ON THE POSSIBILITY OF D-D FUSION STIMULATION BY A HIGH-CURRENT ARC DISCHARGE IN GAS-FILLED METAL

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INTRODUCTION

Beginning in 1989 there appeared many publications on the study of the so-called "cold nuclear fusion" (CNF). Some of the reported results affirm the existence of the CNF phenomena, while others deny it. Distinctive peculiarities of the experiments where the CNF has been observed include poor reproducibility, a sporadic character of the corresponding signals and the observation only under the non-equilibrium conditions in the metal-deuterium system. A generally accepted view on the CNF mechanism up to the present is absent. One widespread hypothesis is the assumption of an "accelerating" or "accelerating-fracture" mechanism, which actually suggests not a "cold" (as in μ-catalysis) but a "microscopically hot" fusion [1,2]. Of interest is the quest for the ways in which CNF initiation can be reproduced to observe the same reactions proceeding under definite conditions. In [3] the initiation of the nuclear reaction was carried out by impact destruction of a monocrystal LiD. In the present study we tried to initiate the CNF by means of a high-current low-voltage pulse arc discharge in a vacuum with palladium or titanium cathodes loaded with deuterium.

The vacuum arc is a low-voltage (U = 20-30 volts) discharge in electrode material vapors. The so-called cathode spots (CS) are formed on the cathode of the vacuum arc. CS are bright luminescent regions of small dimensions, through which there occurs a shorting of the current between the integrally cold metal and plasma. CS on the de-gassed clean metal electrodes are studied in detail [4]. The spot size is tens of microns, the current density $j \approx 10^7$ A/cm^2. The metal surface temperature in the spot is estimated to be several thousands of degrees. A CS exists on the electrode during $\approx 10^{-6}$ s, dying away afterwards. The current, going through one spot is $I_r \leq 10^2$ A. Thus in a discharge with a current $I \geq 10^3$ A several tens of spots are functioning simultaneously on the cathode surface; during the pulse time with a duration of e.g. $\tau \approx 10^{-3}$ s the cathode spots must die away several hundred times and form again on other parts of the surface. The CS are sources of hypersonic jets of the highly ionized plasma.

An arc discharge is also realized on the gas-filled cathodes, its integral characteristics are somewhat different from those of the discharge on a degassed clean metal [5]. The cathode processes in the discharges with gas-filled electrodes are at present poorly studied, but there is evidence to consider that the spot properties, which are the most significant for us, are preserved. These properties include a high current density, short life-time, and a high temperature of the surface.

The above described CS properties render promising the attempts to initiate the CNF by means of an arc discharge with deuterium-filled electrodes. In fact, during the burning of the arc discharge tens of localized thermal sources with a high $\approx 10^8$ W/cm^2 energy flux density to the electrode (volt-equivalent of the cathode ≤ 10 V), as if wandering over the cathode, cause a rapid local heating of near-surface metal regions (which have a characteristic size of $l \approx rs \approx 10^{-3}$ cm) till the temperature nears the melting point

(the current spreading region is implied). The temperature gradient on the metal turns out to be correspondingly > 10^6 K/cm. In the metal-deuterium system a strong local non-equilibrium is created. The high current density leads to an appearance of a strong friction forced between the implanted deuterium nuclei and the electron flux. In the spot formation stage ($\tau \leq 10^{-8}$s) the electron current density and consequently the energy flux density is 1 to 2 orders of magnitude higher. In addition, on the cathode surface in the region directly adjoining the spot, there flows a current of metal and deuterium ions, whose density may reach $j_{ik} \approx 10^5$ A/cm^2, and the ion energy $E_{ik} \approx 10$eV. The deuterium ions, having such energy, may effectively implant themselves in the near surface metal layer. At the anode surface the ion current flows essentially more uniformly, its density is significantly lower $j_{ia} \approx 10^2$ A/cm^2, but the ion energy is $E_{in} \approx 10^2$eV.

