Computer analysis of nuclear track emulsion exposed to thermal neutrons and Cf source

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Abstract. Application of the nuclear track emulsion technique (NTE) in radioactivity and nuclear fission studies is discussed. It is suggested to use a HSP-1000 automated microscope for searching for a collinear cluster tri-partition of heavy nuclei implanted in NTE. Calibrations of α-particles and ion ranges in a novel NTE are carried out. Surface exposures of NTE samples to a Cf-252 source started. Planar events containing fragments and long-range α-particles as well as fragment triples only are studied. Splittings induced by thermal neutrons are studied in boron-enriched emulsion. Use of the image recognition program "ImageJ" for obtaining characteristics of individual events and for events from the large scan area is presented.

1. Introduction

Possessing an excellent sensitivity and spatial resolution nuclear track emulsions preserve their position as a universal and relatively cheap detector for surveying and searching investigations into nuclear and particle physics [1-3]. Unique opportunities of NTE deserve further use in fundamental and applied research in state-of-art accelerators and reactors, as well as with sources of radioactivity, including natural ones. Application of NTE is especially justified in those pioneering experiments in which nuclear particle tracks cannot be reconstructed with the help of electronic detectors.

The NTE technique is based on intelligence, vision and performance of researchers using traditional microscopes. Despite widespread interest, its labor consumption causes limited samplings of hundreds of measured tracks which present as a rule only tiny fractions of the available statistics. Implementation of computerized and fully automated microscopes in the NTE analysis allows one to bridge this gap. These are complicated and expensive devices of collective or even remote usage allow one to describe unprecedented statistics of short nuclear tracks.

To make such a development purposeful it is necessary to focus on such a topical issue of nuclear physics the solution of which can be reduced to simple tasks of recognition and measurement of tracks in NTE to be solved with the aid of already developed programs. One of the suggested problems is a search for the possibility of a collinear cluster tri-partition [4]. The existence of this phenomenon could be established in observations of such a type of ternary fission of heavy nuclei in which a lightest fragment is emitted in the direction of one of the heavy fragments.

Despite distinct observability of fission fragments they can not be fully identified in NTE. However, NTE is valuable due to combination of the best angular resolution and maximum sensitivity. Besides, it is possible to measure the lengths and thicknesses of tracks, and, thus, to classify the fragments. As an initial stage, to provide statistics of ternary fissions it is suggested to analyze a sufficient NTE area exposed to ^{252}Cf source with an appropriate density of tracks of α-particles and spontaneous fission fragments. Such an approach will be developed by a NTE with an admixture of the ^{252}Cf isotope [5,6]. Another option is exposure of NTE manufactured with a ^{235}U isotope addition by thermal neutrons.

A large-scale NTE scanning is suggested to be performed on the microscope HSP-1000 [7] of the Department of radiation dosimetry (DRD) of Nuclear Physics Institute of the ASCR, v. v. i.. The use of the NTE resolution will be full if the microscope will be adapted to operate with lenses of the highest magnification. Development of algorithms for automatic search and analysis of short tracks of heavy ions in NTE will be required. On the experimental side, ion ranges in NTE must be calibrated in the α-decay and fission energy scale [8]. Progress of the preparatory phase of the proposed study is summarized below.

2. Exposure to Cf source

Surface exposures of NTE samples in DRD were performed by a manually moving ^{252}Cf source. Most likely, the ^{252}Cf isotope decays by emission of α-particles of energy of 5-6 MeV, the tracks of which mainly populate an exposed sample. This isotope also undergoes a spontaneous fission to a pair or even triple of fragments with probabilities of 3%, and about 0.1%, respectively.

In the surface exposure should not be observed more than two ternary fission fragments as the third one is emitted in the contacting source side. The sign of a ^{252}Cf exposure consists in presence of α-particle tracks from ternary fission events whose ranges significantly exceed the decay α-particle ranges. This channel dominates in the ^{252}Cf ternary fission having a 90% probability.

