COLD FUSION STUDIES IN THE USSR

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Introduction

The Organizing Committee kindly suggested that I should talk about a state of cold fusion (CF) studies in the Soviet Union. Offering of a special report dedicated to the soviet scientists' works seems to be quite justified, since they are not well known to the western scientific community. Meanwhile, both quantitatively and qualitatively they bring a noticeable contribution to the world "data bank" on this interesting phenomenon. It is even possible that some of these soviet works have been "precursors" of the "cold fusion era". However, inadequate integration of our science with the western one, aggravated by scanty telecommunication media development, has slowed down the process of information exchange on CF not only with outer world, but also in our country. It is sufficient to say that the first Soviet National Conference on CF took place only recently in March of this year (March 22—26, Dubna—Moscow). Figuratively speaking up to now we have been working behind the scenes and watching the play. Now it is time to raise the curtain.

Fig.1 illustrates the "CF geography" in our country as it was presented at the Dubna Conference. These works are carried out by about 45 Institutes. The total number of laboratories which took part in CF experiments is no doubt more. However, many of them stopped or "freezed" their activities after the first unsuccessful attempts and under the pressure of wide-spread scepticism. The CF reputation in our country has suffered greatly from rush and inexact experiments of the initial period, widely boosted with a mass media.

The total number of soviet publications on CF certainly exceeds one hundred (more than 80 papers were submitted at the Dubna Conference). About half of them are devoted to CF experiments, about a quarter are connected with methodical and structural studies, and the rest – with theoretical models.

Until very recently there was no any large–scale program on CF in the Soviet Union, and all investigations were financed from budgets of institutes. Recently, thanks to academician N.A.Baraboshkin's initiative, the first All–Union Academical contest on CF was organized, which had quite a modest fund. At present a wider program is under discussion and preparation.

The lack of any long–term financial support resulted in the fact that a great
"Cold Fusion geography" in the USSR, as it was presented at Dubna—Moscow Conference: Arzamas, Cheboksary, Cheliabinsk, Dônetsk, Dubna, Erevan, Kaliningrad, Kharkov, Kiev, Krasnoyarsk, Leningrad, Lugansk, Moscow, Novosibirsk, Obninsk, Odessa, Omisk, Podolsk, Rostov, Sverdlovsk, Tbilisi, Tomsk.
majority of soviet works on CF are characterized both by small volume and duration. There are only few prolonged well equipped experiments with good statistics aimed to a high reproducibility. Calorimetric measurements were not widely spread and developed. At the same time a number of works based on new original ideas and techniques have been done, which might have interesting continuations. Below I'll concentrate mainly on such representative papers, where some new results have been obtained or new techniques have been used for the first time. Having in mind a specific character of the report, some historical excursus is justified in my opinion. Due to the lack of space, works of more "traditional" character in spite of their importance will be presented only in a tabulated form (Tables I–III). For the same reasons methodical and structural researches are excluded. At the end of the report some selected soviet theoretical works will be mentioned in short. More detailed information on the soviet papers may be found in reviews [54,62,71].

1. Nuclear mechanofusion

It seems to be reasonable to begin the presentation of soviet results with a so-called "nuclear mechanofusion" (NMF), which development has been started by the group from the Institute of Physical Chemistry of the USSR Academy of Science few years before the first publications on CF [46,47]. Now it is difficult to estimate the reliability of NMF experiments and their relation to CF. If it is confirmed and if NMF and CF mechanisms common nature is proved, these works may be considered as the first results on anomalous nuclear effects in deuterium–solid systems.

The experiments [9,17] performed in 1986 revealed an excess of about 2 times the background level (BG = 0.07±0.02 neutrons per shot) of neutron emission during mechanical fracture of heavy ice and LiD crystals. Taking into account the efficiency of the neutron detector (ε ≈ 1–2 %) this leads to about 15–30 neutrons per fracturing act for D₂O–ice or LiD crystals. The detector consisted of 7 proportional counters, immersed into a tank with purified silicon oil, and was used by the group in all subsequent neutron measuring.

Three years later, after the first announcements on CF, the group returned to their investigations and performed the new series of neutron (and β−) measurements under mechanical impact on D–doped materials. The results of these experiments are shown in Table IV.

The authors interpreted their results in the terms of catalytic D₂O decomposition, formation and fracturing of hydrides.

