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APPLICATION OF CR-39 PLASTIC TRACK DETECTOR FOR DETECTION OF DD AND DT-REACTION PRODUCTS IN COLD FUSION EXPERIMENTS

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Abstract

The results of application of CR-39 plastic track detector in Cold Fusion experiments are presented. According to the calibration, this detector registered not only dd-fusion reaction products, but also dT ones. The procedures for identifying different particles of dd and dT-reaction are recommended. According to these procedures the possible levels of dd and dT-reactions in different experiments have been estimated.

1. INTRODUCTION

The problems of identification of different particles and background / foreground separation are very important in cold fusion experiments. CR-39 plastic track detector, which is used for registration of heavy charged particles, is a very convenient means of detection not only dd-fusion reaction products:

$$d + d \rightarrow n\ (2.45\ \text{MeV}) + \text{He-3}\ (0.82\ \text{MeV})\ (\sim 50\%) \tag{1}$$
$$d + d \rightarrow p(3.02\text{MeV}) + T(1.02\text{MeV})\ (\sim 50\%) \tag{2}$$

but also dT ones:

$$d + T \rightarrow n\ (14.01\ \text{MeV}) + \text{He-4}\ (3.5\ \text{MeV}) \tag{3}$$

This detector has characteristic response to every type of particles from reactions (1) - (3). Charged particles are registered directly, and neutrons are detected through the secondary recoil particles or nuclear reactions. Particle tracks on the detector became visible after etching and are investigated using a microscope. The goal of present work is to study the CR-39 detector response using different types of particles from reactions (1) - (3) in different experimental conditions.

2. EXPERIMENTAL METHODS

2.1. CR-39 detector

The CR-39 plastic track detector is a $C_{12}H_{18}O_7$ polymer with density 1.3 g/cm^3. In this work we used CR-39 produced by Fukuvi Chemical Industry Co., (Japan) in 1996. After exposure, the detector was etched in 6N NaOH solution at 70°C for 7 h. After the etching, charged particle tracks became visible and could be investigated using a microscope.

As is well known, the main parameter of track detector is the ratio of etching rates at the start of the track and at the end of the track ($v_T/v_{\mathbf{B}}$). This ratio is a function of energy loss (stopping power, dE/dx). Track diameter is related to this ratio by a parametric equation[1]. The dependence of track diameter on dE/dx makes possible identification of a particle. The critical angle of registration ($\Theta_c = \arcsin(v_B/v_T)$) is also an important characteristic. Θ_c is the minimum angle of particle incidence on the detector in which track formation is possible. It is easy to show that the detection efficiency for a given type of particles is determine by the relation [2]:

$$\eta = 1 - \sin\Theta_c \tag{4}$$

2.2 DD-calibration

The calibration of CR-39 detectors by dd-reaction products has been carried out by low-energy high-current generator in the Laboratory of Nuclear Science of Tohoku University (Sendai, Japan) [3]. A deuteron beam with primary energy of 10 keV was used to bombard the TiD_2 target. DD-fusion products are produced with a minimum deviation in their energy. A CR-39 detector (3 x 1.5 cm^2) was placed at a distance ~4 cm from interaction point. After exposure, the detector was etched and examined using a MBI-9 microscope. The investigation of tracks was carried out on a square centimeter area located in different areas of the detector. The number of tracks versus their diameters is shown in fig. 1. Three peaks are shown on this distribution. According to the relationship between track diameter and dE/dx (the higher dE/dx, the larger track diameter), it is possible to conclude that the peak in the region ϕ ~5 μm corresponds to protons (E_p ~3 MeV); the peak in the region ~6.4 μm to tritons (E_T ~1 MeV); and the peak in the region ~7.2 μm (with long “tail” to ~10 μm) to He-3 nuclei ($E_{He\text{-}3} \leq 0.8$ MeV).

The strong energy dispersion of the third peak may be explained by the He-3 nuclei being emitted from different depths, thereby experiencing different amounts of energy loss.

The calibration shows that under conditions when dd-fusion takes place in the thin (< 0.5 μm) surface layer of the target, charged particles from reactions (1) and (2) can be reliably detected and identified by CR-39 track detector.

2.2. DT-calibration

To investigate the CR-39 response to He-4 nuclei, the detector was irradiated by α–particles from Pu-239 and Ra-226 sources through different Al foils. The dependence of track diameter on the energy of α–particles is shown in fig. 2.

In real conditions of experiment when dT-fusion takes place in a thick sample, α–particles from reaction (3) may have energies from 0 to 3.5 MeV because of energy loss. Thus, investigation of reaction (3), based on α–particle detection, is difficult.

