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Application of nuclear track emulsion in low-energy studies

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Application of the nuclear track emulsion technique (NTE) in radioactivity and nuclear fission studies is discussed. Progress of analysis of NTE samples exposed to ^{252}Cf source is presented. Planar events containing fragments and long-range α-particles, as well as fragment triples only are under study.

Keywords: nuclear track emulsion, heavy nuclei, fission.

INTRODUCTION

Featuring excellent sensitivity and spatial resolution, nuclear track emulsion (NTE) maintains a position of universal and inexpensive detector for survey and exploratory research [1, 2]. NTE with an unsurpassed spatial resolution of about 0.5 μm provides track observation beginning from fission fragments up to relativistic particles. The NTE technique deserves further application in fundamental and applied research at modern accelerators and reactors, as well as with radioactivity sources, including natural ones. The application of NTE is especially well grounded in experiments where tracks of nuclear particles cannot be reconstructed using electronic detectors.

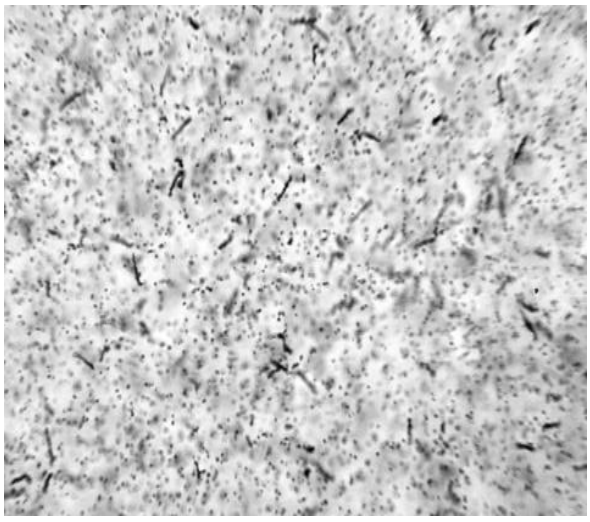

Fig. 1. Example of decay of ^{10}B under the action of thermal neutrons in NTE samples.

When testing the novel NTE a variety of physics tasks related with measurements of alpha-particle tracks were addressed. Decays of stopped ^{8}He nuclei [3, 4], breaking-ups of ^{12}C nuclei by thermonuclear neutrons and ultrarelativistic μ-mesons are analyzed. Splittings induced by thermal neutrons are studied in a boron-enriched emulsion (see Fig. 1). Figure 2 shows decay features of a stopped ^{8}He nucleus with energy of 60 *A* MeV in NTE. After the ^{8}He nucleus is stopped and neutralized in the substance, the formed ^{8}He atom remains unbound and, as a result of thermalization, can move in the substance until it undergoes β decay. The half-life of the ^{8}He nucleus is $\tau_\beta = (119.0 \pm 1.5) \times 10^{-3}$ s. This nucleus undergoes β decay to the 0.98 MeV bound level of the ^{8}Li nucleus with a probability of 84% and energy ΔE = 9.7 MeV. Then the ^{8}Li nucleus with its half-life $\tau_\beta = (838 \pm 6) \times 10^{-3}$ s undergoes β decay to the 2^+ level of the ^{8}Be nucleus (3.03 MeV) with 100% probability and energy ΔE = 13 MeV. Finally, the ^{8}Be nucleus decays from its 2^+ state with a width of 1.5 MeV to a pair of α-particles.

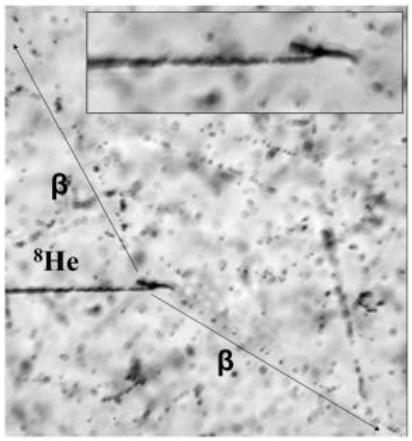

Fig. 2. Decay of a stopped ^{8}He nucleus; arrows indicate directions of emission of relativistic electrons; on insertion - magnified decay vertex with a pair of α-particle tracks (ranges of about 5 μm).

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One of the proposed tasks is the search for collinear cluster tripartition of heavy nuclei [5, 6]. The existence of this phenomenon can be established in observation of such type of tripartition of heavy nuclei in which the lightest fragment is emitted in the direction of one of the heavy fragments. In spite of certain observability of fission fragments, they cannot be completely identified in NTE. The advantage of NTE is the combination of the best angular resolution and maximum sensitivity. Moreover, it is possible to measure the track length and thickness and thus classify fragments. At the initial stage, in order to provide trial statistics of tripartitions, it was proposed to analyze large areas of NTE irradiated by ^{252}Cf source with appropriate density of α-particle tracks and fragments of spontaneous fission [7]. Further on, NTE layers soaked by uranium salt would be irradiated with thermal neutrons. This approach can be developed for NTE irradiation by a source of ^{252}Cf.