The situation with NMF experiments is not clear at present. There are some confirmations in [48], but in [49,50] the effect is not confirmed within the limits of 15–20–fold decrease as compared to the results stated by the IPC group.
<table>
<thead>
<tr>
<th>Reference</th>
<th>Metal</th>
<th>Method</th>
<th>Detector</th>
<th>Efficiency %</th>
<th>Backgr. (c/s)</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arzhannikov [1]</td>
<td>Li</td>
<td>LiD+D$_2$O</td>
<td>CNM - 18x6</td>
<td>10</td>
<td>10$^{-2}$</td>
<td>(1.7±0.14)BG</td>
</tr>
<tr>
<td>Arzhannikov [2]</td>
<td>Pd,Pt</td>
<td>redox reactions</td>
<td>CNM - 18x6</td>
<td>10</td>
<td>10$^{-2}$</td>
<td>(1.5–1.8)BG</td>
</tr>
<tr>
<td>Bashkirov [3]</td>
<td>Pd,Ti</td>
<td>electrolysis</td>
<td>$^3$He plast. scintil.</td>
<td>10</td>
<td>0.06±0.01</td>
<td>2 BG</td>
</tr>
<tr>
<td>Bel’tyukov [4]</td>
<td>Ti</td>
<td>electrolysis laser Heating</td>
<td></td>
<td></td>
<td></td>
<td>18 BG (n)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2 BG (γ)</td>
</tr>
<tr>
<td>Borovoj [5]</td>
<td>Pd</td>
<td>electrolysis</td>
<td>LiI(Eu), LiF(TiO$_2$) scintil.</td>
<td>10</td>
<td>0.06±0.01</td>
<td>10$^{1-10^2}$n/s</td>
</tr>
<tr>
<td>Bushuev [6]</td>
<td>Pd</td>
<td>electrolysis</td>
<td>$^3$He6</td>
<td>10</td>
<td>0.3</td>
<td>Bursts 4±BG N ~BG</td>
</tr>
<tr>
<td>Bystritskij [7]</td>
<td>Ti</td>
<td>electrolysis</td>
<td>BF$_3$(16+22)</td>
<td>26±1</td>
<td>8·10$^{-2}$</td>
<td>Bursts 4·10$^5$BG</td>
</tr>
<tr>
<td></td>
<td>Ti/Ni</td>
<td></td>
<td>BF$_3$(16+22)</td>
<td>26±1</td>
<td>8·10$^{-2}$</td>
<td>Bursts 4·10$^5$BG</td>
</tr>
<tr>
<td>Bystritskij [8]</td>
<td>Ti</td>
<td>D$_2$ gas</td>
<td>BF$_3$(16+22)</td>
<td>26±1</td>
<td>8·10$^{-2}$</td>
<td>Bursts 4·10$^5$BG</td>
</tr>
<tr>
<td>Derjaguin [9]</td>
<td>D$_2$O ice destruction</td>
<td>$^3$He 7</td>
<td>1</td>
<td>0.15±0.06 per shot</td>
<td>3 BG</td>
<td></td>
</tr>
<tr>
<td>Golovkov [10]</td>
<td>Ti</td>
<td>electrolysis</td>
<td></td>
<td></td>
<td></td>
<td>Bursts 100 BG</td>
</tr>
<tr>
<td>Golubnichij [11]</td>
<td>Pd</td>
<td>electrolysis</td>
<td>$^3$He 10</td>
<td>10(SN)</td>
<td>0.005</td>
<td>Bursts 10–10$^2$ BG</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>plastic scintil.</td>
<td>30(FN)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Golubnichij [12]</td>
<td>Pd</td>
<td>electrolysis</td>
<td>$^3$He 10</td>
<td>10</td>
<td>0.004</td>
<td>5 BG</td>
</tr>
<tr>
<td>Gorbachev [13]</td>
<td>Pd</td>
<td>discharge</td>
<td>scintil.</td>
<td>1</td>
<td>5·10$^{-3}$</td>
<td>Bursts 6–10 BG</td>
</tr>
<tr>
<td>Guzhovskij [14]</td>
<td>Ti</td>
<td>electrolysis</td>
<td>$^3$He 12</td>
<td>20</td>
<td>0.014</td>
<td>20 BG</td>
</tr>
<tr>
<td>Guzhovskij [15]</td>
<td>Pd</td>
<td>electrolysis self-heating</td>
<td>$^3$He 12</td>
<td>20</td>
<td>0.014</td>
<td>100 BG</td>
</tr>
<tr>
<td>Karabut [16]</td>
<td>Pd</td>
<td>discharge</td>
<td>CNM - 18</td>
<td>5</td>
<td>10$^{1-10^2}$</td>
<td>10$^8$BG Bursts heat E$_0$$\leq$1.7 MeV</td>
</tr>
<tr>
<td>Reference</td>
<td>Material</td>
<td>Method</td>
<td>Reaction</td>
<td>3He</td>
<td>1±0.5</td>
<td>Notes</td>
</tr>
<tr>
<td>-----------</td>
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</tr>
<tr>
<td>[17] Kluev</td>
<td>LiD desintegr.</td>
<td>3He 7</td>
<td>1±0.5</td>
<td>0.16±0.06</td>
<td>2.5 BG</td>
<td></td>
</tr>
<tr>
<td>[18] Krzhanski</td>
<td>Pd Ti</td>
<td>electrolysis</td>
<td>CH - 17 6</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[19] Kuz'min</td>
<td>Pd Ti</td>
<td>electrolysis</td>
<td>ZnS(Ag) scintil. 3He</td>
<td>1</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>[20] Lipson</td>
<td>Ti LiD, D2Or PP(D6) desintegr.</td>
<td>3He 7</td>
<td>1±0.5</td>
<td>0.05</td>
<td>6 BG</td>
<td></td>
</tr>
<tr>
<td>[21] Lipson</td>
<td>Ti PE(D4) friction</td>
<td>3He 7</td>
<td>1±0.5</td>
<td>0.05</td>
<td>5 BG</td>
<td></td>
</tr>
<tr>
<td>[22] Lipson</td>
<td>Ti D2O, mechanical activation</td>
<td>3He 7</td>
<td>1±0.5</td>
<td>0.04</td>
<td>10 BG</td>
<td></td>
</tr>
<tr>
<td>[23] Lipson</td>
<td>Ti D2O, cavitation</td>
<td>3He 7</td>
<td>1±0.5</td>
<td>0.035± 0.005</td>
<td>1.5 BG</td>
<td></td>
</tr>
<tr>
<td>[24] Novikov</td>
<td>Pd electrolysis</td>
<td>3He 6</td>
<td>10</td>
<td>0.17</td>
<td>10 BG</td>
<td></td>
</tr>
<tr>
<td>[25] Polosukhin</td>
<td>Pd 0.4MPa, 70 - 57 OK</td>
<td>NaI, 3He</td>
<td></td>
<td></td>
<td>10²s⁻¹(γ)</td>
<td></td>
</tr>
<tr>
<td>[26] Rusov</td>
<td>Pd-Ag electrolysis</td>
<td>MAND/p 10⁻⁴tr/n</td>
<td></td>
<td></td>
<td>10 BG</td>
<td></td>
</tr>
<tr>
<td>[27] Sannikov</td>
<td>Ti steam, LiD</td>
<td>NaI(Tl) 2</td>
<td>7</td>
<td>0.2</td>
<td>8 BG</td>
<td></td>
</tr>
<tr>
<td>[28] Yukhimchuk</td>
<td>V, Pd 50MPa,77 - 67OK</td>
<td>3He 15 7</td>
<td>0.074</td>
<td></td>
<td>Bursts 700 BG</td>
<td></td>
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<tr>
<td>[29] Zelenskij</td>
<td>Pd, Ti ion implantation</td>
<td>BF₃</td>
<td>1</td>
<td>2×10⁻²</td>
<td>2 BG</td>
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</tbody>
</table>

