BIOTECHNOLOGICAL METHOD FOR ARTIFICIAL PRODUCING OF ACTINIDES, OTHER VALUABLE RADIOACTIVE ELEMENTS, THEIR ISOTOPES, AND STABLE ISOTOPES OF NOBLE METALS - PLATINUM AND GOLD

V.M. Kurashov, T.V. Sakhno, R.G. Maksimov

Research and Production Centre "Ecological Consortium"
Russia

Sulphide ores containing uranium-238 and thorium-230 are treated with water suspension of iron- and sulphur-oxidizing bacteria of Thiobacillus genus. Valuable radioactive elements and their isotopes such as polonium, francium, radium, actinium, protactinium, artificial isotopes of thorium and uranium, neptunium, americium, hafnium, ytterbium, as well as radioactive and stable isotopes of mercury and noble metals platinum and gold are artificially obtained. Transmutation of chemical elements and transformation of isotopes of chemical elements with the use of microorganisms are discovered and achieved.

Key words: innovation, technology, science, transmutation, radioactive elements, microorganisms.

1.1. Introduction.

Authors discovered methods and technology of producing the most valuable chemical elements that comprise huge amounts of energy [1]. This method allows obtaining artificial ^{234}Th, ^{234}Pa, ^{233}Pa, ^{232}Pa, ^{231}Pa, ^{234}U, ^{233}U, ^{232}U, ^{228}Ra, ^{227}Ac, ^{230}Th, ^{226}Ra, ^{210}Po, ^{209}Po, ^{208}Po, ^{71}Ga, ^{177}Hf , mercury, gold, platinum and their isotopes [1]. The global oil production of 32.5 billion barrels yearly produces energy equivalent to that produced by 150 kg of our actinides. It means that 150 kg of our actinides used as a mixture with uranium-235 or independently would replace all oil yearly produced in the world, while 250 kg of them would replace all oil, gas and coal yearly produced in the world. 1 gram of certain actinides, such as Ac-227, Pa-231, Am-242, Bk, Cf, produces directly or adds to the industries indirectly as much energy as can be produced by 30,000 tonnes (210,000 barrels) of oil. The critical masses of isotope of americium Am-242m or some isotopes of californium in certain conditions makes just several dozens of grams – this also determines the value and significance of these elements. Some of artificial isotopes we obtain can also be used as energy sources for extremely high power lasers. The invention allows obtaining valuable radioactive elements and their isotopes, as well as inactivating nuclear wastes with conversion of dangerous for people radioactive isotopes into stable ones [1] . Those elaborations are unrivalled; the method of obtaining radioactive elements and their isotopes, platinum and gold are based on transmutation of chemical elements and transformation of isotopes of elements with the use of bacteria of Thiobacillus genus.

In contrast to the method claimed, traditional nuclear reactor methods of obtaining and isolation of polonium, radium, actinium, protactinium, neptunium, americium, their isotopes and valuable isotopes of thorium and uranium are technologically complex, high-cost, demands complex high-cost equipment, are dangerous for humans and environmental [2,3,4]. Also, known traditional nuclear methods of obtaining and isolation of polonium, radium, actinium, protactinium, neptunium, americium, their isotopes and valuable isotopes of thorium and uranium do not cover the needs of energy industry, as well as other science and technology branches in given chemical elements and their isotopes [5,6,7].

Described by authors microbiological method of transmutation of chemical elements and transformation of chemical isotopes allows obtaining of all mentioned above chemical elements and their isotopes in practically unlimited amounts by simple and safe for the staff and inhabitants ecologically pure method. This method uses minimum water, electricity, heat, solving herewith the energy, industrial, technical, and scientific problems of civilization.

Described methods of transmutation of elements allows inactivating and neutralizing nuclear wastes, e.g., nuclear fuel (uranium) burn-up wastes from Nuclear Power Plants, which contain uranium, plutonium, their isotopes and fission and decay products (products of isotopic transitions): isotopes of uranium, and plutonium, radium and polonium, radioactive isotopes of strontium, iodine, strontium, xenon, and other products of alpha- and beta-decay, along with spontaneous fission of uranium and plutonium.

2.1. Materials and Methods

Uranium ores from Jordan, Northwest Africa, and Saudi Arabia, thorium sand from Indian Ocean coast, other ores and sands, as well as nuclear waste and other raw materials appropriate for a process were applied for transmutation of elements and obtainment of new elements and isotopes as inputs for microbiological treatment. Raw materials containing radioactive elements were treated with water solution of Thiobacillus bacteria genus, Thiobacillus aquaesullis or Thiobacillus ferrooxidans species, or their mixture in any proportion. Bacteria of Thiobacillus genus (iron- and sulphur-oxidizing bacteria as well as thermophilic and others) contributed to redox processes of metals were used. Solution pH was controlled by sulphuric acid with a normality of 10N, during the process pH was maintained at 0,8-2,5. Temperature of the process was 28-32 degrees centigrade. Redox potential (Eh) of the solutions was 400-800mV. Stirring rate was 300 rpm. Solid to liquid phase ratio was 1:10 (100 g of water per one litre of a solution). pH and Eh of a solution, chemical elements and isotopes concentration, as well as microorganisms' vital activity were measured and traced every 24 hours (daily). Process duration was nine – twenty days. The following methods of water solution analysis were used: X-ray fluorescence method for elements' content determination (apparatus types: CYP–02 «Renom FV»; S2 PICOFOX); atomic adsorption method; mass spectrometric method for isotope composition determination.

