

Research Article

# CR-39 Detector Track Characterization in Experiments with Pd/D Co-deposition

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## Abstract

Four experiments replicating the GALILEO Project were performed. In two of them, excess  $\alpha$ -particle track density was observed in the CR-39 detectors in comparison with background CR-39 detectors.

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## 1. Introduction

In LENR, the excess enthalpy production is followed in some cases by the generation of helium-4 [1] and neutrons [2]. However reliable replication of successful results has been a serious problem. In 2007 a group of researchers from San Diego [3] reported what they called the GALILEO project, in which they obtained anomalous tracks with a method they were able to replicate exactly.

The GALILEO project developers prepared for the experiment two cells made of plastic – one experimental and the other a control cell. The control cell was similar to the experimental cell in all characteristics, timing and processes with the sole exception that it used  $\text{CuCl}_2$  instead of  $\text{PdCl}_2$ . The purpose of the controls was to show that the observed pitting was not due to chemical damage. In each cell electrolysis was conducted with 0.03 M  $\text{PdCl}_2$  and 0.3 M  $\text{LiCl}$  solutions in heavy water with a platinum anode and Pd, Ag, Ni or Au cathodes. The CR-39 track detector was in contact with the cathode. In the process electrolysis current was gradually increased from 0.1 to 0.5 mA. The solution became completely transparent and all Pd accumulated on the cathode (plating phase) to (1–100 mA) – the charging phase. During the last phase the nuclear events (presumably) occur. After the charging phase was finished the CR-39 chips were taken from the solutions of both cells and were etched in etch solution (6.5 M  $\text{NaOH}$  in regular water) at

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**Table 1.** Current quantity and duration during the experiments.

| Experiment N1 |                 |                 |      |                  |     |                 |                |      |
|---------------|-----------------|-----------------|------|------------------|-----|-----------------|----------------|------|
| <i>I</i> (mA) | 0.3             | 1               | 5    | 10               |     |                 |                |      |
| <i>t</i> (h)  | 15 <sup>a</sup> | 10              | 14   | 17 <sup>b</sup>  |     |                 |                |      |
| Experiment N2 |                 |                 |      |                  |     |                 |                |      |
| <i>I</i> (mA) | 0.07            | 0.17            | 0.5  | 1                | 80  | 95              | 95             |      |
| <i>t</i> (h)  | 11.5            | 2               | 15   | 6.5 <sup>c</sup> | 2.5 | 4 <sup>d</sup>  | 6              |      |
| Experiment N3 |                 |                 |      |                  |     |                 |                |      |
| <i>I</i> (mA) | 0.05            | 0.1             | 0.15 | 0.05             | 3   | 10              | 30             | 90   |
| <i>t</i> (h)  | 26              | 18              | 24   | 65 <sup>e</sup>  | 22  | 24              | 24             | 10.5 |
| Experiment N4 |                 |                 |      |                  |     |                 |                |      |
| <i>I</i> (mA) | 0.1             | 2               | 5    | 10               | 2.5 | 80              | 80             | 85   |
| <i>t</i> (h)  | 74.5            | 17 <sup>f</sup> | 6    | 23               | 43  | 11 <sup>g</sup> | 8 <sup>h</sup> | 50   |

<sup>a</sup>Solution became completely transparent.

<sup>b</sup>Current decreased till 2.8 mA and did not increase any more. We have finished the experiment.

<sup>c</sup>Solution became completely transparent.

<sup>d</sup>Pause – 11 h.

<sup>e</sup>Solution became completely transparent.

<sup>f</sup>Solution became completely transparent.

<sup>g</sup>Pause – 64 h.

<sup>h</sup>Pause – 20 h.

a temperature of 68°C for 6 h. Next the track detectors were analyzed for the presence of pits similar to the tracks of alpha particles. There was a much higher number of tracks in the CR-39 chip in the experimental cell than in the control cell. The control cell CR-39 chip had approximately the same number of tracks as the background CR-39 chip. Additional verification was carried out after irradiation of the track detector by a source of alpha particles of known energy and intensity.

