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Research Article

Fusion of Light Atomic Nuclei in Vacuum and in Solids and Two Ways of Mastering Nuclear Fusion Energy

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Abstract

Two ways of mastering nuclear fusion energy, viz., controlled thermonuclear fusion and cold fusion, are considered. This paper deals with the intensive cold fusion model, hereinafter referred to as the *chemo*nuclear fusion hypothesis. The determining role of virtual photons and electrons of anomalous internal γ-conversion in cold fusion is shown. The *chemo*nuclear fusion hypothesis for the 2D-, HD- and (^{7}Li–^{1}H)$_{\rm gas}$-transition metal systems provides an explanation of cold fusion. It is demonstrated that this hypothesis can serve as a base for the development of cold fusion reactors.

Keywords: Anomalous γ-conversion, *Chemo*nuclear fusion, Cold fusion

1. Introduction

Nowadays, the radical solution of ecological and energy problems of the Earth is associated by scientists with the development of nuclear fusion, which present an inexhaustible source of energy. In recent years, consideration has been given to two ways of achieving nuclear fusion: creation of controlled nuclear fusion reactors ("thermonuclear fusion" [1]), and creation of cold fusion reactors (HTE-Cat, "Rossi reactor") [3,4].

It is well known that the non-recognition of any cold fusion research results by the scientific community is based on the universal approval of three theoretical restrictions on the occurrence of low-temperature transmutation of chemical elements [5]: (a) the impossibility of overcoming the Coulomb barrier, (b) extremely small cross-section values of weak processes, and (c) the low probability of multiparticle collisions.

The analysis of numerous cold fusion results (including our results) has led us to the conclusion that the three restrictions listed above are valid only for reactions occurring in vacuum [11,12]. In cold fusion conditions, when the reactions take place in solid-state matter with the participation of virtual photons and electrons of anomalous internal $\gamma-$conversion, the restrictions may be removed, and the process of fusion would be intensified (Section 3.2). This

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phenomenon has been investigated on 2D-, HD- and $(^7\text{Li}–^1\text{H})_{\text{gas}}$-transition metal cold fusion systems. We begin our consideration with the 2D-palladium system, which has received the most study.

2. Three Channels of 2D-fusion Reactions in Vacuum and the Controlled Thermonuclear Fusion Reactor Development

It is known that 2D-fusion reactions in vacuum can be carried out with various probabilities at three channels (see Table 1).

As follows from Table 1, the current practical interest is based on the cross-section values of reactions 1 and 2 in Table 1, because the reaction probability in channel 3 is seven orders lower. For this reason, the thermonuclear scientists of the whole world focus their research efforts on the realization of reactions reactions 1 and 2 in Table 1, and in the first place, on investigating the easier processes, viz. the d–T reactions. Historically, this was the first path to nuclear fusion development [1].

As is known, the nuclear reaction cross-section for fusion

$$\sigma = (S\,(E)/E) \cdot P\,(E) \tag{1}$$

is given by the product of "internal nuclear cross-section"

$$\sigma_0 = S(E)/E \tag{2}$$

by the quasi-classical probability $P(E)$ of charged particle penetration through the Coulomb barrier $V(r)$:

$$P(E) = \exp\left[-2W(E)\right],$$

$$W(E) = \int_{r_1}^{r_2} \sqrt{2\mu(V(r) - E)}\, \mathrm{d}r/h = \sqrt{2\mu\langle V(E)\rangle}\, |r_2 - r_1|\, /h, \tag{3}$$

where $S(E)$, being "the astrophysical factor," is a slowly varying function of particle energy, which at a low relative energy of interacting particles in case of non-resonant nuclear reactions is constant, $S(E) = S_0$ (for non-resonant. reactions of 2D-fusion $S_0 \approx 0.11$ MeV barn); $r_2 - r_1$ – classical "rotational displacement points" at moving of one of particles in the field of another; μ – the reduced mass of interacting particles; $\langle V(E)\rangle$ – medial height of the potential barrier lying above level E.

From (3) follows that the barrier width $(r_2 - r_1)$ which is a linear function of coordinates, influences penetrability of a barrier more essentially, than its medial height $\langle V(E)\rangle$ does entering in (3) in the form of square root.

Table 1. Reaction channels of 2D-fusion in vacuum

Ch. No.	Reaction (within brackets particle energy in MeV)	Penetrable barrier, MeV [7]		Energy yield (MeV)	No. of reactions per 1 W in 10^{12} s^{-1} of energy yield	Reaction cross-section at $E = 1$ keV, cm^2[8]	Reaction yield on channels (%)
		Coul.	Nucl.				
1	d+d $\rightarrow {}^3$He (0.82) +n (2.45)	0	2.2	3.27	1.9	$\sim 6 \times 10^{-33}$	~ 50
2	d + d$\rightarrow$T(1.01) + p(3.02)	0.4	2.2	4.03	1.6	$\sim 6^{-33}$	~ 50
3	d + d $\rightarrow {}^4$He $+\gamma$(23.8)	0.4	0	23.8	0.26	$\sim 1 \times 10^{-40}$	$\sim 1 \times 10^{-5}$

From (2) and (3) it follows that the particle's energy, the Coulomb barrier width and the astrophysical factor value could be the factors defining the reaction rate of deuterium fusion in vacuum. However, for double reactions of traditional hot fusion of deuterium only the first of the named factors has a practical value.

The most widespread method of overcoming Coulomb forces in thermonuclear research is to heat the medium containing atoms of deuterium (or deuterium and tritium) to a temperature high enough that the kinetic energy of these atoms ensures their collision energy is sufficient to trigger fusion reactions by approaching the nuclei. The scientific basis of thermonuclear fusion reactors is well studied [1]. High-temperature deuterium–tritium or deuterium plasma serve as an actuation medium for a controlled thermonuclear reactor. For a reactor producing DT-reactions or 2D-fusion reactions, channels 1 and 2 of Table 1 will be active. A fusion reaction in the thermonuclear reactor occurs with collisions of non-screened ("bare") nuclei that have randomly oriented spins. The low cross sections of these reactions are a main source of difficulty to making a controlled thermonuclear reactor. The temperature of the deuterium-tritium mixture in such a reactor equals approximately 2×10^8 K (10 keV), and for deuterium plasmas this temperature is even higher. The problem of maintaining this temperature over time, sufficiently high enough for a positive energy yield, presents colossal engineering difficulties. To overcome these difficulties major projects with thousands of researchers worldwide have been working for many decades.

Table 2. Some hypothetical nuclear processes involving bineutron and neutron in systems: deuterium–palladium and deuterium–hydrogen–palladium [6,11,12].

$$\begin{aligned}(\mathrm{D}^+ + \mathrm{e}^- + \mathrm{D}^+ + \mathrm{e}^- + \mathrm{D}^+) &\to (\mathrm{D}^+ + \mathrm{e}^- + \mathrm{D}^+) + \mathrm{D}^+ \to ({}^4\mathrm{He}^* + \mathrm{e}^-) + \mathrm{D}^+ \\ &\to {}^4\mathrm{He}_{\mathrm{g\ s}} + \mathrm{e}^-_{\mathrm{conv}}(\Sigma E_{\mathrm{conv}}) + \mathrm{D}^+ \to {}^4\mathrm{He}_{\mathrm{g\ s}} + {}^2\mathrm{n} + \nu_{\mathrm{e}},\end{aligned} \tag{4}$$

$$\begin{aligned}(\mathrm{D}^+ + \mathrm{e}^- + \mathrm{D}^+ + \mathrm{e}^- + \mathrm{H}^+) &\to (\mathrm{D}^+ + \mathrm{e}^- + \mathrm{D}^+) + \mathrm{H}^+ \to ({}^4\mathrm{He}^* + \mathrm{e}^-) + \mathrm{H}^+ \\ &\to {}^4\mathrm{He}_{\mathrm{g\ s}} + \mathrm{e}^-_{\mathrm{conv}}(\Sigma E_{\mathrm{conv}}) + \mathrm{H} \to {}^4\mathrm{He}_{\mathrm{g\ s}} + \mathrm{n} + \nu_{\mathrm{e}},\end{aligned} \tag{5}$$

$$46^{104}\mathrm{Pd}^* + {}^2\mathrm{n} \to {}^{106}_{46}\mathrm{Pd}^* \to \begin{cases} \to f \left\langle \begin{matrix} \mathrm{Nu}_1({}^{58}_{26}\mathrm{Fe}), \\ \mathrm{Nu}_2({}^{49}_{20}\mathrm{Ca}), \end{matrix}\right. & \text{(5a)} \\ \to {}^{105}_{45}\mathrm{Pd} + \mathrm{n}(8.48\,\mathrm{eV}), & \text{(5b)} \\ \to {}^{105}_{45}\mathrm{Rh}(\beta,\ 35.4\,\mathrm{h}) + \mathrm{p}(7.2\,\mathrm{eV}), & \text{(5c)} \\ \to {}^{102}_{44}\mathrm{Ru} + \alpha(11.6\,\mathrm{eV}), & \text{(5d)} \\ \to {}^{106}_{46}\mathrm{Pd} + \mathrm{e}^-_{\mathrm{conv}}(\Sigma E_{\mathrm{conv}}), & \text{(5e)} \end{cases}$$

$$\mathrm{d} + {}^2\mathrm{n} \to \mathrm{T}(1.56\,\mathrm{eV}) + \mathrm{n}(4.64\,\mathrm{eV}) \to \mathrm{d} + \mathrm{T}(1.56\,\mathrm{eV}) \to \alpha(6.9 - 1.44\,\mathrm{eV}) + \mathrm{n}(12.5 - 17.7\,\mathrm{eV}), \tag{6}$$

$${}^{104}_{46}\mathrm{Pd} + \mathrm{n} \to {}^{105}_{46}\mathrm{Pd}^* \to {}^{105}_{46}\mathrm{Pd}_{\mathrm{g\ s}} + \mathrm{e}^-_{\mathrm{conv}}(\Sigma E_{\mathrm{conv}}). \tag{7}$$

The numeral ΣE_{conv} designates the total energy of nuclear reaction which is carried away by conversion electrons (e^-_{conv}).