3.1. Results and discussion

In this paper a treatment of Arabian Peninsula sulphide ore containing uranium-238 and thorium-232 is presented as an example. Microorganisms Thiobacillus halophilus were used. Time of the process was 9 days, medium pH 2,0 – 2,5. Analysis spectrogram of initial Arabian Peninsula ore without microbiological treatment and without transmutation of chemical elements is presented in Fig. 1. Analysis spectrograms of transmutation of chemical elements under microbiological treatment of Arabian Peninsula ore depending on process time after 48 hours (two days), after 120 hours (5 days), after 192 hours (8 hours) are presented in Figures 2, 3, 4, correspondingly. The results obtained were statistically handled. Results of statistically handled experiments depending on the process time are collected in the Table.

Analyses from Figures 1-4 and in the Table show that uranium-238 and thorium-232 were presented in the initial ore (Fig. 1); after microbiological treatment they transmutated into another chemical elements and isotopes of chemical elements (Fig.2, Table) which were absent in the initial ore. During transmutation on the second day (Fig.2, Table) a content of uranium-238 decreased, thorium-232 disappeared, and thorium-234, protactinium-234, radium-228, actinium-227, hafnium-177 and other hafnium isotopes, which were absent in the initial ore, appeared. During transmutation of chemical elements and their isotopes after five days (Fig.3, Table) in compare with the second day of the process, the following processes occur: uranium-238 totally disappeared, a content of thorium-234, protactinium-234, protactinium-232, uranium-234, uranium-233 decreased; radium-225, polonium-209, polonium-208, radioactive and stable isotopes of platinum and mercury appeared; a content of actinium-227, thorium-230, protactinium-231, protactinium-233, uranium-232 increased. From Figures 2, 3, 4 and the Table can be seen that ^{233}U appeared on the third day of the process, it content increased on the forth day and decreased on the fifth day of the process; ^{232}U and ^{230}Th appeared, their content increased, and then decreased on the forth, fifth, and sixth day, correspondingly. ^{225}Ra appeared, its content increased, and decreased on the fifth, sixth, and seventh day; mercury – on the forth, sixth, and seventh day; whereas platinum – on the fifth, eights, ninth day of the process, correspondingly (see Table, Figures 2, 3, 4). During transmutation ^{225}Ra isotope disappeared on the ninth day of the process, all mercury isotopes disappeared on the seventh day; gold appeared on the seventh day of the process, then its content

increased as time went on (Fig. 6, Table). Thus, during treatment of sulphide ore containing uranium or/and thorium a transmutation of chemical elements along with transformation of isotopes of chemical elements occur.

Schemes (1-10) of radioactive decay of elements were derived from experimental data. Schemes of the reactions approved the theory of radioactive decay rather than conflict with it.

Scheme 1. Receiving of various valuable isotopes of protactinium, thorium, actinium, radium, and polonium microbiologically from uranium-238 (^{238}U).

^{238}U(-α)→^{234}Th(-β)→^{234}Pa(-n)→^{233}Pa(-β)→^{233}U(-2n)→^{231}U(+β)→^{231}Pa(-α)→^{227}Ac(-β)→

→^{227}Th(-n)→^{226}Th(-α)→^{222}Ra(-α)→^{218}Rn(-α)→^{214}Po(-α)→^{210}Pb(-β)→^{210}Bi(-β)→^{210}Po

^{210}Po(-n)→^{209}Po

^{210}Po(-2n) → ^{208}Po

Scheme 2. Receiving of protactinium-231(^{231}Pa) microbiologically from uranium-238 (238U) in different ways.

2-1. ^{238}U(-α)→ ^{234}Th(-β)→ ^{234}Pa(-n)→ ^{233}Pa(-β)→ ^{233}U(-2n)→ ^{231}U(+β)→ ^{231}Pa

2-2. ^{238}U(-α)→ ^{234}Th(-β)→ ^{234}Pa(-2n)→ ^{232}Pa(-β)→ ^{232}U(-n)→ ^{231}U(+β)→ ^{231}Pa

Scheme 3. Receiving of protactinium-231(^{231}Pa) microbiologically from uranium-238 (238U) in different ways.