DT-neutrons interact with nuclei in the detector material (C,O,H) and produce different tracks compared to recoil particles or nuclear reaction products. One example of neutron interaction in a CR-39 detector is inelastic scattering on C-12 nucleus causing decay into three $\alpha-$particles:

$$n + C\text{-}12 \rightarrow n+3\alpha \ (Q = -7.37 \text{ MeV}) \qquad (5)$$

The cross section of reaction (5) is ~190 mb at E_n = 14.5 MeV. The threshold of neutron registration in CR-39 by this reaction is ~10 MeV. The presence of three $\alpha-$particle tracks outgoing from a single point allows us to separate these reactions from other neutron interactions with CR-39 nuclei. The efficiency of dT-neutron detection in CR-39 was investigated in ref. [4].

Irradiation of Cr-39 detectors was carried out using a dT-neutron source located at Rare Metal Industry Institute (GIREDMET, Moscow) [5]. The dT-neutrons were generated in a TiT_2 target bombarded by a 350 keV deuteron beam. Density of neutron flux at the target chamber was 4×10^{10} n/cm^2/s. The CR-39 detectors were placed at a distance of 31 cm from the target. CR-39 detectors and detectors covered with 60 µm polyethylene to enhance the effect were used. The detectors were oriented at five different angles (0°, 30°, 45°, 60°, 75°) to the neutron flux. Exposure time was 5 s. Neutron fluence at the detector plane was ~2×10^8 n/cm^2.

After exposure the detectors were etched and investigated using an optical microscope. The microphotographs of several $3\alpha-$events are presented in fig. 3. We can see many different pictures of these events depending on the amount of energy transmitted to C-12 nucleus and direction of $\alpha-$particle emission.

The mean values of the detection efficiency for dT-neutrons by reaction (5) (for five different directions of the neutron flux) were estimated as $(4.7 \pm 0.6) \times 10^{-7}$ and $(1.2 \pm 0.1) \times 10^{-6}$ for detector without and with polyethylene, respectively. The increase in the efficiency for the detector with polyethylene is caused by the detection of 3 $\alpha-$particles from reaction (5) that takes place not only in etched layer (~10 µm) but also in the polyethylene layer near the detector surface.

The investigation of small yields of dT-reaction in cold fusion experiments may be very useful, because the background flux of neutrons with energy more than 10 MeV on the earth surface is negligibly small. The measurements showed that the density of background 3 $\alpha-$events in CR-39 detector do not exceed one per few cm^2. This low background allows experiments to carried out using very long exposures.

3. RESULTS AND DISCUSSION

3.1. The measurement of dd-reaction yield in Pd/PdO deuterated heterostructures

The PdO/Pd/PdO and PdO/Pd/Au samples were prepared in the Institute of Physical Chemistry, Russian Academy of Sciences from 30-60 µm Pd foils by the method described in ref. [6]. This samples were deuterated by electrolysis in 1M NaOD solution using D_2O. The current density was ~20 mA/cm^2 and duration of electrolysis was 5 - 20 min. After electrolysis, the sample was washed with pure D_2O and dried using filter paper. The sample was placed on a CR-39 detector and compressed between two plates with a screw. The sample was heated to ~50°C to stimulate the desorption of deuterium. The time of one cycle of measurements was 1 -

2 h. Then the sample was deuterated again and the cycle was repeated. The full time of exposure was 20 h.

Following this treatment, the detector was etched and investigated using a MBI-9 microscope. As noted above, the investigation of yields for reaction (1) and (2) from thick samples is difficult, because charged particles come to the detector with a large energy spread and their tracks have different diameters. The accurate estimation may be only for dd-reactions that take place in a thin surface layer. So we used the following method of estimation. We chose only events that occur when the track of a proton (E_p~3 MeV, Ø ~5 μm) is spaced near (~15 μm) the other track Ø ~6-7.5 μm (triton, E_T ~1 MeV or He-3, $E_{He-3} \leq 0.8$ MeV). As shown in Fig. 2, tritons and He-3 nuclei have close track diameters and their distributions can intersect. This disposition of two tracks may be accidental or it may be caused by the presence of some zones in the sample with high concentration of D, where dd-fusion is more probable. The registration efficiencies of this event we estimated by (4) taking into account that critical angles for proton (E_p ~3 MeV), triton (E_T ~1 MeV) and He-3 (E_{He-3} ~0.8 MeV) are ~60°, ~40° and ~5°, respectively.