TRIPLE FISSION OF Cf

Surface irradiations of NTE samples were performed at first with manual movement of the ^{252}Cf source. Then a specially developed device was applied; the source was automatically moved over the surface of this device according to a convenient space and time pattern. The most probable is isotope ^{252}Cf decay with emission of α-particles with energy of 5–6 MeV; tracks of these α-particles mainly fill the irradiated sample. This isotope can also undergo spontaneous fission into two or even three fragments with a probability of 3% and 0.1%, respectively. The NTE sample was irradiated by ^{41}Am source emitting α-particles alone in the same energy range for comparison. Since the ranges of decay products are short, the irradiations were performed without a black paper in a darkroom illuminated by red light.

In the case of surface irradiation, not more than two fission fragments should be observed, since the third one is emitted toward the contacting source. The specific feature of irradiation with ^{252}Cf is tracks of α-particles from tripartition whose ranges considerably exceed the ranges of decay of α-particles. This channel dominates in tripartition of ^{252}Cf with a probability of 90%. Figure 3 shows the measured α-particle ranges in the above experiments.

When the NTE surface irradiated by the Cf source was examined, planar trios consisting of pairs of fragments and long-range α-particles and trios of fragments were found (see Fig. 4). It should be underlined that the fact of observation of trios in NTE, rather than just pairs of fragments, is quite remarkable. For this to be possible, the vertices of these trios should be submerged to a depth not smaller than the typical layer thickness. The distribution of 96 vertices of Cf fission into three fragments along the depth of the NTE layer has an average value of (4.1 ± 0.2) μm and an RMS of 2.5 μm. This effect may be due to binding of Cf atoms in AgBr microcrystals and their drift. Probably, the surface protection of the source with an initial thickness of deposited gold of 50 μg/cm^2 (according to the source certificate) was incapable of preventing such penetration.

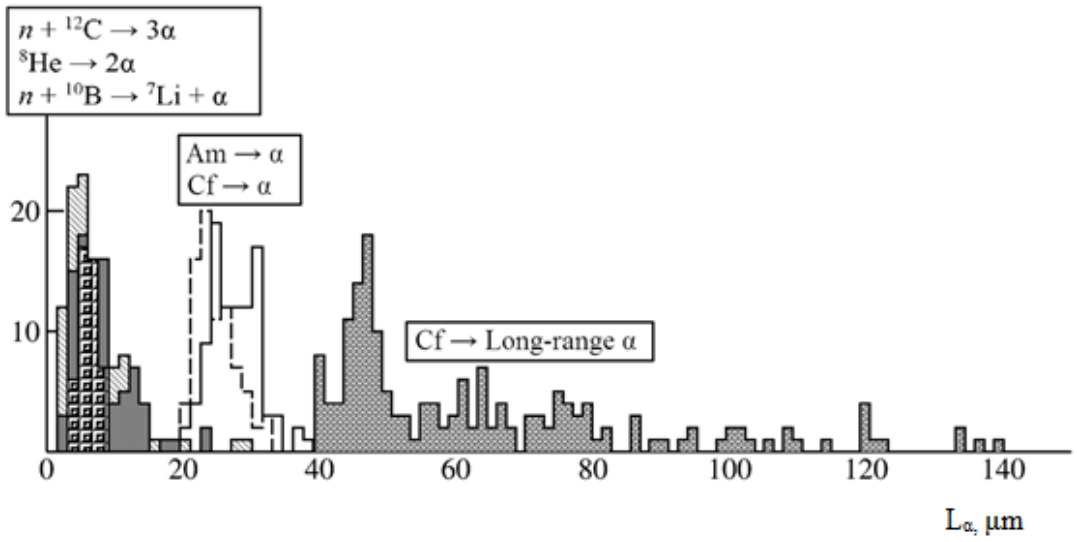

Fig. 3. Distributions of α-particle ranges: (hatching) n(14.1 MeV) + ^{12}C → 3α, (gray shading) ^{8}He → 2α, (solid dots) n_{th} + ^{10}B → ^{7}Li + α, (solid line) Cf → α, (dashed line) Am → α, (dark shading) Cf → long range α.