3-1. ^{238}U (-α) → ^{234}Th (-β)→^{234}Pa(-n)→ ^{233}Pa(-β) →^{233}U(-2n)→^{231}U(+β) →^{231}Pa

3-2. ^{238}U (-α) → ^{234}Th (-β)→^{234}Pa(-2n)→ ^{232}Pa(-β) →^{232}U(-n)→^{231}U(+β) →^{231}Pa

Scheme 4. Receiving of thorium-230(^{230}Th) microbiologically from uranium-238 (^{238}U).

4-1. ^{238}U(-α)→ ^{234}Th(-β)→ ^{234}Pa(-β)→ ^{234}U(-α)→ ^{230}Th

Then either the process is stopped (with the receiving of ^{230}Th) if thorium-230 is a final purpose of the process; or it continues till the receiving of valuable and rare radioactive isotopes of radium (^{226}Ra), radon, astatine, polonium, bismuth, and lead:

4-2. ^{230}Th(-α)→^{226}Ra(-α)→^{222}Rn(-α)→^{218}Po(-β)→^{218}At(-β)→^{218}Rn(-α)→^{214}Po(-α)→^{210}Pb(-β)→ →^{210}Bi(-β)→^{210}Po

^{210}Po(-n)→^{209}Po

^{210}Po(-2n)→^{208}Po

Scheme 5. Receiving of actinium-227(^{227}Ac) microbiologically from uranium-238 (^{238}U) in different ways.

5-1. ^{238}U(-α)→^{234}Th(-β)→^{234}Pa(-n)→^{233}Pa(-β)→^{233}U(-2n)→^{231}U(+β)→^{231}Pa(-α)→^{227}Ac

5-2. ^{238}U(-α)→^{234}Th(-β)→^{234}Pa(-2n)→^{232}Pa(-β)→^{232}U(-n)→^{231}U(+β)→ ^{231}Pa(-α)→^{227}Ac

Scheme 6. Receiving of radium-226(^{226}Ra) and radium-228(^{228}Ra) microbiologically from uranium-238 (^{238}U), (see 6-1), and from natural thorium-232 (^{232}Th) (see. 6-2, correspondingly).

6-1. ^{238}U(-α)→ ^{234}Th(-β)→ ^{234}Pa(-β)→ ^{234}U(-α)→ ^{230}Th(-α)→ ^{226}Ra

6-2. ^{232}Th(-α)→ ^{228}Ra

Scheme 7. Receiving of the most valuable and stable isotopes of polonium (^{210}Po, ^{209}Po, ^{208}Po) microbiologically from uranium-238 (^{238}U).

7-1. ^{238}U(-α)→^{234}Th(-β)→^{234}Pa(-n)→^{233}Pa(-β)→^{233}U(-2n)→^{231}U(+β)→^{231}Pa(-α)→

→^{227}Ac(-β)→^{227}Th(-n)→^{226}Th(-α)→^{222}Ra(-α)→^{218}Rn(-α)→^{214}Po(-α)→^{210}Pb(-β)→

→^{210}Bi(-β)→^{210}Po

^{210}Po(-n)→ ^{209}Po

^{210}Po(-2n)→ ^{208}Po

7-2. ^{238}U(-α)→^{234}Th(-β)→^{234}Pa(-2n)→^{232}Pa(-β)→^{232}U(-n)→^{231}U(+β)→^{231}Pa(-α)→^{227}Ac→ further the way of transformation of elements and isotopes till 210Po,209Po,208Po are identical to scheme 7-1.

7-3.^{238}U(-α)→^{234}Th(-β)→^{234}Pa(-β)→^{234}U(-n)→^{233}U(-α)→^{229}Th(-α)→^{225}Ra(-β)→

→^{225}Ac(-n)→^{224}Ac(+β)→^{224}Ra(-α)→^{220}Rn(-α)→^{216}Po(-α)→^{212}Pb(-β)→^{212}Bi(-n)→^{211}Bi(-β)→^{211}Po(-n)→ ^{210}Po

^{211}Po(-2n)→ ^{209}Po

Scheme 8. Receiving of various isotopes of thorium, actinium, radium, and polonium microbiologically from natural thorium-232 (^{232}Th):

^{232}Th(-α)→^{228}Ra(-β)→^{228}Ac(-n)→^{227}Ac(-β)→^{227}Th(-n)→^{226}Th(-α)→^{222}Ra(-α)→^{218}Rn(-α)→^{214}Po (-α)→ ^{210}Pb (-β)→ →^{210}Bi (-β)→ ^{210}Po

^{210}Po(-n)→^{209}Po

^{210}Po(-2n) → ^{208}Po

Scheme 9. Receiving of stable isotopes of mercury and gold (^{197}Au) microbiologically by initiation and acceleration of the reactions from polonium-209 (^{209}Po):

^{209}Po(+β)→^{209}Bi(-α)→^{205}Tl (bacterial capture -α)→^{201}Au(-β, T1/2=26min.)→^{201}Hg(-n)→^{200}Hg

^{201}Hg(-2n)→ ^{199}Hg

^{201}Hg(-α)→^{197}Pt (-β, T1/2 = 17,4 hours and 88 minutes)→^{197}Au, unique stable gold isotope.