**Negative (non-conclusive) results**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Material</th>
<th>Method</th>
<th>Reaction</th>
<th>3He</th>
<th>1±0.5</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>[30] Anan'ev</td>
<td>Ti ion implantation</td>
<td>CNM - 18 polymer 10⁻²</td>
<td></td>
<td></td>
<td></td>
<td>posteffect</td>
</tr>
<tr>
<td>[31] Bashko</td>
<td>Pd electrolysis</td>
<td>SNM - 18×14 10</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[32] Brudanin</td>
<td>Pd electrolysis</td>
<td>SNM - 14×2 0.32</td>
<td></td>
<td></td>
<td>A_d&lt;6×10⁻²⁵</td>
<td></td>
</tr>
<tr>
<td>[33] Brudanin</td>
<td>Ti electrolysis D₂ gas</td>
<td>- -</td>
<td>- -</td>
<td></td>
<td>A_d&lt;8×10⁻²⁵</td>
<td></td>
</tr>
<tr>
<td>[34] Artyukhov</td>
<td>Ti,Zr D₂ gas</td>
<td>BF₃ 33</td>
<td>20</td>
<td>8×10⁻²</td>
<td>A_d&lt;10⁻²⁵</td>
<td></td>
</tr>
<tr>
<td>[35] Grigor'ev</td>
<td>Pd, Ti electrolysis</td>
<td>3He 10</td>
<td>6</td>
<td></td>
<td></td>
<td>0</td>
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</table>
### TABLE II: Charged Particles Registration