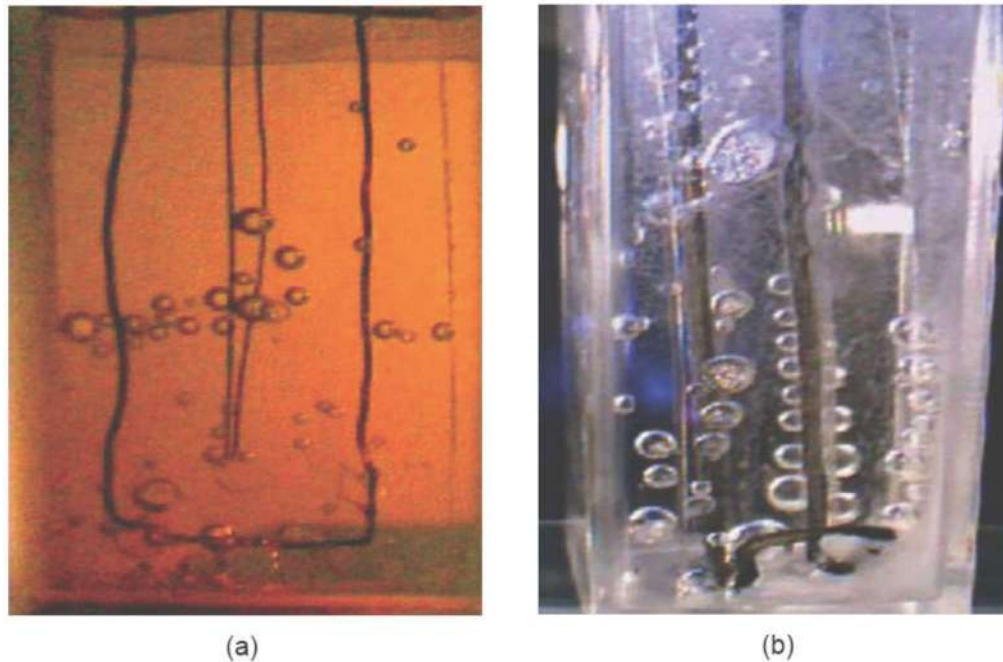
As of today only eight groups of researchers [4] in the world have tried to replicate the reported results and only a few of them have obtained positive results. These first results reported at the conference of four groups in March 2007 [5]. Other groups for various reasons have not been able to carry out the experiment. At the time of the conference there was a problem with the interpretation of tracks. Some believed that the tracks were due to the chemical damage caused by oxygen and chlorine or even corona discharge [6]. All the teams brought CR-39 detector outside the cell close to it (a dry experiment). After that pits were not observed in the detector, but that can be caused both lower energy of alpha particles and not taking into account water layers of varying thickness [7].

Based on what is described above, the purpose of this study was to replicate the GALILEO Project [3] in a wet configuration, which has the detector immersed in the cell and to obtain the  $\alpha$ -particles tracks using a silver cathode.

## 2. Materials and Methods

During electrolysis, one cell was used, and the cell with CuCl<sub>2</sub> solution was not used. Four experiments were done. In all the experiments the same D<sub>2</sub>O, PdCl<sub>2</sub>, LiCl substances and anodes were used.

The cell was made from Quartz glass (outer size 1.1 × 2.4 × 4 cm, inner size 0.5 × 1.8 × 3.7 cm, wall thickness 0.3 cm, volume 3.3 cm<sup>3</sup>). We bought this cell from the vender of chemical reactants in Kiev, called “Isotope.” Our assembled cell in experiment N1 was the same as in the GALILEO project (except for the size), which was shown in photo on page 16 of Ref. [3]. Heavy water, PdCl<sub>2</sub> and LiCl salts, silver and platinum wires were bought from the same vendor. The Ag cathode placed in the electrolyte in this experiment was 0.1 mm thick and 48 mm long, while the Pt anode in the experiment N1 and in all following ones was 0.3 mm thick and its length was 147 mm in this experiment only.



