Notice

DESCRIPTION WO2015156698A1

[0001]

DESCRIPTION OF THE INVENTION

[0002]

METHOD OF WATER PURIFICATION FROM RADIONUCLIDES

[0003]

The invention relates to the field of processing liquid radioactive waste, in particular to methods for purifying water from radionuclides.

[0004]

The problem of purifying water contaminated with radionuclides is one of the most pressing environmental issues.

The appearance of such water is associated with both planned technological operations, due to the specific nature of the activities of nuclear-oriented production, and with emergency situations caused, in particular, by accidents at nuclear-oriented facilities.

[0005]

During the nuclear fission reaction in nuclear reactors, a large number of radioactive isotopes and isomers (high-level waste) with medium or long lifetimes are formed:

[0006]

N³, Be⁷, C¹⁴, F¹⁸, Na^{22*24}, Si³¹, P³² ³³, S³⁵, C1³⁶-³⁸, K^{42,43}, Ca⁴⁵'⁴⁷, Sc⁴⁶'⁴⁷'⁴⁸, V⁴⁸, Cr⁵¹,

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[0007]

Q_q67

[0008]

d₅73,74,76,77t gg75 g_f82 ^86 g_r85,85m,87m, 89,90,91,92 y90,91,91t,92,93 £^3,95,97 j^93m,94,95,97,98 j j_o90,93,99,101 QJ109, 115,115m

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[0010]

j_nlll,H3m,114m,115m g_n113,125 ^^122,124,125 j_e123m,125m,127,127m,129,129m,131,131m,132,133,133m,134 jl23,125,126,129,130,131,132,133,134,135 £_s129,131,132,134,134m,135,136,I37,138 β_&131,140 1^1 0 £^139,141,143,144 p_r142,143 Nd^{1 7}*¹⁴⁹Pm¹⁴⁷

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¹⁴⁹Eu^{15,}-l⁵3Sm, 152,152m,154,155 £₎y¹⁶⁵*¹⁶⁶Hθ'⁶⁶

[0011]

g_ri69,i7i -r_m¹⁷⁰'¹⁷¹Yb¹⁷⁵Lu¹⁷⁷Hf¹⁸¹Ta¹⁸²w¹⁸¹'^{185,187} Re¹⁸⁶'¹⁸⁸Os¹⁸⁵'¹⁹¹'¹⁹¹"^{1,193}ΐι-¹⁹⁰·¹⁹²·¹⁹⁴

[0012]

241,242,243,244 ^_m241,242,242m,243 £_m242, 243,244,245,246,247,248 gj^.24 QJ246,248,249,250,251,252,253,254 g_s253, 254,254m p_m254,255

[0013]

Of these radionuclides, the most dangerous for biological objects are the isotopes Sr, Tc, Cs, Np, Pu, Am, Cm

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[0014]

A method for biological purification of water from man-made radionuclides is known (Patent RU2255906, published 10.07.2005), based on the phenomenon of high absorption properties of some algae (in particular, Phillophonia elongata, Ulwa regid, Thalassiosira, etc.), the seedlings of which are placed in biocontainers installed in the volume of contaminated water to be purified.

When these algae are grown for 20-40 days, the metabolism process involves active absorption based on metabolic and biochemical processes and the accumulation of certain types of radionuclides, which leads to water purification.

Once filled with growing algae, the biocontainer is removed from the water, the algae are then dried and burned, and the radioactive ash residue is disposed of.

The maximum coefficient of accumulation of radionuclides by these algae (in relation to a similar mass of water) is 30 (for Cs¹³⁷) and 40 (for Sr⁹⁰).

[0015]

The disadvantage of this method is that it does not solve the problem of deactivation of radionuclides, since dangerous radionuclides are not destroyed, but converted into another state (ashed).

[0016]

A method for disposing of radioactive waste by irradiating it with thermal neutrons is known (Patent US4721596 A published on January 26, 1988).

With such irradiation, neutron capture by the nuclei of long-lived isotopes occurs, followed by a cascade of nuclear transformations and the formation of other isotopes, which, in particular, may be shorter-lived, which reduces the duration of natural deactivation by spontaneous decay.