<table>
<thead>
<tr>
<th>Reference</th>
<th>Metal</th>
<th>Method</th>
<th>Detector</th>
<th>Results</th>
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<tbody>
<tr>
<td><strong>Positive Results</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Borovoj (36)</td>
<td>Pd</td>
<td>electrolysis</td>
<td>scintil.</td>
<td>$&gt;10^2 s^{-1}$</td>
</tr>
<tr>
<td>Golubnichij (37)</td>
<td>Pd</td>
<td>electrolysis</td>
<td>CsI</td>
<td>$A_{dd} \approx 10^{-22} s^{-1}$</td>
</tr>
<tr>
<td>Karabut (16)</td>
<td>Pd</td>
<td>discharge</td>
<td>semicond.</td>
<td>$E_{ch} \lesssim 20 \text{ MeV}$</td>
</tr>
<tr>
<td>Zelenskij (29)</td>
<td>Pd,Ti</td>
<td>ion implant. 100–800 K</td>
<td>semicond.</td>
<td>$A_{dd}=5.5\cdot10^{-19}(\text{Pd})$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100–78 K</td>
<td></td>
<td>$A_{dd}=1.6\cdot10^{-19}(\text{Ti})$</td>
</tr>
<tr>
<td><strong>Negative (non–conclusive) Results</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anan'ev (30)</td>
<td>Ti</td>
<td>ion implant.</td>
<td>semicond.</td>
<td>$\Lambda_{dd}&lt;2\cdot10^{-22}$</td>
</tr>
<tr>
<td>Bertsev (38)</td>
<td>Ti,Nb</td>
<td>$D_2,300–600$ K</td>
<td>semicond.</td>
<td>$\Lambda_{dd}&lt;4\cdot10^{-27}$</td>
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<tr>
<td>Brudanin (39)</td>
<td>Pd</td>
<td>electrolysis</td>
<td>CR–39 (a) semicond.</td>
<td></td>
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</tbody>
</table>

### TABLE III: Tritium Production

<table>
<thead>
<tr>
<th>Reference</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Positive</strong></td>
<td></td>
</tr>
<tr>
<td>Bazhutov (40)</td>
<td>Ti, $D_2O$ electrolysis with current cycling, 5 BG</td>
</tr>
<tr>
<td>Golubnichij (11)</td>
<td>$TiD_x$, thermodesorption, 70 BG</td>
</tr>
<tr>
<td>Grigor'ev (35)</td>
<td>Pd, Ti, $D_2O + KOD$ electrolysis, 10 BG</td>
</tr>
<tr>
<td>Guzhovskij (14)</td>
<td>$Ti$, $D_2O$ electrolysis (10–100) BG, $T/n \approx 10^{8.1}$</td>
</tr>
<tr>
<td>Kosjachkov (41)</td>
<td>The first paper with discharge, Ti, positive</td>
</tr>
<tr>
<td>Lipson (42)</td>
<td>$Ti + D_2O + PP(D_6)$, desintegration, 1.5 BG</td>
</tr>
<tr>
<td>Romadanov (43)</td>
<td>Y, Er, Nb, Ta, discharge, 109 T/s</td>
</tr>
<tr>
<td><strong>Negative (non–conclusive)</strong></td>
<td></td>
</tr>
<tr>
<td>Simonov (44)</td>
<td>many metals and alloys, electrolysis, 100 experiments $N_T &lt; 2\cdot10^{-18}$ s$^{-1}$</td>
</tr>
<tr>
<td>Vershinin (45)</td>
<td>Pd, Pt, Mb, high–voltage, nanosecond discharge</td>
</tr>
<tr>
<td>Yukhimchuk (28)</td>
<td>V, thermocycling, $N_T/N_n &lt; 3\cdot10^7$</td>
</tr>
</tbody>
</table>
TABLE IV: Results on nuclear mechanofusion

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Materials</th>
<th>Impact</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>[20]</td>
<td>Ti + 10% D₂O + 4% PP(D₆)</td>
<td>agitation</td>
<td>n: 6 BG</td>
</tr>
<tr>
<td>[42]</td>
<td>Ti + PE(D₄) + D₂O</td>
<td>friction</td>
<td>β: 1.5 BG</td>
</tr>
<tr>
<td>[21]</td>
<td>TiDₓ; LaNi₅</td>
<td>mechanical activation (abrasive wheel)</td>
<td>n: 5 BG</td>
</tr>
<tr>
<td>[22]</td>
<td>Ti + D₂O</td>
<td>cavitation</td>
<td>n: 10 BG</td>
</tr>
</tbody>
</table>

2. Nuclear chemofusion

The first observations of neutron emission from chemical reactions have been reported by the group from Novosibirsk [1,2].

