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Experimental Examination of Ternary Fission in Nuclear Track Emulsion

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Abstract—Activities performed in preparation for the search for ternary fission of heavy nuclei and the analysis of fragment angular correlations with nuclear track emulsion and an automated microscope are detailed. Surface irradiation of nuclear emulsion by a Cf source was initiated. Planar events containing nothing but fragment triples were found and studied.

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The nuclear emulsion (NE) method [1–3] with analysis performed using an automated microscope provides unique opportunities for experiments in nuclear and neutron physics and radiation dosimetry. It can be used to find and measure short nuclear tracks with the most precise spatial resolution (0.5 μm) at an unprecedented statistics level. The first step toward this goal is to reproduce the past results that were obtained using traditional measurement microscopes with 90X lenses. Such resolutions have not yet been achieved with an automated microscope. This may serve as the basis for working out recommendations regarding the development of specific algorithms for track search with practical complications taken into account.

Ternary fission physics is one of the current drivers of interest in NE. Ternary fission of ^{235}U induced by thermal neutrons was discovered using NE that was soaked with a chemical compound enriched in this isotope [4]. Spontaneous fission of ^{252}Cf introduced into NE has been studied for quite a while [5, 6]. The ratio of probabilities of ternary and binary fission is yet to be determined. The collinear ternary fission hypothesis has been proposed recently [7, 8]. This process should manifest itself in events with the emission of the lightest fragment in the direction of one of the heavy fragments. Naturally, it is not possible to identify fission fragments completely in NE. The NE method is notable as having the highest angular resolution, which provides an opportunity to verify the existence of such a phenomenon by analyzing angular correlations. In addition, it is possible to measure the length and the diameter of tracks and thus to classify them.

The interest in further use of NE was stimulated by its production at the MICRON division of Slavich (Pereslavl-Zalessky) [9]. The samples used in the present study were fabricated by coating glass substrates with a ~100-μm-thick NE layer. The NE sample surface irradiation at the Radiation Dosimetry Division of the Nuclear Physics Institute (Czech Academy of Sciences) was first performed by shifting a ^{252}Cf source manually, but now the source is repositioned according to a program by a specially designed device. A proposal was made to analyze a sufficient NE area irradiated by a ^{252}Cf source with a suitable density of tracks of α-particles and spontaneous fission fragments [10]. This proposal may be developed further to include the use of NE samples enriched in ^{235}U and irradiated with thermal neutrons. The findings made at the preliminary stage of NE irradiation are reported below. They are of interest in themselves and raise the possibility of their application in full-scale analysis of large NE areas.

The dominant decay mode of ^{252}Cf is the decay with emission of α-particles with an energy of 5–6 MeV, the tracks of which fill the studied sample. In addition, this isotope undergoes spontaneous fission to a pair (3%) of fragments or a three (0.1%) fragments. For comparison, the NE sample was irradiated by a ^{241}Am