For the detector in contact with deuterated sample, the track density of events satisfying the criteria mentioned above is estimated as (24.0 ± 3.4) cm^{-2}. For the background detectors in contact with unloaded sample and the sample loaded by hydrogen it was (4.0 ± 1.4) cm^{-2}. Thus, the density of double tracks caused by “coincidence” (not in time but in space) of products of reactions (1) and (2) taking place in the thin (< 0.5 μm) layer of sample, is (20 ± 4) $1/cm^2$. For an exposure time 20 h, the mean flux of dd-fusion reactions may be estimated as $(2 - 6) \times 10^{-3}$ s^{-1} into 4π solid angle per 1 cm of the sample. This value is in good agreement with the result of measurements for reaction (2) yield carried out using a Si SSB detector, i.e. $(3.6 \pm 1.0) \times 10^{-3}$ s^{-1} into 4π solid angle [7].

3.2. The measurement of dd-reaction yield in glow discharge of D_2

The CR-39 detector was also used in the measurements of dd-reaction yield in glow discharge of D_2 with Pd, Ti and Nb cathodes[6]. The detectors were placed at a distance of ~3 cm from the cathode. The detectors with different covers were used to prevent irradiation by ultraviolet rays. Control experiments were carried out using glow discharge of H_2. The mean flux of dd-protons during the long-time exposition (~10 h) was estimated as (0.03 - 0.18) s^{-1} into 4π solid angle per 1 cm^2 of the cathode. These results are presented in more detail at this conference (A. Karabut, A. Lipson, A. Roussetski).

3.3. The measurement of dT-reaction yield in deuterated Pd/PdO heterostructures

In this experiment, we used Au/Pd/PdO and PdO/Pd/PdO samples with a thickness of 8, 20, 40, 60 μm and dimensions 2 - 4 cm^2. Loading of samples with deuterium and exposure of detectors were carried out using the procedure mentioned above, except the thermostimulation of D_2 desorption. The exposure time for CR-39 detectors was 7 - 72 h. Hydrogenated samples were used for background measurements. After the exposure, the detectors were etched using standard conditions. Investigation of tracks was carried out by a microscope supplied with Hitachi video-system in the NHE-laboratory, Sapporo (Japan).

We looked for events with a characteristic disposition of three α–particle tracks directed to a single point (3α–events). These events corresponded to decays of C-12 nucleus in CR-39 material into 3a-particles caused by high-energy neutron (E_n> 10 MeV). We scanned ~30 cm^{-2} of detector surface, both in background and in foreground measurements. The mean track density of 3α–events was in the foreground $<n_{3\alpha f}> = (0.81 \pm 0.16)$ cm^{-2}, and in the background $< n_{3\alpha b}> = (0.20 \pm 0.09)$ cm^{-2}. Taking into account the exposure time we get a mean value of 3α–event flux $<n_{3\alpha f}> = (1.2 \pm 0.3) \times 10^{-6}$ cm^{-2} s^{-1}. If we know the registration efficiency for dT neutrons by reaction (5), we can to estimate the mean dT neutron flux emitted from deuterated samples. This value was estimated to be $n_n < 1$ n/s/cm . We need to note that to explain this flux of dT-neutrons we need to suppose the production 10^2 - 10^5 tritons/s/cm^2 with energies from few keV to few MeV. This value is higher than the yield of tritons from dd-reactions. So there are, at least, two explanations for the 3α–events:

(1) The emission of dT-neutrons resulting from fast tritons by an unknown mechanism.

(2) The emission of high-energy neutrons (E_n > 10 MeV) resulting from some unknown nuclear reactions. These processes may be 3d and 4d fusion reactions predicted by A. Takahashi [8].

4. CONCLUSION

It is established that CR-39 track detector can detect all particles from reactions (1) - (3). This detector can be successfully used in long-duration experiments in cold fusion.

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References

1. Samogyi G., Shalay S.A. Nucl. Instr. And Mem., **109**, (1973), N 2, 211.
2. R. L. Fleisher, P. B. Price, R. W. Walker. Nuclear Tracks in Solids. Principles and Applications. University of California Press, 1975, v. 1.
3. H. Yuki, T. Sato, T. Otsuki et al. J. Phys. Soc. Jpn. **66**, (1997) 73.
4. Marenny A.M., Nefedov N. A., Roussetski A. S., Kratkie Sobshenia po Fizike FIAN (Bulletin of Lebedev Physics Institute) **6**, (1998) 42.
5. Andreev A.V., Baryt I.J., Varych O.M. Atomnaia Energuia (Atomic Energy) **66**(2), (1989) 134.
6. A. G. Lipson, B. F. Lyakhov, B. V. Deryaguin, D. M. Sakov. Sov. Tech. Phys. Lett. **18**(10), (1992) 673.
7. A. G. Lipson, B. F. Lyakhov, A. S. Roussetski et. al. Fusion Technology. 2000. In press.
8. A. Takahashi. Fusion Technology, **26**(4T), (1994) 451.