[0017]

The disadvantage of this method is that fission reactions under the action of slow neutrons can occur only in some heavy radioactive isotopes (in particular in U and Pu) and, in addition, the absorption of such neutrons by many stable nuclei of medium-mass elements can lead to the formation of radioactive isotopes of these nuclei.

[0018]

The technical result to which the invention is directed is the creation of a method for purifying aqueous solutions containing radionuclides, due to the phenomenon of transmutation (nuclear transformation) of ions of radioactive isotopes (radionuclides) into other stable isotopes in growing microbiological cultures.

[0019]

The technical result is achieved in the invention by creating conditions in the purified aqueous solution for the nuclear transmutation of radioactive isotopes of some chemical elements into non-radioactive isotopes of other chemical elements in growing microbiological cultures, for which purpose a nutrient medium is prepared for the growth of microbiological cultures, deficient in the chemical element corresponding to the isotope

obtained as a result of transmutation (Isotope 1), and containing the initial isotopic components necessary for transmutation (Isotope 2); microbiological cultures requiring Isotopes 1 for their growth and development are grown in this nutrient medium, for which purpose microbial biomass is added, for example, in the form of granules, including microbial syntrophic associations in a viable state to the said nutrient medium, and the transmutation process is carried out in three stages, during the first of which the effect of mutagenic adaptation of microorganisms contained in the biomass to specific types of radionuclides (Isotopes 3) contained in the aqueous solution to be purified is stimulated by gradually maintaining the microbial biomass at an optimal (elevated to 30-40° C) temperature, accelerating the mutagenesis process, for a time in the range from 10 hours for aerobic microorganisms to 24 hours for anaerobic microorganisms, in a liquid, the composition of which includes water in an amount sufficient to cover the volume of biomass with the nutrient medium and, gradually increasing, by adding portions of the substance to be purified purification of an aqueous solution with radionuclides that do not lead to the death of biomass due to radioactive irradiation, until the concentration of the solution to be purified is reached, after which, during the second stage, the biological part of the transmutation process in the resulting solution is optimized by separately adding the main necessary microelements and/or combinations of these microelements to different small parts of the resulting aqueous solution, and, after keeping an equal amount of biomass that has undergone mutagenic adaptation in these parts for a certain time, selecting those microelements and/or combinations of these microelements that maximize the acceleration of the transmutation process, and then, in the third stage, adding the selected microelements and/or selected combinations of microelements to the aqueous solution to be purified in the required amount, ensuring the maximum rate of transmutation of radioactive isotopes in the entire volume of the aqueous solution to be purified, after which the biomass is removed from the purified water.

The duration of the third stage is determined by the time it takes to achieve the required value of residual radioactivity of the purified solution.

In this invention, in order to block the direct absorption of radionuclides by the biomass of microorganisms without their transmutation, a sufficient amount of those microelements necessary for the growth of the biomass and which are stable analogues (stable isotopes) of

those radionuclides that need to be disposed of are introduced into the water or biomass to be purified.

[0020]

In one embodiment of the invention, after combining the microbial biomass with the nutrient medium, it is granulated in the presence of compounds that form stable, water-resistant granules whose structure does not impede the free movement of water and dissolved salts and radionuclides throughout the granule volume. In one embodiment of the invention, the microbial biomass is formed using syntrophic associations of aerobic and anaerobic microorganisms.

[0021]

Preferably, for the purpose of purifying solutions containing seawater (not freshwater) or based on such water from radionuclides, a biomass of microorganisms is used, including microbial syntrophic associations in a viable state, adapted to seawater, for example, based on viable sludge, for which seawater is a natural habitat.

[0022]

Preferably, during the third stage of the transmutation process, continuous mixing of the

aqueous solution with the biomass and/or blowing air (bubbling) through the aqueous solution with the biomass is carried out.

[0023]

When purifying aqueous solutions from radionuclides Cs^m and Sr⁹⁰ by transmuting them into stable isotopes of other elements from the nutrient medium, it is preferable to exclude (or reduce the concentration) of the elements Mg and K.

[0024]

The above-mentioned distinctive features make it possible to implement a method for purifying aqueous solutions containing radionuclides of some chemical elements by transmuting them into stable isotopes of other chemical elements.

[0025]

Fig. 1 shows the spectrum of relative intensity of gamma radiation of reactor isotopes contained in purified water, 10 days after removal from the active zone of a water-cooled nuclear reactor.