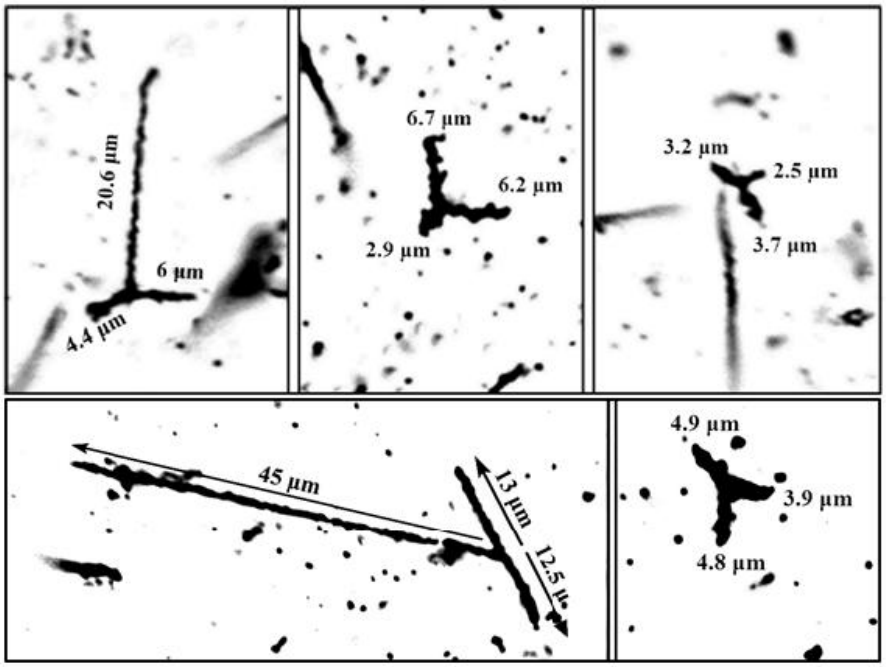

Fig. 4. Examples of observed tripartition events; track lengths are shown.

The ranges of all fragments were measured in 96 events of true tripartition, i.e., without α particles. The comparison with the data in Figure 2 indicates that the average energy of fission fragments is about 400 *A* keV. This is, however, a rough estimate. The calibration of ion ranges in NTE should begin much lower than 1 *A* MeV in controllable conditions provided by accelerators and ion sources. An efficient criterion of splitting into three heavy fragments is their total range. The fragment opening angles were also measured in these events. Their distribution is characterized by an average value of (111 ± 2)° and an RMS of 36°. It can be concluded that no candidates for collinear fission have been found yet, and their search should be continued.

SOAKING OF NTE BY URANIUM SALT SOLUTION

Uranium is one of the most mysterious elements in nature. In fairly significant concentrations it is found in many rocks, oceans and seas, in the lunar soil, in meteorites. The large presence of uranium is explained by the high chemical activity, the good solubility of its salts, the ability to take part in various chemical reactions and form compounds with many other elements.

In this work 20 samples of NTE deposited on one of the sides of glass plates with size of 6 × 4.5 cm^2 were selected. The thickness of NTE was 60 μm. The saturation procedure was performed in a dark room at room temperature. Drying of the samples was carried out under the same conditions. For lighting light with a red light filter was used.

A solution prepared of $UO_2(NO_3)_2$ (natural uranium) was poured into a plexiglas cuvette with grooves for mounting the samples in an upright position. The thickness of the solution layer in the cuvette was ~ 20 mm. The initial concentration of the solution of uranium, determined by X-ray fluorescence analysis, was 600 μg/ml.

The experiment was conducted in 2 stages. At the first stage, 12 samples were soaked with the initial concentration. At the second stage, the remaining 8 samples were immersed in the same solution. After 60 minutes the samples were removed from the same. After all 12 samples were removed from the solution an aliquot was taken from the solution cuvette to determine the possible change in the concentration of uranium in the solution at the first stage.

The X-ray analysis of the uranium solutions selected in the first and second stages showed a change in the concentration of uranium in the solution from 600 μg/ml to 500 μg/ml in the first stage and from 500 μg/ml to 410 μg/ml in the second stage. This suggests that the emulsion has sorption properties with respect to uranium.

The plates were scanned over an area of 16 points 1 cm apart from each other. In each point photographing was carried out at a depth of field with a step 1 μm with a microscope objective × 60 and adapter for camera × 0.5. Tracks were counted visually from the obtained images with a step of 3

μm in depth. The tracks lying in the plane of the emulsion were the criterion for selection (Fig. 5).

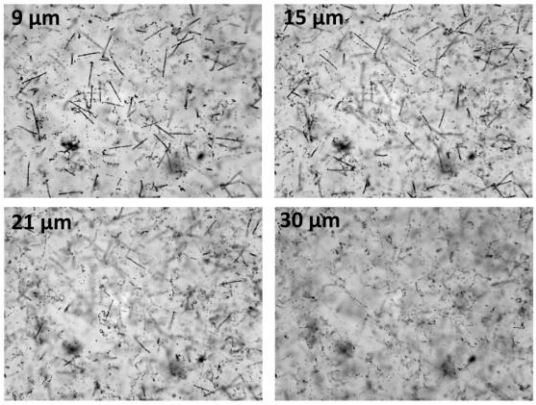

Fig. 5. Examples of observed tracks lying in the plane of the emulsion in different depth.

