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TERMINATION OF THE MAIN FACTOR OF RADIOACTIVE EQUILIBRIUM BREAKING BETWEEN RADIONUCLIDES IN THE URANIUM DECAY CHAIN

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ABSTRACT: This article presents the results of a theoretical and experimental study to determine the factors of disruption of the radioactive equilibrium coefficient between radionuclides in the uranium decay chain. A theoretical calculation formula for the mixing of daughter radionuclides in the uranium decay chain is found, and based on this formula, the mixing distance between daughter radionuclides is calculated. A schematic view of the mixing of daughter radionuclides between themselves due to the recoil energy is constructed.

KEY WORDS: uranium decay chains, decay factors, radioactive equilibrium, recoil energy, nuclear decay laws, atomic mass number, number of protons, daughter radionuclides, mixing distance.

INTRODUCTION In uranium production one has to deal with radioactive elements emitting harmful ionizing radiation**.** From the literature it is known [1-2] that natural uranium consists of three natural radionuclides - ^{238}U, ^{235}U and ^{234}U.

Their quantitative ratio is ^{238}U-99,27%, ^{235}U-0,72%, ^{234}U-0,0053%,, and the specific activity of these radionuclides in mutual radioactive equilibrium is - $1{,}23 \cdot 10^4$ Bq/g, $4{,}9 \cdot 10^4$ Bq/g and $2{,}3 \cdot 10^8$ Bq/g respectively [3-5].

In the world, studies conducted in recent years show [7-9] that there is a violation of the radioactive balance between these radionuclides in the uranium decay chain, which negatively affects the quality of the finished uranium product and creates an additional gamma background of ionizing radiation. There are many nuclear physical factors that cause disturbances in the radioactive equilibrium between these radionuclides, such as the age of minerals, migration coefficients of radionuclides, geochemical factors, recoil energy, geotechnological leaching conditions, etc. [10-16].

To determine the main factor of disturbance of the radioactive equilibrium between daughter radionuclides in the uranium decay chain from the above, it is advisable to conduct theoretical and experimental research to determine the factors of disturbance of radioactive equilibrium between daughter radionuclides.

The purpose of this study is to conduct a theoretical and experimental study to determine the main factor in the disturbance of radioactive equilibrium between daughter radionuclides to solve current problems of nuclear physics, radioecology and technology for obtaining finished uranium products.

Level of knowledge of the problem: An analysis of the literature of foreign and domestic researchers shows that the factors of disturbance of the radioactive equilibrium between daughter radionuclides in the decay chain of uranium have been little studied. The literature provides only some reasons for the violation of the coefficient of radioactive equilibrium between radionuclides in the uranium decay chain. Having studied the variety of nuclear physical properties of chemical elements, examining the mechanism of recoil energy, the properties of daughter radionuclides, and so on, factors, we can determine the main one. Radionuclides in a closed homogeneous system are in a state of radioactive equilibrium between themselves. Over time, nuclear transformations occur in the nuclei of radioactive elements on the basis of α - and β - decay. The parent nucleus ^{238}U on the basis of 8 α - decay and 6 β - decay transforms into stable ^{206}Pb. It is known that the specific activity of each radionuclide has different values, that is, the activity of 1 g of ^{238}U is equal to 12,500 Bq, and the activity of 1 g of ^{226}Ra is equal to $3.7 \cdot 10^{10}$ Bq, etc. [13-14].

In addition to the above, there is information in foreign and domestic literature that disturbances in the radioactive balance between radionuclides may be associated with the age of minerals [15, 16].

THEORETICAL PART OF THE RESEARCH As is known, during α-decay, the daughter radionuclides of the uranium chain receive recoil energy. This reaction can be written as follows:

$$M_\alpha E_\alpha = \mathrm{M}_{\text{отд}} \mathrm{E}_{\text{отд}} \qquad (1)$$

where Mα and Eα are the mass and energy of the alpha particle, respectively, and Mtd and Etd are the mass and energy of the radionuclide that has undergone decay. In order for alpha decay to be energetically possible, the following inequality must hold::

$$M(A, Z) > M(A-4, Z-2) + M({}^4_2He) \qquad (2)$$

that is, the mass (energy) of the parent nucleus must be greater than the sum of the masses (energies) of the resulting nucleus and the α-particle. Excess energy of the parent nucleus during α-decay is released in the form of kinetic energies of particles:

$$E_{\text{пол}} = [\mathrm{M(A,Z)} - \mathrm{M(A-4, Z-2)} - \mathrm{M}({}^4_2He)]c^2 = \mathrm{E}_\alpha + \mathrm{E}_{\text{отд.я}} \qquad (3)$$

Here $E_{k.e.}$ - kinetic energy of pulsed core, E_α - α-particle binding energy.