The absence of generally accepted theory on the CNF-mechanism does not allow the identification of the enumerated factors which may turn out to be essential for the CNF initiation. It may be presumed e.g. that the local overheating of the surface, caused by the pulsed voltage, will produce a formation of microfractures and thereby induce fusion [1]. It may be thought that the arc effect on the deuterium-filled metal will locally increase the possibility of exciting two deuterium nuclei in one octahedral cavity, which may lead (according to the presumption expressed in [6]) to cause a fusion reaction.

EXPERIMENTAL SET-UP AND TECHNIQUE

In the experiment an attempt was made to record the neutrons, emitted from a gas-filled electrode, if the reaction D + D → ^{3}He+n is produced. The experimental set-up is shown in Fig. 1. The discharge was initiated in a vacuum chamber constructed of stainless steel (100 mm diameter, 180 mm long). The anode was a Cu cylinder 20 mm diameter (in this experiment the gas-filled anode was not used). The contact gap d =8 to 10 mm. The cathodes were of two types:

1. A Cu cylinder 20 mm diameter, with one end coated with 57.4 mg Ti layer (h ≈ 50μ), containing either 22.8 cm^3 of deuterium at normal conditions (which corresponds approximately to about 1 atom of D per atom of Ti), or 2.8 mg Ti (h ≈ 2.5μ), containing 0.92 cm^3 of deuterium.

2. A cylinder of stainless steel with a thin Pd disk welded on it, l = 0.5 mm thick. Directly before the measurement began, the Pd was filled with D during the electrolysis D_2O with an admixture of a water-free salt K_2CO_3, or an alkali CsOD in an open ditch with a current I ≈ 100-300 mA. The electrolysis duration was either 1.5 to 2 hours or 22-24 hours.

The discharge was triggered by a current break in the auxiliary circuit. For creating the discharge a square-wave voltage pulse generator was used, V=90 V, duration $\tau \approx$ 0-5 ms. The voltage generator provided a stable output $\pm$ 2% at a current I ≤ 2kA. The current was controlled by a ballast resistor. In the present study current pulses (I ≈ 1 kA, $\tau \approx$ 1 ms) were used. The details of this part of the experiment are described in [7]. For the purpose of diminishing electrical interferences, the high-current circuit was made coaxially, including the inside of the vacuum chamber (Fig. 1). In order to measure the discharge radiation in the anode cylinder along the axis, a 1.5 mm diameter hole was drilled, and an optical fiber was introduced (a quartz monofiber of 0.8 mm diameter), with the end sealed into the anode to avoid the fiber being coated by cathode erosion products [8]. The measurements were carried out in the single pulse regime. A strong gas-release during the pulse made it necessary to provide continuous mechanical pumping (p ≈ 10^{-2} Torr).

The vacuum chamber was inserted into an all-wave 4π neutron counter. The counter was calibrated using a standard neutron source ^{244}Cm. The efficiency of neutron recording with an energy of E ≈ 2.5 MeV was

$\alpha \approx$ 11-13%.

Before sinking the vacuum chamber into the counter, it is placed inside a special copper screen shaped like a bottle. The neck is used for ignition and high-current supply cables as well as vacuum hose through which the optical fiber is placed. A special press provided reliable contact between the screen neck and the exterior copper sheeting of the counter. In this way we succeeded in making an effective screening of the recording equipment from the interferences, arising during the arcing process. The interferences at the arc ignition and extinction were so strong, that they were registered as false signals. Therefore, activation of the recording devices was begun about 100 μs after the arc ignition, and the strobing duration was selected to complete the strobing pulse ≈100 μs before the end of the discharge pulse. Note that the technique used by us (the coaxial input, the screen, a special organization of the chains, synchronizing the recording facilities) permitted to suppress the interferences, generated by the discharge when using the gas-filled cathode. The vacuum arc on the de-gassed metal is such a strong interference source, that the measures taken by us (as will be seen further on) turned out to be not sufficiently effective.

During the experiment with the help of oscilloscope C9-8 the current and the arc discharge voltage were controlled. The discharge plasma radiation and the measurements from the counting block were also recorded. The radiation was recorded by a multichannel optical analyzer, joined to the exit split of the monochromator MDR-3, to the entrance split of which the light conductor was attached. Both a spectrum plot $4760 \leq \lambda \leq 4960$A, involving line D_{β}, as well as the spectrum plots, involving the most sensitive spectral lines TiII and PdII were recorded. A calibration of the optic analyzer was made using a spectral lamp filled with deuterium. The measurements were carried out by the alternation of two kinds of regimes: a "working" one (during the high voltage pulse) and an "idle" regime (the high voltage is turned off).