[0026]

Figure 2 shows the dependence of the activity Q(t) of the reactor isotope La¹⁴⁰ in samples of reactor water in the transmutation experiment (activity Qcuitures in cuvettes in the presence of granules containing syntrophic associations of metabolically active microorganisms) and in control cuvettes without microorganisms (activity Qcontroi)-

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[0027]

In fig.

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3. accelerated utilization (deactivation) of the isotope Cs¹³⁷ in “biological cells” in the presence of microbiological granules and various chemical elements is shown.

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- Cs¹³⁷(control), τ* « 30 years; 2 - Cs¹³⁷+ granules + KCl, τ* « 10 years; 3 - Cs¹³⁷+ granules + NaCl, τ* « 480 days; 4 - Cs¹³⁷+ granules, τ* * 380 days; 5 - Cs¹³⁷+ granules + CaCO3, τ* * 310 days.

[0028]

Fig. 4 illustrates the principle of formation of giant fluctuations of momentum and kinetic energy in a coherent correlated state (on the right).

[0029]

The process of isotope transmutation in a growing microbiological culture and syntrophic association of such cultures is associated with two factors.

The first of these relates to the actual biological processes of using and assimilating chemical elements in metabolic processes, and the second to the physical processes of nuclear transformation stimulated by biological processes.

[0030]

The growth process of any specific biological object requires a strictly defined set of chemical micro- and macroelements.

The absence of even one of these elements completely inhibits this growth.

[0031]

Vital elements include:

[0032]

O (typical concentration in living culture is about 24%), H (about 64%), C (about 9%), N (about 0.13%)).

[0033]

Microelements necessary for the growth of various biological crops include:

[0034]

Na (7.10-³%), K (4.5.10-²%), Ca (7.5.10^{"2}%), Mg (2.10 ^{"2}%), Fe (8.10["]%), P (1.3.10^{"2}%), Si (3.5.10<sup>"2< /sup>%), C1 (7.

KG³%), A1 (6.10^{"3}%), B (6.

W⁴%), Ti (10^{"4}%), Zn (3.10-⁵%), Li (U⁻⁴%), Cu (10^{"5}%), Sr (10^{"5}%), Ba (5.10^%), F (EVIL^{"5}%), Br (6.10^{'6}%), Rb (4.10["]%), Sn (10 ⁶%), Ni (5.10<sup>"6< /sup>%), Mo (10^{'6}%), Co (10^%).

[0035]

The concentrations given are typical, but may differ several times for different crops.

[0036]

For some of their microbiological cultures, microelements S, Mn, J, Hg and others are also necessary.

[0037]

In the absence of any of the necessary chemical elements, it can be replaced by a biochemical (stereochemical) analogue that has a similar ionic radius and the same (or similar) valence.

In particular, if the atoms of the required chemical element are absent from the nutrient medium, but they can be formed in the process of nuclear synthesis from suitable nuclides, then after the synthesis process, the newly formed nucleus of the required element, together with its electron environment, is immediately integrated into the growing culture.

A similar situation corresponds to the case when, in the absence of atoms of the required chemical element, the synthesis process leads to the formation of its stereochemical analogue.

[0038]

The process of “integrating” the synthesized element (isotope 1) into a growing biological system is, in fact, the process of fixation and irreversibility of this synthesis.

The process of nuclear fusion occurs with the participation of the original nuclei due to, for example, a short-term fluctuation in energy δE over a time of 5t.

If this fluctuation is sufficient to overcome the Coulomb barrier of the reaction and, as a result of the reaction, energy ΔE>δE is released over time δί, then the synthesis process becomes irreversible.

In the opposite case, when ΔE< δE, the reaction is reversible and does not lead to the formation of the required isotope.

[0039]

Another feature of the claimed method is the use of not pure microbiological cultures, but syntrophic microbiological associations, including many thousands of different types of microorganisms belonging to different physiological groups, which represent different groups of microbial metabolism and are characterized by different mechanisms of microbial accumulation.

[0040]

These microorganisms are not in the form of a simple mechanical mixture.

They coexist in a syntrophic association in such a state of joint symbiosis that, in fact, they form a single macroorganism (albeit with separate internal metabolic systems).

Within its scope, each member and each physiological group of the community is maximally adapted to joint life and is in a state of collective mutual assistance and mutual protection.