If the decaying nucleus is in a relatively stable state, then their momentum will be

$$P_\alpha = P_{отд.я.} \qquad (4)$$

Then the kinetic energy of the resulting daughter nucleus from the momentum equation (4) is expressed as follows:

$$E_{отд.я} = \frac{E_\alpha M_\alpha}{M_{отд..я}} \qquad (5)$$

in accordance with (3)

$$E_{пол} = \left(1 + \frac{M_\alpha}{M_{отд.я}}\right) E_\alpha \qquad (6)$$

$$E_\alpha = \left(\frac{M_{отд.я.}}{M_\alpha + M_{отд.я.}}\right) E_{пол} \qquad (7)$$

here $M_{отд.я.}$ - impulse mass of the nucleus.

During the alpha decay of a radionuclide, the energy of the alpha particle released from the parent nucleus causes a change in its position. Because an alpha particle is one of the heaviest elementary particles having an electrical charge equal to 2 and an atomic mass number equal to 4. Since alpha particles have the largest mass of particles found in nature, when leaving the nucleus they cause daughter radionuclides move a certain distance from your original location. To find how far the daughter radionuclide has moved due to alpha decay, use the following formula [6].

$$\delta = \frac{(M_\alpha+M_U)*\big((M_\alpha*E_k^U*N_A\big)*(Z_U^{\frac{2}{3}}+Z_\alpha^{\frac{2}{3}})}{(M_U*Z_U*Z_\alpha*\rho)} \qquad (8)$$

Here M_α и M_U - mass of alpha particle and uranium nucleus (mother nucleus), E_k^U - radionuclide reaction energy, Z_u и Z_α - the charge number in the uranium nucleus and the charge number of the alpha particle, respectively, ρ - core density.

RESULTS OBTAINED AND THEIR DISCUSSIONS Formula (8) is used to calculate how far the radionuclides have moved as a result of the recoil energy from alpha decay. Nuclear physical characteristics of alpha decay of radionuclides in the uranium decay chain and their calculated displacement distances are given in Table 1.

Table 1

Nuclear physical characteristics of alpha decay of radionuclides in the uranium decay chain and their calculated displacement distances

Radionuclide	E_α - alpha decay energy, MeV	$E_{от}$ - recoil energy, MeV	Z	δ - calculated distance displacement of radionuclide. (нм)
1	2	3	4	5
^{238}U	4,196	0,0700	92	17,10
^{234}U	4,777	0.0816	92	19,81
^{230}Th	4,688	0,0813	90	19.99
^{226}Ra	4,785	0,0846	88	21,02
^{222}Rn	5,490	0,0989	86	24,81
^{218}Po	6,002	0,1100	84	27,87
^{214}Po	7,692	0,1438	84	36,44

As can be seen from the results given in table. 1 The calculated displacement distance of the daughter radionuclide in column 5 is interrelated with the radius and atomic mass number of the radionuclide. That is, the higher the atomic mass number of the radionuclide, the smaller its displacement distance, namely for - ^{238}U - 17.1 nm, ^{234}U - 19.81 nm, ^{230}Th - 19.99 nm, ^{214}Po - 36.44 nm. etc. Knowing the relationship between the atomic mass number of a radionuclide and its displacement distance, one can find how far the radionuclide is displaced within 1 second, since the half-life - $T_{1/2}$ of each radionuclide has its own constant value.

Table 1

Nuclear physical constants of radionuclides and their interconnected characteristics

Радио-нуклид	Масса в 1 гр	Half life, $T_{1/2}$	Number of particles in a given mass, pcs	Number of particles used in 1 s, pcs.	RN displacement distance during one decay event, δ (nm)	RN offset distance for 1 s, µm
1	2	3	4	5	6	7
^{238}U	1,00	$4{,}5\cdot10^{9}$ y.	$25{,}2\cdot10^{20}$	12500	17,10	213,75
^{234}U	$53{,}41\cdot10^{-6}$	$2{,}5\cdot10^{5}$ y.	$1{,}3\cdot10^{14}$	12300	19,81	243,66
^{230}Th	$173\cdot10^{-10}$	$8{,}0\cdot10^{4}$ y.	$4{,}5\cdot10^{16}$	12460	19.99	249,08
^{226}Ra	$0{,}34\cdot10^{-9}$	1602 y.	$9{,}0\cdot10^{14}$	12580	21,02	264,43
^{222}Rn	$0{,}22\cdot10^{-14}$	3.8 d.	$6{,}0\cdot10^{9}$	12540	24,81	311,12
^{218}Po	$12\cdot10^{-16}$	3.1 min	$3{,}3\cdot10^{9}$	12000	27,87	334,44
^{214}Po	10^{-20}	$1{,}6\cdot10^{-4}$ s	$28{,}0\cdot10^{3}$	12750	36,44	464,61