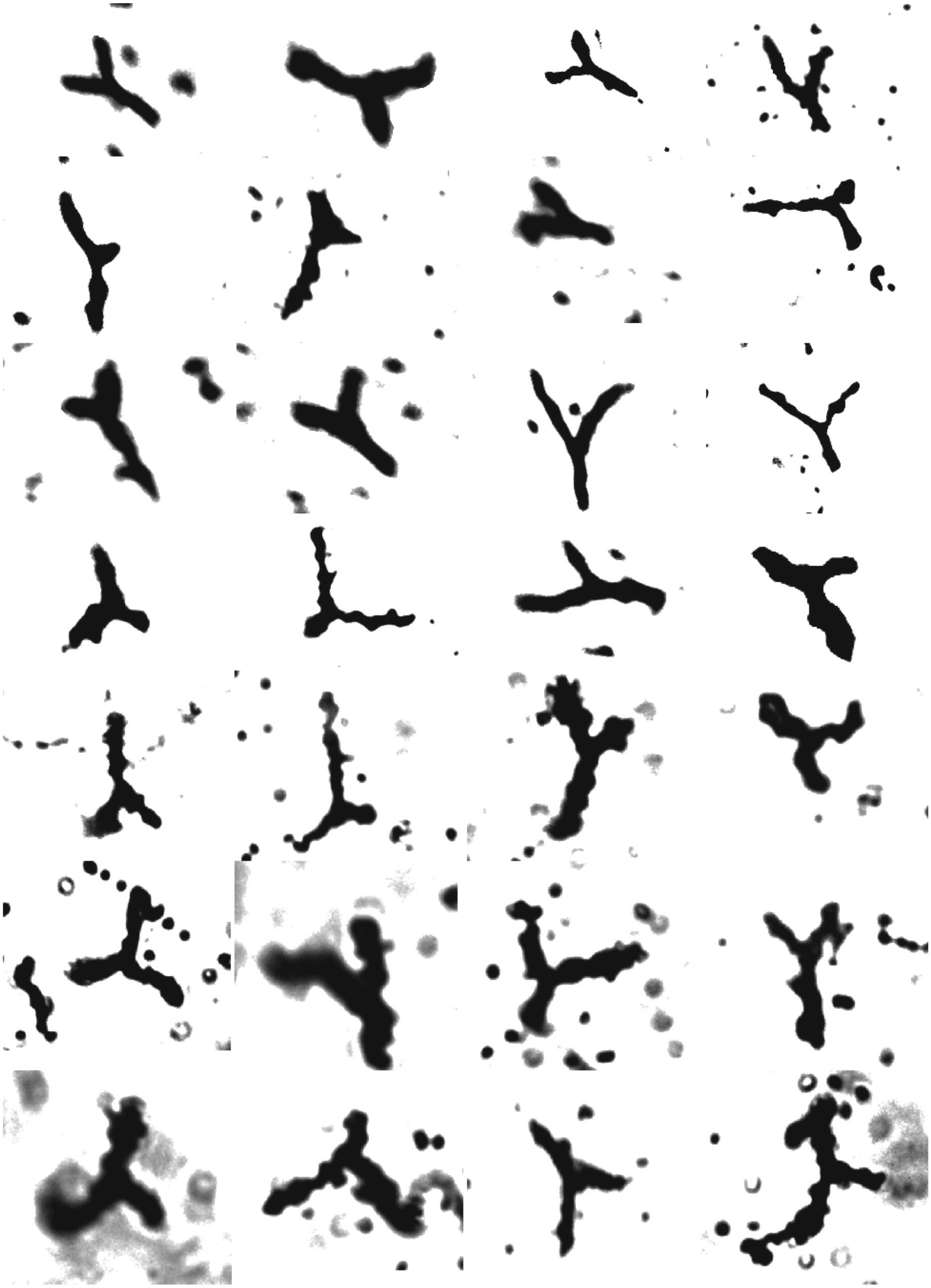

Fig. 1. Examples of observed ternary fission events.

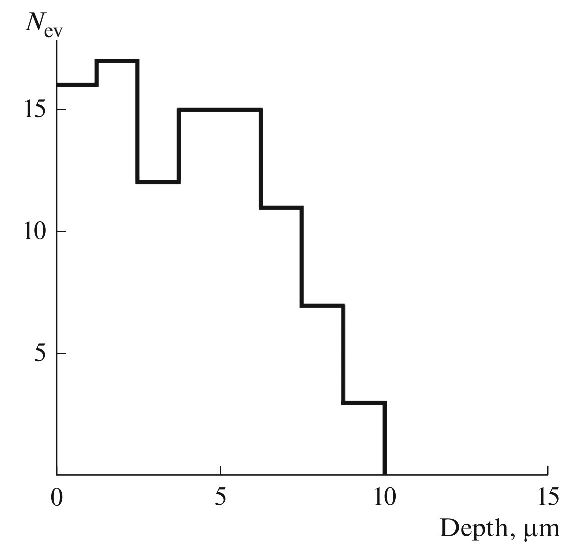

Fig. 2. Distribution of ternary ^{252}Cf fission events over the NE layer thickness.

