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## **ANALYSIS OF EXPERIMENTAL RESULTS ON EXCESS HEAT POWER PRODUCTION, IMPURITY NUCLIDES YIELD IN THE CATHODE MATERIAL AND PENETRATING RADIATION IN EXPERIMENTS WITH HIGH-CURRENT GLOW DISCHARGE**

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### **Abstract**

So far a considerable collection of results on Excess Heat registration, the cathode material impurity nuclides yield (with changed natural isotopes ratio) and generation of high-energy penetrating radiation (fast electrons, X-ray and gamma emissions) has been accumulated in experiments with high-current Glow Discharge.

Analysis of these results allows one to assess possible basic processes going on in the cathode material exposed to high-current Glow Discharge (GD).

### **1. Experimental**

**Excess Heat power production** [1] presents results on Excess Heat power production up to several tens W with Efficiency up to 150% and even higher.

Excess Heat values depend upon the cathode material and the plasma-forming gas being used. The highest Excess Heat value (up to 4.0 MJ) obtained on one of the cathode samples exposed to Glow Discharge operation for a long time duration (up to 150 hours) assumedly points out that the said energy is nuclear origin.

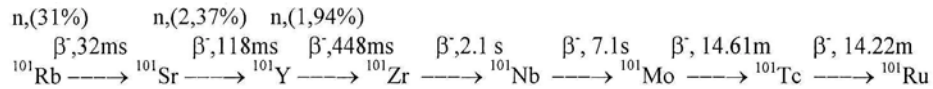
**Yield of impurity nuclides with altered (by several tens of times) natural ratio of elements isotopes.** Proceeding from the assumption that the registered Excess Heat [1] results from going on nuclear reactions [2] the impurity yield content in the cathode samples material was analysed before and after the experiments with the high-current Glow Discharge device [1]. The following procedures were used: spark mass spectrometry, secondary ion mass spectrometry, secondary neutral mass spectrometry. Those were used for analysis of impurity nuclides in the cathode samples material before and after the experiment. The difference in impurity elements content before and after the experiment was defined as the yield of impurity elements in the course of the experiment. Impurity elements with masses by approximately two times less than that of Pd and the ones with their masses close to that of Pd have been registered in 100 nm thick surface layer in quantities up to several tens %. The main recovered impurity nuclides (with more than 1% content) are  $^7\text{Li}$ ,  $^{12}\text{C}$ ,  $^{15}\text{N}$ ,  $^{20}\text{Ne}$ ,  $^{29}\text{Si}$ ,  $^{44}\text{Ca}$ ,  $^{48}\text{Ca}$ ,  $^{56}\text{Fe}$ ,  $^{57}\text{Fe}$ ,  $^{59}\text{Co}$ ,  $^{64}\text{Zn}$ ,  $^{66}\text{Zn}$ ,  $^{75}\text{As}$ ,  $^{107}\text{Ag}$ ,  $^{109}\text{Ag}$ ,  $^{110}\text{Cd}$ ,  $^{111}\text{Cd}$ ,  $^{112}\text{Cd}$ ,  $^{114}\text{Cd}$  (Fig. 1). The total content of these impurities amounts to  $10^{17}$ , the experiment duration being up to  $2 \times 10$  sec. The observed change of natural isotope ratio for these impurity nuclides is up to several tens of times, some main isotopes of impurity elements (with high natural abundance percentage) being absent. The following isotopes were registered as being absent:  $^{58}\text{Ni}$ ,  $^{70}\text{Ge}$ ,  $^{73}\text{Ge}$ ,  $^{74}\text{Ge}$ ,  $^{113}\text{Cd}$ ,  $^{116}\text{Cd}$ . These peculiarities are also registered within 100nm thick surface layer (Fig. 2), the observed natural Pd isotopes ratio of the sample being changed (Fig. 4).

The said results obtained by various methods show good agreement with each other and are 100% reproducible.