At the same time, as was noted for the first time in [7], we can expect that under certain conditions the fusion reaction 3 in Table 1, as an energy source, will be favored. Authors of this work pay attention to the fact that reaction 3 in Table 1 for its realization demands only overcoming a rather low Coulomb barrier ~0.4 MeV, while reaction (1) is interfaced to a rupture of nucleus of deuterium 2.2 MeV, and a reaction 2 with that and another: ~0.4 and 2.2 MeV. Because the tunneling reactions to an extremely strong degree depend on barrier height and barrier width, there are reasons to expect that under conforming conditions reaction 3 can become a favorable source of pollution-free nuclear energy. However, implementing this concept presents huge difficulties.

The problem is that the low cross section of a reaction on channel 3 is due to the fact that only one particle figures in the outcome. As is well known, for such reactions, the laws of conservation of energy and impulse can be fulfilled simultaneously only under conditions when the lifetime of the excited nucleus exceeds the time necessary for a discharge of the nucleus excitation energy.

The energy discharge of the excited nucleus of helium by γ-quanta radiation is impossible. According to the selection rules, the birth of a photon is forbidden for transitions when initial and final states of the nucleus both have spins equal to zero as it takes place for the ground state and for the first two excited states of $^4\mathrm{He}^*$. In the case of 2D-fusion, an excited virtual $^4\mathrm{He}^*$ compound-nucleus exist for $\sim 10^{-22}$ s [9]. Until now, no process has been proposed which would make it possible to remove the excitation energy of the nucleus in such a short time, and consequently it is considered that a fundamental prohibition of a reaction passing on channel 3 (Table 1) must exist.

3. Cold Fusion – 2D-Fusion Reaction in Solids (“Chemonuclear” Fusion)

3.1. Introduction

The second way to master nuclear fusion energy is by exploring cold fusion. This was disclosed in 1989 when Fleischman and Pons published sensational results of their research of this phenomenon [2][a]. Unlike the enormous technical difficulties developers of thermonuclear fusion reactors have met, practical development of cold fusion, in particular, development of $(^7\mathrm{Li}–^1\mathrm{H})_{\mathrm{gas}}$–nickel system was much easier and has far outstripped the creation of a theoretical basis of this phenomenon. The E-Cat reactor presentation was held by S. Focardi and A. Rossi in March 2011 in Italy [3]. Since then work of “Rossi reactor” “cell” has already been successfully reproduced in a number of countries (Russia, China, Kazakhstan, etc.) [10].

In 2012, our claims to explain the intensive (self-sustaining) cold fusion [11][b] were published. The fusion model offered in this work is the *chemo*nuclear fusion hypothesis is a complex, two-stage, cluster fusion process of light nuclei in deuterium–metal and natural hydrogen–metal systems (see below) which has passed from the moment of the publication of works [11] four years has undergone experimental testing and has gained further development in [6], in this paper and confirmation in our verification experiment [13]. *Chemo*nuclear fusion hypothesis is consistent also with the results carried out in this period by a group of independent experts in Lugano (Switzerland) the HTE-Cat reactor study [14]. Today this gives reason to consider a *chemo*nuclear fusion hypothesis [6] a consistent qualitative intensive cold fusion model in 2D-, HD- and $(^7\mathrm{Li}–^1\mathrm{H})_{\mathrm{gas}}$-transition metal systems.

The main positions of the *chemo*nuclear fusion hypothesis are set forth in Section 3.2 for the example of the Fleischmann and Pons experiment analysis.

Let us focus on the history of this model development.

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[a] Fleischman–Pons electrolysis experiment and its results interpretation from the perspective of the *chemo*nuclear fusion hypothesis is described in Section 3.2.

[b] This work was published in journal in April 2013 [12].

3.2. Intensive cold fusion – 2D-fusion reactions in solids with virtual photons and electrons of anomalous γ-conversion participation

In our approach to studying cold fusion, we proceeded from the assumption that the probability of tunneling through the Coulomb barrier at temperatures of cold fusion experiments is extremely small and virtually eliminates the occurrence of nuclear reactions. With this in mind, in one of our earlier works [15] (1991), we already assumed that a two-stage cold fusion natural process and formation in cold fusion conditions of the accelerator mechanisms is able to accelerate charged particles to energies up to $\sim$1 keV. We proposed to call this phenomenon “nuclear fusion in matter” (NFM). We used this phenomenon name in [6,11–13] and here.

Since we first published studies on this method, anomalously high heat generation and low radioactivity from cold fusion processes have given us reasons to intuitively expect that cold fusion is a result of nuclear reactions occurring in 2D-fusion on “light,” not interfaced with the rupture of nuclear bonds, neutronless channel 3 (in Table 1). The confidence level in this type of fusion process increased after the Bush and Lagowski experiments [16] obtained correlations between the energy generation and ^{4}He yield. This work has been confirmed as a reaction of cold fusion [15]. We expected and stated that in such conditions the interdiction of the reaction on channel 3 had disappeared. This result did not contradict the foundations of modern nuclear physics because, as mentioned above, the prohibition of photon birth relates to events in vacuum. Removal of excitation energy of the nucleus in solid-state matter can be carried out by the “anomalous” internal γ-conversion virtual photon on which birth the specified above interdiction does not apply. In solid-state matter a virtual photon transmits energy to the “anomalous” internal γ-conversion electron and process of energy discharge of the excited nucleus is terminated by energy absorption of a conversion to an electron by the matrix.

The anomalous process of conversion by “penetration” electrons is the process in which the electron penetrates into the nucleus more deeply than the nucleon with which it interacts in the course of conversion at the moment of nuclear transition (the “penetration effect”). One essential role of this effect in the case of strongly slowed γ-transitions was specified for the first time in Church and Wenser’s work [17] in 1956. In that same work, the experimental results relating to this effect were analyzed. Many authors have conducted further similar analysis of experiments, the phenomenon has gained wide recognition, and tables of known anomalous cases of the coefficient of electronic γ-conversion [18] have been compounded.

Let us estimate the parameters of an internal γ-conversion, which could ensure – in the conditions of cold 2D-fusion – a timely energy discharge of the excited ^{4}He* nucleus and, thereby, would remove the prohibition for fusion passing in the “light” channel 3, Table 1. For this purpose, let us use the scheme of 2D-fusion reaction decay channels (Fig. 1) from Ref. [19].

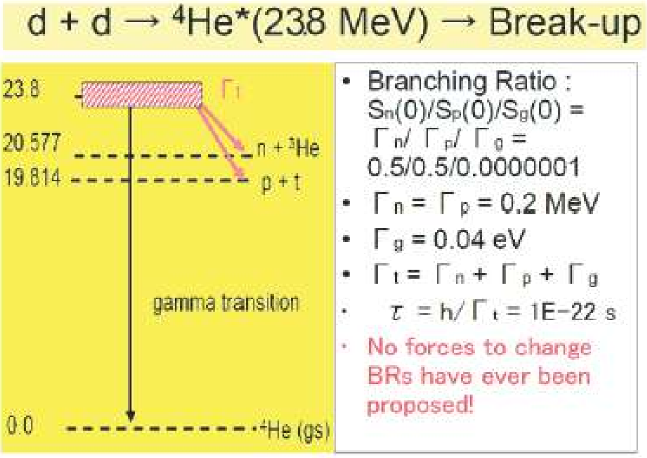
According to this scheme ^{4}He* nucleus excitation energy decreases from 23.8 to 19.8 MeV ($\Delta E = 4$ MeV) on channels 1 and 2 in Table 1 forbids the decay of the nucleus. The further energy discharge of ^{4}He* excited nucleus is carried out already by standard for these conditions γ-conversion $\Delta E \leq 9$ keV [11,12] (“standard” γ-conversion in this case is energy transfer from nucleus to electrons owned by an electronic shell of a quasimolecule (the cluster–heavy superficial atom of matrix). Let us estimate, proceeding from an uncertainty principle [50]

$$\Delta E\,\Delta t \approx h, \tag{8}$$

the greatest possible distance ΔR of an electron from the excited ^{4}He* nucleus on which the virtual photon still can carry out transmission to an electron energy $\Delta E = 4$ MeV and time necessary for transmission Δt.

$$\Delta t = h/\Delta E \approx 1.6 \times 10^{-22}\text{s}, \tag{9}$$

$$\Delta R = \Delta t\, c \approx h/\Delta E\, 3 \times 10^{10}\text{s} \approx 4.9 \times 10^{-12}\text{cm}. \tag{10}$$



- Branching Ratio : $S_n(0)/S_p(0)/S_g(0) = \Gamma_n/\Gamma_p/\Gamma_g = 0.5/0.5/0.0000001$
- $\Gamma_n = \Gamma_p = 0.2$ MeV
- $\Gamma_g = 0.04$ eV
- $\Gamma_t = \Gamma_n + \Gamma_p + \Gamma_g$
- $\tau = h/\Gamma_t = 1E{-}22$ s
- No forces to change BRs have ever been proposed!