EXPERIMENTAL RESULTS

The experiments carried out by us can be arranged into 3 series.

1. Experiments with a Ti-cathode.
2. Experiments with a Pd-cathode, preliminary exposed to electrolysis for 22 to 24 hours.
3. The same with the electrolysis duration of 1.5 to 2 hours.

Unlike the vacuum arc with degassed electrode, where the arcing is followed by strong high-frequency voltage oscillations, in all three experimental series using gas-filled electrodes during the first ten pulses the arc was burning with a low noise level. Accordingly, the interference level was kept low (small counts during the idle regime). Some peculiarities in the intensity radiation of the spectral line of the discharge plasma gas components were observed in this initial measurement period using low-noise arcs. The dependence of radiation intensity J_D on the pulse number was non-linear; in some experiments it had a clearly pronounced maximum. Beginning from the pulse numbers 20-25 the J_D was monotonically dropping, and in the voltage oscillograms the noise level was increased. Apparently there was a decrease in the cathode gas saturation.

The characteristic results for the first series (the thickness of the Ti layer is $h = 50\mu$) are presented in Fig. 2. Note the initial plot of the curve ($N \leq 20$). We did not succeed in finding a satisfactory explanation of the dependence $J_D = J_D(N)$ in this section. Any significant differences in the counter indications in a "working" and "idle" regime could not be found. A similar result was received also on the cathode with a thin ($h=2.5\ \mu$) Ti layer. The received results taking into account the efficacy of the counter record indicate that the neutron flux out of the examined sample at any rate did not exceed 10^4 neutron/s.

A discouraging result has also been received in the second series. However, such an issue of the experiment in this case is probably quite natural. From Fig. 3 (curve 1) it can be seen that the spectral line observed by us near $\lambda = 4860$ A is not symmetrical and represents a superposition of H_β and D_β. Apparently after long-duration electrolysis (near 20 hours) in an open channel there occurs a replacement of deuterium, dissolved in Pd during the initial electrolysis stage by the hydrogen. It would not seem to be surprising, because the Pd-hydrides reveal an inverse isotopic effect, but it is not clear what the source is for the large quantity of hydrogen that appears in the solution. In the present work we did not intend to study this effect, but only reduced the duration of the electrolysis. The electrolysis duration was limited to 1.5 - 2 hours with the purpose of transferring a quantity of D-ions to the cathode, which by 2-3 times exceeded the minimal necessary quantity to fill the cathode with "one-to-one" ratio of deuterium to metal atoms.

The results received in one of the experiments in the third measurement series, obtained with a fresh cathode, are presented in Fig. 4. In this series the spectral line observed by us is quite symmetrical, and the position of its maximum corresponds to $\lambda = 4860$ A (D_β, Fig. 3, curve 2). The characteristic results for this series is the existence of the maximum in dependence $J_D = J_D$ (N), although it was not measured in all experiments as clearly as in the experiment whose results are given in Fig. 4. In this experiment the average count in the "working" regime exceeds the counts in the "idle" regime (averaging was made after first 21 pulses till the appearance of noises in the discharge).

DISCUSSION

It may be thought that we succeeded in realizing by means of an arc discharge the stimulation of the D-D fusion in the Pd filled with the deuterium. The neutron flux out of the sample may be estimated as 10^4 neutrons per second. Assuming that the reaction may be realized in the near surface layer $l \approx 10^{-3}$cm, the volumetric density of the neutron flux is: $q \approx 10^7$ neutron/s/cm^3. Assuming that the deuterium content in the sample corresponds to the β-phase ($c \approx 0.6$), one may estimate that Λ - the counting rate related to a pair of deuterium nuclei is: $\Lambda \approx 10^{-16}$s^{-1} per deuteron pair, which exceeds the so-called "Jones level" by 7-8 orders of magnitude [1,9]. Supposing that the reaction could proceed in the whole sample volume, then $\Lambda \approx 10^{-18}$s^{-1} per deuteron pair.

