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Recent applications of nuclear track emulsion

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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. NTE samples are calibrated by ions Kr and Xe of energy of 1.2 and 3 A MeV. Use of the image recognition program "ImageJ" for obtaining characteristics of individual events and for events from the large scan area is presented.

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1 Introduction

Nuclear track emulsion (NTE) retains the status of a universal and inexpensive detector. With unsurpassed spatial resolution NE provides complete observation of tracks starting from fission fragments and down to relativistic particles [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× 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× objective. Planar triples are found consisting of a pair of fragments and a long-range α-particle as well as of fragments only. 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. Fig. 1a shows the distribution of vertices of Cf fissions into three fragments over NTE layer depth which has an average value of 2.7 ± 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 are measured. Effective criteria for a fission into three heavy fragments is their amount range (Fig. 1b), which has an average value of 15.5 ± 0.9 μm when RMS 6.2 μm. In addition, the opening angles between the fragments are measured in these events (Fig. 1c). Their

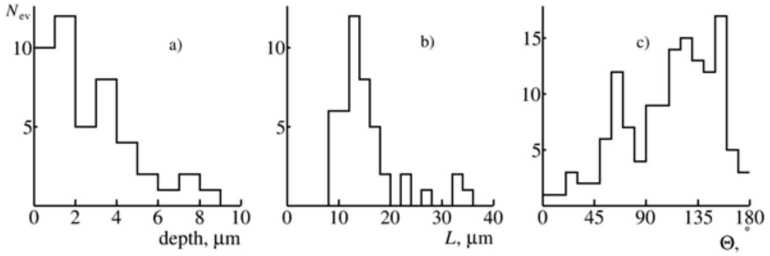

Figure 1: Distributions for the ^{252}Cf fissions into three fragments over depth in NTE layer (a), amount ranges of three fragments (b) and opening angles between fragments (c).

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 heavy ion tracks in NTE is obtained using the ImageJ program [9], available online. Steps and results of image recognition of such event analysis are presented in [8]. Recently, the microscope HSP-1000 with a lens 20$\times$ was used to scan a large area of NTE exposed to 3 A MeV ^{84}Kr ions at a 30^0 inclination. An analysis by orders of magnitude beyond a man possibility is carried out on an array of 8 frames of 3000 $\times$ 2000 pixels. The program ImageJ has found 571 tracks on an area of 0.74 mm^2 and determined their lengths and planar angles ^{84}Kr in an ellipse approximation (Fig. 2). The distribution of lengths is described by a Gaussian function with a parameter of 1.4 μm corresponding to the manual measurements. Statistics ^{84}Kr is divided into two groups differing of 11^0 in the average values. These groups ^{84}Kr are described by Gaussian functions with parameters of 1.8^0 and 3.1^0. Apparently, ^{84}Kr splitting is caused by a change of a magnetic rigidity of approximately 20% fraction of ions extracted from the accelerator U400M as a result of an electron pick-up in the residual magnetic field. The noticed effect can be used to analyze an ion beam composition. Currently, similar approaches to computer analysis are developed for the NTE exposures discussed above.

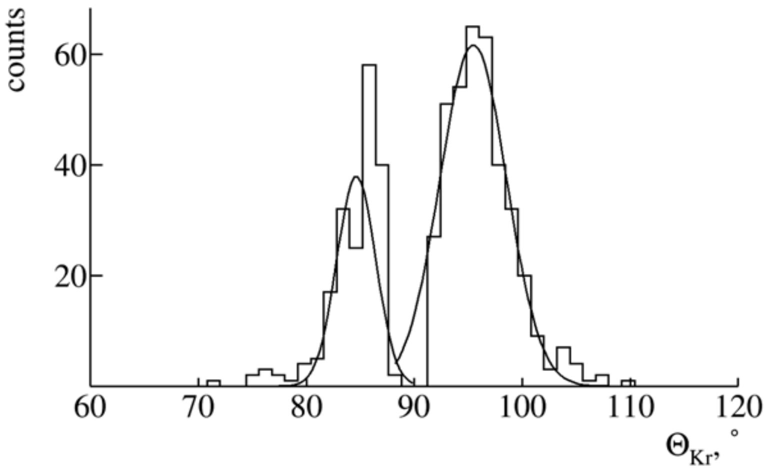

Figure 2: Distribution over planar angles of 3 A MeV ^{84}Kr ions.

4 Conclusions

Computer analysis of images will allow one to select the decays for a perfect manual analysis. Automation of search for ternary fission events will drastically reduce the most time-demanding stage and will help to focus the manual analysis on already found events. Thus, manual and automatic analyses complement each other. When the time of the NTE exposure is controlled the computer analysis can be applied in a desired scale and the diversity of tracks with estimation of ion energy, both to ion beam profilometry and to α-dosimetry with random track directions.

In general, the synergy of modern radioactive sources, NTE proven metrology and advanced microscopy seems to be a promising prospect for α-radioactivity and nuclear fission research. It can be assumed that ions of transfermium elements will be implanted some when in NTE. Their bright decays can be found as common vertices of few α-particles and fission fragments. This perspective emphasizes the fundamental value of preservation and modernization of the NTE technique.Thus, the present study focused on the NTE return in practice of nuclear experiment will serve 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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