ARTIFICIAL OBTAINING OF f-ELEMENTS – ACTINIDES AND OTHER VALUABLE RADIOACTIVE ELEMENTS AND THEIR ISOTOPES, AS WELL AS STABLE ISOTOPES OF PLATINUM AND GOLD WITH THE USE OF MICROORGANISMS

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Abstract

Monazite (thorium-containing) sand of Indian Ocean Coast and uranium- and thorium-containing ore of Arabian Peninsula were treated separately with water suspension of Thiobacillus genera bacteria. Valuable radioactive elements and their isotopes such as hafnium, polonium, francium, radium, actinium, protactinium, artificial isotopes of thorium and uranium, neptunium, americium, 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. The invention also allows inactivating nuclear wastes by transfer hazardous for people radioactive isotopes into stable ones.

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 ^{228}Ra, ^{227}Ac, ^{226}Ra, ^{210}Po, ^{209}Po, ^{208}Po, ^{234}Th, ^{234}Pa, ^{233}Pa, ^{232}Pa, ^{231}Pa, ^{234}U, ^{233}U, ^{232}U, ^{230}Th, ^{226}Ra, as well as some isotopes of ytterbium and hafnium, radioactive and stable isotopes of mercury, platinum and gold [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 and Cf isotopes, produces directly or adds to the industries indirectly as much energy as can be produced by 30,000 tones (210,000 barrels) of oil. 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

Thorium sand of Indian Ocean coast, uranium ores from Jordan, Northwest Africa, and Arab Peninsula, 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. Bacteria of Thiobacillus genus (iron- and sulphur-oxidizing bacteria as well as thermophilic and others) contributed to redox processes of metals were used. 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). 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

A treatment of monazite thorium-containing sand of Indian Ocean Coast and uranium ore of Arabian Peninsula were presented as an example. Microorganisms of Thiobacillus genera Thiobacillus ferrooxidans or Thiobacillus acidophilus kind were used. Temperature of the process was 28-32 degrees centigrade, solution pH was 0,8-1,5. Duration of the process was ten days. Spectrograms of the analyses of chemical elements transmutation under microbiological treatment of thorium-containing sand of Indian Ocean Coast depending on the duration of the process (during 24 hours (1 day), after 120 hours (five days), after 240 hours (ten days)) are presented in Figs. 1, 2, 3, correspondingly. Fig. 4 contains spectrogram of the initial ore of Arabian Peninsula without microbiological treatment and without transmutation of chemical elements. Figs. 5 and 6 contain spectrograms of the analyses of chemical elements transmutation under microbiological treatment of the Arabian Peninsula or depending on the duration of the process (after 120 hours (five days) and after 168 hours (seven days), correspondingly. The results of done and statistically handled experiments depending on the duration of the process are gathered in Table 1 for thorium-containing sand of Indian Ocean Coast and Table 2 for uranium ore of Arabian Peninsula. Thus, under microbiological treatment of thorium-containing sand of Indian Ocean Coast and uranium ore of Arabian Peninsula a transmutation of chemical elements and chemical elements isotopes occur. Schemes of radioactive decay of elements were derived from experimental data: schemes (1-4) – for thorium-containing sand of Indian Ocean Coast, schemes (1-11) for uranium ore of Arab Peninsula. Schemes of the reactions approved the theory of radioactive decay rather than conflict with it.

Scheme 1. Receiving of radium-228 (^{228}Ra) microbiologically from natural thorium-232.

^{232}Th(-α)→ ^{228}Ra

Scheme 2. 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 3. 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

$^{201}Hg(-2n)\rightarrow\ ^{199}Hg$

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

Scheme 4. 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):

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

4-1.$^{204}Tl(+\beta)\rightarrow^{204}Hg(-n)\rightarrow^{203}Hg(-\beta)\rightarrow^{203}Tl(+\beta)\rightarrow^{203}Hg(-\beta)\rightarrow^{203}Tl(-n)\rightarrow^{202}Tl(+\beta)\rightarrow$

$\rightarrow^{202}Hg(-n)\rightarrow\ ^{201}Hg$

$^{202}Hg(-2n)\rightarrow\ ^{200}Hg.$

$^{202}Hg(-\alpha)\rightarrow^{198}Pt$ (stable platinum isotope).