Search for heavy ion tracks on surface of the NTE samples exposed to the ^{252}Cf source is carried out on the KSM microscope with a 15$\times$ objective. Usually MBI-9 microscopes are used for this stage. Using of KSM to search for very rare fission events has eased immediate transitions to their precise measurements with a 90$\times$ objective. Planar triples are found consisting of a pair of fragments and a long-range α-particle as well as of fragments only. Their examples are given in figure 1. It is worth to emphasize a remarkable fact of the observation of triples in NTE but not only pairs of fragments. For such a full observation of triples their vertices should be dipped to a depth not less than a typical track thickness. Figure 2a shows the distribution of vertices of Cf fissions into three fragments over NTE layer depth which has an average value of 2.7 $\pm$ 0.3 μm (RMS equal to 2.2 μm). Perhaps this effect is due to the binding of Cf atoms of AgBr micro crystals and their drift. Apparently, the source surface protection with initial thickness of the 50 μg/cm^2 gold deposition (according to the source passport) does not prevent such a penetration.

In 45 events of a true ternary fission, i. e., not containing α-particles the ranges of all fragments (figure 1, mid and right photo) are measured. Effective criteria for a fission into three heavy fragments is their amount range (figure 2b), which has an average value of 15.5 $\pm$ 0.9 μm when RMS 6.2 μm. In addition, the opening angles between the fragments are measured
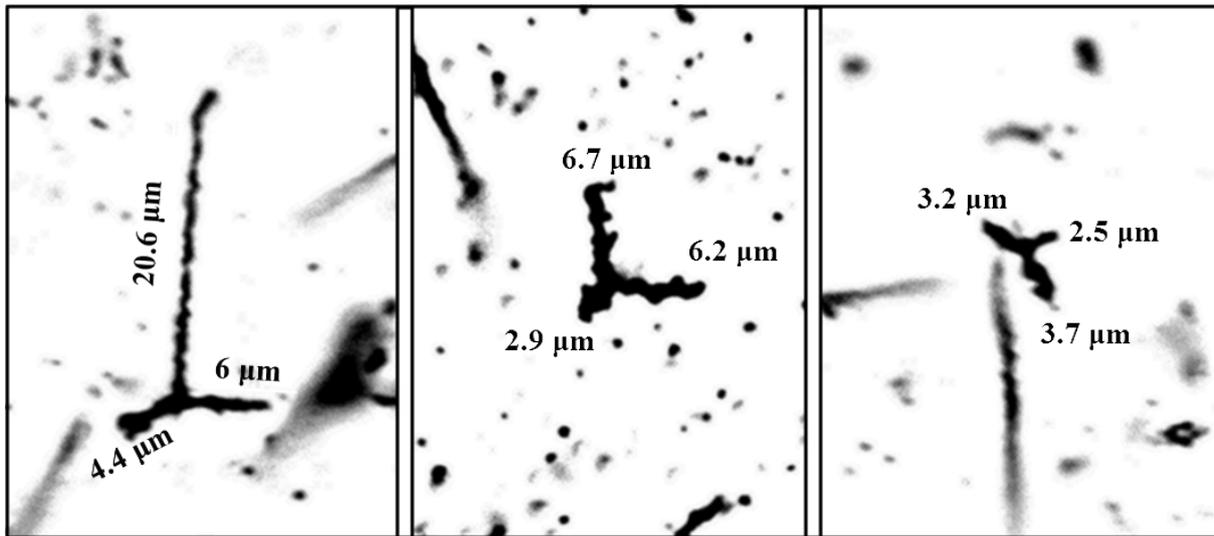
Figure 1. Examples of observed events of ternary fission; track lengths are specified. Left photo: long-range α-particle (long arrow), fragment (middle arrow). Mid and right photo: three fragment tracks.
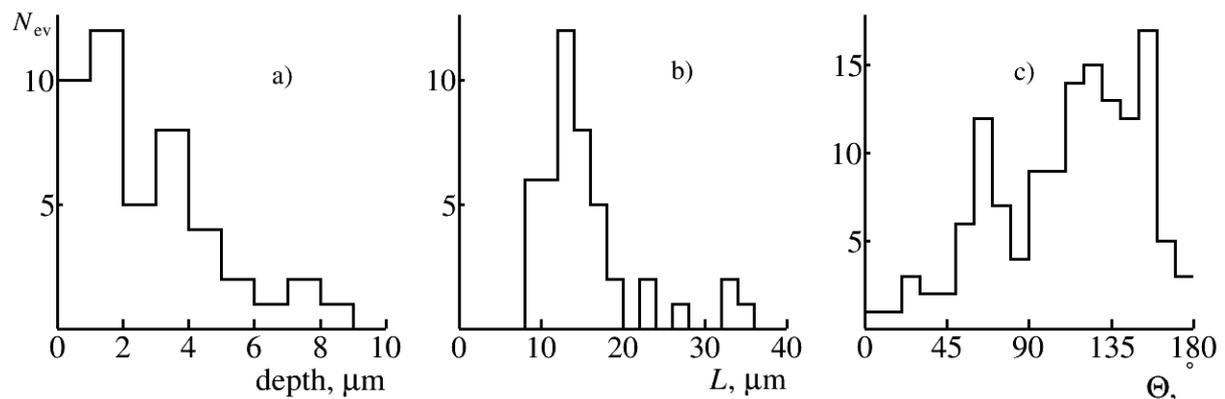
Figure 2. Distributions for the ^{252}Cf fissions into three fragments over depth in NTE layer (a), amount ranges of three fragments (b) and opening angles between fragments (c).