**Figure 1.** Photo of the cell with cathode and anode assemblies which used in experiments N2, N3 (a) and N4 (b).

It is necessary to note that the initial current was  $300 \mu\text{A}$  during experiment N1. At lower current the cell had a negative potential. As a result of the initial current being too high, the plating was done non-uniformly on the surface of the cathode. The maximum current was only 10 mA (see Table 1), current density was  $J = 80 \text{ mA/cm}^2$ , cathode area =  $0.125 \text{ cm}^2$  in experiment N1 and it did not increase any more. These circumstances became the possible reason for the insignificant number of excess tracks in the CR-39 chip in the solution in experiment N1, compared to the number of tracks in the background chip.

In experiments N2 and N3 cathode and anode assemblies were used in which both the shapes and a spatial arrangement differed from ones described in Galileo protocol [3] (see Fig. 1(a)).

In these experiments the polyethylene base was absent. Both the cathode and anode were mounted on the same CR-39 chip. In the chip openings were bored through and a silver wire (diameter – 0.1 mm, length – 42 mm) passed through them (in Fig. 1(a) this wire is more thin and is located in the middle of the CR-39 chip). Platinum anode (length – 62 mm) also was passed through the additional openings made in CR-39 and folded around the cathode from three sides (on the left, on the right and from below as shown in Fig. 1(a)). In experiments N2 and N3 both the anode and cathode were located on one plane.

In experiment N4 the cathode with a bigger diameter ( $d = 0.3 \text{ mm}$ , length – 72 mm) was used (see Fig. 1(b)), which was fastened on the CR-39 chip. The anode was mounted from the cell opposite side in the form of a wire with length 31 mm (see Fig. 1(b)). In this experiment both cathode and anode were located in different planes, as opposed to the experiments N2 and N3. We used 15 mg of  $\text{PdCl}_2$  and 36 mg of  $\text{LiCl}$  on 2.8 ml of heavy water and this solution was poured in our cell. We added heavy water to the cell during the experiments. On average we added nearly 1.5 ml of heavy water per experiment.

The CR-39 track detectors were fabricated in the Radium institute of V.G. Hlopina. They were wrapped in a polyethylene film the entire time, and stored in the freezer chamber of a refrigerator. The thickness of the CR-39 chips is 300  $\mu\text{m}$  and the velocity of etching – 1  $\mu\text{m}/\text{h}$ . Dimensions of the track detectors were in the first experiment (Height  $\times$  width) – 1.5  $\times$  1.0 cm, in the second and third ones – 3.3  $\times$  1.5 cm, and in the fourth experiment – 3.6  $\times$  0.8 cm.

We made a custom-built current source with power 3 W, made from the following components: transistor KP931A (range of values of a direct current on the exit: 20  $\mu\text{A}$  – 95 mA) and transformer, which is switched in the alternating current network with  $U = 220$  V (range of values of a direct voltage on an exit: 0–40 V). The resistance of the source on the exit is  $R \geq 1$  M $\Omega$ .

When the experiments were terminated, the cell was disassembled and the CR-39 detectors were etched in an aqueous 6 M sodium hydroxide solution at 68–70°C for 7.5 h. Microscopic examination of the etched CR-39 detectors was done using an MTKF-1 microscope.

### 3. Results and Discussion

After etching, the number of excess tracks on the CR-39 detectors placed in electrolytic cell was compared to the CR-39 blanks. Extra tracks were observed in experiments N1 and N4. We used blank detectors which were exposed for a week in the room in air near the experimental cell. The calculation of the number of pits was made by manual procedures with the consecutive passage of the frames by MTKF-1 microscope. In experiment N1 on CR-39 in a cell, the track density 167  $\text{tr cm}^{-2}$  was measured (blanks 97  $\text{tr cm}^{-2}$ ), and in experiment N4 – 545  $\text{tr cm}^{-2}$  (back side – 292  $\text{tr cm}^{-2}$ ).