4-2. $^{204}Tl(+\beta)\rightarrow^{204}Hg(-n)\rightarrow^{203}Hg(-\beta)\rightarrow^{203}Tl(-\alpha)\rightarrow^{199}Au(-\beta,$ T1/2=3,14 days)→

$\rightarrow^{199}Hg(-n)\rightarrow\ ^{198}Hg$

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

$^{199}Hg(-\alpha)\rightarrow$ 195Pt (stable platinum isotope).

4-3. $^{204}Tl(-\beta)\rightarrow^{204}Pb(-n)\rightarrow^{203}Pb(+\beta)\rightarrow^{203}Tl(-2n)\rightarrow^{201}Tl(+\beta,$T1/2=72hours 5 ms)$\rightarrow^{201}Hg(-n)\rightarrow^{200}Hg$

$^{201}Hg(-2n)\rightarrow\ ^{199}Hg$

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

Scheme 5. Receiving of various valuable isotopes of protactinium, thorium, actinium, radium, and polonium microbiologically from uranium-238 (^{238}U).

$^{238}U(-\alpha)\rightarrow^{234}Th(-\beta)\rightarrow^{234}Pa(-n)\rightarrow^{233}Pa(-\beta)\rightarrow^{233}U(-2n)\rightarrow^{231}U(+\beta)\rightarrow^{231}Pa(-\alpha)\rightarrow^{227}Ac(-\beta)\rightarrow$

$\rightarrow^{227}Th(-n)\rightarrow^{226}Th(-\alpha)\rightarrow^{222}Ra(-\alpha)\rightarrow^{218}Rn(-\alpha)\rightarrow^{214}Po(-\alpha)\rightarrow^{210}Pb(-\beta)\rightarrow^{210}Bi(-\beta)\rightarrow^{210}Po$

$^{210}Po(-n)\rightarrow^{209}Po$

$^{210}Po(-2n)\ \rightarrow\ ^{208}Po$

Scheme 6. Receiving of protactinium-231(^{231}Pa) microbiologically from uranium-238 (238U) in different ways.

6-1. $^{238}U(-\alpha)\rightarrow\ ^{234}Th(-\beta)\rightarrow\ ^{234}Pa(-n)\rightarrow\ ^{233}Pa(-\beta)\rightarrow\ ^{233}U(-2n)\rightarrow\ ^{231}U(+\beta)\rightarrow\ ^{231}Pa$

6-2. $^{238}U(-\alpha)\rightarrow\ ^{234}Th(-\beta)\rightarrow\ ^{234}Pa(-2n)\rightarrow\ ^{232}Pa(-\beta)\rightarrow\ ^{232}U(-n)\rightarrow\ ^{231}U(+\beta)\rightarrow\ ^{231}Pa$

Scheme 7. Receiving of protactinium-231(^{231}Pa) microbiologically from uranium-238 (238U) in different ways.

7-1. $^{238}U\ (-\alpha)\ \rightarrow\ ^{234}Th\ (-\beta)\rightarrow^{234}Pa(-n)\rightarrow\ ^{233}Pa(-\beta)\ \rightarrow^{233}U(-2n)\rightarrow^{231}U(+\beta)\ \rightarrow^{231}Pa$

7-2. $^{238}U\ (-\alpha)\ \rightarrow\ ^{234}Th\ (-\beta)\rightarrow^{234}Pa(-2n)\rightarrow\ ^{232}Pa(-\beta)\ \rightarrow^{232}U(-n)\rightarrow^{231}U(+\beta)\ \rightarrow^{231}Pa$

Scheme 8. Receiving of thorium-230(^{230}Th) microbiologically from uranium-238 (^{238}U).