**Gamma emissions registration** was carried out with the help of Ge-Li detector and the multi-channel spectrum analyzer. The detector was placed into 10 mm thick lead chamber together with the GD device. Gamma emissions ranging 0.1 - 3 MeV were observed when the Glow Discharge was on and in the course of 8 days after the discharge current switch off. When using cathodes of various materials it was observed that after the discharge current switch off the induced gamma emissions value grows proportional to the increase of deuterium ions dose

received by the cathode from the discharge plasma (Fig. 6). In spectra registered for one and the same Pd cathode sample in the course of 8 days after the discharge current switch off (Fig. 5) groups of radioactive nuclides were discovered, their semi-decay period ranging from 1 to 6-7 days (Fig. 7).

The induced gamma activity range included areas exceeding the uniform spectrum (continuum) and separate lines imposed upon them. In these conditions the excess of gamma-line area over the background was of a small value ( $\delta=2.5 - 5$ ). The meaning of  $\delta$  for the continuum was equal to 8-10 ( $\delta=8 - 10$ ). The gamma spectra obtained when the Glow Discharge was on and after the Discharge current switch off were processed with the help of a database [2] to compare the gamma-lines of irradiating nuclides. The analysis showed neutron-excessive nuclei with masses ranging from  $A=16$  to  $A=136$ , resulting in formation of  $\beta$ -radioactive decay chains, to be the source of gamma emissions. Given below is an example of such a chain for an atomic mass of  $A=102$ . All the gamma lines presented in this chain were registered in the experiment.



The total quantity of radioactive atoms (Fig. 8) was determined taking into account the gamma-lines area, the detector efficiency and the quantum output value. The main contribution to gamma emissions (radioactive nuclides impurity yield up to  $10^3$  of atoms) was made by beta-radioactive chains with masses  $A=16; 17; 23; 30; 46; 47; 51; 54; 55; 58; 63; 64; 71; 75; 80; 84; 92; 97; 99; 100; 101; 102; 103; 104; 105; 106; 107; 108; 109; 110; 118; 123$ .

Experimental results on nuclear products registration show that presumably there exists a certain mechanism for conversion of low-energy (hundreds of eV) initial excitation from electric discharge into high-energy processes. The X-ray emissions may serve as a testimony for the existence of such a mechanism.

**The X-ray emissions registration** was carried out on modified GD device. The X-ray emissions were allowed to escape from the GD area through a number of holes bored in a flat anode body. X-ray film, Al-oxide-based thermo-luminescent detectors (TLD) and thick-film nuclear emulsion were used to register said emissions. The picture of anode-cathode area left by the X-ray irradiation upon the X-ray film or nuclear emulsion was obtained with the help of obscure chamber covered by 0.015 mm thick beryllium filter. TLD-based seven-channels spectrometer with beryllium filters of varying thickness was used to estimate the emissions spectrum constituents. The X-ray pictures show that it is the anode walls and the central cathode area which irradiate the emissions of highest intensity. The overall X-ray irradiation dose for 6 hours of the experiment amounted to 5000 Roentgen. Registration results obtained by the seven-channels spectrometer (Fig. 9) allow to single out spectrum areas with energy of 1.5 and 2 keV. There are areas of intensified registered irradiation, which imply presence of harder irradiation constituents. Pd-D system results in 10-15 times more intensive irradiation, than W-H and T-H systems, correspondingly. The procedure for analysis of photo-electrons tracks (counting of darkened grains) obtained upon the nuclear photo-emulsion using the obscure chamber was also used in the experiment for defining x-ray emissions spectrum. These results show more intensive (high-energy up to 30 keV) X-ray irradiation (Fig. 10).

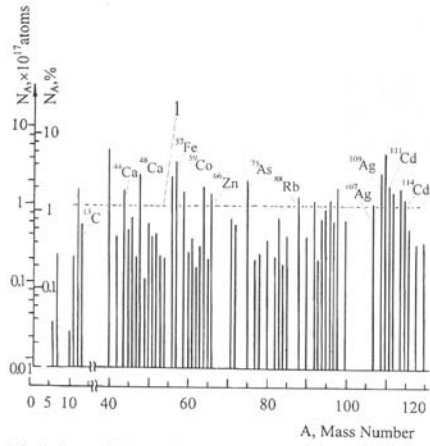


Fig. 1. Post-Glow Discharge impurity yield in Pd cathode.