The experiments carried out by us have several drawbacks, the most serious of which, in our opinion, are as follows:

1. We did not control the deuterium content in the sample. The electrolysis was carried out blindly.

2. The Pd-plate, of which the cathode was made, did not have any certificate of purity. The metallographic analysis was not made either before or after the experiment.

3. The two Pd-cathodes were used more than once (before the second use the deuterium filled cathode was annealed in the air) although after the first use their surfaces were covered with erosion traces (CS autographs). The surfaces of the cathodes were remelted (the results presented in Fig. 4 belong to the fresh sample).

4. No attempts were made to record the formation of tritium in the sample, whose appearance is possible from the CNF occurring in the $D + D \rightarrow T$ channel.

5. A pure Cu, but not gas-filled electrode, was used as anode.

CONCLUSIONS

The absence of financial support forced us to break off this study. Therefore, we did not check the reproducibility of the results. The experiments were fulfilled in spring 1990, and we did not publish them because we hopped to continue this work and to receive definite results. Since we consider that the results received in this study show good prospects for CNF production by using our method we decided to publish the results of our work. We hope that we will be able to resume the study. We hope that by improving some of the drawbacks of this work future experimenters will have a tool for a reliable replication of CNF, consequently it will make the study of these phenomena easier.

REFERENCES

[1] (In Russian)
[2] (In Russian)
[3] (In Russian)
[4] (In Russian)
[5] (In Russian)
[6] (In Russian)
[7] S.M. Shkolnik, "The Plasma Parameters in the Interelectrode Gap of the Vacuum Arc," *IEEE Trans. Plas. Sci.*, 1985, vol ps-13, no 5, pp 336-338.
[8] V.P. Afanaseyev, A.A. Logatchev, N.K. Mitrofanov, S.M. Shkolnik, "Spectroscopy Measurements of High Resolution in High-current Vacuum Arc," Proc. XIV ISDEIV, Santa Fe, NM, September 1990, pp 187-191.
[9] S.E. Jones, E.P. Palmer, J.B. Czirr et al., "Observation of Cold Nuclear Fusion in Condensed Matter," *Nature*, 1989, vol 338, pp 737-740.

Fig. 1. Experimental set-up.

1. cathode; 2. gas-filled metal; 3. anode (Cu); 4. glass insulator; 5. current feed cylinder (Cu); 6. vacuum chamber (stainless steel); 7. inner screen (Cu); 8. detectors; 9. polyethylene; 10. external screen (Cu); 11. quartz fiber; PG - pulse generator, C9-8 - digital store oscilloscope, MDR-3 - monochromator, PM - photo multiplier.

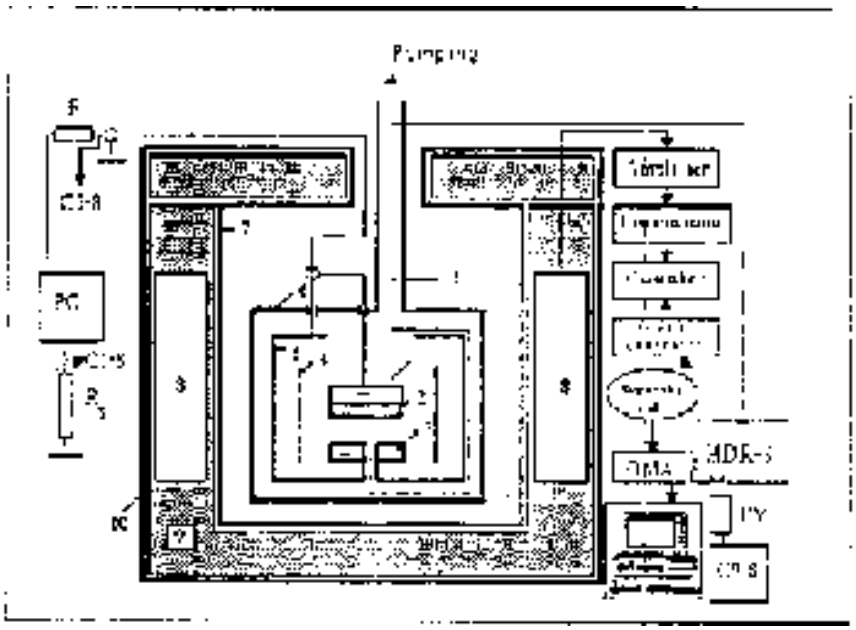
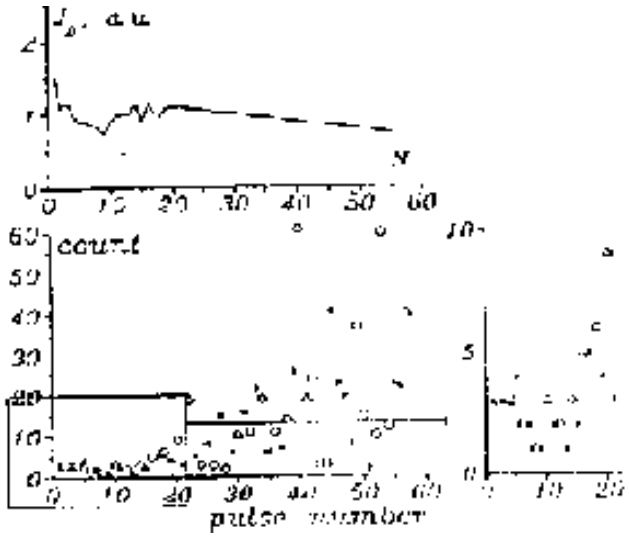