8-1. $^{238}U(-\alpha)\rightarrow\ ^{234}Th(-\beta)\rightarrow\ ^{234}Pa(-\beta)\rightarrow\ ^{234}U(-\alpha)\rightarrow\ ^{230}Th$

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:

8-2. $^{230}Th(-\alpha)\rightarrow^{226}Ra(-\alpha)\rightarrow^{222}Rn(-\alpha)\rightarrow^{218}Po(-\beta)\rightarrow^{218}At(-\beta)\rightarrow^{218}Rn(-\alpha)\rightarrow^{214}Po(-\alpha)\rightarrow^{210}Pb(-\beta)\rightarrow\ \rightarrow^{210}Bi(-\beta)\rightarrow^{210}Po$

$^{210}Po(-n)\rightarrow^{209}Po$

$^{210}Po(-2n)\rightarrow^{208}Po$

Scheme 9. Receiving of actinium-227(^{227}Ac) microbiologically from uranium-238 (^{238}U) in different ways.

9-1. $^{238}U(-\alpha)\rightarrow^{234}Th(-\beta)\rightarrow^{234}Pa(-n)\rightarrow^{233}Pa(-\beta)\rightarrow^{233}U(-2n)\rightarrow^{231}U(+\beta)\rightarrow^{231}Pa(-\alpha)\rightarrow^{227}Ac$

9-2. $^{238}U(-\alpha)\rightarrow^{234}Th(-\beta)\rightarrow^{234}Pa(-2n)\rightarrow^{232}Pa(-\beta)\rightarrow^{232}U(-n)\rightarrow^{231}U(+\beta)\rightarrow\ ^{231}Pa(-\alpha)\rightarrow^{227}Ac$

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. 9-2, correspondingly).

10-1. $^{238}U(-\alpha)\rightarrow\ ^{234}Th(-\beta)\rightarrow\ ^{234}Pa(-\beta)\rightarrow\ ^{234}U(-\alpha)\rightarrow\ ^{230}Th(-\alpha)\rightarrow\ ^{226}Ra$

10-2. $^{232}Th(-\alpha)\rightarrow\ ^{228}Ra$

Scheme 11. Receiving of the most valuable and stable isotopes of polonium (^{210}Po, ^{209}Po, ^{208}Po) microbiologically from uranium-238 (^{238}U).

11-1. $^{238}U(-\alpha)\rightarrow^{234}Th(-\beta)\rightarrow^{234}Pa(-n)\rightarrow^{233}Pa(-\beta)\rightarrow^{233}U(-2n)\rightarrow^{231}U(+\beta)\rightarrow^{231}Pa(-\alpha)\rightarrow$

$\rightarrow^{227}Ac(-\beta)\rightarrow^{227}Th(-n)\rightarrow^{226}Th(-\alpha)\rightarrow^{222}Ra(-\alpha)\rightarrow^{218}Rn(-\alpha)\rightarrow^{214}Po(-\alpha)\rightarrow^{210}Pb(-\beta)\rightarrow$

$\rightarrow {}^{210}Bi(-\beta)\rightarrow {}^{210}Po$

${}^{210}Po(-n)\rightarrow {}^{209}Po$

${}^{210}Po(-2n)\rightarrow {}^{208}Po$

11-2. ${}^{238}U(-\alpha)\rightarrow {}^{234}Th(-\beta)\rightarrow {}^{234}Pa(-2n)\rightarrow {}^{232}Pa(-\beta)\rightarrow {}^{232}U(-n)\rightarrow {}^{231}U(+\beta)\rightarrow {}^{231}Pa(-\alpha)\rightarrow {}^{227}Ac\rightarrow$ further the way of transformation of elements and isotopes till ${}^{210}Po$, ${}^{209}Po$, ${}^{208}Po$ are identical to scheme 11-1.

11-3. ${}^{238}U(-\alpha)\rightarrow {}^{234}Th(-\beta)\rightarrow {}^{234}Pa(-\beta)\rightarrow {}^{234}U(-n)\rightarrow {}^{233}U(-\alpha)\rightarrow {}^{229}Th(-\alpha)\rightarrow {}^{225}Ra(-\beta)\rightarrow$

$\rightarrow {}^{225}Ac(-n)\rightarrow {}^{224}Ac(+\beta)\rightarrow {}^{224}Ra(-\alpha)\rightarrow {}^{220}Rn(-\alpha)\rightarrow {}^{216}Po(-\alpha)\rightarrow {}^{212}Pb(-\beta)\rightarrow {}^{212}Bi(-n)\rightarrow {}^{211}Bi(-\beta)\rightarrow {}^{211}Po(-n)\rightarrow {}^{210}Po$

${}^{211}Po(-2n)\rightarrow {}^{209}Po$

Mechanisms:

From Table data, spectrograms, and derived schemes (1-11) 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.