This system has a high adaptability to various variations and "aggressive" manifestations of the external environment (in particular, to high levels of radiation, the presence of toxins or low pH values).

[0041]

In each type of specific biochemical environment, the most favorable conditions for development are found in microorganisms belonging to a specific physiological group.

All other groups of the syntrophic association "play" a supporting role, working for the leader, who develops most effectively.

When external conditions change (change in temperature, change in the composition of the nutrient medium, the action of toxins and ionizing radiation, additional action of free radicals, etc.), the role of leader can pass to another physiological group, maximally adapted to the changed conditions.

Former leaders become participants in collective assistance, contributing to the development of the leading group and the association as a whole.

[0042]

This system turns out to be maximally adapted to changing aggressive conditions, which corresponds to their growth, including under conditions of radiation exposure.

The effectiveness of such "collective defense" is extremely high.

It is known, for example, that in an acidic environment with pH = 2 (concentrated hydrochloric acid) no “pure” strains of microorganisms can develop.

At the same time, the syntrophic association, after a certain transitional period of adaptation, successfully grows and develops in such an environment.

The time interval for complete adaptation corresponds to the change of 5-10 generations, which allows us to estimate this interval as a period from 10 hours to 10 days.

[0043]

In the experiment, the water under study had an activity of about 10^{"4}Ci/l and contained a number of highly active unstable isotopes (in particular, Na²⁴, K⁴⁰, Co⁶⁰, Sr⁹⁰'⁹¹, I¹³¹, Xe, Ba¹⁴⁰, La¹⁴⁰, Ce¹⁴¹, Np²³⁹) see.

Fig.1.

[0044]

Water samples of equal volume (about 5 ml) were placed in identical thin-walled glass cuvettes with a volume of about 10 ml.

An equal amount of granulated microorganism biomass was placed in a portion of the cuvettes with radioactive water.

The remaining cuvettes with similar radioactive water but without the presence of granulated biomass served as controls.

[0045]

The studies were conducted based on an analysis of the amplitude changes of spectral lines with energies exceeding 500 eV. This was done to improve accuracy, as the softer radiation is significantly affected by the Compton background and absorption by the bulk of water in the cuvette.

[0046]

Figure 2 shows the averaged results of the dependence of the activity of the La¹⁴⁰ isotope in the experimental cuvettes (Qcuitures) and in the control cuvettes (Q_{CO}ntroi) on the time after the start of the experiments.

This isotope has a relatively short lifetime (τ = 40.3 hours), is formed by beta decay Ba^т— > La¹⁴⁰+ β[~]+ ν and is a daughter unstable isotope of the longer-lived isotope Bλ4°, which has a lifetime of τba⁼12.7 days.

[0047]

The initial specific activities of the isotopes Ba^ш and La¹⁴⁰ (on the 10th day after taking a water sample from the reactor core) for each of the cuvettes were, respectively,

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[0048]

Q_{Bal40}IV = 5400 bkll and Q^IV = 8500 bkll.

Since (ti« tva), the observed decrease in La¹⁴⁰activity reflected a decrease in Ba¹⁴⁰activity.

[0049]

It was found that the decrease in the activity of La¹⁴⁰ in the control cuvettes approximately corresponded to the law of the "standard" decay of the Ba isotope with a "tabular" value of the lifetime.

The same law of decreasing La¹⁴⁰activity was observed in cuvettes with granules up to the 10th day of the experiment.

After this initial period of adaptation, periodic measurements showed that the rate of decrease in the activity of La¹⁴⁰ (and hence the activity of Ba^ш) corresponds to (is equivalent according to the law of change in activity) a more accelerated decay.

Extrapolation showed that the effective lifetime of this isotope decreased by approximately 2 times in relation to the lifetime of Ba^ш.

[0050]

These results can be explained on the basis of the assumption that the radioactive isotope Ba^{XA} is transformed in the experimental cuvettes into a non-radioactive isotope of another chemical element.

In this case, the presence of an initial, unchanging section in the decay law can be explained by the above-discussed processes of adaptation of the microbiological association to the action of radioactive irradiation in a cuvette with active water.

This time (about 10 days) correlates well with the expected time for the change of 5-10 generations of microbiological cultures.