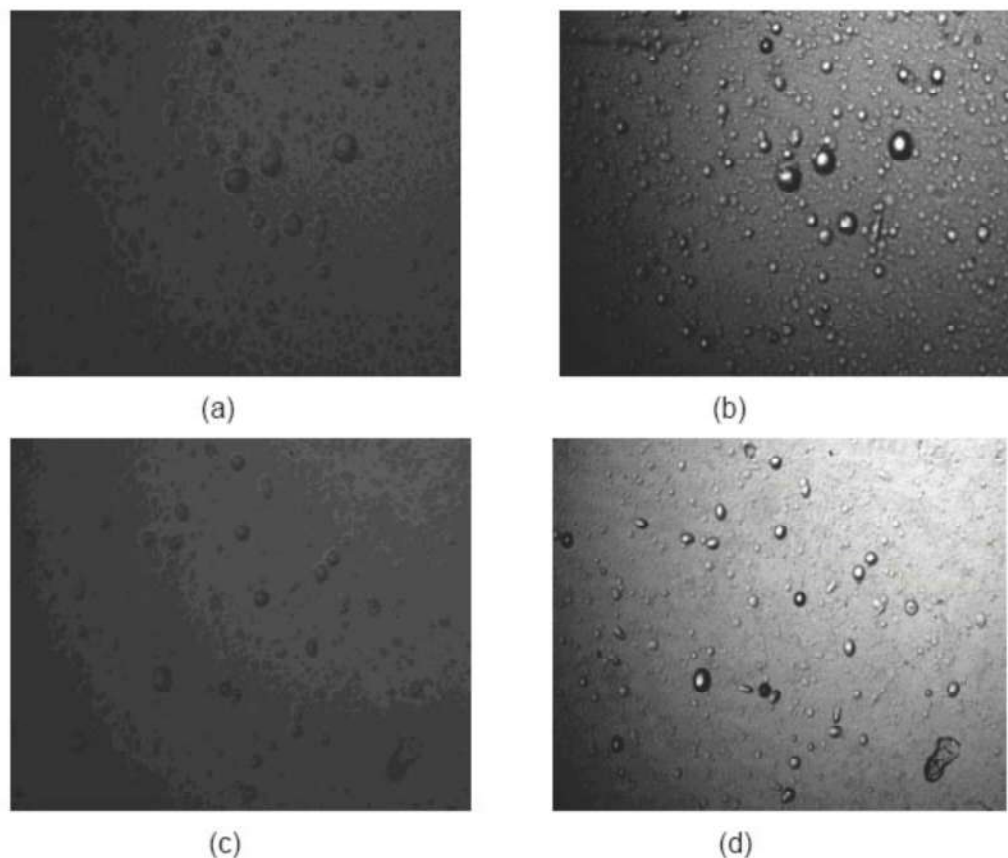
We could best satisfy the condition of the GALILEO Project [3] only in experiment N4. We have carefully analyzed this recent experiment.

Figure 2(a) and (b) shows two images taken at two different focal depths, at the surface (Fig. 2(a)) and bottom of the tracks (Fig. 2(b)) of the same CR-39 detector. This sample was in the electrolytic cell during experiment N4. To determine whether the pits are due to energetic particles or to chemical damage, we compared the pits obtained from the Pd/D co-deposition experiment with those obtained when CR-39 was exposed to an alpha particle source [8]. The CR-39 detector was irradiated by  $^{238}\text{Pu}$ , 35 kBk activity for 3 s. The  $^{238}\text{Pu}$  nuclei decay on  $^{234}\text{U}$  irradiating alpha particles with the following energy (intensity): 5.499 MeV (70.9%), 5.456 MeV (29.0%), 5.358 MeV (0.1%). Tracks are created by  $\alpha$ -particles have the conic form. Figures 2(c) and (d) show two images taken at two different focal depths (surface (Fig. 2(c)) and bottom of the tracks (Fig. 2(d))) of the same CR-39 detector, which was irradiated by the  $\alpha$ -particles. We used the microscope Axioscop 2 MAT mot (Carl Zeiss, Germany) with the digital chamber AxioCam MRc Rev 2 at high resolution to photograph the CR-39 chips shown in Fig. 2. This microscope is located in the diagnostic centre for collective use at V. Lashkaryov Institute of Semiconductor Physics of NAS of Ukraine.

