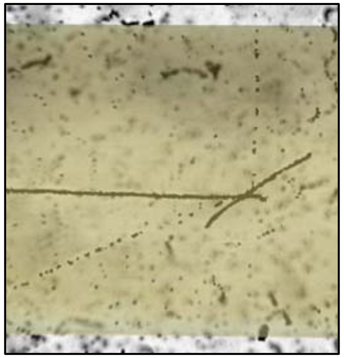
Computer analysis of nuclear track emulsion exposed to thermal neutrons and Cf source

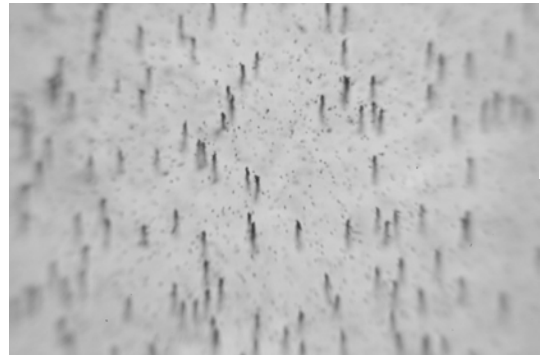
K Z Mamatkulov[1], I Ambřozová[2], D A Artemenkov[1,3], V Bradnova[1], D V Kamanin[1], R R Kattabekov[1], L Majling[2], A Marey[4], O Ploc[2], V V Rusakova[1], R Stanoeva[5], K Turek[2], A A Zaitsev[1,6], P I Zarubin[1,6], I G Zarubina[1,6]

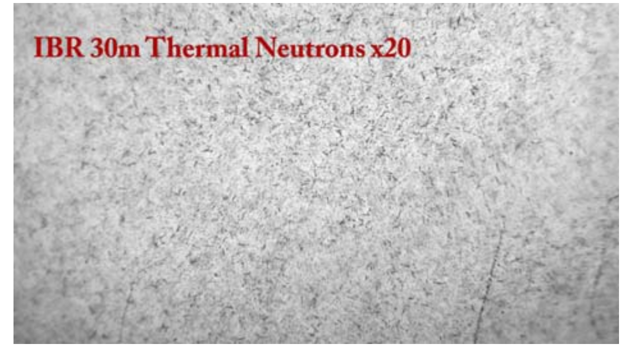
[1] Joint Institute for Nuclear Research, Joliot-Curie 6, Dubna, Moscow region,141980, Russia
[2] Nuclear Physics Institute, of the ASCR, v.v.i., Řež 130, 250 68 Řež, Czech Republic
[3] National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe Shosse 31,Moscow, 115409, Russia
[4] Minoufia University, Tala't street, EL azhar territory, Menouf city, Menofia, Egypt
[5] South-West University, Ivan Michailov st. 66, 2700 Blagoevgrad, Bulgaria
[6] P. N. Lebedev Physical Institute of the Russian Academy of Sciences, Leninskij Prospekt 53, Moscow, 119991, Russia

E-mail: `zarubin@lhe.jinr.ru`

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.







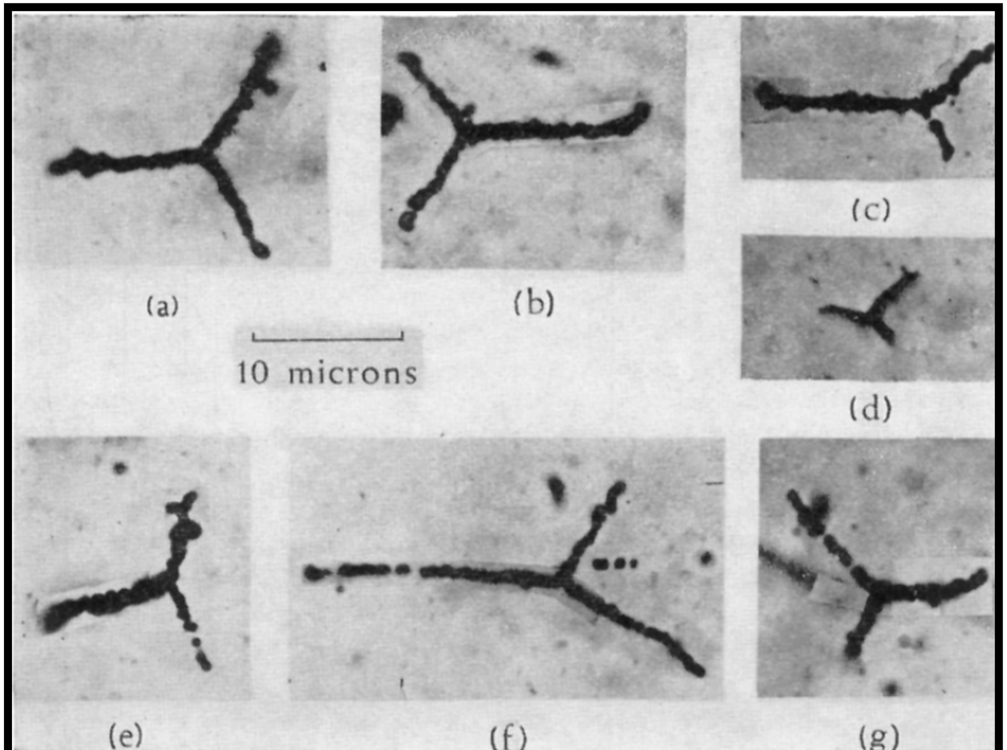
Possessing an excellent sensitivity and spatial resolution nuclear track emulsion preserve the position as a universal and relatively cheap detector for surveying and searching investigations into nuclear and particle physics. Unique opportunities of NTE deserve further use in fundamental and applied 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.