Two different chemical reactions were used:

a) LiD + D₂O → LiOD + D₂. About 30 grammes of D₂O were placed into the test-tube and LiD crystals were put into it in small portions. The intensity of the neutron emission, accumulated in 30s intervals is shown in Fig.2a. During the chemical reaction neutron bursts with a duration of ≤ 5s were observed. The ratio R is:

\[
R = \frac{\text{counts during the chemical reaction}}{\text{background counts}} = 1.70 \pm 0.14.
\]

b) The oxidation-reduction reactions with Pd(ND₃)₂Cl₂, (ND₄)₂(PtCl₆) and Pd(NH₃)₂Cl₂, (NH₄)₂(PtCl₆) salts were compared. Results after six identical experiments are presented in Fig.2b.

The ratios R:

\[
R(\text{Pd}, H) = 0.96 \pm 0.09; \quad R(\text{Pd}, D) = 1.52 \pm 0.10
\]
\[
R(\text{Pt}, H) = 1.06 \pm 0.13; \quad R(\text{Pt}, D) = 1.87 \pm 0.08
\]

cannot be explained by the fluctuations, as it is seen from Fig.2c. Thus, a number of neutrons emitted in chemical reactions is a few dozens per gramme of deuterated material. The results were reproducible for about 100 runs.

3. Simultaneous direct registration of neutrons and charged products of dd–fusion

The work of the Khar'kov Physical Technical Institute group [29] (the first announcement appeared as early as in April 1989) is interesting from the point of view,
Fig. 2.

The emission of neutrons a) in the LiD–D$_2$O experiment; b) in reaction between Pd salts and Zn; c) the number J of 50s intervals with selected number of counts N. Crosses—counts during the chemical reaction.
Fig. 3. The neutron rate measured from a) Pd, b) Ti samples as a function of temperature: the ordinate is a ratio of detected neutrons to background. Energy spectra of charged particles from c) Pd and d) Ti targets. The position of the energies corresponding to $^3$He, T and p are indicated.
that it was the first and may be up to date the unique experiment, where all the products of dd-fusion (except 4He) were registered just in the same experiment. Besides, a clear temperature dependence of the CF rate (for 78–1300 K interval) was established for the first time. In the methodical sense it was the first CF experiment with successful application of ion implantation.

They used two kind of targets: thin Pd films (0.15–0.6 μm) precipitated on Ni layers (21 samples) and Ti foils (300 μm, 27 samples).

Loading was made using D₂⁺–ion beam with E_p = 25 keV at T = 100 K. Saturation under irradiation controlled by the yield of ³He, T and p was about D/Ti ≈ 5 and D/Pd ≈ 3 (Dose: ~10¹⁹D⁺/cm³).

Results are shown in Figs.3a–3d.

a) Fig.3a displays the dependence of neutron counting rate on temperature for the temperature range of T = 78–1300 K, which has some correlation with D₂ thermo-desorption rate. The source estimate is N ~ 10²n/s. Some excess of N_n above the background was also observed during repeated Ti heating from 78 to 1300 K and cooling from 100 to 78 K. But N_n ≥ N_back at T = 78–1300 K for samples implanted with H⁺ ions.

b) Charged particles emission has been measured during cooling from 100 to 78 K and heating from 100 to 800 K. Fig.3c displays the spectra measured in 60 experiments with 10³s duration for 9 samples, while Fig.3d shows the same for Ti (66 experiments). The excess above the background is clearly seen from the channels, which correspond to p, T and ³He. Reaction constant is estimated as A_dd = 5.5·10⁻¹⁹s⁻¹(dd)⁻¹ for Pd and A_dd = 1.65·10⁻¹⁹s⁻¹(dd)⁻¹ for Ti.

4. Correlation measurements

In their early work ([51], April 1989) the group from Lebedev Physical Institute and Lugansk Machine-Building Institute suggested to measure the correlations between fusion products and acoustic (A) and electromagnetic (EM) emission. Thorough study of this phenomenon was conducted by this group through a series of experiments started in the middle of 1989. The first results of these experiments were presented at the Provo Conference [37,12] and might serve as a convincing arguments in a favor of "fractoacceleration model" (FAM) [51–55]. But strictly speaking it is possible that fracturing is only accompanied with CF, but not causes it. To clarify this problem the LPI–LMBI group continued their study of acoustic signal time–structure and space location of their sources [56]. Fast and slow neutrons were registered and acoustic signals from two sensors placed at the opposite ends of the sample were recorded. High statistics is collected on double correlations (hundreds events) between slow neutron counter
Fig. 4. Correlations of slow neutrons with a) electromagnetic and b) acoustic signals for Pd and Ni (reference) cathodes.
(SNM, $^3$He 12, $\epsilon \approx 10\%$) and one of the acoustic detector signals; triple – from SNM plus both acoustic detectors; four-fold – from all four detectors. (Fast neutron detector presents a plastic scintillator with $\epsilon \approx 20\%$ effectiveness). Some of these measuring results are shown in Fig.4. Positive results for Nb and steel were also obtained by this group.