[0051]

An analysis of possible isotope transformations showed that in this case the following transmutation reaction of the radioactive isotope Ba^ш to a stable nucleus of a different type is possible

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[0052]

Ba⁴⁰+ C -> Smⁱⁿ

[0053]

This reaction is energy-favorable and is characterized by positive reaction energy.

The carbon required for this reaction is contained in excess in the volume of microbiological granules.

[0054]

Due to the law of constancy of the chemical composition of biological objects, which is one of the fundamental properties of living matter, the reaction of isotope transmutation in a biological system will be possible in the case where the result of the reaction is an isotope corresponding to a chemical element, which is either itself one of the necessary chemical elements, or is a biochemical analogue of such an element.

In the latter case, it should have approximately the same ionic radius and, preferably, the same valence.

In this case, the reaction efficiency will be high only when the required chemical element or its biochemical analogue is not contained in the nutrient medium or is contained in small quantities.

[0055]

Comparison of the Sm²⁺ and Ca²⁺ ions shows that they are biochemical analogues and have a similar ionic radius in the divalent state (Rsm « 1.2 A, Rca « 1-06 A).

Calcium is one of the essential elements, and if its concentration in the volume of microbiological granules was small, it can be argued that the growing microbiological association could compensate for the lack of calcium by synthesizing its biochemical analogue (samaria).

[0056]

It is also necessary to take into account that the composition of granulated biomass, which is formed on the basis of natural syntrophic associations obtained, for example, on the basis of fermented waste products of animals or natural sludge, can have a different chemical composition.

To optimize the growth of this biomass, a balanced complex of essential macro- and microelements is required.

The composition of the latter can only be determined experimentally by independent addition of essential microelements and analysis of the associated changes in the efficiency of the transmutation process.

[0057]

The studies used identical closed glass cuvettes, each containing 10 ml of distilled water containing a solution of SU¹³⁷with a specific activity of Q_{Cs}m & 2A0⁶bq/l.

[0058]

The same number of granules was placed in 7 cuvettes.

In 6 cuvettes, purified salts of K, Ca, Na, Fe, Mg and P were additionally added to the active water, respectively.

These chemical elements are among those necessary for the development of any biological system.

Two additional cuvettes were used as controls: one containing radioactive water and pellets (but no additional salts), and the other containing only radioactive water.

[0059]

All cuvettes were closed and kept at a temperature of 20°C. The amplitude spectrum of gamma radiation from the cuvettes was measured every 7 days on the same detector.

Particular attention was paid to reducing the influence of errors associated with the measurement process.

For this purpose, low-height cuvettes were used, and a detector with a large Ge crystal diameter was used. The cuvettes were positioned in the same position in the center of the detector crystal for each measurement.

[0060]

The results of the change in the activity of the isotope Cs¹³⁷ are presented in Fig.

Z.

[0061]

In a control cuvette containing only radioactive water, the change in the activity of the Cs isotope corresponded to standard spontaneous decay with a lifetime of about 30 years.

[0062]

The fastest decrease in activity (it was equivalent to a 35-fold decrease in lifetime to τ* « 310 days) was observed in the cuvette containing calcium salt.

In a cuvette containing additional potassium salt, the decrease in Cs¹³⁷activity corresponded to a lifetime of 10 years.

This decrease in activity was not due to accelerated decay, but was the result of a reaction in

which the radioactive isotope Cs'³⁷ was converted into a stable isotope of another element.

[0063]

The presumed disposal of the radionuclide Cs¹³⁷ is associated with a reaction involving water protons.

The result of the reaction is the stable isotope Ba^ш.

[0064]

The Ba²* and K* ions are biochemical analogues; they have approximately the same ionic radii in the divalent state (R^ « 1.4 A, RR * 1.33 A).

Since the replaced element (potassium) is one of the essential microelements, the probability of such a replacement seems quite high and the synthesized barium ions can replace potassium ions in metabolic processes during crop growth.

This replacement appears to be more effective than the “direct” replacement of potassium

with cesium in the case of potassium deficiency (this is evident from the large difference in the ionic radii of cesium Rc_s« 1.65-1.69 A and potassium R« 1.33 A).

It should be noted that a similar replacement of ions was previously observed and analyzed in experiments with the microbiological culture of Blastocladiella emersonii [Van Brunt J., Caldwell J. H., Harold F. M. Circulation of potassium across the plasma embryo of Blastocladiella emersonii: K-chanel // J. Bacteriol., 1982, v.150, N 3, pp.