Scheme 10. Receiving of stable isotopes of mercury, thallium, platinum (^{195}Pt), and gold (^{197}Au) microbiologically by initiation and acceleration of the reactions from polonium-208 (^{208}Po):

^{208}Po(+β)→^{208}Bi(-α)→^{204}Tl(+β, -β, T1/2=3,56years)→bacterial initiation and acceleration:

10-1.^{204}Tl(+β)→^{204}Hg(-n)→^{203}Hg(-β)→^{203}Tl(+β)→^{203}Hg(-β)→^{203}Tl(-n)→^{202}Tl(+β)→

→^{202}Hg(-n)→ ^{201}Hg

^{202}Hg(-2n)→ ^{200}Hg.

^{202}Hg(-α)→^{198}Pt (stable platinum isotope).

10-2. ^{204}Tl(+β)→^{204}Hg(-n)→^{203}Hg(-β)→^{203}Tl(-α)→^{199}Au(-β, T1/2=3,14 days)→

→^{199}Hg(-n)→ ^{198}Hg

^{199}Hg(-2n)→ ^{197}Hg(+β, T1/2 = 65 hours and 24 hours)→ ^{197}Au (unique stable gold isotope).

^{199}Hg(-α)→ 195Pt (stable platinum isotope).

10-3. ^{204}Tl(-β)→^{204}Pb(-n)→^{203}Pb(+β)→^{203}Tl(-2n)→^{201}Tl(+β,T1/2=72hours 5 ms)→^{201}Hg(-n)→^{200}Hg

^{201}Hg(-2n)→ ^{199}Hg

^{201}Hg(-α)→^{197}Pt (-β, T1/2 = 17,4 hours and 88 minutes)→^{197}Au (unique stable gold isotope).

Mechanisms:

From Table data, spectrograms, and derived schemes (1-10) one can see that microorganisms initiate and enhance alpha decay (-α), beta-minus (-β), and beta-plus (+β) decays (electron capture). Microorganisms capture protons, alpha-particles (two protons and two neutrons) and electrons (beta-minus decay) in nuclei of heavy elements (mostly in any f-elements and heavy s-elements), moving captured protons, alpha-particles, and electrons to other elements (mostly to d- and p- elements, e.g., at arsenic and iron). Microorganisms can transfer protons, alpha-particles, electrons, and positrons to other elements, e.g., to f-element ytterbium if is presents in the medium.

Thus, bacterial capture and detachments of proton, alpha-particles, and electrons occur for alpha- and beta-radioactive isotopes of f-, s-, and p- elements which are naturally alpha- or beta- radioactive. Bacteria therewith initiate and million-fold enhance alpha- and beta- decay processes.

At bacterial transfer of alpha-particles from f-elements to iron, iron transforms into nickel (see Table); at bacterial transfer of protons and alpha-particles from f-elements to arsenic, arsenic transforms into bromine (see Table); at bacterial transfer of protons and alpha-particles from f-elements to ytterbium, ytterbium transforms into hafnium (see Table).

<u>Bio-beta-decay (-β,+β):</u>

Bacteria provoke and manifold enhance the both types of beta-decay: beta-minus and beta-plus decays.

Beta-minus (-β) decay is an electron emission by nucleus so that neutron transfers into proton with transformation of an element into the next located in the Mendeleyev Periodic Table of Elements (transition on one cell forward along the Mendeleyev Periodic Table of Elements).

Beta-plus (+β) decay is a capture of electron by nucleus so that proton transfers into neutron with transformation of an element into the previously located in the Mendeleyev Periodic Table of Elements (transition on one cell back along the Mendeleyev Periodic Table of Elements).

During provoked and enhanced by bacteria beta-decay in some cases a subsequent emission of so-called delayed neutron occurs, namely spontaneous natural isotope decays and transitions with obtaining lighter isotope of the given

element in accordance with physical laws. The use of a mechanism of the delayed neutron emission allows widening the list of obtained elements and isotopes, as well as forecasting and controlling the process of bio-mutation (stop it in due time).

Bacteria initiate and enhance beta-decay - electron emission or introducing an electron into the nucleus (an electron capture) - of beta-radioactive chemical elements. Bacteria initiate and enhance beta-decay of both isotopes of elements initially presented in the ore, and isotopes of elements obtained artificially in bio-process after alpha-decay provoked by bacteria. The last event, beta-decay after bacterially-induced alpha-decay, has considerable practical significance in the area of obtaining valuable scarce energy-important elements and their isotopes.