Figures

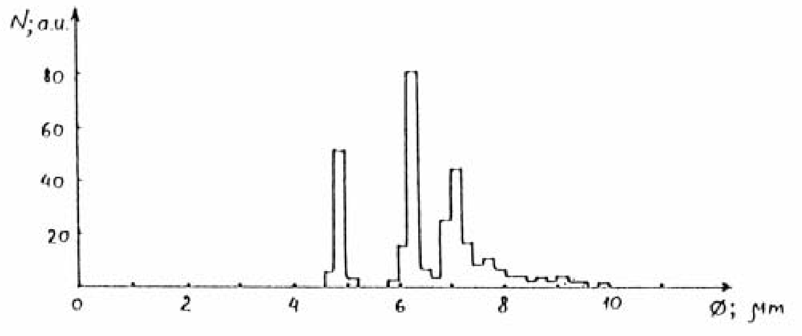

Fig. 1. Distribution of track diameters of dd-fusion reaction products in CR-39 detector etched in 6N NaOH solution at 70°C for 7 h.

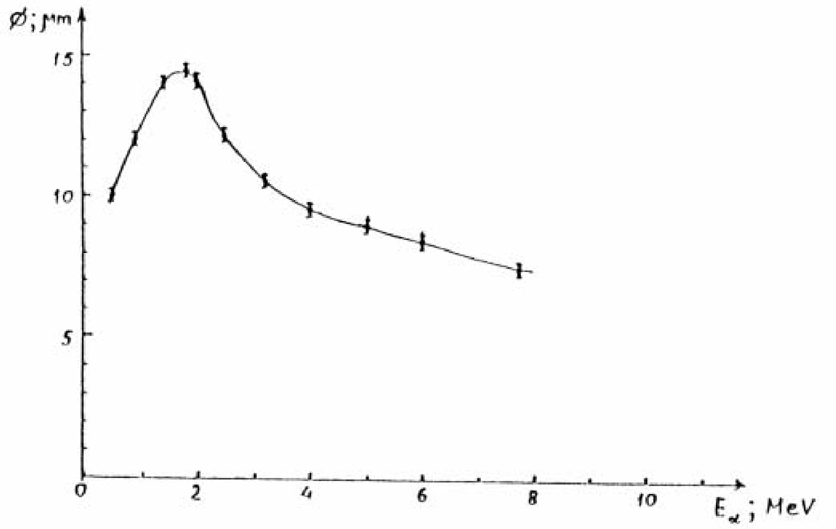

Fig. 2. Dependence of α–particle track diameter on particle energy for CR-39 detector etched in 6N NaOH solution at 70°C for 7 h.