Figure 1. 2D-fusion reaction decay channels.

The results obtained can be treated so that in the conditions of cold fusion in a deuterium-loaded metal matrix are the transitive formations, the "deuterium microclusters" in which distance "trapped electron"– merge of deuterons zone does not exceed the specified above value of $\Delta R \approx 4.9\times\ 10^{-12}$ cm. It is important to note that the close values for Δt and ΔR can be gained with another approach. According to A.S. Davidov's theoretical calculations, the maximum admissible radius of a deuteron in the conditions of cold fusion can reach $r \sim 4\times\ 10^{-12}$ cm [20]. Then time Δt, necessary for transmission by virtual γ-quantum to an electron captured in "microcluster" of excitation energy portion $\Delta E = 4$ MeV will be $\Delta t = r/c \approx 1.33\times\ 10^{-22}$ s, and the distance $\Delta R = r\ \approx\ 4\times\ 10^{-12}$ cm.

Note that the obtained value of ΔR is five times smaller than of muon orbits radius ($4.9\times\ 10^{-12}$ and $25\times\ 10^{-12}$ cm, respectively). Therefore, the process of fusion in conditions of intense cold fusion should proceed at velocities significantly higher compared to the muon catalysis.

The conversion electron yield in cold fusion experiments is poorly understood.

However, as has been indicated in our study [11], the radiation detected by Karabut in cold fusion experiments outside the discharge chamber (see [21]), may give evidence to the yield of 5–6 MeV electrons, and this is in qualitative agreement with the *chemo*nuclear 2D-fusion hypothesis. The yield of conversion electrons of the $\sim 10^6$ eV energy range in the course of intense cold 2D-fusion is attested by the results of work [22]. However, the authors of this work and the author of [21] do not consider the participation the phenomena of anomalous γ-conversion in the process of fusion [11,12].

These data and the results of theoretical studies by Gryzinski, Barut and Vigier (see below) have encouraged us to start work on the development of the two-stage, cluster cold fusion model, i.e., the *chemo*nuclear fusion hypothesis. The main requirement of the model was that it had to explain the functioning of the anomalous internal γ-conversion in cold fusion conditions with parameters ΔR and Δt obtained above.

The first person who has predicted the existence of "microclusters" (H^++e^-+H^+ quasimolecules) in the hydrogen-filled transition metal matrix was Gryzinski.

The idea that electrons are responsible for tunneling of protons through the Coulomb barrier was developed and advanced for the first time by Gryzinski in his research on chemical bonds in research from 1967 to 1987 [23–26]. Studying within the limits of the classical physics the bound states of the system consisting of two protons and an electron, Gryzinski discovered that there is a whole class of solutions when the attraction between protons and negatively charged electron predominates over pushing apart of protons, and two originally free nuclei can come nearer to each other over very small distances and organize a quasimolecule (H^++e^-+H^+). Gryzinski concludes that overcoming of the Coulomb barrier during atomic collisions by tunneling of particles is a process of three bodies, one of which is an electron. Addressing the phenomenon of cold fusion Gryzinski in 1989 in work [26] in "Nature" journal concludes: "… basically, two deuterons in the presence of an electron can merge at any temperature," and in 1990 he published his quasimolecular cold fusion model [27].

In 1990 Barut [28], using the Bohr–Zommerfeld quantum theory of metals, came to a similar conclusion about the existence in a three bodies system (two deuterons and one electron) of the superbonded metastable quasimolecule -D_2^+, which gained for quasimolecule energy bond a value of 50 keV. In 1992 Vigier [29] published an analysis very similar to Barut's analysis.

For various reasons, the cold fusion model proposed by Gryzinski [27] has not received recognition [11,12]. One of the main reasons for this is the fact that, as noted in review [30], in real cold fusion conditions in condensed matter, the existence in the proposed model of strict symmetry of the quasimolecule, and consequently, it's long existence – is an extremely unlikely event. The second reason is that in research specially carried out to search for a superbonded quasimolecule, the particle has not been confirmed [31]. An essential drawback in the model [27] is that the timely energy discharge mechanism of a fused nucleus is not offered [6].

In the *chemo*nuclear fusion hypothesis [11,12] the "Gryzinski quasimolecule" exists already only as a short-lived transition state of the interacting particles system. In work [6] the *chemo*nuclear fusion hypothesis gained further development. In this work the necessity of participation of a "Gryzinski quasimolecule" cluster in a successful cold fusion experiment is shown. We will demonstrate how the *chemo*nuclear fusion hypothesis explains the sensational Fleischman and Pons electrolysis experimental results [2].

The saturation of a palladium matrix by deuterium serves as the basic process of Fleischman and Pons experiments. Saturation of a transition metal matrix by deuterium in electrolysis experiments is followed by a growth in matrix of internal tensions and accumulating of a large number of "voids" in it with sizes ranging from macrocracks to subatomic size pores [11,12]. In the process of fusion, the voids in the matrix are filled by deuterium. It is important to note that in voids deuterium is in the form D_2 molecules. Irradiation of molecular deuterium by a flow of energetic conversion electrons is followed by generation in a deuterium of D_2^+ diatomic ions. According to Gryzinski, Refs. [23–27] representations developed in works, a certain part of diatomic ions of a deuterium will be transformed at the same time to a quasimolecule D^++e^-+D^+ ("Gryzinskis quasimolecule" [11,12]) in which an attraction between deuterons and a negatively charged electron prevail over pushing apart of deuterons. In these conditions, the two initially free nuclei may approach each other to very small distances, when the processes of anomalous internal γ-conversion is brought into action. As appears from the assessment given above, with a decrease of a quasimolecular cluster to a size R = 4–4.9× 10^{-12} cm becomes possible an energy discharge of a fused ^{4}He* nucleus by a virtual photon of anomalous internal γ-conversion from 23.8 MeV to 19.8 MeV (see Fig. 1). As a result, a $\Delta E = 4$ MeV energy portion on chain (11) is transferred to the matrix:

$$\begin{aligned} \mathrm{D}^+ + \mathrm{e}^- + \mathrm{D}^+ &\to {}^4_2\,\mathrm{He}^*(23.8\,\mathrm{MeV}) \\ &\to {}^4_2\mathrm{He}^*(19.8\,\mathrm{MeV}) + \mathrm{e}^-_{\mathrm{conv}}(E = 4\,\mathrm{MeV}) \\ &\to {}^4_2\mathrm{He}_{\mathrm{g.s}} + \mathrm{e}^-_{\mathrm{conv}}(E = 4\,\mathrm{MeV},\ \Sigma E = 4\,\mathrm{MeV}) + \mathrm{e}^-_{\mathrm{conv}}(E \le 9\,\mathrm{keV},\ \Sigma E = 19.8\,\mathrm{MeV}). \qquad (11) \end{aligned}$$

where E-conversion electron energy, ΣE- total energy carried away by the conversion electrons. A quasimolecule of such size limits will be called a "Gryzinski microcluster."

As it has been noted earlier (see p. 5), the decrease in the excitation energy of ^{4}He* below 19.8 MeV makes it impossible for the ^{4}He* to decay with the yield of neutrons and charged particles. The time of 1.3–1.6× 10^{-23} s of the transfer of the energy portion $\Delta E = 4$ MeV to the matrix is comparable with the lifetime of the ^{4}He* excited nuclei ($\sim 10^{-22}$ s [9]). This gives reason to assume that at least some ^{4}He* excited nuclei involved in the cold fusion process have time to lose excitation energy to a level where decay is impossible. A further energy discharge of this part of fused ^{4}He* nuclei will be realized with conversion electrons of the "standard" internal γ-conversion, $\Delta E \leq 9$ keV (see above)[c]. The qualitative picture of the process is represented by the chain (11). The fusion process by the chain is not connected with the nuclear bond rupture, it requires overcoming of a rather low Coulomb barrier (0.4 MeV), and therefore has an intense character.

From the foregoing, it follows that cold fusion intensity is directly connected with the concentration of voids in the matrix filled with deuterium. In Sections 4, 7 and 8 it will be shown that deuterium-hydrogen and $(^7\mathrm{Li})_{\mathrm{gas}}$-hydrogen mixtures can also be used as working gases, while the working gas-filled nickel or other transition metals can serve as matrix. It is just in this sense that we further use the terms "working gas" and "matrix."

Previously, in our paper [6], we called the transition metal matrix containing a high concentration of cracks, pores or other voids filled with this gas, a "pseudo-composite." The mechanism considered above of cold fusion occurrence in this matrix is in good agreement with the well-known observation that: "The matrix, containing a large number of cracks, gaps and other voids is the only common condition in all successful cold fusion experiments medium" [32].