Bacteria capture and remove electrons also from lighter nuclei in compare with f-elements, namely from beta-minus radioactive isotopes – products ("debris") of uranium and plutonium fission, e.g., from nuclei of stroncium-90, yttrium-90, iodine-130, cesium-137, and some other elements which transform into stable elements during the given beta-decay. At that in the nucleus of chemical element a transformation of neutron into proton takes place, as well as a shift of the atomic number of element on one or two cells (depending on the initial isotope) forward along the Mendeleyev Periodic Table of Elements. This process allows radical and ecologically getting rid of high-radioactive wastes of nuclear production and Nuclear Power Plants, i.e., of burn-up wastes which contain radioactive elements - "debris" of uranium, plutonium, and other transuranium elements fission, as well as fission fragments of thorium in the case of its use in thorium nuclear cycle. Herein form natural thorium-232, uranium-238, and plutonium-239, extremely valuable chemical elements and artificial isotopes can be obtained, e.g., uranium-232, uranium-233, plutonium-238, americium-242, curium-242, berkelium, californium, and other isotopes and chemical elements. Those transformations occur by means of increasing the number of protons and the atomic number of the initial element with the shift on one or two cells forward (to the right) along the Mendeleyev Periodic Table of Elements, with possible spontaneous shifting forward (to the right) due to natural beta-decays of the newly obtained elements and their isotopes.

4. Conclusions:

4-1. Bacteria of Thiobacillus genera (e.g., Thiobacillus aquaesulis or Thiobacillus ferrooxidans species) initiate and enhance natural processes of radioactive decay and isotopic transitions of radioactive elements. Duration of natural nuclear reactions and isotopic transitions is enhanced thousands-, million- and milliard-fold depending on natural half-life period of one or another chemical element.

4-2. During treatment of radioactive raw materials containing radioactive chemical elements or their isotopes with suspension of bacteria of Thiobacillus genera a transmutation of chemical elements along with transformation of isotopes of chemical elements occur.

4-3. During transmutation of chemical elements and chemical elements isotopes transformation the valuable chemical elements are obtained: polonium, radon, francium, radium, actinium, thorium, protactinium, uranium, neptunium, americium, hafnium, ytterbium, mercury, gold, platinum and their isotopes.

4-4. Described microbiological method of transmutation of chemical elements and transformation of chemical elements isotopes solves the problem of energy and rare deficient material supplement of various branches of industry, science and technology.

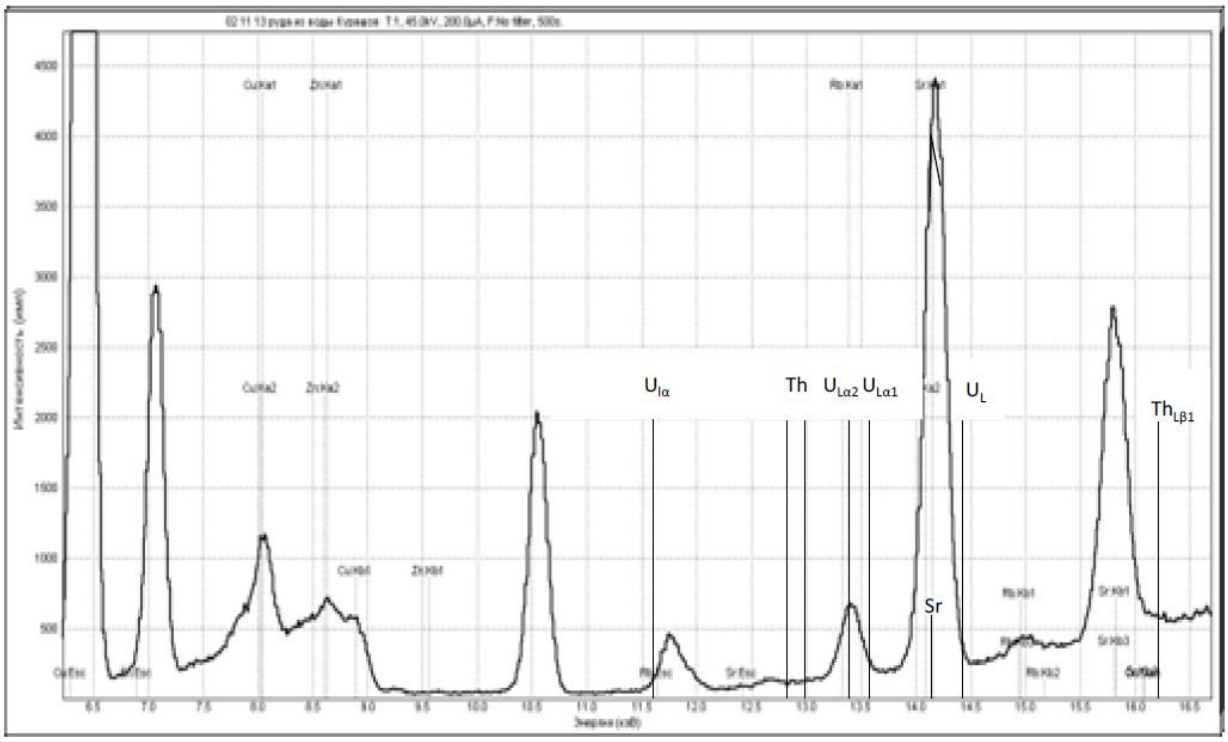

Fig.1. Initial Arabian Peninsula ore without microbiological treatment and without transformation of chemical elements.