source that emits only α-particles in the same energy range. Since the ranges of decay products are short, irradiation was performed without backing paper in a dark room under a red light. We did not expect to observe more than two fission fragments upon surface irradiation, since the third one is emitted toward the source. The sign of irradiation by ^{252}Cf is the presence of tracks of α-particles of ternary fission that have significantly longer ranges than the decay α-particles [10].

Planar events with fragment triples (Fig. 1) were also found during examination of the surface of NE layers irradiated by the Cf source. Unfortunately, the quality of presented images does not reproduce fairly the level of detail of actual observations. The remarkability of this observation of triples needs to be stressed. The vertices of triples should be located deeper than the track diameter in order for the track triples to be observed fully. Figure 2 shows the distribution of 96 vertices of Cf fission into three fragments over the NE layer thickness. The mean value is 4.1 ± 0.2 μm (RMS 2.5 μm). This effect is probably associated with the binding of Cf atoms in AgBr microcrystals and their drift. The surface shielding of the source with the initial thickness of deposited gold of 50 μg/cm^2 (according to certificate) apparently did not prevent this penetration.

Track lengths L_{fr} of all fragments were measured in 96 found ternary fission events (Fig. 3, left panel). The mean value of L_{fr} is 4.6 ± 0.13 (RMS 2.1) μm, and a rough estimate of the average energy is 400 *A* keV. The calibration of ion range in NE should be extended below 1 *A* MeV. The opening angles of fragments were measured in these events (Fig. 3, right panel). Their distribution has a mean value of 111 ± 2 (RMS 36)°. It can be concluded that no candidates for collinear fission have been found yet. The total track length of fragments L_{sum} (Fig. 4, left panel) is a useful indicator of the energy release in ternary fission. The L_{sum} distribution has a mean value of 14 ± 0.4 (RMS 3.5) μm. The degree asymmetry of a triple is characterized by the length of the total range vector L_{ecc} (Fig. 4, right panel) that is related to the aggregate momentum of fragments. The L_{ecc} distribution is a Rayleigh one with a parameter of 3.7 ± 0.3 μm.

Thus, nuclear emulsion was used successfully in a physical experiment with heavy ions of an extremely low energy. The posed problem of analysis of