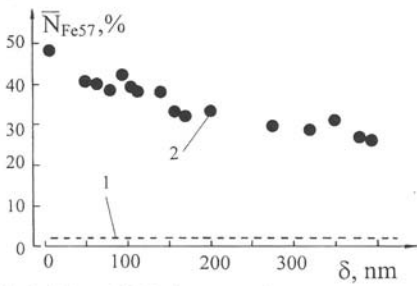


Fig. 3.  $^{57}\text{Fe}$  and  $^{56}\text{Fe}$  isotopes ratio change in Pd cathode superficial layer. 1-natural ratio, 2-after Glow Discharge.

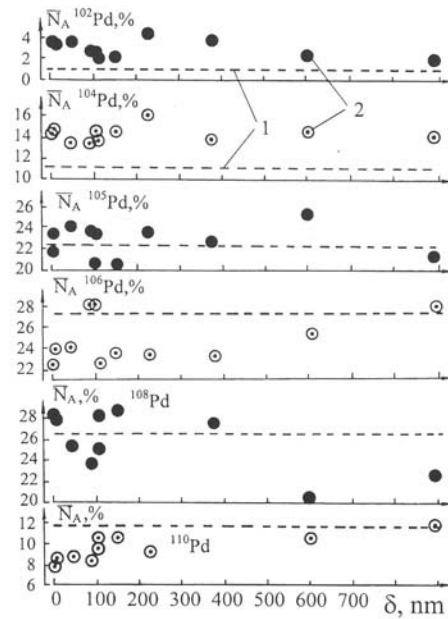


Fig. 4. Post-Glow Discharge Pd isotopes ratio change in Pd cathode superficial layer.

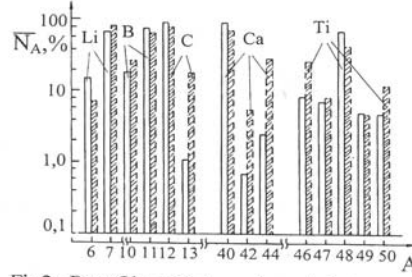


Fig. 2a. Post-Glow Discharge impurity isotopes ratio change (in comparison to the natural abundance) in PD cathode.

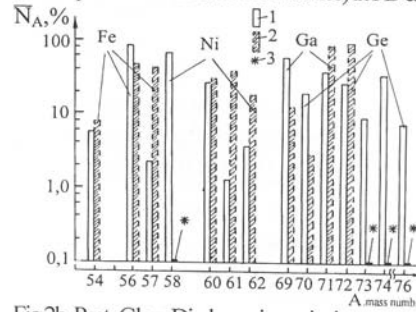


Fig. 2b. Post-Glow Discharge impurity isotopes ratio change (in comparison to the natural abundance) in PD cathode.

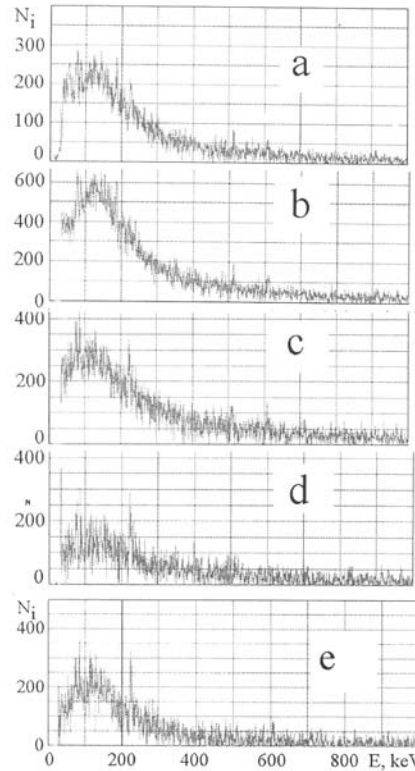


Fig. 5. Post-Glow Discharge induced gamma-emissions spectra, a-During Glow Discharge operation ( $\tau = 23000$  sec.); b-1 day later, c-2 days later, d-6 days later, e-8 days later (b-e -  $\tau = 60000$  sec.).