5. Cold fusion observations in gas–discharge devices

The possibility of utilization of D–loading during a gas discharge in CF experiments was demonstrated for the first time in the early work [41] accomplished in April 1989 in the Institute of Metalophysics of the USSR Academy of Sciences. The standard titanium magnetic–discharge pump was used for the large Ti surface (0.5 m$^2$) treatment by deuterium ion beam with energies up to 9 keV. Mass spectrometry of the gas after a few hours of work revealed the presence of tritium produced in a course of device operation. However, the experiment was not quite determined quantitatively. Thereafter gas discharge experiments on CF were intensively carried out by two groups from NPO "Luch" (Podol'sk).

a) V.A.Romadanov et al. results [43]. This group concentrated mainly on tritium search. For some cathode materials they registrated high rate of tritium production $\sim 10^7$–$10^9$ at/s (see Table V). Contact autoradiography of metal surface and its

<table>
<thead>
<tr>
<th>Sample</th>
<th>Experim. duration (n)</th>
<th>Relative activity count/100s 2ml</th>
<th>Tritium content Bk/ml</th>
<th>Production rate at/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>D$_2$</td>
<td>238</td>
<td>131</td>
<td>1.2 $\times 10^5$</td>
<td></td>
</tr>
<tr>
<td>Yttrium</td>
<td>1238</td>
<td>287</td>
<td>5.0 $\times 10^5$</td>
<td></td>
</tr>
<tr>
<td>Erbium</td>
<td>2271</td>
<td>551</td>
<td>4.2 $\times 10^5$</td>
<td></td>
</tr>
<tr>
<td>Erbium</td>
<td>8010</td>
<td>1602</td>
<td>1.1 $\times 10^6$</td>
<td></td>
</tr>
<tr>
<td>Erbium</td>
<td>2800</td>
<td>526</td>
<td>1.4 $\times 10^5$</td>
<td></td>
</tr>
<tr>
<td>Erbium</td>
<td>2590</td>
<td>1253</td>
<td>3.1 $\times 10^5$</td>
<td></td>
</tr>
<tr>
<td>Niobium</td>
<td>1.65 $\times 10^5$</td>
<td>4.7 $\times 10^4$</td>
<td>10$^7$</td>
<td></td>
</tr>
<tr>
<td>Niobium</td>
<td>7.75 $\times 10^8$</td>
<td>3 $\times 10^6$</td>
<td>10$^9$</td>
<td></td>
</tr>
<tr>
<td>Tantalum</td>
<td>3148</td>
<td>3078</td>
<td>9.6 $\times 10^5$</td>
<td></td>
</tr>
</tbody>
</table>

$\beta$–activity measurements were conducted both with positive results. A slight excess of neutron emission above a background level was also observed ($< 2$ BG).
b) A.V. Karabut et al. results [16]. Experiments of this group were carried out mainly with Pd with reproducibility of about 80%. The most important results are the following: 1) Neutron emission up to $\sim 10^7$ s was registered. 2) Neutron spectrum was measured and the maximum observed neutron energy constituted $E_{n,\text{max}} = 17\pm1$ MeV; 3) 150% heat release excess over the electrical input is claimed which is about 3–5 kJ per 0.1 g of cathode sample. The correlation between heat excess and neutron emission is observed. 4) The emission of charged particles with energies up to 20 MeV was registered. 5) Emission gamma—spectra were measured for various cathode materials. The majority of radioactive isotopes corresponded to the scheme (for palladium, as an example): $^{46}\text{Pd}^{110} \rightarrow ^{45}\text{Rh}^{110}$, i.e. the main reaction type were probably k—capture or (d,2p).

In order to check the Karabut group results [16] specialists from the Tomsk Nuclear Research Institute carried out experiments on gas discharge loading of palladium foils [13]. In the course of deuterium loading neutron bursts were observed within the time intervals of $\sim 10^2$ s and with signal—to—background ratio of 5—10. However, after the current switching off the neutron emission disappeared. It might testify that the "overvoltage" effect, but not CF resulted in neutron emission both in this experiment and in the Karabut et al. works [16]. The results on charged particles were not confirmed as well: semiconductor surface-barrier detector didn't registered any excess of p and T emission.

6. 14.1 MeV neutrons registration from $^{\text{d}}t \rightarrow ^{4}\text{He}+n$ reaction [26]

This work completed in June 1989 is interesting from the viewpoint of the first evidence of CF proceeding via $^{\text{d}}t \rightarrow ^{4}\text{He}+n$ channel. In respect to methodics it is the first example of dielectric track detector application for CF studying, known to me. Electrolysis of the mixture of 50% D$_2$O and 50% dissolved tritium water has been carried out with the (72% Pd, 25% Ag and 3% Au) cathode. Two rare events were found in the CN—85 detector: three—ray "track stars", which arose due to carbon nuclei desintegration through $^{12}\text{C}(n,n')$ reaction and were considered as an unambiguous evidence of fast neutron existence with energies greater than 10 MeV. Later the $^{\text{d}}t$—CF presence was confirmed by the Czechoslovak group electronic measurements [57].