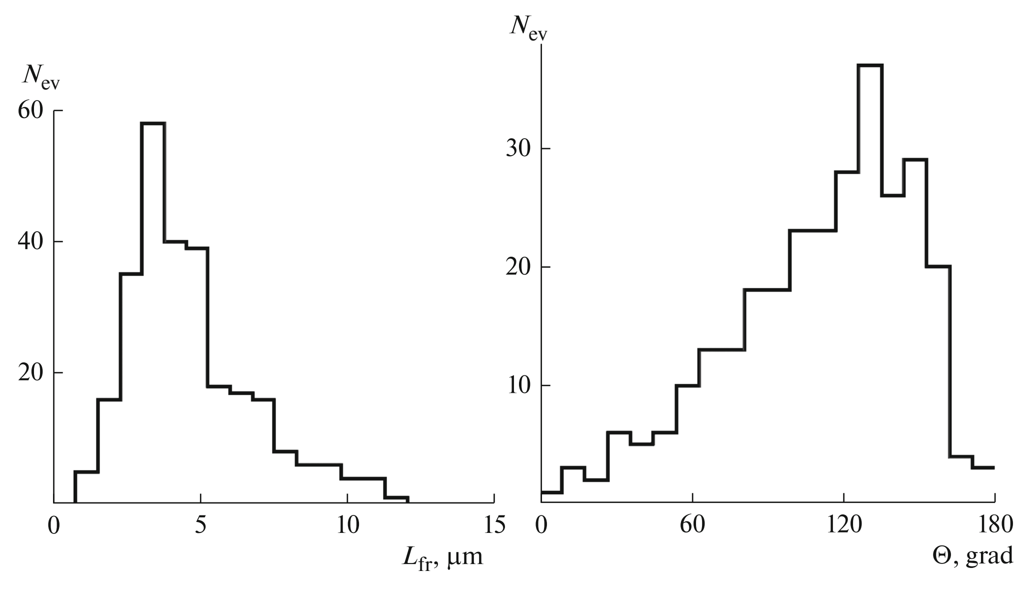

Fig. 3. Distribution of ternary ^{252}Cf fission events as a function of the fragment range L_{fr} (left) and opening angle Θ (right).

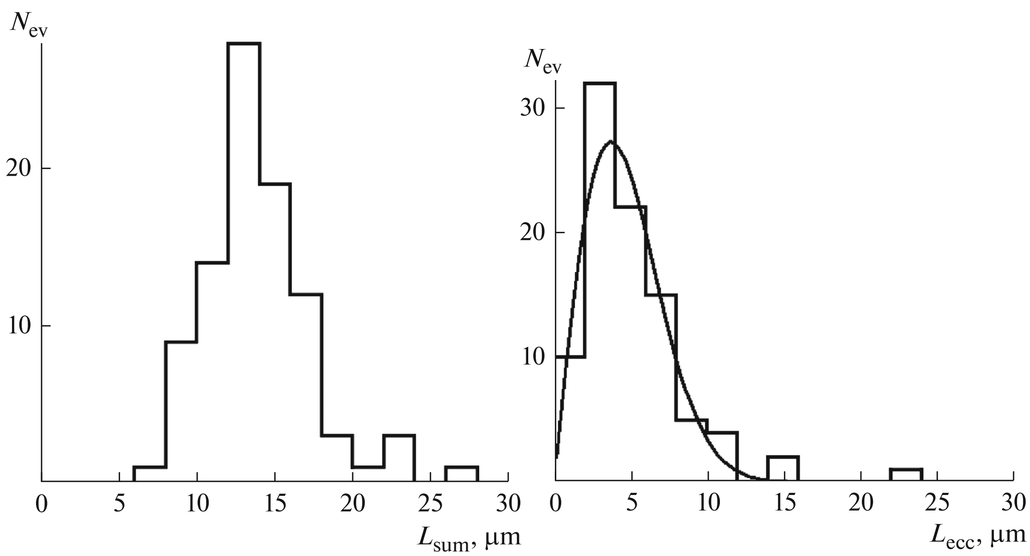

Fig. 4. Distribution of ternary ^{252}Cf fission events as a function of the total track length of fragment triples L_{sum} (left) and the length of the total range vector L_{ecc} (right).

extremely rare ternary fission events may be reduced to the search for planar nuclear fragment triples. Their tracks should have a length falling within the interval of 1–10 μm and have a common vertex. Computer analysis of images provides an opportunity to select the decays for thorough manual analysis. The automated search for ternary fission events should reduce the time costs and help focus the efforts of researchers on the already discovered events. Thus, manual and automated analysis techniques complement each other.

Macrophotographs of the discovered events, which are archived at the BECQUEREL project site [11], can serve as prototypes for the development of programs for searching for fragment triples with an HSP-1000 automated microscope (Radiation Dosimetry Division of the Nuclear Physics Institute, Czech Academy of Sciences) [12]. This microscope is used to perform trial scanning (at 20X magnification) of considerable areas of NE irradiated by the californium source. In order to utilize the NE resolution fully, the microscope is being fitted with a 60X lens immersed in oil. In general, the present study, which was aimed at reintroducing NE into nuclear experiments based on advanced microscopy techniques, may be used as a reference in solving a variety of problems.

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