Bio-beta-decay (-β,+β):

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

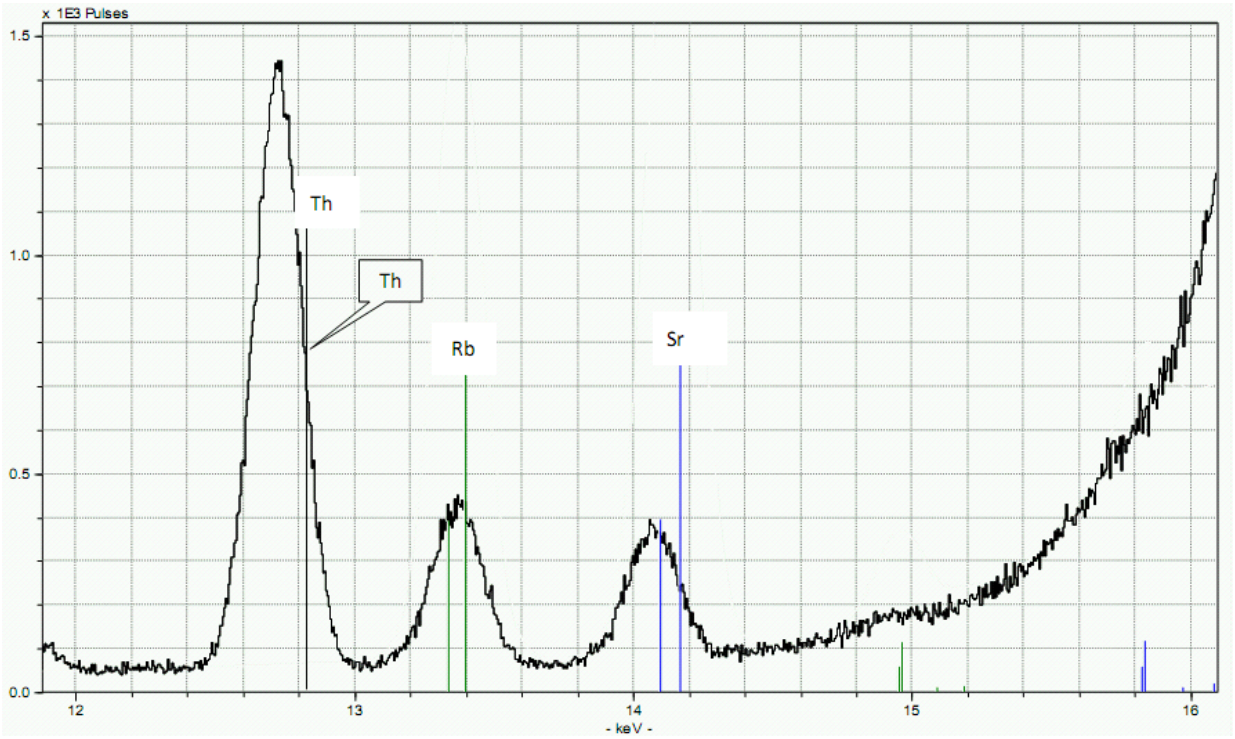

Fig.1. Transmutation of chemical elements under microbiological treatment of thorium-containing sand of Indian Ocean coast (first day in process).