PHYSICAL REVIEW VOLUME 121, NUMBER 1 JANUARY 1, 1961

Tripartition in the Spontaneous-Fission Decay of Cf^{252}†

M. LUIS MUGA, HARRY R. BOWMAN, AND STANLEY G. THOMPSON.
Lawrence Radiation Laboratory, University of California, Berkeley, California

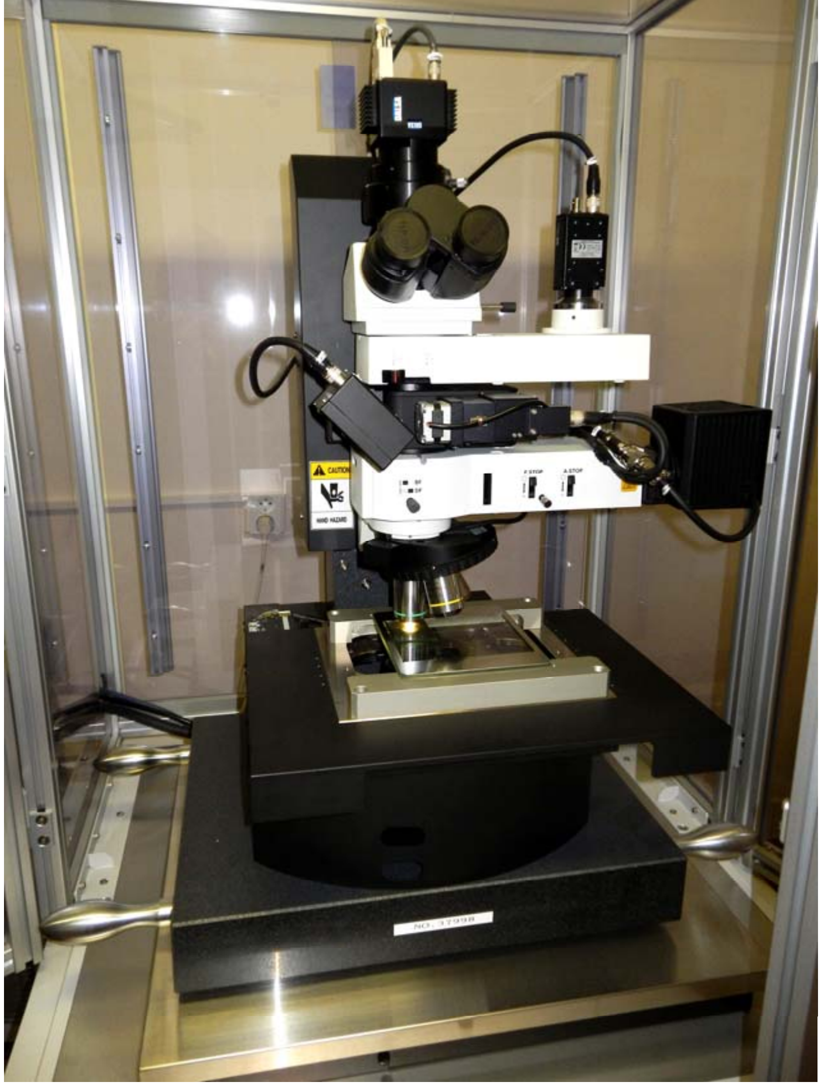


To make such a development purposeful it is necessary to focus on such a topical issue of nuclear physics the solution of which can be reduced to simple tasks of recognition and measurement of tracks in NTE to be solved with the aid of already developed programs. One of the suggested problems is a search for the possibility of a collinear cluster tri-partition. 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 _ssions 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. Another option is exposure of NTE manufactured with a ^{235}U isotope addition by thermal neutrons.