7. Neutron burst during PdD self—heating

A curious phenomenon has been registered by a group from the Institute of Experimental Physics (Arzamas) in the course of electrolytic experiments with Pd [15]. After their D—loading Pd samples were taken out from electrolyte and placed into 4t—neutron detector together with a thermocouple. The self—heating occurred in some
cases due to the well-known physical-chemical reasons. In the experiments with 8.2 g Pd sample high counting rate was recorded in the sixth absorption-desorption cycle within two neighboring time intervals: 12337 counts/100s and 886 counts/100s. Integrated neutron yield is estimated as $7 \cdot 10^4$ neutrons.

8. Surface electron spectra measurements

The Moscow State University group performed the investigation on tritium content in Pd and Ti electrodes using the original method of electron spectra registration from a sample surface [19]. Some samples exhibited an extra-ordinary $\beta$-activity. The rough estimation of tritium amount gave approximately $10^8$–$10^9$ atoms on the surface and about $10^{12}$–$10^{13}$ atoms in the electrode. The appearance of T in the electrode could not be explained by adsorption from the electrolyte (approximately 5 Bk/ml – initial $D_2O$ activity).

9. Gamma quanta emission during electrolysis in the Ti–steam–gas–LiD system

In order to study CF in high temperature electrolytes a group from the Institute of Electrochemistry (Sverdlovsk) developed an original method [27]. Titanium sample was placed inside titanium or steel drum. The cell was heated up to 700–800°C in vacuum; 30 min later it was filled with $D_2$ gas ($P \approx 1$ atm) and then cooled down. At 200–250°C $D_2$ gas was refilled. Then the cell was cooled and LiD added. Then the cell was heated again with simultaneous voltage application (500–1400 V) to Ti and drum electrodes. Gamma peaks at $E_\gamma \approx 2.2–2.5$ MeV, approximately by an order of magnitude exceeding the background, were registrated.

10. Methods of CF stimulation

The possibility of CF stimulation with various "external effects" has been discussed in the early soviet paper [51], and later in [52]. Based on FAM the following methods have been suggested: mechanical deformation and desintegration in the course of $D$-loading, or after it, thermo- and cryoshocks, supersonic activation, current shocks (pulsing or stepwise current), ionizing radiation (both "external" and "internal" in a course of CF in stressed hydrides). Many of these methods were used in CF experiments (see [5,10,11,14,15,20,28,29,37,59,60] etc.) Some new CF stimulation methods have been reported by soviet groups at Dubna meeting: laser heating [4], nanosecond high-voltage discharge [45], X-ray irradiation [40].

11. Dubna group results

As an example of "traditional" approach let us consider the recent results of the
Dubna group [7,8]. They are worth to be mentioned for some reasons. This highly qualified group, which has experience in work on muon catalyzed fusion, started their CF experiments soon after the first announcement from Utah. They carried our very thorough study [32], but failed to find positive effect and presented very low limits on reaction constant (see Tables I, II). The group returned to the problem three times more [33,34,39], but again without any success. As for me, their results permanently clouded my belief in CF, and I was very glad, when just before this Conference Dr. V.M.Bystritskij informed me that in two latest experiments with some new procedure they at last managed to receive positive results. They changed both equipment and procedure and used amplitude and time information. The amplitude information essentially increased the degree of selection of "useful" events. The processing was of Menlove—type (two or more neutrons observed within 1 ms). These changes allowed a much lower background and a much higher reliability of identifying the effect.

Two types of experiments were performed: with electrolytic and D₂—gas loading. For electrolysis they used cathodes from pure Ti and Ti coated by 0.4 μm layer of nickel. For saturation with gaseous D₂ Ti chips send by Prof. S.Jones and H.Menlove from LANL were used.

The main results are the following:

a) In experiment with Ti cathode coated with Ni emission of neutrons in the form of separate bursts stochastically distributed in time was observed. (There was no effect for pure Ti).

b) Intensity of neutron in bursts is

$$I_n \approx (3.6 \pm 0.9) \cdot 10^4 \text{s}^{-1}.$$  

c) The burst frequency is $$\langle N_b \rangle \sim 1 \text{ h}^{-1}$$ and it decreases in time.

d) Burst duration is equal to

$$\tau \approx 300 \mu\text{s}.$$  

e) No correlations were observed between neutrons and acoustic signals. (However, it should be mentioned that they used too high threshold in the acoustic channel).