Along with the described process, another possible variant of the cluster mechanism of intensive cold fusion has been offered (see [11,12]), where "the Gryzinski quasimolecule," preaccelerated in the electric field is responsible for the fusion process. The matter is that, as shown in [11,12], formation in a matrix of cracks and gaps, and also spatial separation of electric charges by a flow of conversion electrons create in system in intensive cold fusion conditions of an inner electric fields capable to accelerate charged particles to energy ~ 1 keV.

Then part of "Gryzinski quasimolecules" formed in the conditions of intensive cold fusion can be exposed to a fusion [11,12] variant in a cluster mechanism. According to this mechanism, the "Gryzinski quasimolecule," getting in electric field, accelerated and built along a direction of movement. Colliding with heavy atom built quasimolecular cluster immerses into an electronic cloud of heavy atoms and forms, in turn, a quasimolecule (quasimolecular cluster-heavy atom) with it. In this case an energy discharge of a fused ^{4}He* nucleus considered above occurs in extreme conditions – in the "Gryzinski microcluster," immersed in an electronic cloud formed by a cluster and a heavy atom of a quasimolecule, in the conditions of electronic supershielding in immediate proximity from a nucleus of a heavy atom ($\sim$0,1 Å [11,12]).

The matrix microvolume where there is an act of fusion, acquires on a short period ($\sim 10^{-7}$–10^{-18} s) anomalously high local values of nucleus and electron density and extremely high level of fusion energy, unattainable for macrolaboratories. We can expect, that in these conditions intensity of such phenomena as Compton scattering of γ-radiation, weak interaction reactions (see also Sections 5, 7 and 8) and others, can be extremely change. Fusion energy by a standard and anomalous internal γ-conversion is transmitted to matrix through electrons and the cycle of fusion is repeated [6].

In both the considered variants, the cold fusion process requires for it implementation involvement of the phenomena of two – gas (the first stage) and intercluster – "condensed" (the second stage) mediums. Experimental conditions determine contribution to the fusion process of each described above processes.

From considered follows that the cold fusion is a complex process, which in the characteristic distance ΔR between the interacting particles can be conditionally divided into two stages. The first stage – the characteristic distance $\Delta R \geq 10^{-8}$ cm, occurs in the gas medium and "Gryzinski quazimolecule" formation ends. The second stage occurs into the quazimolecule at continuous convergence ("condensation") of interacting particles from 10^{-8} to 5×10^{-12} cm. The second stage ends by the merge of nuclei. In this sense, it should be understood the stages names, used here.

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[c] In [11,12] the attention that measuring devices in experiences of cold fusion were always closed by protective films, impenetrable for electrons of such energies is paid. Such circumstance has led to impossibility of electrons of such energies registration.

Thus, main "secret" of high intensity cold 2D-fusion that the transition state of the interacting particles which is created in the course of cold fusion – "Gryzinski microcluster," provides a timely energy discharge of a fused ^{4}He* nucleus through participation in process of a discharge of virtual photons and electrons of anomalous internal γ-conversion. The last opens reactions normally forbidden in the vacuum "light" channel 3 of Table 1, which is not interfaced with rupture of nuclear bonds. As it was noted reaction of fusion on this channel requires overcoming of rather low Coulomb barrier (0.4 MeV) and therefore has high intensity.

As follows from the considered, the important role in the *chemo*nuclear fusion belongs to conversion electrons. In addition to the function considered above of providing a timely discharge of the ^{4}He* excited state, with direct participation of conversion electrons in the *chemon*uclear fusion hypothesis, there are also two more processes listed below.

(1) Conversion electrons ionize working gas, viz. molecular deuterium, and, thereby, for the account of energy of nuclear fusion carry out reproduction of ionic clusters. It is a primary factor defining efficiency of conversion electrons in the course of cold fusion. Efficiency of conversion electrons "using" is defined by thickness of an "active" "pseudo-composite" layer and depth of conversion electrons run. Obviously, the efficiency of conversion electrons will reach high rates depending on the diffusion saturation of an active layer by deuterium and the growth of concentration of voids in this layer. After reaching the limits of admissible concentration, the rate of increase of intensity of the process will be slowed down and reach saturation._

(2) Intensive cold fusion is a two-stage process. The melting of a matrix and the elimination of "voids" forbids the first stage and thereby prohibits the fusion process. That is why melting of a matrix should be considered as the "passive" protection method to prevent runaway reactions in cold fusion reactors.

From these considerations it follows that conversion electrons provide an effective feedback and high intensity of cold fusion process due to its participation [6,11,12].

4. Cold Fusion in 2D-, HD- and (^{7}Li–^{1}H)$_{\mathrm{gas}}$-Transition Metal Systems

Consideration of the *chemo*nuclear 2D-fusion hypothesis causes us to anticipate that qualitatively similar processes of fusion will take place in other systems of light nuclei: HD- and (^{7}Li–^{1}H)$_{\mathrm{gas}}$-transition metal. At the same time for each system the "Gryzinski quasimolecule" and "Gryzinski microcluster" will have its own element composition (see the left-hand side of reactions (12)–(14)).

In all these cases, cold fusion is caused by what in the system pass the "light," not interfaced with rupture of nuclear bonds, fusion reactions. It is testified by the inert gases (^{3}He, ^{4}He) yield as reaction product and absence of essential radioactivity in the course of fusion. For the passing of such reactions overcoming only rather low Coulomb barrier, inherent to light nuclei, is required. It can be one of (or a few of) the reactions listed below:

$$\mathrm{D}^+ + \mathrm{e}^- + \mathrm{D}^+ \to {}^4_2\mathrm{He} + \mathrm{e}^-_{\mathrm{conv}}(\Sigma E = 23.8\,\mathrm{MeV}), \tag{12}$$

$$\mathrm{D}^+ + \mathrm{e}^- + \mathrm{H}^+ \to {}^3_2\mathrm{He} + \mathrm{e}^-_{\mathrm{conv}}(\Sigma E = 5.5\,\mathrm{MeV}), \tag{13}$$

$$({}^7_3\mathrm{Li}^+ + \mathrm{e}^- + \mathrm{H}^+)_{\mathrm{gas}} \to {}^8_4\mathrm{Be} + \mathrm{e}^-_{\mathrm{conv}}(\Sigma E = 17.25\,\mathrm{MeV}), \tag{14}$$

$${}^8_4\mathrm{Be}\,(\tau \approx 10^{-15}\,\mathrm{s}) \to {}^4_2\mathrm{He} + {}^4_2\mathrm{He} + E(0.095\,\mathrm{MeV}). \tag{15}$$

In a vacuum, these reactions are accompanied by the emission of high-energy γ-radiation, and have extremely low intensity. The latter caused by the smallness of $\sigma_{\rm nuc}$, determined by γ-quantum radiation. Therefore, in a fuel cycle of a traditional thermonuclear reactor, the reaction on third neutronless 2D-fusion channel is not considered.

In matter, as noted in Section 3, a fusion reaction occurs inside the "Gryzinski microcluster" and removal of nucleus excitation energy is carried out by a virtual photon of "anomalous" internal γ-conversion. In such a case, excitation energy of a fused nucleus on a chain: the excited nucleus–a virtual photon–electron anomalous internal γ-conversion-matrix transfers to matrix. The interdictions connected with γ-quantum radiation are eliminated, and the process of fusion on reactions (12)–(14) becomes intense. This is the main reason for the high intensity of the fusion processes in the "Rossi reactor" and in the experimental source of *chemo*nuclear HD-fusion created in the present work. The *chemo*nuclear fusion hypothesis well explains the fuel cycle and nuclear processes accompanying "Rossi reactor" operation and our *chemo*nuclear fusion power source operation (see Sections 7 and 8).

5. Weak Interaction Reactions Amplification and Bineutrons Generation under the Intensive Cold Fusion Conditions

The above-described extreme conditions, under which the reactions of *chemo*nuclear fusion occur, create preconditions for a dramatic amplification of weak interaction reactions due to intensive 2D-, HD- and $(^7\rm{Li}–^1\rm{H})_{\rm gas}$-fusion reactions. Direct evidence of dramatic amplification of weak interaction reactions in the conditions of intense cold fusion is observed in the expanded deuterium reproduction in "co-deposition" experiments [33]. In these experiments deuterium concentration in the light-water electrolyte increased up to 70–80% during the experiment. The high generation level of heat in the HTE-Cat reactor evidences the high rate of deuterium reproduction in active zone, since the deuterium reproduction – a link in the chain of reactor fuel cycle processes (see Section 8)

Another example of the weak interaction reaction amplification under conditions of intense cold fusion is the existence in these conditions of a bineutron bound state. In works [11,12] the generation of a bineutron in these conditions is shown in the example of fusion reaction in a $\rm D_3^+$-cluster. If in the process of *chemo*nuclear fusion one of three deuterons, which have got to the collision zone of a $\rm D_3^+$-cluster with a heavy superficial atom, owing to any reasons, do not participate in process of a merge of deuterons, that deuteron having appeared in extreme conditions merging with two other cluster deuterons zone, such deuteron can be involved in a reaction responsible for a birth of a bineutron with the Pokropivny mechanism [34]:

$$\rm D + e^-_{conv} \to {}^2n + \nu_e, \tag{16}$$

where ^{2}n is a bineutron.