in these events (figure 2c). Their distribution is characterized by a mean value $111 \pm 3°$ when RMS $39°$.

3. Experience of automatic measurements

The initial experience of a computer analysis of tracks in NTE is obtained using the ImageJ program [9], available online. Boron-enriched NTE samples was exposed with thermal neutrons. Steps and results of image recognition of such event analysis are presented in figure 3 (a-d).

By computer analysis (ImageJ recognition) from scanned area of 2.64 mm^2 were found about 245 events of type of $n_{th} + {}^{10}B \rightarrow {}^7Li + {}^4He$ (figure 3d). A mean Li range (at RMS) by distribution is equal to 1.8 ± 0.01 (0.15) μm, and the ^{4}He one is 4.3 ± 0.3 (0.5) μm. Which corresponds with results of 30 manual measured events – $< L(Li)> = 1.9 \pm 0.1$ (0.5) μm, $< L(He)> = 4.1 \pm 0.1$ (0.6) μm.

Thus, the present study focused on the NTE return in practice of nuclear experiment will serve
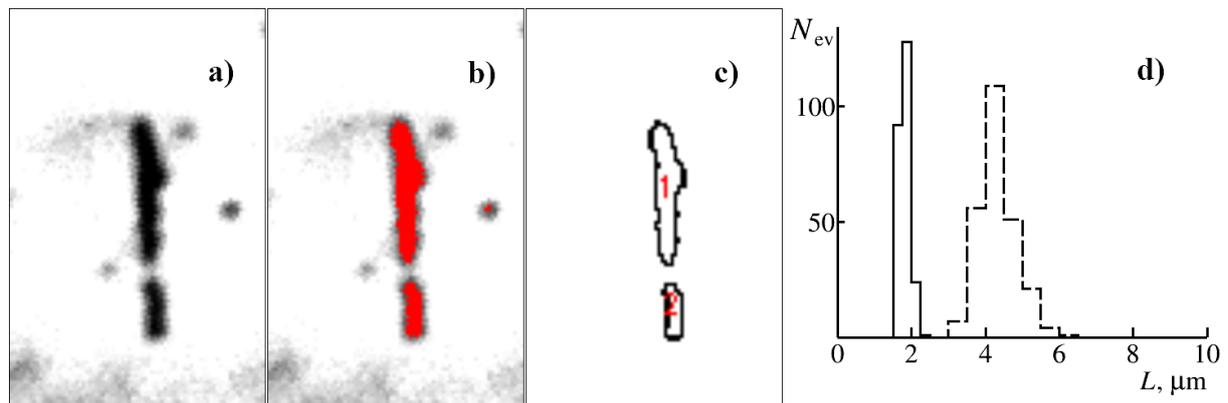
Figure 3. Example of disintegration of boron nucleus by thermal neutron to the Li and He n_{th} (a) and steps of image recognition via the ImageJ program (a-c). Distribution of mean range of Li (solid line) and He (dotted line) (d).

as a prototype of solution of an impressive variety of problems. Macro photos of the discussed exposures and videos based on them are available on the BECQUEREL project website [10].

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