Fig. 2.

* - "working" regime
o - "idle" regime



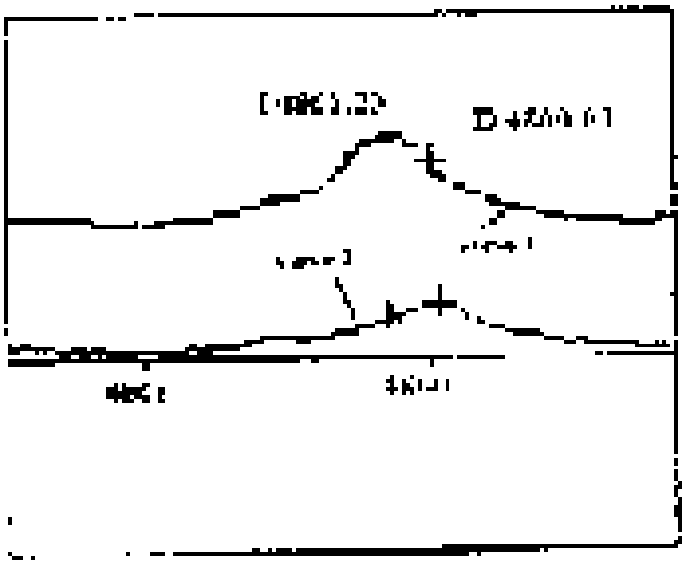


Fig. 3.

Dβ spectral line profile
1. electrolysis 22 h
2. electrolysis 2 h

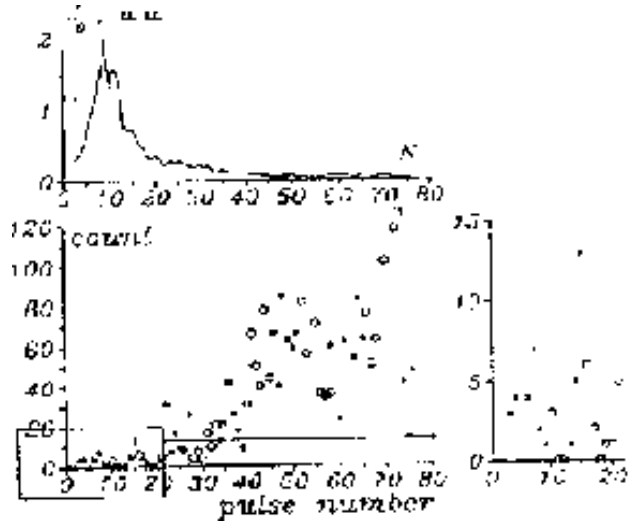


Fig. 4.

* - "working" regime.
o - "idle" regime.