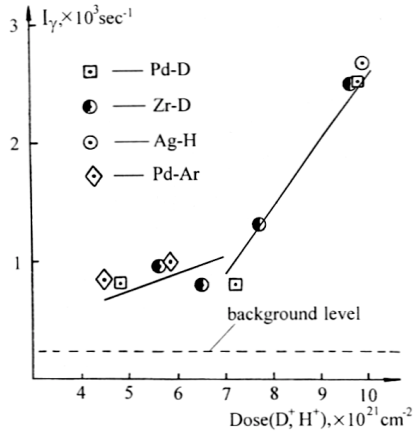


Fig. 6. Post-Glow Discharge induced gamma-emissions intensity versus deuterium ions dose in the cathode.

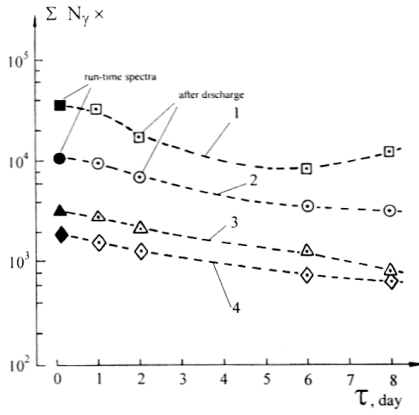


Fig. 7. Induced gamma-emissions intensity change (total number of events within specified energy range) for different spectrum areas. 1) 100 - 150 keV energy range, 2) 300 - 350 keV energy range, 3) 650 - 700 keV energy range, 4) 1100 - 1150 keV energy range.

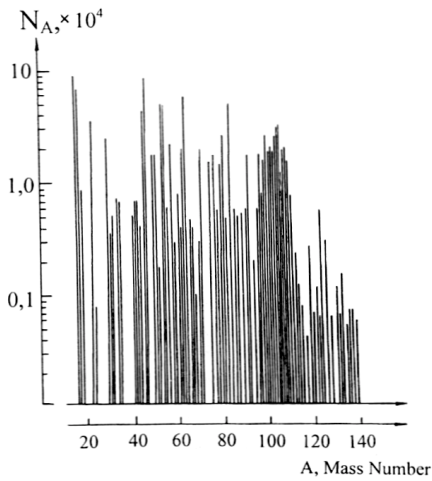


Fig. 8. Total quantity of radioactive nuclides in post-GD Pd cathode.

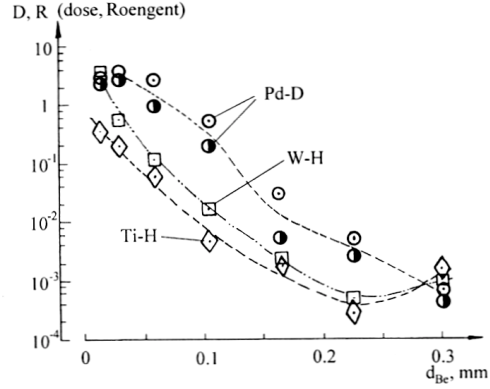


Fig. 9. X-ray emissions dose absorbed by TLD behind Be filters of various thickness.

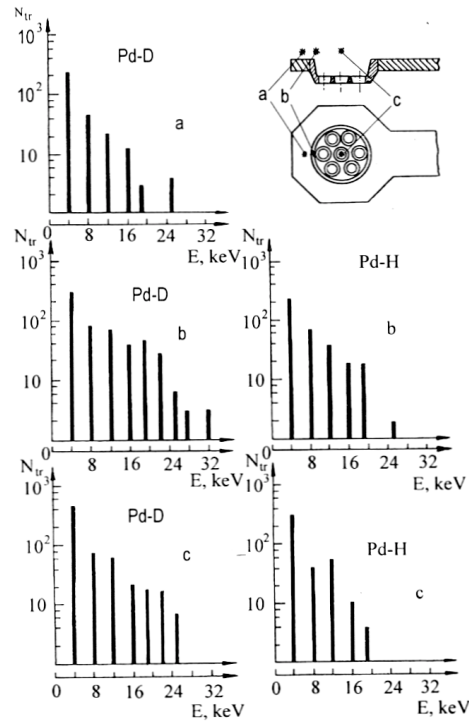


Fig. 10. X-ray emissions spectra obtained by procedure of tracks registration in nuclear photo-emulsion using the obscure chamber. Pd-D system. a- plasma area, b- anode wall, c- cathode central part. Pd-H system. b- anode wall, c- cathode central part.