1449-1561].

In these experiments, the replacement of K ions by Rb⁺ and Ba²* ions was recorded.

These ions can replace each other in processes associated with ion transport through the membrane into the cell.

[0065]

Another very dangerous radionuclide formed during the fission process and contained in spent reactor fuel is the isotope Sr⁹⁰.

This isotope can be utilized by conversion into different stable isotopes of other elements in one of the reactions

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[0066]

_{3S}Sr⁹⁰+_nNa" =₄₉In^{u3}

[0067]

These reactions produce stable isotopes of Ru, Pd and In, which are biochemical analogues of such essential microelements as, respectively, Fe and Mg, Ca and Mg, Fe and Mg.

This correspondence is determined by the approximate equality of the ionic radii of these elements.

[0068]

D£ = 0.77L; D£ = 0.6 - 0.67;L£ = 0.7 - 0.78L;

[0069]

R = 0.85 - 0.88 A\B& = 0.96 - 1.

4;R²_g= 0.7 - 0.

784

[0070]

R = 0.8- 0.9 R_F* = 0.75 - 0.83; R^ = 0.7 - 0.78 In the absence of these necessary chemical elements, they can be replaced by newly synthesized stable isotopes of the elements Ru, Pd and /// ,.

It is evident that all these elements are, in particular, biochemical analogues of Mg and Fe.

Therefore, in the absence of Mg and Fe in the purified water and active medium, they can be replaced by the products of all three possible reactions of radioactive strontium utilization.

[0071]

The reason for the increased efficiency of utilization when using additional calcium salt is the general pattern of metabolism of microbiological cultures: optimal culture growth corresponds to the required balance of all micro and macroelements.

Presumably, it was calcium deficiency that was the "bottleneck" that inhibited the growth process and the accompanying transmutation in a particular growing microbiological system.

Obviously, when using granules prepared on the basis of other natural syntrophic associations, the effect of different salts may be different and should be determined experimentally.

[0072]

To ensure nuclear interaction between two nuclei, it is necessary to provide conditions for overcoming the Coulomb barrier, which prevents these nuclei from coming together.

The height of this barrier is very large, and its transparency (in the model case of the absence of atomic electrons) can be determined using the dependence cl <img file="

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[0073]

which depends on the total E = μv²/2 and potential (Coulomb) energy V(r) = Z Z₂e²1 g of mutual repulsion of nuclei with charges 2 e and 2₂e .

Here μ = ηι τη₂I{ιηχ+ηι₂) is the “reduced” mass of the interacting nuclei, depending on the mass of each nucleus.

For particles in a state of thermal equilibrium,

[0074]

Taking into account the screening effect of atomic electrons leads to a decrease in the width of this barrier and, accordingly, to an increase in the transparency coefficient, which can be taken into account by introducing additional effective energy, which corresponds to the replacement E = kT + E_{eff}.

When hydrogen atoms interact, E_{eff}m 27eV.

In the case of a biological system, E = E_{eff}, and the transparency of the barrier is equal to a very small value D * 10^{"100}.

[0075]

When heavier nuclei interact, this probability will be much smaller.

For example, during the interaction of cesium and hydrogen nuclei E^ « 300eG, and the transparency of the barrier at a temperature of kT « E_{eff} is equal to £<sup>)< /sup>« 1(¹⁰⁰⁰. Approximately the same negligible probability corresponds to the case when one or both interacting particles (interacting nuclei with the electron environment) are in a stationary potential well.

[0076]

These estimates show that at the temperature characteristic of the growth process of microbiological cultures, “normal” nuclear reactions in living organisms are impossible.

This conclusion corresponds to the case when pairwise interaction of nuclei in free space or in a stationary potential well is considered.

[0077]

In the works of the author (V.I.Vysotskii, MV.Vysotskyy.