The gas experiment results are about the same ($I_n = (3.0\pm0.9) \cdot 10^4 \text{s}^{-1}$) and nicely confirmed the results of Menlove et al.

12. CF models

Due to the lack of space I can only mention some selected soviet theoretical works on CF, presented at the Dubna—Moscow Conferences.

a) Fracto—acceleration model (FAM). It was first suggested by IPC group for interpretation of their data on NMF [9,17] and later used by Lebedev—Lugansk group [51] for explanation of CF experiments [46,47] and presenting some predictions. (See also [52–55,61,62]).
b) Possible narrow resonances in DD-system. The idea of narrow Coulomb states for a system of two charged particles has been put forward in [63]. It is based on assumption of oscillating form of the potential at large distances [64] and predicts several resonances for DD-system in the kev energy region.

c) Catalysis by heavy stable particles. This model [66] combines the ideas of FAM and those of heavy particles catalysis [67], but with more sophisticated scheme of new catalytic particles ("erzions").

d) Barrierless fusion in crystal. Special conditions for D-atoms in cavities (cracks, defects) in crystal lattice suggested in [68], which may lead to higher fusion rate.

e) CF for geo- and astrophysics. A possible role of CF in the energy (and element) balance of the Earth, the Sun, the Jupiter and other planets is discussed in papers [69,70].

More information on soviet theoretical papers on CF can be traced from the review [71].

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References

4. I.L.Beltyukov et al. DMWCA, Suppl. p.7
5. I.A.Borovoj et al. Preprints Institute of Monocrystals (Kharkov) IMK–89–5; 89–9, 1989
6. V.S.Bushuev et al. KSF 1990, 5, 41, DMWCA p.11
7. V.M.Bystritskij et al. Contr. paper at this conference
8. V.M.Bystritskij et al. Contr. paper at this conference
10. V.M.Golovkov et al. DMWCA p.8
13. A.F. Gorbachev et al. DMWCA p.9
14. B.Ya. Guzhovskij et al. DMWCA p.6
15. B.Ya. Guzhovskij et al. DMWCA p.3
16. A.B. Karabut et al. DMWCA p.13
17. V.A. Klyuev et al. Sov. JTF Letters 1986, 12, 1333
18. L.M. Krizhanskij et al. Talk at the DMWCA
19. R.N. Kuz'min et al. Preprint Institute for Nuclear Physics, Moscow State University, 90–58/204, 1990; DMWCA p.31
24. A.G. Novikov et al. DMWCA papers
25. B.G. Polosukhin et al. DMWCA p.19
27. V.I. Sannikov et al. DMWCA p.19
28. A.A. Yukhimchuk et al. DMWCA p.7
34. V.M. Bystritskij et al. DMWCA paper, contr. paper at this conference
35. Yu.V. Grigor'ev et al. DMWCA paper
36. I.A. Borovoj et al. Preprint Institute of Monocrystals (Khar'kov) IMK–89–9, 1990
38. V.V. Bertsev et al. DMWCA Suppl. p.13
40. Yu.N. Bazhutov et al. DMWCA p.34
41. A.A. Kosjachkov et al. Sov. JETP Letters 1989, 49, 648
42. A.G. Lipson et al. Sov. JTP Letters 1989, 15, 88
43. V.A. Romodanov et al. DMWCA p.3
44. Yu.N. Vershinin et al. DMWCA p.33
45. M. Fleishmann, S. Pons, J. Elect. and Chem. 1989, 261, 301
47. M.A. Yaroslavskij. DAN USSR 1989, 307. 369
53. V.A. Chechin et al. Paper submitted to Provo Conf. 1990
55. P.I. Golubnichij et al. KSF, 1990, No 9, 15
56. P.I. Golubnichij et al. DMWCA p.22
57. P. Bern et al. Provo 1990
58. R.N. Kuz'min, B.N. Shvilkin "Cold Nuclear Fusion", Znanie, Moscow, 1989/10
59. F. Celani et al. Provo, 1990
60. P.I. Golubnichij et al. DMWCA p.23
61. S.S. Gerstein, L.I. Ponomarev. Talk at the Erice meeting, April 1989
64. J. von Neumann, E. Winger. Phys. Z. 1929, 30, 365
68. V.I. Vysotskij, R.N. Kuz'min. DMWCA p.50; Preprint Institute for Theor. Physics, Kiev, ITF-90-82R, 1990
69. P.I. Golubnichij, V.A. Tsarev. DMWCA p.40
70. Yu.N. Bazhutov, G.M. Vereshkov. DMWCA p.44
71. V.A. Tsarev, D.H. Worledge. To be published

Abbreviations used in the list of references:
3. KSF: Kratkie Soobsheniya po Fizike (Lebedev Physical Institute).