## 2. Experimental Results and Discussion

The following processes may lead to initiation of nuclear reactions:

1. Deuterium ions acceleration in the Glow Discharge near-cathode area to energies of several hundred eV.

2. Non-resilient processes of deuterium ions collision with the crystal lattice ions ( $\text{Pd}^{4+}$  ions for Palladium). Under these conditions the electron frame is displaced relative to nucleus and a dipole or optic polar phonon is formed. The initial optic polar phonons frequency is  $\omega_{op} = 2\pi \cdot \nu$ , where  $\nu = W_{op}/2\pi \cdot h$ . At energies  $W=1$  keV  $\omega_{op} = 0.95 \times 10^{19} \text{ sec}^{-1}$  which is higher than the plasma frequency  $\omega_p = (1.3 - 2.5) \times 10^{16} \text{ sec}$ , plasmons are not produced and there is no compensation for the arising spatial division of charges. These processes cross-section related to non-adiabatic transition is determined according to Massey criterion:

$$\xi = \Delta E \times a \times 2\pi / (h \times \nu) .$$

Here  $\Delta E$  represents the bombarding deuteron energy variation,  $a$  stands for the area dimension, where the adiabatic wave function is essentially changed,  $h$  is the Plank constant,  $\nu$  shows the relative deuteron velocity. For  $\Delta E = 0.07 - 1.5$  keV (the discharge conditions) the Massey criterion  $\approx 1$  and the non-resilient processes cross-section for optic polar phonons formation becomes close to gaso-kinetic one.

3. The local electric field intensity  $E_{loc}$  resulting from the displacement of both the electron shell and the nucleus is characterized by a very big value because the distance between the electric charges is very small. At the said electric field frequency being higher than plasma frequency the electric induction value is close to zero. The electric field intensity is identified by the number of dipoles being formed. The macroscopic electric field intensity  $E_a$  builds up with the increase in the number of atoms  $n_a$  assuming the state of polar phonon excitation (the dipoles number):  $E_a \sim n_a \cdot E_{loc}$  .

At big values of macroscopic electric field intensity  $E_a$  the largest share in the distribution of energy is taken by non-linear (anharmonic) occurrences The medium dynamic polarization can be represented as follows:

$$P = \epsilon_0 \cdot (\chi_1 E_1 + \chi_2 E_1^2 + \chi_3 E_1^3 + \dots)$$

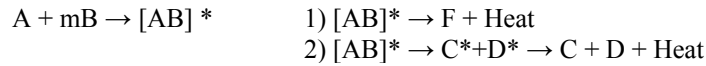
Here  $P$  denotes environment polarization,  $\chi_1, \chi_2, \chi_3 \dots$  stand for non-linear media susceptibilities. The intensity of non-linear processes is determined by the following members:  $\chi_2 E_1^2, \chi_3 E_1^3, \dots$  In the general case  $\chi_2, \chi_3$  susceptibilities are defined by the kind of material, type and state (physical parameters) of the crystal lattice. At big concentration of initial optic phonons (high charge current density) non-linear unharmonic processes start playing their essential part. Presumably, processes of the 3-rd and the 4-th order begin.

$$\begin{aligned} h\omega_{1 \text{ in}} + h\omega_{2 \text{ in}} &\rightarrow h\omega_3 \quad \text{and } \omega_1 < \omega_3 > \omega_2 \\ h\omega_{1 \text{ in}} + h\omega_{2 \text{ in}} + h\omega_{3 \text{ in}} &\rightarrow h\omega_4 \quad \text{and } \omega_1 < \omega_4 > \omega_2, \omega_4 > \omega_3 \end{aligned}$$