As noted in Zeldovich and Novikov's book [35], "… excess-neutron nuclei are stabilized by the presence of electrons." More certain, this is indicated by Pokropivny [34]: "… a necessary condition for obtaining a quasi-stable bineutron on an endothermic e-capture reaction is a high energy and density of electrons …" In cold fusion conditions (the second variant of fusion, see Section 3.2) a bineutron is born in the vicinity ($\sim$ 0,1 Å [11,12]) of the nucleus of a heavy atom of a matrix, and from birth until its absorption by the nucleus of a heavy atom may not go beyond the quasimolecule electronic cloud. The high density of an electronic cloud contributes to the existence of a bineutron bound state, which closely agrees with the results of many cold fusion experiments (see [6,11–13] and the present work).

6. Experimental Confirmation of Chemonuclear Fusion Hypothesis

6.1. Chemonuclear fusion hypothesis confirmation in cold fusion experiments

As specified in Section 3.2, as the most important direct experimental confirmation of the *chemo*nuclear fusion hypothesis, the well-established observation made by many researchers can serve: "The matrix, containing a large number of cracks, gaps and other voids is the only common condition in all successful cold fusion experiment medium" [32]. Such description in [32] of the medium responsible for cold fusion, matches the description of a "pseudo-composite" matrix in the *chemo*nuclear fusion hypothesis (see Section 3.2). In [6,11–13] and in this paper, we consider the numerous other experimental results that can be interpreted as evidence of the validity of the *chemo*nuclear fusion hypothesis.

These results are the reproduction of deuterium, nuclei fission and anomalous isotopic composition impurity generation, energetic particles generation (neutrons, protons, tritons and α-particles), the low radioactivity of cold fusion processes, etc. Some of these results are considered below.

6.2. Bineutronic mechanism of energetic α-particles, protons and neutron generation

Emission of energetic (10–14 MeV) α-particles is one of the well-established and yet not explained phenomena of cold fusion [36,37]. Other phenomena that have not been explained include a proton yield with energies in the range of 5.8–7.8 MeV [36] and a neutron yield with energies ranging from 3 to 10 MeV in [37,38]. Let us show that the emission of such particles may be due to the occurrence of a reaction involving a bineutron in these experiments.

At absorption of a bineutron, the nucleus of heavy atom is excited to a level when excitation energy of the nucleus E_{exc} (excitation energy) essentially exceeds the energy of nucleon separating – $E_{\mathrm{nucl\ sep}}$ (nucleon separation). In that case the removal of excitation energy of the nucleus, if it has not had time to be divided [11,12], will occur due to an emission of nucleons n, p or their clusters d, T, ^{3}He, ^{4}He. γ-Quanta radiation by the nucleus in an excitation high-energy range ($E_{\mathrm{exc}} > E_{\mathrm{nucl\ sep}}$) occurs with a probability, essentially lower, than the probability of nucleons emission, because the constant of an electromagnetic interaction is two orders below a strong interaction constant (see Table 2).

In Table 2 a process of a nucleus discharge by emission of fast particles by reactions (5b)–(5d) is shown.

In Table 3, compiled by us from reactions (5b)–(5d) (Table 2), the calculated values of energies of these particles with ones observed in experiments are compared. From Table 3, it follows that all calculated values of energies are in close agreement with the experiment.

6.3. Anomalous isotopic composition impurities generation

The process of fast particle generation in Section 6.2 and the fission process [11,12] is accompanied by an accumulation process of the anomalous isotopic composition of impurities in the matrix, which is also observed in many works on cold fusion [32].

It is especially necessary to pay attention to the extreme changes of nickel isotopic composition (see Table 4 and Section 8) found in the Lugano experiment [14] and in our verification experiment [13]. Concentration decrease of all nickel isotopes, except the ^{62}Ni isotope, where there is a concentration raise is easily explained by the assumption that

Table 3. High-energy α-particles, protons and neutrons in the *chemo*nuclear fusion hypothesis of deuterium [6,11,12].

Palladium isotopes	102	104	105	106	107	108	110
E_α (Rated) (MeV)	14.44	11.63	12.05	11.46	12.0	10.14	8.76
E_α (Experimental) (MeV) [36,37]	14.0–9.2						
E_{p} (Rated) (MeV)	8.86	7.2	6.74	5.26	5.45	–	–
E_{p} (Experimental) (MeV) [36,37]	7.8	–	–	5.6	–	–	–
E_{n} (Rated) (MeV)	7.54	8.84	9.48	6.47	9.47	6.09	5.7
E_{n} (Experimental) (MeV) [37,38]	10–3						

Table 4. Nickel isotopic structure in nature, in “ashes” of HTE-Cat reactor [6] and in present work.

No.	Isotope	Natural composition (%)	Isotope composition in “ashes,” (%) [6]	Composition on a cathode surface (the present work) (%)	Proton energy in reaction ^{x}Ni $+^{2}$n $\rightarrow$ $^{x+1}$Co $+$p (E)) (MeV)	Columbs barrier E_c (MeV)	$(E_p - E_c)$ (MeV)
1	^{58}Ni	67.76	0.8	66.52	10.7	$\sim 7 \pm 1$	+3.7
2	^{60}Ni	26.16	0.5	26.72	10.24	$\sim 7 \pm 1$	+3.2
3	^{61}Ni	1.25	0	1.24	6.06	$\sim 7 \pm 1$	-1
4	^{62}Ni	3.66	98.7	4.42	3.9	$\sim 7 \pm 1$	-3.1
5	^{64}Ni	1.16	0	1.1	–	–	–

the observed changes of the isotopic composition is the result of bineutron absorption by the nickel nucleus in reaction (17) (see [11,12], Table 11):

$$ {}^{x}_{28}\mathrm{Ni} + {}^{2}\mathrm{n} \rightarrow {}^{x+2}_{28}\mathrm{Ni}^{*} \rightarrow {}^{x+1}_{27}\mathrm{Co} + \mathrm{p}(E). \tag{17} $$

The reaction of bineutron absorption by ^{62}Ni nucleus cannot be accompanied by the yield of a proton (Coulomb barrier interdiction, proton energy is lower than a Coulomb barrier, see Table 4) and, therefore, there is found in [14] and in our verification experiment [13] the accumulation of the ^{62}Ni isotope takes place.

6.4. Tritium generation

Tritium generation is one of the first reliably established and yet not explained cold fusion phenomena [32,39,40]. The intensity of this process is 5–9 orders above intensity of a neutrons yield. This indicates that the tritium yield in these experiments is not related directly with occurrence of traditional hot fusion.

The results of our experiments (Table 5) on research of tritium generation in the impulse electric discharge process in heavy water electrolyte and an electrolyte representing a solution 0.2 M K_2CO_3 [41] in normal water are presented.

Two features of the results of these experiments should be noted: very high level of accumulation of tritium in heavy water electrolyte, and tritium accumulation in an electrolyte of normal water (although at essential lower rates). In both experiments the accumulation level of tritium far exceeds a possible error that leaves no doubts in the reality of tritium generation process in these experiments.

As shown in Table 2, in *chemo*nuclear fusion hypothesis of deuterium generation of tritium is a result of deuteron reactions with a bineutron on the channel (18) this table:

$$ \begin{aligned} \mathrm{d} + {}^{2}\mathrm{n} &\rightarrow \mathrm{T}(1.56\,\mathrm{MeV}) + \mathrm{n}(4.64\,\mathrm{MeV}) \rightarrow \mathrm{d} + \mathrm{T}(1.56\,\mathrm{MeV}) \\ &\rightarrow \alpha(6.9 - 1.44\,\mathrm{MeV}) + \mathrm{n}(12.5 - 17.7\,\mathrm{MeV}). \end{aligned} \tag{18} $$

Table 5. Tritium generation from passing an impulse electric discharge in electrolytes with deuteroxide and water of natural composition [41]

Experiment	Electrolyte composition	Material of the Cathode–anode	Content of tritium (Bk/kg*)	Background excess
1	D_2O+1M Li	Nb–W	1340	450 times
2	0.2 M K_2CO_3+H_2O	Ta–W	160	53 times

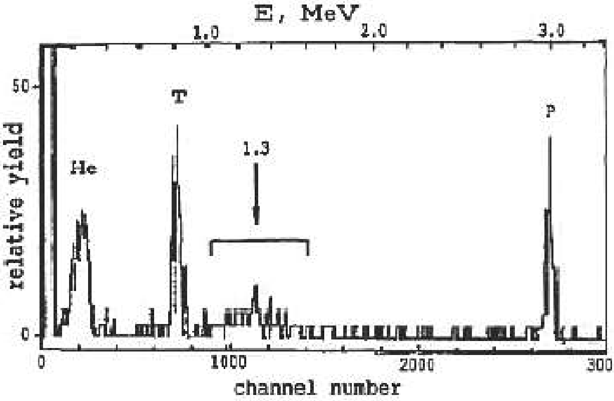

Figure 2. The energy distribution of charged particles from a sample Ti irradiated with ions D_n^+ ($E = 25$ keV) to a dose of 1×10^{19}cm^{-2}. The peak in the middle of the spectrum belongs to the neutrons having energy ~1.0–1.6 MeV [43].