From the table 2 it can be seen that in columns 1, 2, 3 and 4 of the table the nuclear physical constants of radionuclides are given, and columns 5, 6 and 7 are given the number of particles emitted in 1 s (5), the distance of their displacement during one decay event (6) and displacement distance in 1 sec (7). As can be seen from the results given in column (5) of the table. 2. the number of particles emitted per 1 s for radionuclides - ^{238}U is 12500 pcs., ^{234}U is 12300 pcs., ^{230}Th is 12460 pcs., ^{226}Ra is 12580 pcs., ^{222}Rn is 12540 pcs., ^{218}Po is 12000 pcs., ^{214}Po is 12750 pcs. PC. The number of particles emitted per 1 s for radionuclides varies from 12000 to 12750. and on average 12450 pcs. This fact shows that in radioactive equilibrium the number of particles emitted over the same period of time is the same number. Based on the law of conservation of momentum of a body, the greater the mass of the radionuclide, the smaller its displacement distance obtained during alpha decay, that is, the distance of displacement of radionuclides in 1 s. - ^{238}U is - 213.75 microns, ^{234}U is - 243.66 microns, ^{230}Th is - 249.08 microns, ^{226}Ra is - 264.43 microns, ^{222}Rn is - 311.12 microns, ^{218}Po is - 334, 44 microns., ^{214}Po is - 464.61 microns. This fact, in turn, confirms that the fundamental law of physics - the law of conservation of momentum - is satisfied even during radioactive decay. Based on the calculated data, it is possible to construct a graphical relationship with the atomic mass number of the radionuclide with its displacement distance Fig. 1.

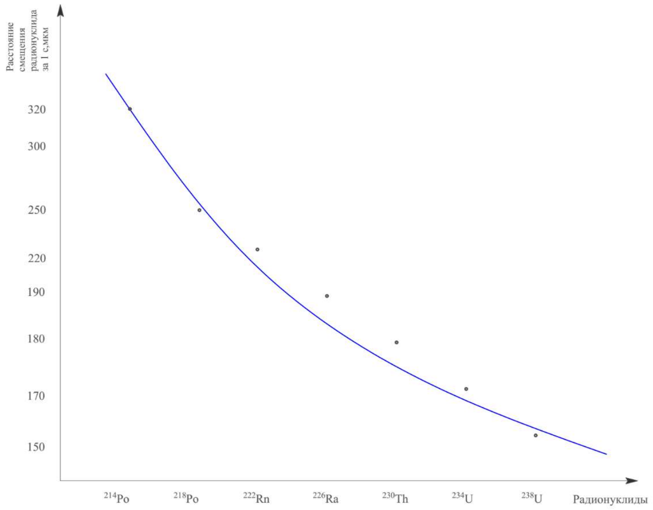

Fig.1. Relationships between the atomic mass number of a radionuclide and its displacement distance

As can be seen from Fig. 1. from radionuclides - ^{238}U shifts by a distance of 17.10 nm during one decay event; when 12500 alpha particles leave, this radionuclide shifts by a distance of 213.75 microns. - ^{234}U shifts by a distance of 19.81 during one decay event nm,, when 12300 pieces of alpha particles leave, this radionuclide shifts by a distance of – 243,66 microns., - ^{230}Th during one decay event moves by a distance of 19.81 nm,, when 12460 pieces of alpha particles leave, this radionuclide shifts by a distance - 249.08 microns., - ^{226}Ra shifts by a distance of 21.02 nm during one decay event, when 12580 alpha particles leave, this radionuclide shifts by a distance of – 264,43 microns., - ^{222}Rn shifts by a distance of 24.81 nm during one decay event, , when 12540 pieces of alpha particles leave, this radionuclide moves to a distance of – 311,12 microns., ^{218}Po during one decay event moves to a distance of 27.87 nm, when 12000 pieces of alpha particles leave, this radionuclide moves to a distance of - 334.44 µm., ^{214}Po during one decay event moves by a distance of 36.44 nm, and when 12750 alpha particles leave, this radionuclide moves by a distance of 464.61 µm.

Thus, it was found that during alpha decay, the daughter radionuclide receives recoil energy and moves a certain distance from the parent nucleus. Based on these facts, we can conclude that the daughter radionuclides of the uranium decay chain, which form during alpha decays, are displaced a certain distance from the parent nucleus due to recoil energy and the radioactive equilibrium between the radionuclides in a given object is disrupted.

As a result of theoretical calculations and existing nuclear physical constants of the uranium decay chain, the number of alpha particles emitted in 1 s, the distance of their displacement in one decay event and the displacement distance in 1 s were found. From the results obtained, it became clear that the number of particles emitted in 1 s for radionuclides of the uranium decay network varies from 12000 to 12750 pieces. and on average 12450 pcs. It has been established that in radioactive equilibrium in objects the number of particles emitted over the same period of time is the same number. And based on the law of conservation of body momentum, the greater the mass of the radionuclide, the smaller its displacement distance. This confirms that the fundamental law of physics - the law of conservation of momentum - is satisfied even during radioactive decay.

Based on the graphical relationship with the atomic mass number of the radionuclide with its displacement distance, it was established that the radionuclides of the uranium decay chain - ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{222}Rn, ^{218}Po and ^{214}Po during one decay event, the radionuclides are displaced by different distances; with different amounts of alpha particles, these radionuclides are displaced by different distances.

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