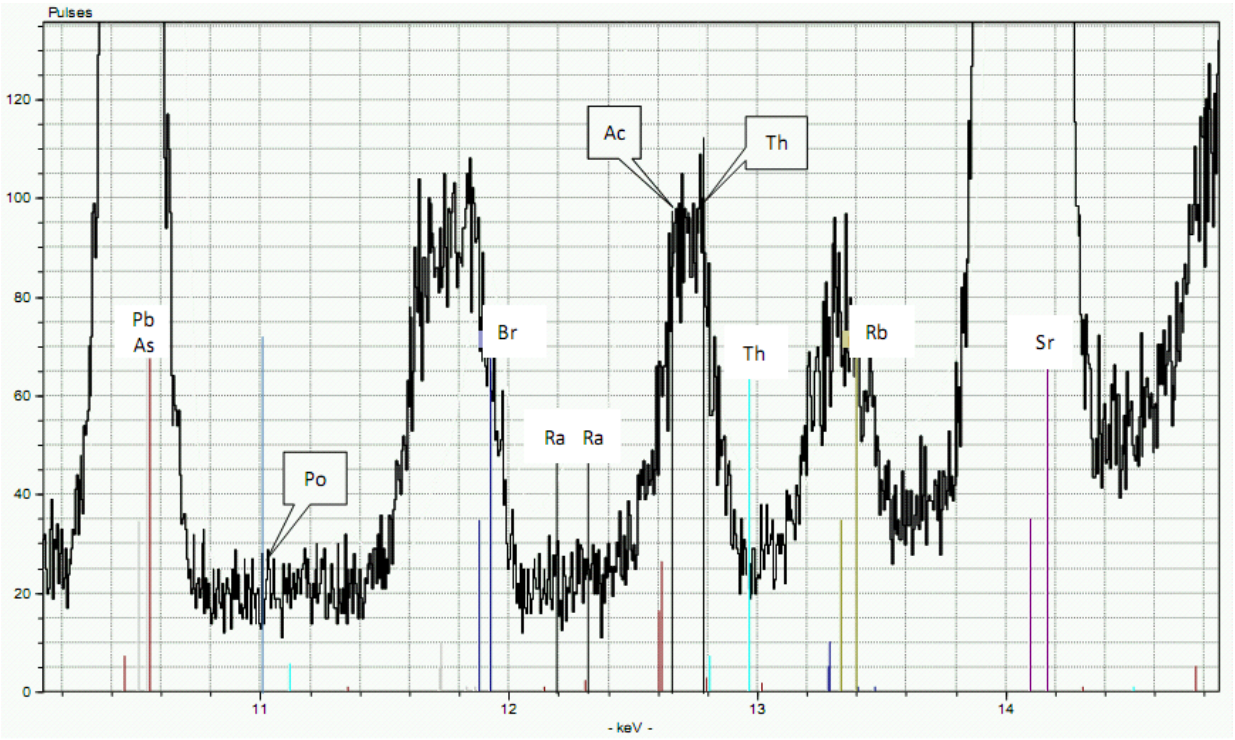

Fig.2. Transmutation of chemical elements under microbiological treatment of of thorium-containing sand of Indian Ocean coast after 120 hours (five days in process).