Figure 2 shows the energy spectrum of the particles emitted by a titanium target during the cryogenic implantation process of deuterons (with energy 25 keV) in our experiments in 1989 [42] and 1998 [43]. The detector in this experiment was covered by a nickel film with 0.57 μm thickness. The analysis of spectrums (Fig. 2) with the count of energy losses and the conforming spectrum peak shift (caused by a proper traditional 2D-fusion of energetic α-particles, tritons and protons output), has allowed us to determine that in spectrum Fig. 2 making along with process of traditional hot fusion of deuterium the processes responsible for an of tritons generation with energy 1.5–1.6 MeV (peak ~ 1.3 MeV on a spectrum, Fig. 2) participates.

As shown in Table 2, a source of tritons with such energy is reaction (18), initiated by a bineutron. This is additional convincing evidence of the reliability the *chemo*nuclear fusion hypothesis of deuterium, which is described in the present work.

6.5. Three α-particles yield

Let us focus on one phenomena well established in cold fusion experiments – the three α-particles yield from a very small volume of the detector Fig. 3. In [44–46] this phenomenon is interpreted as evidence of a fission reaction passing of carbon nucleus under the influence of a fast neutron:

$$\mathrm{C} + \mathrm{n} \rightarrow 3\alpha + \mathrm{n} + Q.$$

At emission of α-particles, made in work [46] energy estimations of an initiating (26) reaction neutron have gained values $E_\mathrm{n} \approx$ 13.25–13.47 MeV. The generally accepted generation mechanism of such neutrons does not exist today.

Considered as a source of neutrons the secondary DT-reaction of hot fusion [46] demands for the realization of passing of primary 2D-reactions at the level never watched in experiments on cold fusion. The attention was paid to this circumstance in [43] (1998), and also in work of [48] (2000). As appears from Table 2, in *chemo*nuclear fusion conditions responsible for fission of carbon nucleus are neutrons initiated by bineutrons in the chain of reactions (18). As it was already noted, tritons having energy 1.5–1.6 MeV, generated in this chain of reactions are well watched on a spectrum (see Fig. 2) that is the additional testimony in favors for this statement.

6.6. Low radioactivity of cold fusion processes

The low radioactivity of the cold fusion processes is one of the best known and attractive features of this phenomena. In the *chemo*nuclear fusion hypothesis low radioactivity is explained by a series of reasons. Let us list the main ones.

(1) The reactions responsible for the fusion process (12)–(13) are not due to a rupture of nuclear bonds.
(2) The energy generated in the course of nuclear fusion is carried away by conversion electrons. This eliminates a second potential source of γ-radiations in cold fusion experiments.
(3) The process of nucleus fission – the third potential source of a radioactivity in the cold fusion conditions, occurs with intensity 8–10 orders lower in comparison with the first group phenomena, and as it was noted in [11,12], is not accompanied by formation of radioactive products, γ-quanta emission and energetic heavy particles.
(4) An energy discharge of an excited nucleus occurs due to the emission of nucleons and their clusters [6,11,12].

Thus, *chemo*nuclear fusion hypothesis adequately explains reasons where there is low radioactivity in cold fusion experiments.

To conclude this section, we note that Refs. [6,11,12] demonstrate the close accordance expected of Table 2 reaction results with the well-established results from cold fusion experiments, and can be considered experimental confirmation of the participation of weak interaction reactions and bineutron reactions in cold fusion processes, and the *chemo*nuclear hypothesis as a qualitative model of cold fusion process in the 2D-, HD- and $(^{7}\mathrm{Li}{-}^{1}\mathrm{H})_{\mathrm{gas}}$-transition metal systems.

Of course, any of such consideration without a serious study of anomalous γ-conversion mechanism in relation to such "exotic" object, as "Gryzinski quazymolecule," and no comprehensive study of the other features of the fusion model, can only have the hypothetical character. However, as shown in [6,11,12] a compliance with the conclusions of

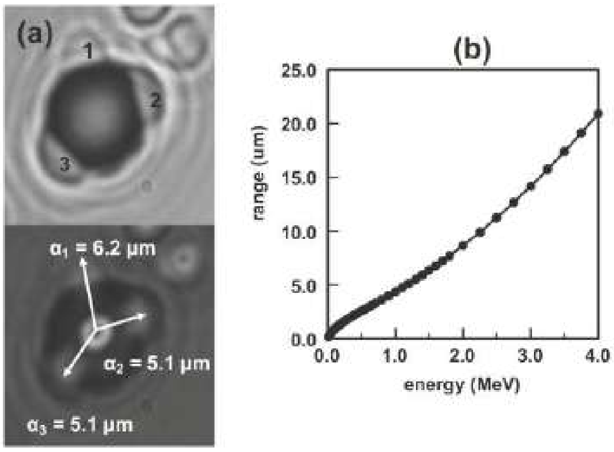

Figure 3. Photos of the triple track [46]: (a) Photo of the triple track shown. The top image was obtained with the optics focused on the surface of the CR-39 detector. The bottom image is an overlay of two photos taken at different focusing depths (surface of the detector and the bottom of the pits). On the bottom image, the bright circle observed in the track indicates where the neutron impacted the carbon atom. Arrows are drawn to show the directions the alpha particles traveled after the carbon atom shattered. The distances traveled by the alpha particles are indicated. (b) Linear energy transfer (LET) curve for alpha particles in CR-39 calculated using the SRIM-2003.26 code of Ziegler and Biersack [47].

Table 6. The radioactivity composition of lithium in nature and reactor HTE-Cat "ash".

Isotope	Natural composition (%)	The radioactivity composition in leach, method SIMS (%)	An isotopic composition in "ash," method JCP-MS (%)
^{6}Li	7	92.1	57.5
^{7}Li	93	7.9	42.5

the review with well-established numerous experimental results is, in our opinion, a serious reason for broad deployment of operations on the practical use of cold fusion and for a further deep study of this phenomenon.

7. Pilot Chemonuclear Fusion Energy Generator Development and Testing (Verification Experiment)

The model of intensive (self-sustained) cold 2D-fusion developed in works [11,12] – the *chemo*nuclear fusion hypothesis – explains this phenomenon at a qualitative level. Since the publication of Ref. [11] four years ago, the model has received an experimental verification in [14] and in our papers of 2013–2015. The model modernized to account for the experimental verification results is shown in [6] and here. In work [13] results of our 2013–2015 work on the creation and testing of a *chemo*nuclear fusion energy source (verification experiment) are presented. In this section, the main results of this work are shown.

The source of *chemo*nuclear energy is created on the basis of gas-discharge installation (KD-installation) [41], equipped with a tool-kits set for studying of the physical phenomena accompanying cold fusion.

The verification experiment details include:

(1) Studied system – HD-nickel system.
(2) Working gas – a mix of D_2 (85%) and H_2 (15%).
(3) Heat generating materials – "pseudo-composite" – the nickel containing high concentration of filled by gas voids: micro cracks, ruptures, pores, etc. (see [6,13] and Section 3 of the present work). "The pseudo-composite" layer is created on a surface of nickel electrodes by special processing of electrodes in the gas discharge in the energy source chamber [6,13].

In verification experiment it has been established:

(1) Thermal power of a source $\sim$35 W, efficiency – 1.8–1.9.
(2) Responsible for process of cold fusion in HD-nickel system is an intercluster reaction (13).

This confirms:

(1) generation of rare ^{3}He gas atoms in the experiment,
(2) heat generation is not accompanied by emission of γ-radiation,
(3) emission of conversion electrons.

A sharp drop in resistance of an order of magnitude (from 8–7 to 2 kΩ) confirms the last claim when the energy source reaches a heat generation mode. This effect is well reproduced.

(1) Work by an energy source in a mode of intensive cold fusion is accompanied by change of isotopic structure of nickel in a superficial "pseudo-composite" layer of electrodes. In Section 6.2, it is shown that changes of nickel isotopes concentrations are a result of bineutron absorption of nickel nucleus on reaction (17).

Based on the bineutron absorption dramatically change the nickel isotopic composition in the course of experiments in Lugano [14], on our verification experiment [13], and on the emission of fast particles in cold fusion experiments

[11,12] – the *chemo*nuclear fusion hypothesis is justified both for the cold fusion "HTE-Cat" reactor and for our pilot *chemo*nuclear energy source.

Neither in the course of experiment, nor in the subsequent "flashing" was any γ-radiation above background revealed. This absence of the induced activity in experiments with nickel can be explained by a deep reorganization of a nickel nucleus in the conditions of intensive cold fusion. This question demands the further study (see also Sections 3, 5 and 8).

8. Cold Fusion HTE-Cat Reactors Creation – A New Stage in Nuclear Power Engineering Development

8.1. HTE-Cat reactor development

Today the history of the evolution of a new scientific direction – cold fusion, transfers in a responsible phase. The process of practical exploration of this phenomenon begins.

As it was noted, the beginning of exploration of cold fusion it is possible to consider development of the first thermal reactor of cold fusion E-Cat with a power of 1 MW [3]. Presentation of this reactor was made by Focardi and Rossi in March 2011 in Italy. In subsequent in the USA, where Rossi has transferred the research, on the same principle a more effective generator HTE-Cat with operating temperature 1000–1200°C has been created that gives a possibility of its usage in superheated steam production (600°C) for turbines of a modern power plant.