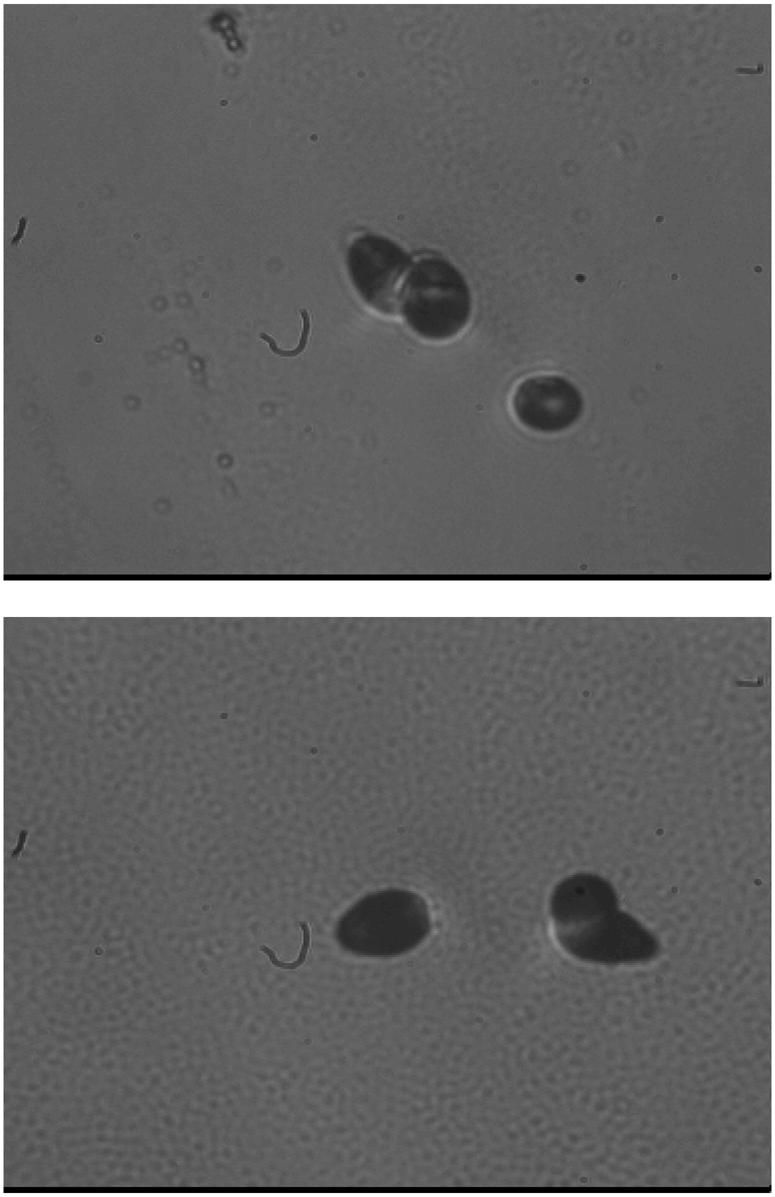

Fig. 3. Microphotographs of tracks in CR-39 detector exposed to dT-neutrons.

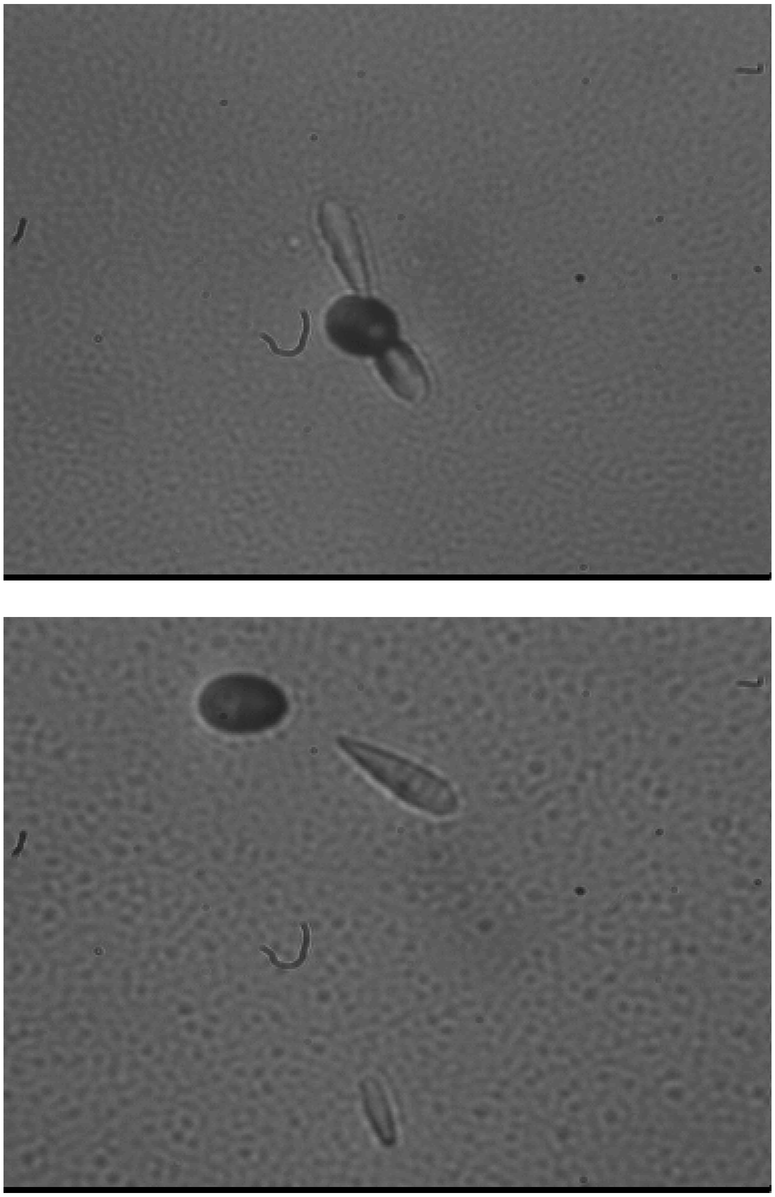

Fig. 3, continued. Microphotographs of tracks in CR-39 detector exposed to dT-neutrons.