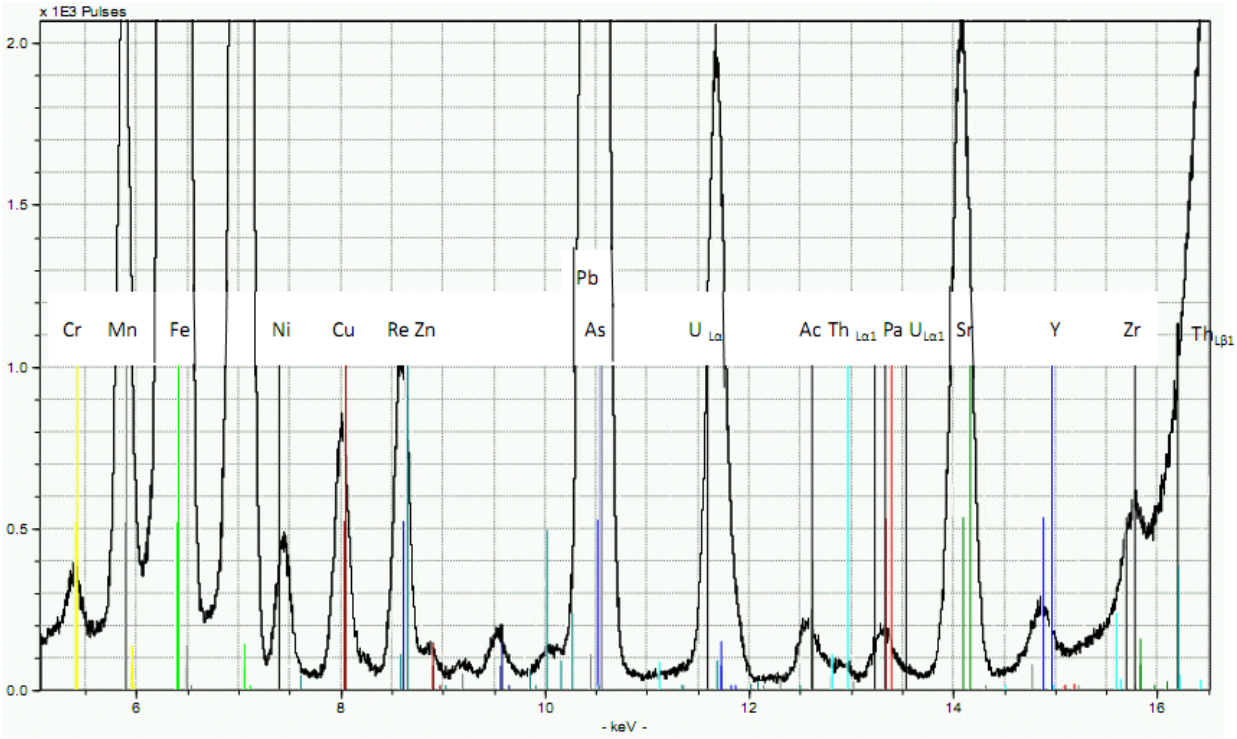

Fig.2. Transmutation of chemical elements under microbiological treatment of of Arabian Peninsula ore after 48 hours (two days in process).