Rossi in an interview with "The Huffington Post" in October, 2015, declared that Leonardo Technologies Inc. already has orders to manufacture of 600,000 generators of a different power levels for the total of three billion US-dollars, from Europe, the USA and other parts of the world. This year he planned to begin commercial production of the generators (including major units of 1 MW capacity).

Unfortunately, very little data about the construction of these reactors and the composition of the fuel has been published. As declared in Ref. [4], the fuel in the HTE-Cat reactor is a mixture of powders of lithium aluminum hydride ($\mathrm{LiAlH_4}$) and a nickel powder. When heated, lithium aluminum hydride undergoes three stages of decay:

$$3\mathrm{LiAlH_4} \rightarrow \mathrm{Li_3AlH_6} + 2\mathrm{Al} + 3\mathrm{H_2} \quad (\text{first stage}), \tag{19}$$

$$2\mathrm{Li_3AlH_6} \rightarrow 6\mathrm{LiH} + 2\mathrm{Al} + 3\mathrm{H_2} \quad (\text{second stage}), \tag{20}$$

$$2\mathrm{LiH} + 2\mathrm{Al} \rightarrow 2\mathrm{LiAl} + \mathrm{H_2} \quad (\text{third stage}). \tag{21}$$

In work [4] it is noted that the third stage of decay becomes reversible and that LiH pressure equilibrium at 500°C has a value of 0.25 bar.

According to developers of HTE-Cat reactor, nickel in composite fuel plays role of the catalytic agent and in the reactor operation process is not spent. For initiation of reactor operation the fuel is necessary to heat up to temperature when lithium and hydrogen intensively diffuse into nickel. In crystal lattice of nickel heated to 600–1200°C the lithium and hydrogen nuclei merge at collision ("Rossi effect"), forming two ^{4}He nuclei on a reaction

$$^7_3\mathrm{Li} + {}^1_1\mathrm{H} \rightarrow {}^8_4\mathrm{Be}^* \rightarrow {}^4_2\mathrm{He} + {}^4_2\mathrm{He} + 17.35\,\mathrm{eV}. \tag{22}$$

The authors of work [4] suppose that in this reaction the energy of fusion is released in the form of a kinetic energy of "hot" helium nuclei, which are thermalized in a crystal lattice of nickel and the material of the walls of the reactor. Such a result, according to the authors, makes the "Rossi effect" an ideal phenomenon for nuclear energy utilization with a total absence of radioactive materials and radiation.

8.2. Experiment in Lugano

In October, 2014, results of studying the HTE-Cat [14] reactor operation which was carried out in Lugano (Switzerland) by a group of independent experts was published. According to this group, reactor fuel – a mixture of nickel powders and hydrogen containing $\mathrm{LiAlH_4}$ solution – in the amount of 1 g was placed in the reactor before its start. Reactor start was carried out by heat of an active core of the reactor by a resistive heater. The total of the excess energy produced over 32 days in the reactor was $\sim$1.5 MW h. Experts note that this amount of energy is much more than can be produced by the small volume of fuel in the reactor from any of known chemical energy sources.

The analysis of the used fuel (“ash”) has shown that except nickel there are lithium and aluminum impurities with amounts, allowing to conclude that it was in the nickel powder before it was filled in the reactor with $\mathrm{LiAlH_4}$ powder added. In the “ash” iron, oxygen and carbon are also found. Deuterium presence in “ash” is not revealed. In work [14] it is revealed that in the course of experiment significant modifications of the isotopic composition of nickel (Table 4) and lithium (Table 6) take place.

“These results are difficult to correspond with the fact that radioactivity at experiment carrying out has not been discovered,” authors of expertise [14] state that the process of fast nucleus $^4\mathrm{He}^*$ on reaction (22) thermalization declared by Rossi should be accompanied by radiation which could not be missed in their experiments.

Thus, the results gained by a group of experts in Lugano do not confirm the model of the HTE-Cat reactors declared by the developer.

As was already noted (see Section 3.2), the experiment in Lugano [14] (work of Rossi “cell”) has already been successfully reproduced in a number of the countries [10].

8.3. HTE-Cat reactor fuel cycle in chemonuclear fusion hypothesis

The “Rossi reactor” operation is successfully explained by the *chemo*nuclear fusion hypothesis.

As noted above, developers of the HTE-Cat reactor believe the reaction is fusion of lithium and hydrogen nuclei in a fuel cycle of the reactor as shown on reaction (22) and in which the reaction with nickel is a catalyzer and is not consumed in the operation process. However, this was not confirmed in [14] as explianed in Section 8.2.

At the same time lithium with hydrogen reaction (23):

$$^7_3\mathrm{Li} + {}^1_1\mathrm{H} \to {}^8_4\mathrm{Be}^* \to {}^8_4\mathrm{Be} + \gamma(17.25\,\mathrm{eV}), \tag{23}$$

Has a strongly pronounced resonance character and reaches a maximum level at energy of 440 keV of a proton [49]. In vacuum this reaction is accompanied by high-energy ($E = 17.25$ MeV) γ-quanta emission and has low intensity caused by the small scale of σ_{nuc}, defined by γ-quanta radiation. However, as it is shown many times (see Section 3.2), the intercluster character of cold fusion reaction provides a timely removal of energy of the excited fused nucleus (in this case this nucleus of beryllium $^8\mathrm{Be}^*$) due to a virtual photon and electron of anomalous γ-conversion participation. In such a case, the fusion process in “Rossi reactor” becomes intense.

Immediately after producing a reaction (14) ($\tau \approx 10^{-15}$ s) the $^8\mathrm{Be}$ nucleus decays on two low-energy α-particles (reaction (15)). Decay from a ground state is possible [49] as the mass of $^8\mathrm{Be}$ at 0.095 MeV exceeds the mass of two α-particles. This explains the observations in the Lugano experiments [14] of the burning of $^7\mathrm{Li}$ isotope in the fuel, and the absence of γ-radiation in this experiment.

Thus, in the *chemo*nuclear fusion hypothesis the fuel cycle of “Rossi reactor” is accompanied by a following set of nuclear reactions:

(a) The fusion processes are not related to a break-up of nuclear bonds considerably enhanced with medium *chemo*factors intercluster reaction (14) and, as a result, after a very short delay there is reaction (15) (see Section 4).

The lower "gas" index says that fuel has to be heated to temperature when the lithium component of fuel (LiH or Li) is in a gaseous state.

$$\begin{aligned}({}^7_3\mathrm{Li}^+ + \mathrm{e}^- + \mathrm{H}^+ + \mathrm{e}^- + \mathrm{H}^+ + \mathrm{e}^- + \mathrm{H}^+)_{\mathrm{gas}} &\to \left[{}^8_4\mathrm{Be}^* + (\mathrm{H}^+ + \mathrm{e}^- + \mathrm{H}^+)\right] \\ &\to \left[{}^8_4\mathrm{Be} + \mathrm{e}^-_{\mathrm{conv}}(17.25\,\mathrm{eV}) + (\mathrm{H}^+ + \mathrm{e}^- + \mathrm{H}^+)\right] \\ &\to {}^4_2\mathrm{He} + {}^4_2\mathrm{He} + \mathrm{D} + \nu_{\mathrm{e}} + \mathrm{e}^-. \end{aligned} \tag{24}$$

(b) Reactions of weak interaction. First of all, these the intercluster [11,12] reactions of a deuteron generation which are dramatically strengthened in the conditions of intensive cold fusion:

and a bineutron [34]:

$$\mathrm{D} + \mathrm{e}^-_{\mathrm{conv}} \to {}^2\mathrm{n} + \nu_{\mathrm{e}}. \tag{25}$$

(c) Reactions of bineutron interaction with a nickel, working gas and others elements of reactor active zone nuclei.

Reaction (17) of bineutron absorption by a nickel nucleus (Sections 6.3 and 7) which is already considered above is important for a fuel cycle of "Rossi reactor."

(d) Secondary reactions.

Interactions reactions of fast protons from reaction (17) with elements of reactor active zone nuclei. First of all it is reaction (26):

$$^{\mathrm{x}}_{28}\mathrm{Ni} + {}^1\mathrm{p} \to {}^{\mathrm{x}+1}_{29}\mathrm{Cu} \tag{26}$$

and other element of active zone of reactor nuclei.

Generating on reaction (26) copper nuclei with the exception of stable ^{63}Cu and ^{65}Cu isotopes decays by one of channels:

$$^{x+1}_{29}\mathrm{Cu} \to {}^{x+1}_{28}\mathrm{Ni} \;+\; \mathrm{e}^+ \;+\; \nu_{\mathrm{e}} \quad (\text{positron decay}), \tag{27}$$

$$^{x+1}_{29}\mathrm{Cu} + \mathrm{e}^- \to {}^{x+1}_{28}\mathrm{Ni} \;+\; \nu_{\mathrm{e}} \quad (\text{electron capture}). \tag{28}$$

Nuclear reactions "products" in "Rossi reactor":

- On Item (a) ^{4}He, conversion electrons and excessive energy will be observed.
- "Products" of interaction of a bineutron with a matrix and working gas must follow reactions according to Items (b) and (c): fast nucleons yield of p, n and their clusters of d, T, ^{3}He, ^{4}He, generations of the anomalous isotopic composition impurities, γ-radiation of radioactive impurity nuclides and others. We can expect that in verification experiment first of all will be the following: (1) an anomalous isotopic composition of lithium (^{7}Li burning) and nickel (the concentration of ^{62}Ni growth and remaining isotopes burning out), (2) γ-rays of 0.067 MeV line $T_{1/2} = 1.65$ h [6,13]. Reactions according to Item (b) (reaction (24)) can be registered on growth of the deuterium content in a work medium.
- Reactions product yield on Item (d) (secondary reactions) studied a little now. However, as it was noted in [51], in long-term experiment in a cell of "Rossi reactor" accumulation of copper atoms with anomalous isotopic composition is observed. In work [14] in similar experiment revealed a presence of iron, oxygen and carbon. These questions demand further studying.