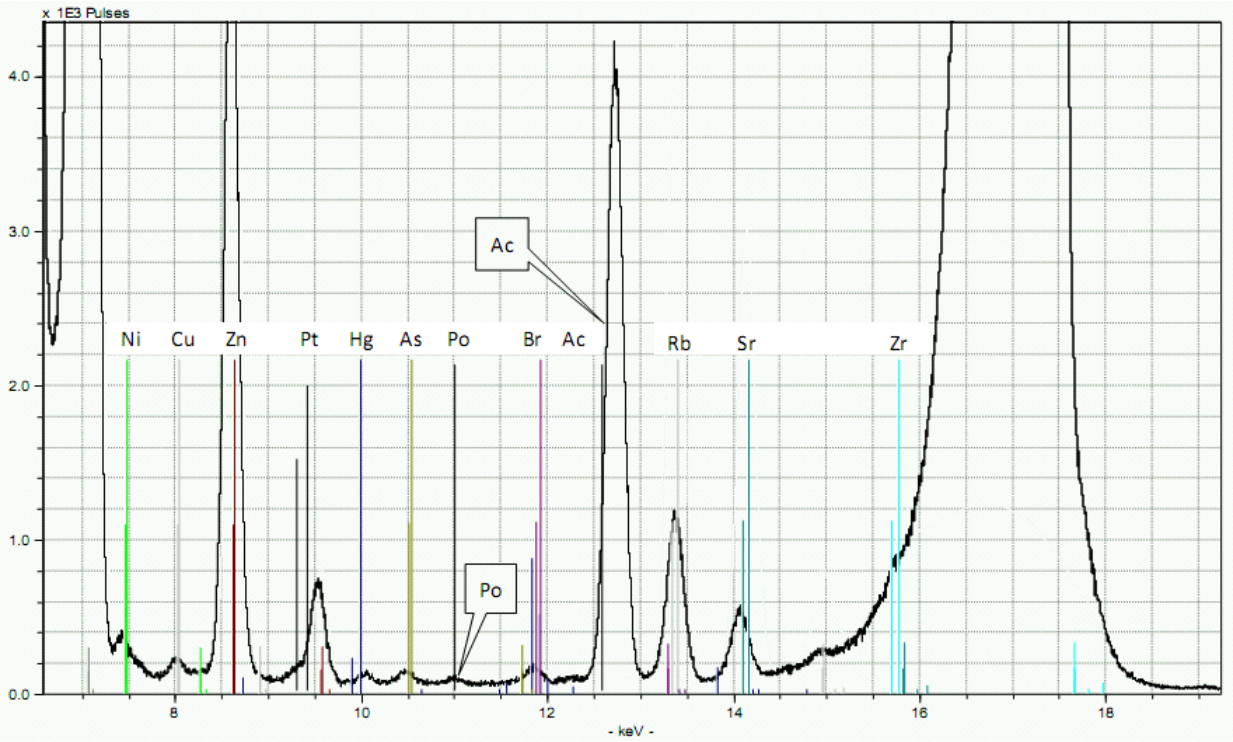

Fig.3. Transmutation of chemical elements under microbiological treatment of of thorium-containing sand of Indian Ocean coast after 240 hours (ten days in process).

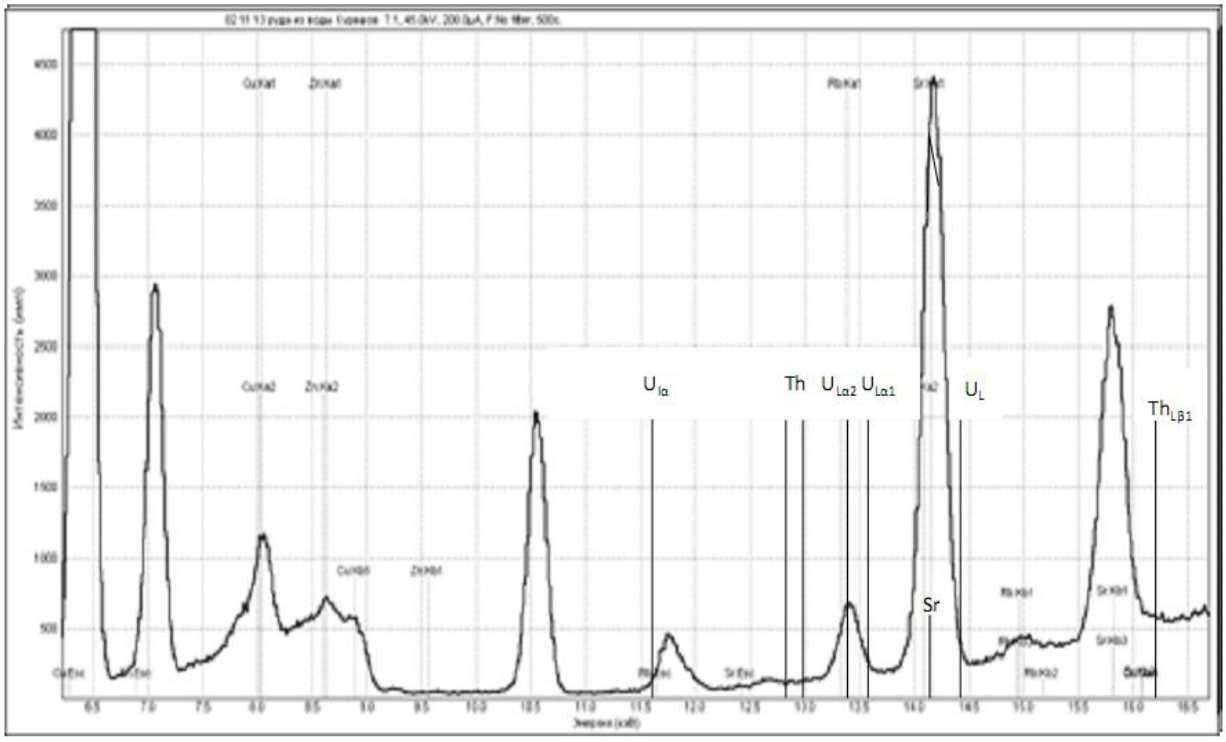

Fig.4. Initial Arabian Peninsula ore without microbiological treatment and without transformation of chemical elements.