"Coherent correlated states and low-energy nuclear reactions in non stationary systems". European PhysicalJoumal. A, 2013, v.49, issue 8: 99; and V.I.Vysotskii, S.V.Adamenko, MV. Vysotskyy. 2013. "Acceleration of low energy nuclear reactions by formation of correlated states of interacting particles in dynamical systems", Annals of Nuclear Energy, 2013, v.62, 618-625), it was shown that in the case of a certain non-stationary deformation of the potential well in which at least one of the interacting particles is located, a significant increase in the transparency of the nuclear barrier occurs. This effect is associated with the formation of coherent correlated states of a particle, for which there is an effect of synchronization and effective addition (interference) of fluctuations of different components of its momentum in a non-stationary superposition state. With such addition, large final fluctuations of the total momentum and fluctuations of the kinetic energy of the particle are formed, which contributes to a significant increase in the transparency coefficient of the potential barrier and, naturally, a similar increase in the probability of a nuclear fusion reaction.

A simple interpretation of this quantum mechanical phenomenon is as follows.

[0078]

In a state of superposition, a particle can be found with different probabilities at different energy levels of the E_npotential well (see Fig. 4).

[0079]

In such a system, the variance of the total momentum of a particle and the average value of the kinetic energy are determined by the formulas

[0080]

< T >= σρ12m

[0081]

In the case of a "normal" (i.e. incoherent and uncorrelated) state, the momentum fluctuations at different states are mutually independent and (ΔρηΔρη} = 0 .

In this case, the average value of the kinetic energy of a particle is determined by the value

[0082]

This relationship corresponds to standard concepts: the average kinetic energy of a particle in a system of quantum levels in a potential well is equal to the sum of the average energies at these levels.

[0083]

In the case of a coherent correlated state (&ρηίφηΦ θ and the average kinetic energy is equal to

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[0084]

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[0085]

< T_{noncorr}> +N²(&p_nAp_n)/2m

[0086]

In this case, there is a significant increase in the average kinetic energy of a particle in a multilevel system.

[0087]

In particular, if

[0088]

then in the case of an incoherent (uncorrelated) state < >= N < Tη>, and for a coherent correlated state < T_{corr}>= (N+ 1) < T_{mncorr}>.

[0089]

It is evident that in this case there is an increase in the average kinetic energy by N + 1 » 1 times.

The presence or absence of such giant momentum fluctuations is schematically depicted by the large vector under the right figure in Fig. 4 and the very small vector under the left figure.

In a real situation, the ratio between these fluctuations is many orders of magnitude greater.

[0090]

Formally, the presence of such a state is characterized by a correlation coefficient determined by the formula

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[0091]

r(t) =< qp + pq > l25q5p, 6q = ^0_q[~], Sp =_yfaT ,

[0092]

as well as a modified uncertainty relation (the Schrödinger-Robertson uncertainty relation)

[0093]

6qdp > hll i - r²The value | r | varies in the interval 0 <| r |< 1 .

In the absence of correlation between the coordinate q and the momentum p of the particle, we have r = 0, and the last formula takes the form of the Heisenberg uncertainty relation dqdp > hi 2.

[0094]

In the limiting case of a completely correlated state | r |-» 1 , the particle momentum dispersion becomes infinitely large, and the transparency coefficient D of any potential barrier increases to a maximum value D— > 1 at an arbitrary low particle energy.

[0095]

In particular, it has been shown in the works that with a rapid monotonic compression of the potential well in which one of the interacting particles is located, the correlation coefficient increases to a value of \ r \> 1 - \0⁶, which leads to an increase in the transparency coefficient by many orders of magnitude from the extremely small values D_{mncorr}« 10^{~100}...1(Γ¹⁰⁰⁰ for "normal" (uncorrelated) states of the particle to a value of - 1.

[0096]

Such potential wells, due to the local heterogeneity of the growth process and the dynamic nature of biophysical phenomena (cell division, DNA replication, etc.), inevitably arise in the growth zone of any biological object, exist for a certain time, and then disappear due to the influence of random collisions of atoms and molecules.

[0097]

In each of these changing potential wells, the formation of coherent correlated particles located in this place is possible for a short time.

If both nuclei potentially suitable for the required synthesis (for example, strontium and hydrogen atoms) are present in this place, then the probability of the reaction of utilization of the radionuclide Cs¹³⁷+ p = Ba^ш will be very high.

[0098]

Moreover, in rapidly growing biological objects there is a continuous self-reproduction of a large number of such contracting potential wells, each of which, in the presence of all the required conditions, is a disposable nuclear microreactor.

In static systems such an effect is impossible.