All listed above the expected accordingly the *chemo*nuclear fusion hypothesis results, except γ-activity, observed at "Rossi reactor" cell operation.

Thus, the *chemo*nuclear fusion hypothesis well describes a fuel cycle and nuclear processes of "Rossi reactor" provided that as the nucleus initiating fusion process in this case the ^{7}Li-nucleus serves. The reaction of ^{7}Li with hydrogen is responsible for the process of fusion. The expected outcomes of the reactions such as the excess heat, the variations in the isotopic composition of lithium and nickel, have been reliably confirmed by the Lugano experiment [14]. As well as in our verification experiment, at studying operation of "Rossi reactor" radioactivity had not been found. The absence of γ-radiation in the nickel experiments may be caused in this case by nuclear transformation. As it was noted above, the problem of physical phenomena taking place in the matrix microvolume, where the event of nuclear fusion takes place, demands further studies (see also Sections 3,5 and 7). The presence of deuterium in the spent fuel, which may be due to its high temperature, has not been observed, too. The experimental data on the deuterium content in the working gas are unavailable.

9. Conclusion

In recent years two ways of mastering nuclear fusion energy have been defined.

(1) Historically the first way of solving this problem was the heating of medium comprising atoms of deuterium (or deuterium and tritium) up to the temperature when the kinetic energy of the atoms at their impacts would be sufficient to cause the mutual approach of nuclei necessary for realization of fusion reactions ("thermonuclear fusion") [1]. The scientific base of the controlled nuclear fusion reactor has been studied reasonably well. The working matter in this reactor is a high-temperature deuterium–tritium or deuterium plasma. In the first case, the DT-fusion reactions are responsible for reactor operation, and in the second case, these are the 2D-fusion reactions on channels 1 and 2 (see Table 1). In the controlled thermonuclear reactor, the occurrence of reactions in the "light" channel (3), which exhibits no nuclear bond rupture (Table 1), is fundamentally prohibited (see Section 2) since in vacuum there are no conditions for the synthesized ^{4}He* nucleus to discharge energy.

Fusion reactions in the thermonuclear reactor occur at collisions of unscreened (bare) nuclei having randomly oriented spins. Low nuclear reaction cross-sections in these conditions cause the main difficulties on the way of creating the controlled thermonuclear reactor. The deuterium–tritium mix temperature in this reactor equals $\sim 2\times10^8$ K ($\sim$10 keV), for the deuterium plasma this temperature is still higher. The problem of maintaining this temperature for the time sufficient to gain positive energy yield presents great technical difficulties, which have been attacked for many decades by numerous teams of scientists from different countries [1].

(2) The second way of fusion energy mastering is the development of cold fusion by Fleischman and Pons, who reported in 1989 the sensational results of their investigations into this phenomenon [2]. Unlike the technical difficulties encountered by the developers of the controlled thermonuclear fusion reactor, the practical development of the cold fusion reactor, in particular, the creation of the (^{7}Li-^{1}H)$_{\mathrm{gas}}$-nickel system was a much easier task and is far ahead in the formulation of theoretical foundations of the phenomenon. The first cold fusion reactor ("E-Cat reactor") based on these reactions was presented by Focardi and Rossi in March 2011, in Italy. Since then, the "Rossi reactor" "cell" operation has been successfully reproduced in a number of countries (Russia, China, Kazakhstan, etc.) [10]. However, there is no generally accepted model of this phenomenon today.

Our first paper claiming to explain intensive (self-sustaining) cold fusion was published in 2012 [11]. During the four years since publication, the fusion model presented in [11], – the *chemo*nuclear fusion hypothesis, has gained further development in the present work and in [6]. The model was checked and confirmed by the results of our verification experiment [13]. The c*hemo*nuclear fusion hypothesis is in good agreement with the results of comprehensive study of the HTE-Cat reactor [14], made during that period in Lugano (Switzerland) by a group of independent experts. So, it gives us reason to now treat the *chemo*nuclear fusion hypothesis as a self-consistent, qualitative model of intensive cold fusion in 2D-, HD- and $(^7\mathrm{Li}–^1\mathrm{H})_{\mathrm{gas}}$-transition metal systems [6].

In the *chemo*nuclear fusion hypothesis, cold fusion, being a complex, two-stage cluster process, is determined by nuclear reactions not involving nuclear bond rupture, viz., the 2D-reactions on the neutron-free "light" channel of 2D fusion, and also, HD- and $(^7\mathrm{Li}\text{-}^1\mathrm{H})_{\mathrm{gas}}$-reactions (see Section 4). These reactions are accompanied by high-energy gamma emission and are of extremely low intensity. This is due to the smallness of σ_{nuc} governed by γ-quantum radiation. In cold fusion conditions, the cluster nature of fusion provides an anomalous γ-conversion function. As a result, the excitation energy of the synthesized nucleus is transferred to the matrix by the following chain: excited nucleus–virtual γ-quantum–anomalous γ-conversion electron–matrix. This eliminates the prohibitions associated with the γ-quantum radiation, and the process of intense cold fusion starts. It is one of the most important causes of cold fusion occurrence in media.

The extremely high intensity of cold fusion is determined by the joint action of the following factors ("*chemo*factors").

(a) The transition state formed during fusion in the interacting particle system – the "Gryzinski quasimolecule" – provides a timely energy discharge of the synthesized nucleus due to participation of virtual photons and electrons of anomalous internal γ-conversion in the discharge process. This removes restrictions specified by γ-quantum radiation. When this occurs, the fusion process is intense in character, as it proceeds without rupture of nuclear bonds, and it requires overcoming a low Coulomb barrier peculiar to light nuclei (see Sections 3 and 4).

(b) According to the second variant of the *chemo*nuclear fusion hypothesis (see Section 4), the processes of nuclear fusion and synthesized nucleus formation as parts of the synthesis event take place under extreme conditions, namely, in the "Gryzinski microcluster" immersed in the electron cloud of quasimolecule (Gryzinski microcluster–heavy matrix atom), under electronic superscreening conditions in the immediate vicinity of the heavy atomic nucleus ($\sim$0.1 Å), in the matrix microvolume, where the density of nuclei and electrons as well as the released energy of nuclear fusion reach for a short time (10^{-7}–10^{-18} s) anomalously high values, unattainable in most laboratories.

(c) In the extreme conditions of intense cold fusion, the cluster nature of fusion promotes the dramatic enhancement of weak interaction reactions owing to nuclear fusion reactions that result in the generation of deuterons and bineutrons (see Section 5).

(d) A "pseudo-composite" is assumed to be an optimum matrix for the initiation of intense cold fusion. The transition metal matrix has a high concentration of cracks, pores and other voids filled with a working gas. This choice is proved by the following final statement of numerous cold fusion papers: "The matrix, containing a large number of cracks, gaps and other voids is the only thing common to all successful cold fusion experiment media." [32].

(e) The *chemo*nuclear fusion hypothesis is a two-stage process. The matrix melting forbids the first stage (processes in the gas medium) and, thereby, terminates the fusion process. Therefore, melting of a metal matrix should be considered as a technique of "passive" protection in cold fusion reactors.

(f) The cold fusion process is provided with an effective feedback mechanism. The energy of nuclear fusion is transferred through the conversion electron emission channel to the matrix, and is spent (partially) for reproduction (and under certain conditions, expanded reproduction) of the fusion process, for working gas ionization and cluster ion generation, and also, for the formation of internal electric fields, acceleration of ion clusters and other processes.

(3) In view of the above, the HTE-Cat generator can be considered a cold fusion reactor, the operation of which is based on the *chemo*nuclear fusion reaction in the $(^7\mathrm{Li}\text{–}^1\mathrm{H})_{\mathrm{gas}}$-nickel system, while the KD installation represents a prototype reactor using the HD-nickel system. As regards to *chemo*nuclear fusion, it is hoped to be a source of clean and safe energy.

(4) The *chemo*nuclear fusion hypothesis is a hypothetical, qualitative model of intense cold fusion. Even now, the investigation level of the model attained so far opens the way for practical mastering of the phenomenon. However, the development of the quantitative model calls for further deep investigation of the cold fusion mechanism and the model optimization with a careful choice of the "pseudo-composite" matrix structure, the temperatures and pressure of the working gas, etc. The use of the magnetic field can be a promising direction in improving the model efficiency. The tasks of primary importance in the development of the research program include the meeting of the ecological and safety requirements under operating conditions of cold fusion reactors.

Mastering of *chemo*nuclear fusion energy as the direction opening the way to clean, nuclear-safe and practically inexhaustible source of energy should become the priority of state energy programs.

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