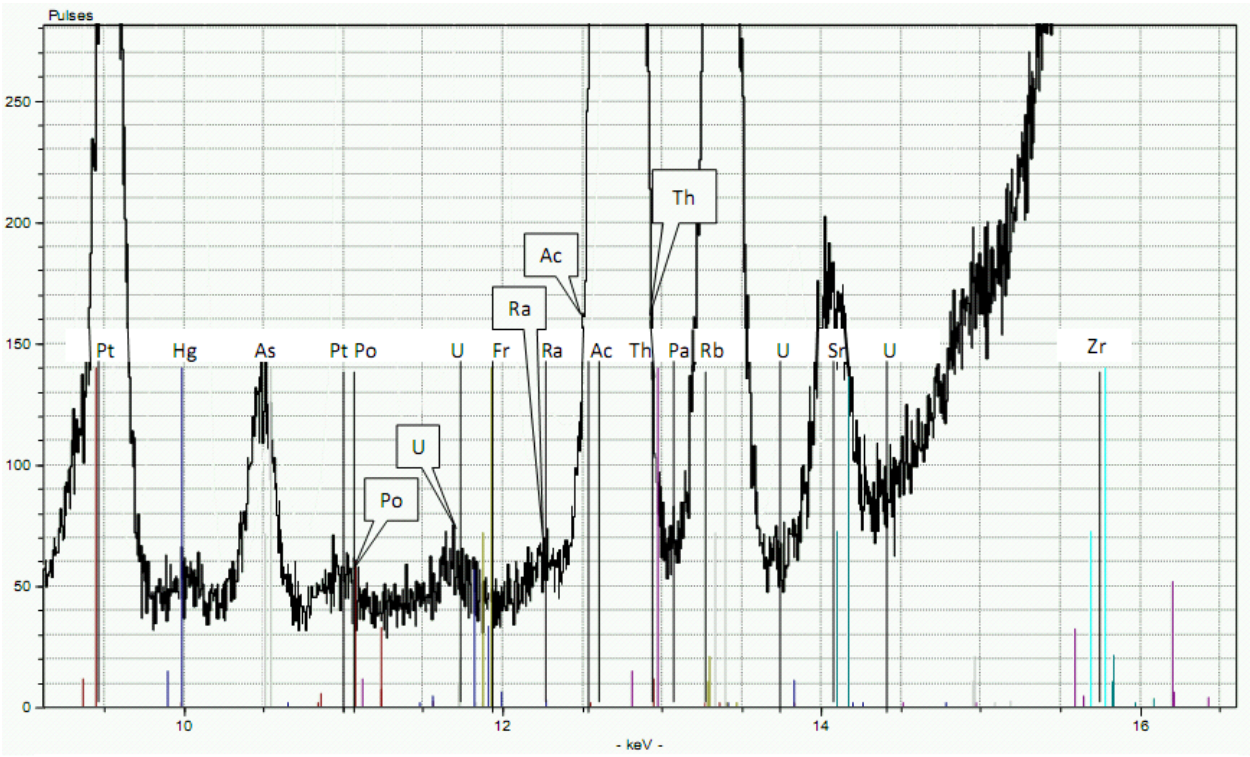

Fig.3. Transmutation of chemical elements under microbiological treatment of of Arabian Peninsula ore after 120 hours (five days in process).

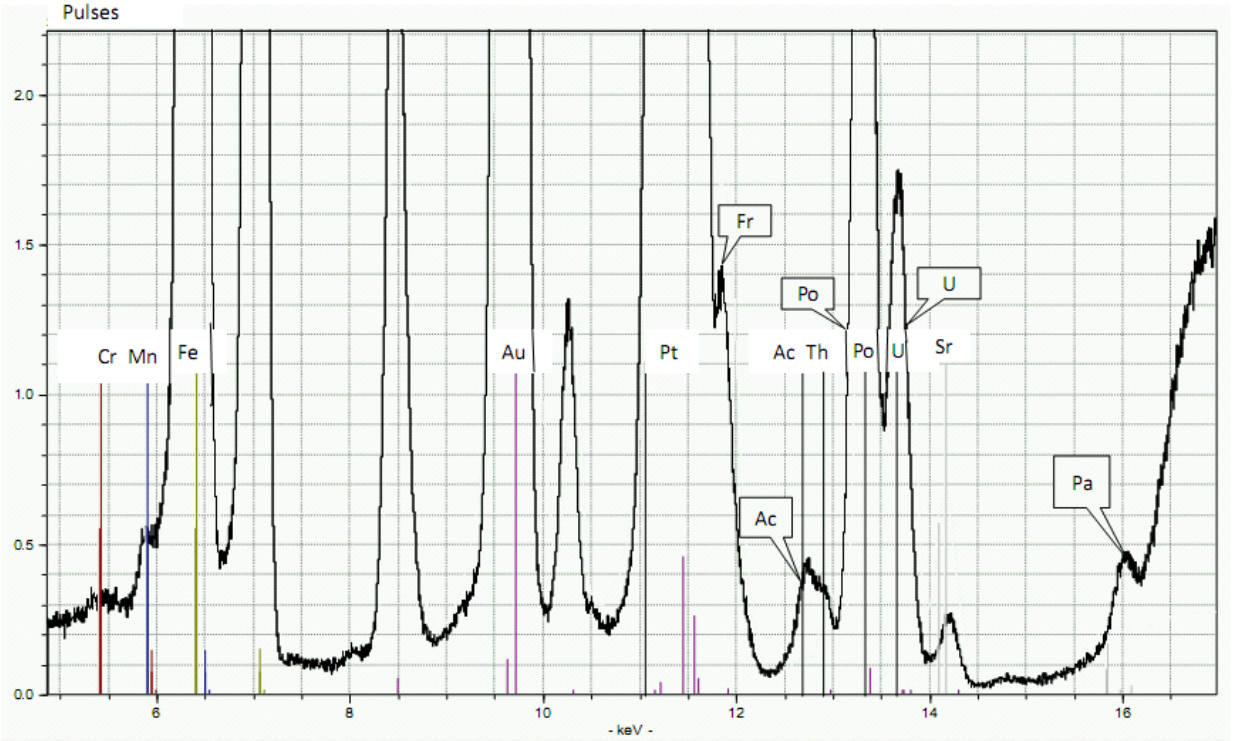

Fig.4. Transmutation of chemical elements under microbiological treatment of Arabian Peninsula ore after 192 hours (eight days in process).

Table. Results of transmutation of chemical elements and transformation of isotopes under microbiological treatment of Arabian Peninsula sulphide ore containing 238U and 232Th.