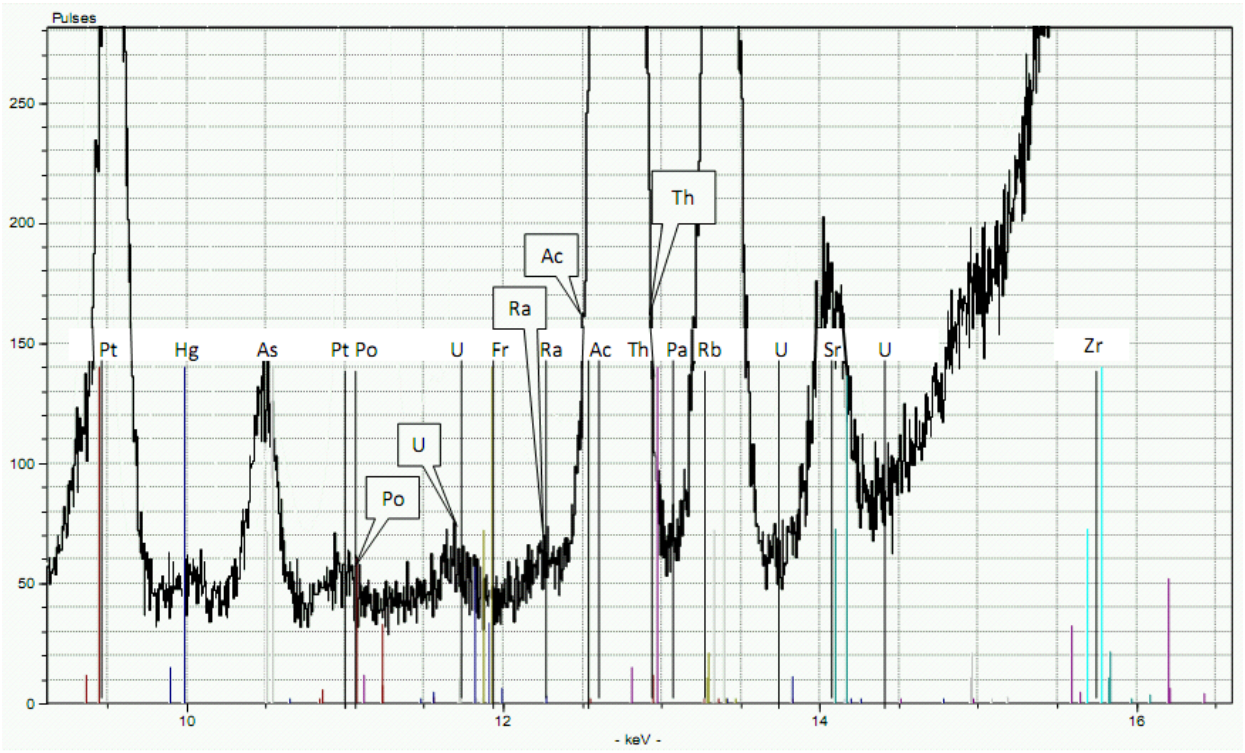

Fig.5. Transmutation of chemical elements under microbiological treatment of of Arabian Peninsula ore after 120 hours (five days in process).