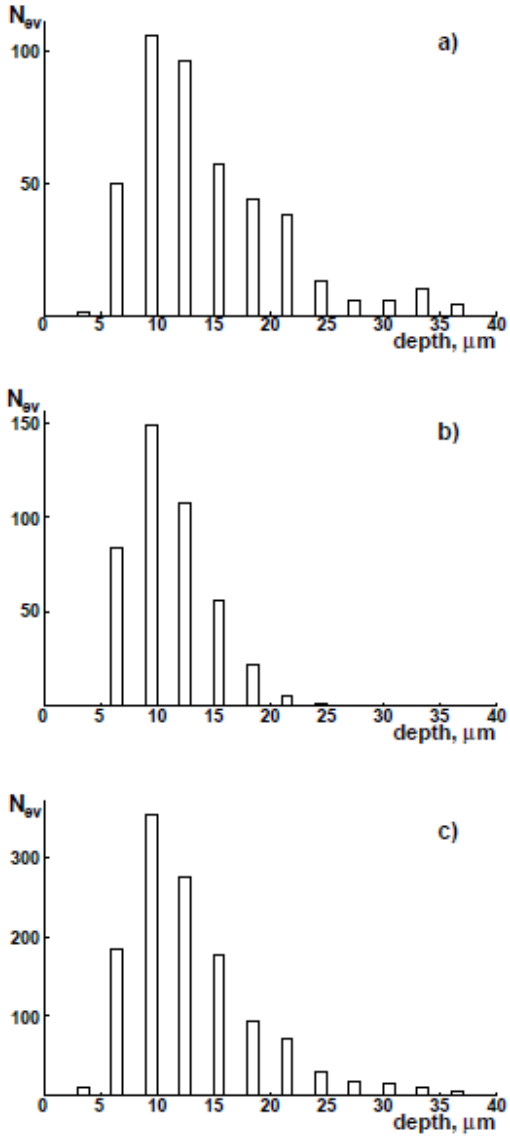

Fig. 6. Distribution of the number of α-tracks in a NTE sample soaked in uranium solution with concentration of 600 μg/ml (a) and 500 μg/ml (b). Common distribution is shown in (c).

Figure 6 shows the distribution of the number of α-tracks in the NTE sample soaked in uranium solution with concentration of 600 μg/ml (a) and 500 μg/ml (b). Common distribution is shown in (c). It was found that the number of α-tracks in the sample from the second batch is less by 10 % than in the samples from the first batch. The distribution of 1243 α-tracks along the depth of the NTE layer has a mean value of (12.6 ± 0.2) μm and an RMS of 5.8 μm. It can be concluded that the absorption of uranium had proceeded in the surface layer of gelatin (in fact, protein medium). As the next step in our experiment will be measurements of the track length of an α-particle in the emulsions.

CONCLUSIONS

So far, the NTE technique is based on intelligence, eyesight, and efficiency of researchers using traditional microscopes. In spite of the broad interest in the capabilities of this method, its cumbersome character results in limited statistics of hundreds of measured tracks, which is, as a rule, a negligibly small part of the available events. The application of computerized and completely automated microscopes makes it possible to overcome this difficulty. These complex and expensive devices of shared and even remote use provide unprecedented statistics of nuclear tracks. In order to make this development purposeful, it is necessary to focus on such topical problems of nuclear physics whose solution can be reduced to simple tasks of recognition and measurement of tracks in NTE solved using existing codes. Thus, conditions for wide dissemination of this experience could be created.

In particular, the proposed problem of analysis of extremely rare events of tripartition is reduced to finding planar trios of nuclear fragments. Beginning at the common vertex and being randomly directed, their tracks should have a length from 1 to 10 μm. Computer image analysis is capable of selecting appropriate decays for subsequent manual analysis. The automation of the search for tripartition events would sharply reduce the most cumbersome stage and assist in focusing manual analysis on discovered events. Thus, manual analysis and automatic analysis are complementary.

On the whole, the synergy of modern radioactivity sources, verified NTE metrology, and advanced microscopy seems promising for investigation of α-radioactivity and nuclear fission. It can be anticipated that ions of transfermium elements would be implanted in NTE. Pronounced decays of these ions could then be observed as common vertices for several α-particles and nuclear

fragments. These prospects prove the fundamental value of preservation and improvement of the NTE technique. Thus, this study, focused on reintroducing NTE into the practice of nuclear experiments, would serve as a prototype for solving an impressive amount of problems. The macrophotos of the experiments under discussion and the corresponding videos are available on the website of the BECQUEREL project [8].

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