These tracks have a round form and dark color. When the microscope is focused more deeply in CR-39 than in the track centre a bright spot is observed (see Fig. 2(d)). This is caused by the bottom part of a conic track. The tracks also have beautiful optical contrast range. These signs: the optical contrast range, the form and the bright spot in the track centre are important factors which help to distinguish the present  $\alpha$ -particle tracks from chemical damage. By comparing Fig. 2(a) and (b) with Fig. 2(c) and (d) which are the  $\alpha$ -particles tracks after  $^{238}\text{Pu}$  decay it is possible to see that they are similar, but the track diameters of the  $\alpha$ -particles are twice as large, as shown in Fig. 2(a) and (b). We do not have the calibration curve for a given CR-39 detector type, nevertheless the increase in diameter can be caused by both the longer etching times (7.5 h in comparison with 6 h for the CR-39 detector irradiated by  $\alpha$ -particles from  $^{238}\text{Pu}$  source), and possible smaller value of  $\alpha$ -particle residual energy which are generated in the solution.

The photomicrographs were obtained using a magnification of 640 $\times$ .

On the entire surface of the CR-39 detector which was in the cell, the pits are distributed nonhomogeneously in area



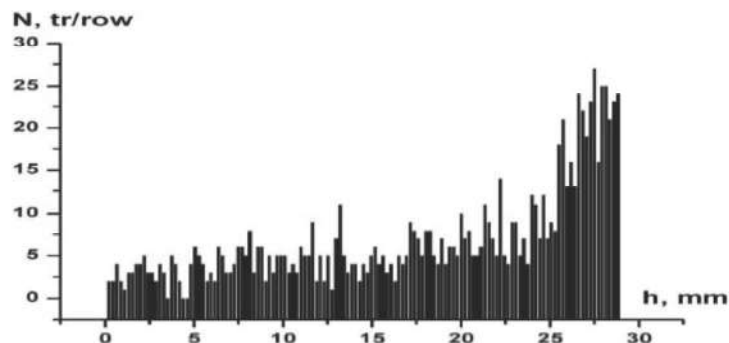
**Figure 2.** Images of pits in the CR-39 detector surface (Fig. 2(a)), and bottom (Fig. 2(b)) taken at two different focal depths of the same CR-39 detector. This sample was in electrolytic cell during experiment N4. The similar images created by exposure to  $^{238}\text{Pu}$  source (Fig. 2(c) and (d) using a magnification of  $640\times$ .

extent. Figure 3 shows the spatial distribution of the pits along the CR-39 surface. The count on the axis of abscises is measured from the upper part of the CR-39 detector to the depth of the cell. The thickness of the row is 0.22 mm. The quantity of pits increases in the lower part of the CR-39 detector, but they are distributed regularly along the surface. There is no higher concentration of the pits near the cathode.

Unsuccessful experiments N2 and N3 prove that pits formed during Pd/D co-deposition are not due to radioactive contamination of substances used in the experiments nor are they caused by impingement of gas bubbles on the surface of the CR-39, nor by chemical reactions of the surface of CR-39 with  $\text{D}_2$ ,  $\text{O}_2$  or  $\text{Cl}_2$  present in electrolyte. The maximum current in experiment N4 was 85 mA, and its density  $J = 220 \text{ mA/cm}^2$ .

Based on the evidence presented above, it is possible to draw the following conclusions:

- (1) The tracks on the CR-39 detector which were observed at their arrangement in electrolytic cells during experiments N1 and N4 had a nuclear origin.
- (2) The source of the charged particles was in the solution volume adjacent to the CR-39 detector, and correlates



**Figure 3.** Pits quantity on the row (N) in comparison with the depth of the immersion of CR-39 – detector in the solution (h).

with the Pd deposit.

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