These expressions mean that two ( $h\omega_{1 \text{ in}}, h\omega_{2 \text{ in}}$ ) or three primary phonons are combined and formed into one  $h\omega_3$  or  $h\omega_4$ , the frequency and energy of the newly formed phonons being bigger  $W_{op} = h\omega_{op}/4\pi^2$ . In this way out of a big number of primary phonons with energies of 0.07 - 1.5 keV a small number of high energy phonons (up to tens and hundreds keV) is formed. The primary phonons energy spectrum is displaced in the direction of bigger values. As this takes place the Pd crystal lattice is "cold" (300-400°) K, Pd ions are located at the lattice points and perform oscillations, corresponding to this temperature. Deuterium ions are also spatially fixed between Pd ions. But Pd ions are in a state of optic polar oscillatory excitation with energy up to tens and hundreds keV (Fig. 11). An environment with non-equilibrium excitation of one of its energetic states (similar to isomers nuclei) is formed. It is known that the rate of nuclear reactions of spontaneous fission for nuclear isomers is bigger by  $10^{23} - 10^{26}$  times [3].

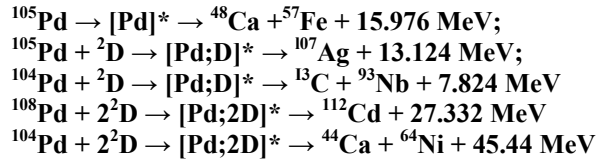
4. At densities corresponding to those of solids and energies of several tens keV the intensity of nuclear reactions is high enough.

The following types of nuclear reactions of transmutation resulting in formation of stable nuclides are possible:



Where **A** stands for Pd or other element nucleus; **B** represents deuterium or hydrogen; **[AB]\*** is a short-lived intermediate compound nucleus; **m-1,2,3 .., C\*, D\*** denote nuclear isomers of nuclides with masses less than that of Pd; **C,D** are stable nuclides; **F** stands for a nuclide with a mass more than that of Pd. At first a composite compound-nucleus in excited state is formed. Then one of the two possible modes is realized: 1) the compound nucleus may lose its excitation and form a stable nucleus of a heavier than Pd element; 2) the compound nucleus may split into two nuclei fragments with masses less than that of Pd. In so doing the two nuclei should be in excited isomer state (experiments show that the nuclear reactions energy is not produced in the form of nuclear fragments kinetic energy).

The possible types of nuclear transmutation reactions (2), which may be considered in the course of analysis of experimental results, are the following:



The nuclear reaction value being assumed as 10-15 MeV per an atom of nuclear product, the heat energy value registered per a cathode sample (1) shows good agreement with the quantity of discovered stable nuclides impurity yield (2).

The following types of nuclear reactions of transmutation accompanied by formation of radioactive nuclides are possible:



Where **A** is Pd or other element nucleus; **B** stands for deuterium or hydrogen; **e<sup>-</sup>** denotes an electron; **[AB]\*\*** represents an intermediate short-lived neutron excessive compound-nucleus; **m=1,2,3..., x=1,2,3..., C\*\*, D\*\*** shows neutron excessive nuclear isomers of nuclides with masses less than that of Pd; **C\*, D\*** are neutron excessive nuclides; **F\*** stands for a neutron excessive nuclide with a mass bigger than that of Pd.

5. The last stage of the process is conversion of nuclear reaction energy into heat. Presumably, relaxation of the compound nucleus or nuclear isomers excited state proceeds by multi-stage transitions, with the energy transfer to all the atoms of macro-monocrystal (up to  $10^8$ .) at each transition stage by multi-phonon processes.

Acoustic phonons (resilient sound-wave) interact with all the macro-monocrystal atoms in the course of one nuclear isomer transition stage converting this energy into energy of crystal lattice heat oscillations.

## References

1. A. B. Karabut, "Excess Heat Registration in High Current Density Glow Discharge", Proceedings of the Sixth Conf. on Cold Fusion, Vol.2, October 13-18, 1996, Japan, p.463.
2. Table of Isotopes, 8<sup>th</sup> Edition, Editor: V.S.Shirley, 1996, by John Wiley & Sons, Inc.
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