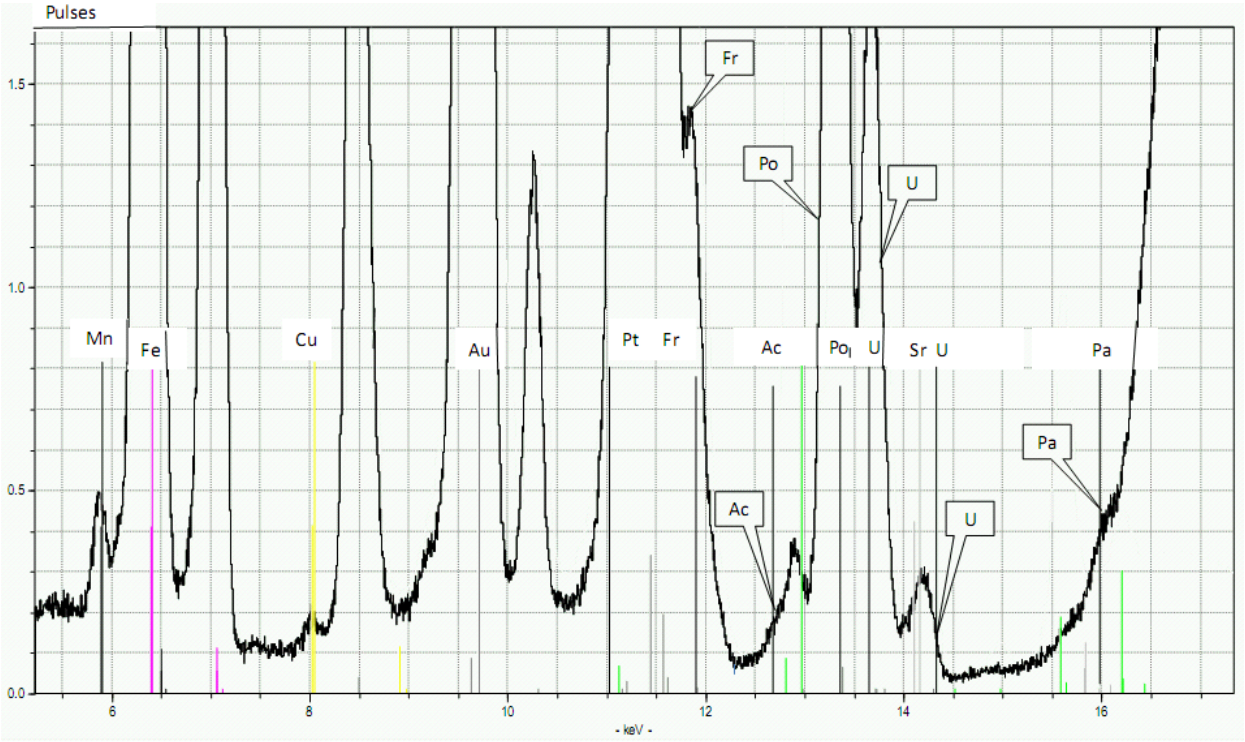

Fig.6. Transmutation of chemical elements under microbiological treatment of of Arabian Peninsula ore after 168 hours (seven days in process).

Table 1. Results of transmutation of chemical elements and transformation of isotopes under microbiological treatment of monazite thorium-containing sand of Indian Ocean coast

Elements	**Contents 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. (monazite thorium-containing sand of Indian Ocean coast mass fraction of thorium ^{232}Th=440g/tone)**									
		Days									
		1	2	3	4	5	6	7	8	9	10
^{232}Th	44	44	42,4	33,92	20,88	17,08	8,80	6,08	1,92	1,44	0
^{228}Ra	0	0	1,57	3,18	4,37	6,00	4,00	2,93	2,03	1,56	0
^{227}Ac	0	0	0	6,71	18,33	16,62	25,60	28,03	28,57	28,78	29,31
^{210}Po	0	0	0	0	0	3,33	3,30	2,53	2,33	2,19	2,15
^{209}Po	0	0	0	0	0	0	0,27	0,83	3,57	4,01	4,41
^{208}Po	0	0		0	0	0	0	1,22	2,65	2,92	1,61
Hg	0						0	0,53	0,32	0,26	0,10
Pt	0						0	0	0,27	0,44	0,75

Table 2. Results of transmutation of chemical elements and transformation of isotopes under microbiological treatment of Arabian Peninsula sulphide ore containing ^{238}U and ^{232}Th.

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	2×10^{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

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