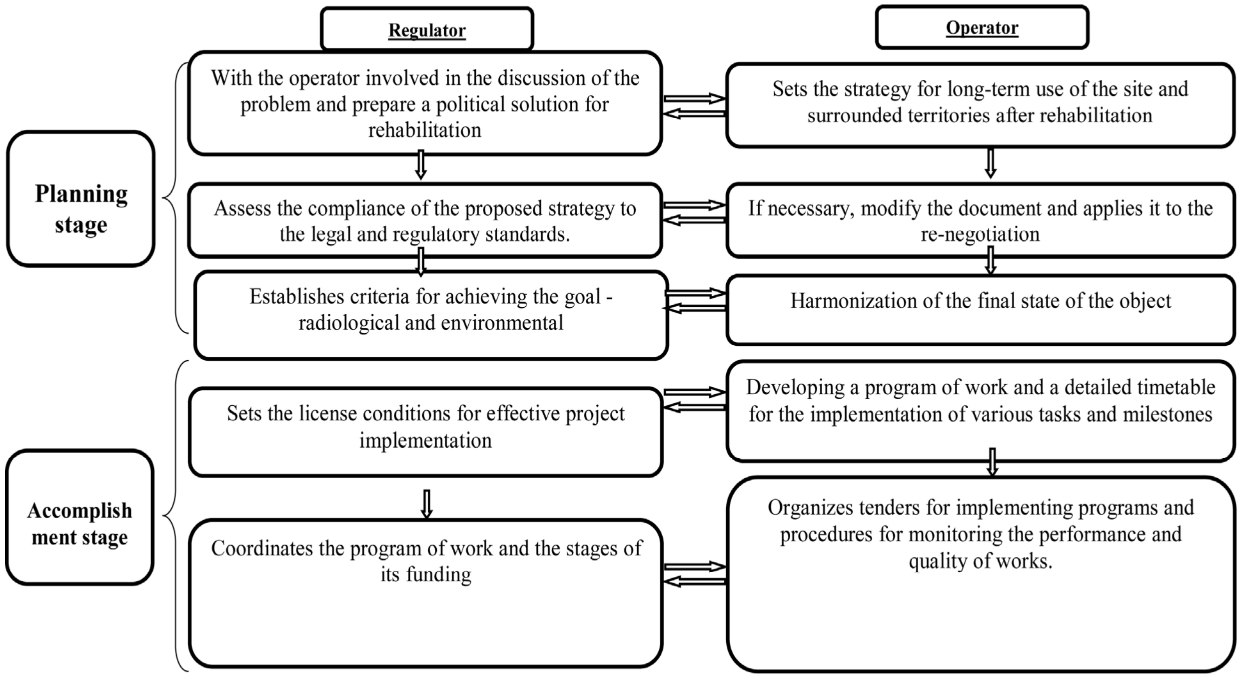

Fig. 1. Algorithm of sequential actions in planning and implementing programs for the rehabilitation of former uranium industries

In Ukraine, Russia and Central Asian countries are still the basic document for planning and implementing remediation of former uranium industries remain "Sanitary rules on liquidation, conservation and conversion of former uranium production" (СП-ЛКП-91) or their modifications, which contain many recommendations, criteria and requirements that do not meet modern international standards. In addition, after the release in 2007 of regular recommendations of the International Commission on Radiological Protection (ICRP-103), as well as some of the IAEA to implement rehabilitation measures, it became obvious that the criteria can not be universal.

Target final state of the object after rehabilitation should be installed in accordance with economic opportunities and social expectations of society. And what will be the criteria below dose constraints, the more they will cost you at operation to achieve them.

Currently, the projects of the IAEA, bilateral cooperation with Norway, Sweden and the United States in Ukraine, the Russian Federation, Central Asia is taking measures to improve harmonization and regulatory requirements and criteria to support the preparatory phase of the planning and implementation of rehabilitation programs. However, this process is still very slow.

While there are uncertainties in the definition of safety criteria that must be met (radiological and environmental). Accordingly, the final state of the rehabilitation program will depend on the further use of the industrial site of the former PA "PChP" and adjacent areas of the city Dniprodzerzhinsk [14].

Dose limits for different categories of personnel of enterprises, which should be provided at this site, the regulator should be installed depending on the intended use of the strategy of the industrial site. In addition, the safety criteria for adjacent areas should be established taking into account the possible options for their future socially meaningful use. Categorization of waste should be adapted to the materials of former uranium industries with the recommendations of the IAEA (IAEA RS-G-1.7).

It is also necessary to establish control of pollution levels at the boundaries of the sanitary protection zone or rehabilitated objects (such as surface coatings of tailings). Developed reference levels for exposure dose of γ-radiation, the volume concentration of ^{222}Rn in the former industrial buildings, radon exhalation from the surface of the tailings, the content of ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Po, ^{210}Pb in soil and aerosols, surface and ground water, food.