Elements	Half-life period $T_{1/2}$	Content of elements in 100 g of ore, mg	Content of mg of elements in 1 litre of solution per 100 g of ore, mg of element/100 g of ore in 1 l of solution. (Arabian Peninsula ore, mass fraction ^{238}U=620g/tone, ^{232}Th=40g/tone)								
			Days								
			1	2	3	4	5	6	7	8	9
^{238}U	$4,5x10^9$ years	62,0	62,0	43,6	17,2	4,2	0	0	0	0	0
^{234}Th	24,1 days	0	0	11,01	12,61	8,57	6,23	4,01	2,98	1,27	0
^{234}Pa	6,66 hours	0	0	3,08	1,87	1,69	1,38	1,02	0,71	0,23	0
^{233}Pa	27 days	0	0	0	3,23	3,62	3,72	3,54	2,97	1,38	0
^{232}Pa	1,31 days	0	0	0	5,46	6,63	2,14	0,53	0,28	0,12	0
^{231}Pa	$3,43 \times 10^4$ years	0	0	0	0	5,73	6,85	6,90	7,09	8,21	8,24
^{234}U	$2 x10^{16}$ years	0	0	0	9,14	8,45	8,26	6,96	6,77	3,20	1,00
^{233}U	$1,62 \times 10^5$ years	0	0	0	7,64	7,93	7,73	7,51	6,29	5,97	2,68
^{232}U	8×10^{13} years, 74 years	0	0	0	0	6,14	7,31	6,65	4,03	1,27	0
^{232}Th	$1,39 \times 10^{10}$ years	4,00	4,00	0	0	0	0	0	0	0	0
^{228}Ra	6,7 years	0	0	2,80	2,56	0	0	0	0	0	0
^{227}Ac	21,6 years	0	0	5,15	5,37	8,91	12,02	15,11	15,2	20,7	22,87
^{230}Th	8×10^4 years	0	0	0	0	1,74	2,53	2,01	1,78	0,83	0
^{226}Ra	1617 years	0	0	0	0	0	1,71	1,93	1,09	0,54	0
^{210}Po	138,4 dys	0	0	0	0	0,20	1,01	2,25	6,25	9,23	9,56
^{209}Po	103 years	0	0	0	0	0	0,61	1,32	2,74	3,17	7,27
^{208}Po	2,93 years	0	0	0	0	0	0,20	1,08	2,73	3,19	7,42
^{56}Fe	Stable	201,9	201,8	201,7	201,48	201,23	201,01	200,59	200,5	200,2	199,6
^{60}Ni	Stable	0	0	0,1	0,21	0,34	0,46	0,68	0,75	0,88	1,20
^{55}Mn	Stable	143	143	143,1	143,19	143,31	143,42	143,63	143,7	143,8	144,1
^{75}As	Stable	270	270	269,8	269,48	269,16	268,86	268,30	268,1	267,8	267,0
^{79}Br	Stable	0	0	0,11	0,28	0,45	0,61	0,91	1,00	1,17	1,60
^{71}Ga	Stable	0	0	0,09	0,25	0,40	0,54	0,80	0,89	1,04	1,42
^{173}Yb	Stable	0,02	0,02	0,01	0,005	0	0	0	0	0	0
^{177}Hf	Stable	0	0	0,01	0,015	0,021	0,021	0,021	0,021	0,021	0,021
Hg		0	0	0	0	0,26	0,39	0,85	0	0	0
Pt		0	0	0	0	0	1,01	1,65	1,94	3,07	2,52
Au		0	0	0	0	0	0	0	0,18	0,23	0,29

References

[1] V.M. Kurashov, T.V. Sakhno. Microbiological method of transmutation of chemical elements and conversion of isotopes of chemical elements. Patent RU 2563511 C2, May 15, 2014.

[2] B.I. Shestakov, E.A. Volkova Method for receiving actinium-227 and thorium-228 from treated by neutrons in reactor radium-226. Patent RU 2339718 C2, November 27, 2008.

[3] Shenter Skott, Satts Stehn. Method for production of the actinium-225 and its daughter elements. Priority data 60/167,910 30.11.1999 (US). Patent RU 2260217 C2, September 10, 2005.

[4] G.A. Evsyukov. Method for receiving gold. Claim RU 2003111981 A. 20.11.2004.

[5] B.V. Kuteev, P.R. Goncharov, V.J. Sergeev. Method of element transmutation. Patent RU 2415486 C1 March 27, 2011.

[6] V.I. Vysotskii, A.A. Kornilova, I.I. Samoilenko. Method for receiving stable isotopes by nuclear transmutation of elements through the cold nuclear fusion in microbiological culture. Patent RU 95100839 A1, 27. 12.1995.

[7] A.A. Kornilova, V.I. Vysotskii, I.I. Samoilenko. Method of isotopes transformation with the use of microorganisms. Patent RU 2002101281 A, 27.09.2003.

.

.