Should be further improved: the procedure for licensing of activities related to the rehabilitation activities, requirements for the content and structure of technical passports of former uranium facilities, processes and procedures planning, assessment procedures for security requirements for the structure and content of the FS, EIA, as well as the structure of the design studies, the order of events for technical supervision at facilities requirements and recommendations for conducting environmental monitoring programs and inspections, data management and reporting. Such deficiencies are common for other CIS countries, it is reasonable to harmonize and accelerate their development.

5. Conclusion

Currently in Ukraine developed a framework document "Requirements and safety conditions at the decommissioning of the uranium facilities as a result of liquidation, conservation or redevelopment", the structure and content of which meets international standards. It is therefore advisable to harmonize the basic principles and to help developing similar documents for other countries that are faced with the need to solve such problems. Since the problematic issues that exist in these industrial sites which are complex and relate to many aspects, namely, environmental, technological, medical, social. Therefore, it is difficult to decide on a local or regional level, the government should take full responsibility for the security of such objects.

It is also highly relevant an international cooperation. It should evolve at both experts and managers and regulators to address a wide range of issues and exchange of experience on project planning using the best examples of world practice. To do this, to use the tools wisely regional technical cooperation programs of the IAEA, as well as information network program ENVIRONET. The forces should be focused on training of specialists in the management and planning of rehabilitation projects, as well as modern security techniques and technology programs of long-term rehabilitation of former uranium production.

References

[1] *Cameron I. R.* University of New Brunswick Nuclear fission reactors. — Canada, New Brunswick: Plenum Press, 1982.

[2] *Kulish E.* Geochemistry, mineralogy, genesis and classification of uranium deposits / Edit by E. Sobotovych. Kiev, 2006. – 213 p. (In Russian).

[3] *Kulish E.* World's uranium ores. Geology, resources, economy / Edit by E. Sobotovych. Kiev, 2004. – 277 p. (In Russian).

[4] *Kovalenko G.* Radioecology of Ukraine. – Kharkov: Publishing house "Inzhek", 2008 (In Russian).

[5] *Law of Ukraine* on processing and production of uranium ore Available from: http://zakon2.rada.gov.ua/laws/show/645/97-%D0%B2%D1%80 [Accessed 25th January 2014] (In Ukrainian).

[6] *Lysychenko G.* Uranium ores of Ukraine. Geology, Use, Industrial Wastes Management / Edit by G. Lysychenko. – Kyiv : Naukova dumka. – 2010. – 221 p. (In Ukrainian).

[7] Siegfried Flügge and Gottfried von Droste Energetische Betrachtungen zu der Entstehung von Barium bei der Neutronenbestrahlung von Uran, Zeitschrift für Physikalische Chemie B Volume 4, 274-280 (1939). Received on 22 January 1939.

[8] Situation with storage tails in Ukraine Dniprodzerzhynsk). http://dndz.ru/2008/05/20/dneprodzerzhinskie-xvostoxranilishha [Accessed 2nd December 2013] (In Russian).

[9] A. Suhodolov. World's uranium reserves: prospects of nuclear energy raw materials supply Proceedings of Irkutsk State Academy of Economics. 2010. № 4 (72). – P. 166–169 (In Russian).

[10] Ukrainian Centre for Economic & Political Studies Named after Olexander Razumkov. Nuclear energy in the world and in Ukraine: state and prospects of development. – № 3. – 2008. – 60 p.

[11] Uranium mining and uranium processing industry of Ukraine Available from: http://ru.uatom.org, [Accessed 3rd March 2013] (In Russian).

[12] Ukratom. Storage tails in Ukraine Укратом. http://ru.uatom.org/posts/28 [Accessed 2nd December 2013] (In Russian).

[13] Ulrich Brosa, Siegfried Grossmann and Andreas Müller Nuclear scission // Physics Reports. – 1990. – T. 197. – № 4. – C. 167-262.

[14] Report on nuclear safety in Ukraine in 2012 Available at: http://www.snrc.gov.ua [Accessed December 1st 2013] (In Ukrainian).

[15] E. Rezerford. Atomic Structure and artificial transmutation of elements. // Selected Scientific / Edit by H. Flerov — M.: Science, 1972 (In Russian).

[16] World Nuclear Association. Uranium production figures. Available at: http://www.world-nuclear.org/info/Facts-and-Figures/Nuclear-generation-by-country/ [Accessed 2nd December 2013].

Received 10 June 2014.

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В статті містяться дані про основні країни, де в період Холодної війни проводився інтенсивний видобуток, переробка і збагачення уранової руди. Охарактеризовано екологічну ситуацію, що склалася в місцях видобутку уранової сировини та визначені економічні витрати, що були залучені на ліквідацію наслідків її видобутку.

Ключові слова: міжнародне співробітництво; оператор; регулятор; родовища; уранове виробництво; уранові хвостосховища.

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В статье содержатся данные об основных странах, где в период Холодной войны проводилась интенсивная добыча, переработка и обогащение урановой руды. Охарактеризована экологическая ситуация в местах добычи уранового сырья и определены экономические расходы, которые были привлечены на ликвидацию последствий его добычи.

Ключевые слова: международное сотрудничество; месторождения; оператор; регулятор; урановое производство; урановые хвостохранилища.

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