www.odz.ujf.cas.cz

A large-scale NTE scanning is suggested to be performed on the microscope HSP-1000 of the Department of radiation dosimetry (DRD) of Nuclear Physics Institute of the Academy of Czech Republic. 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. Progress of the preparatory phase of the proposed study is summarized below.



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. For comparison an NTE sample was exposed to a ^{241}Am source emitting only α-particles in the same energy range. Since the ranges of decay products are small the source exposures are performed without a light protective paper in a darkroom when illuminated with red light.

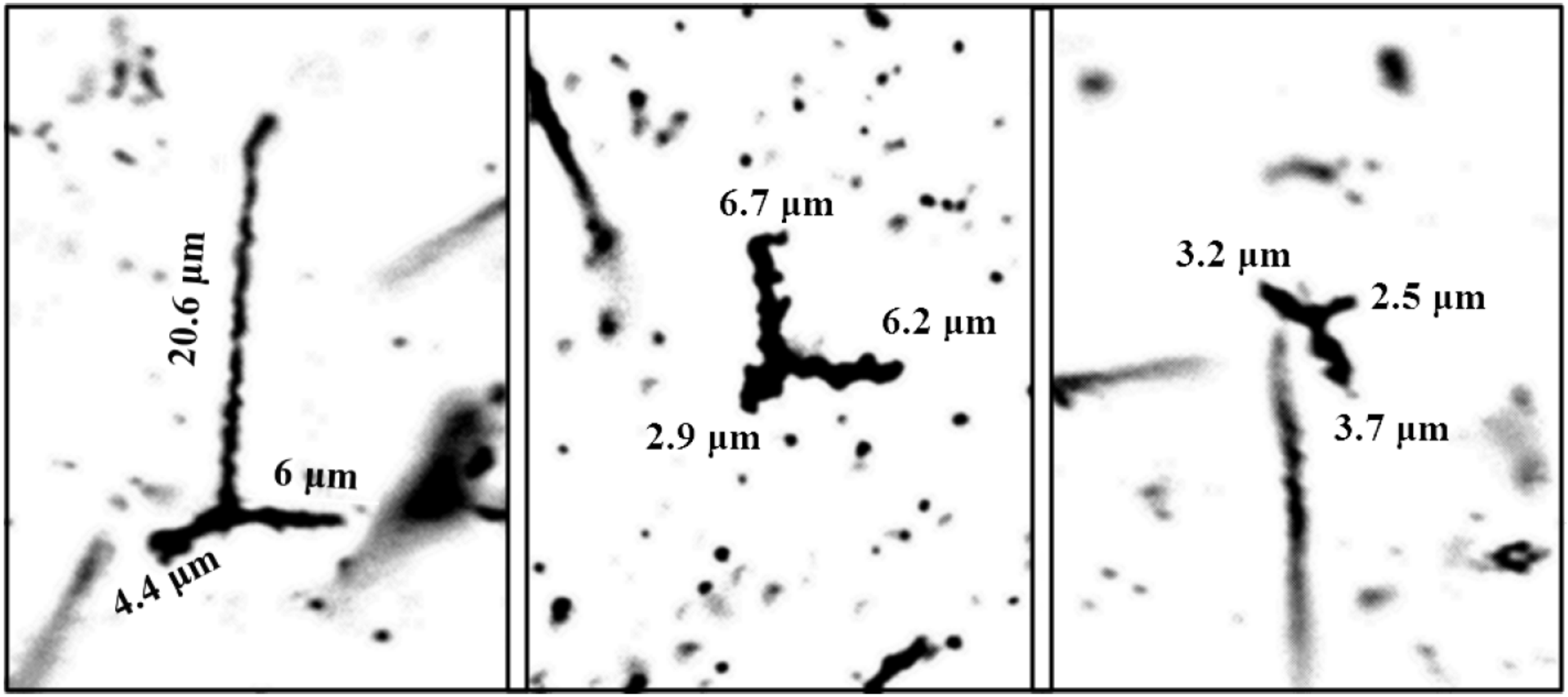
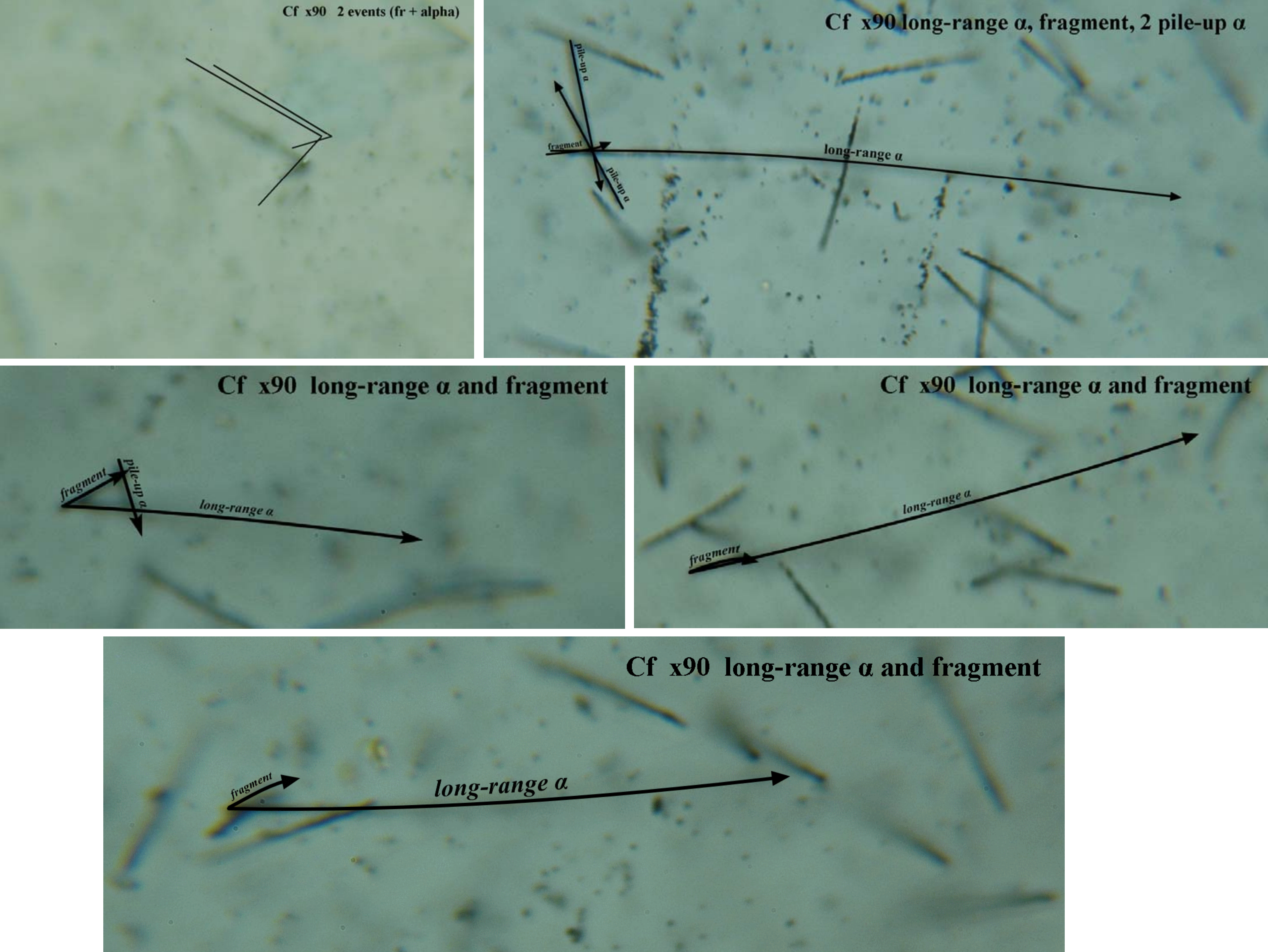


Figure 1. Examples of observed events of ternary fission; track lengths are specified. Left photo: long-range α-particle (long arrow), fragment (middle arrow). Mid and right photo: three fragment tracks.


Cf x90 2 events (fr + alpha)
Cf x90 long-range α, fragment, 2 pile-up α
pile-up α
fragment
long-range α
pile-up α
Cf x90 long-range α and fragment
fragment
pile-up α
long-range α
Cf x90 long-range α and fragment
fragment
long-range α
Cf x90 long-range α and fragment
fragment
long-range α

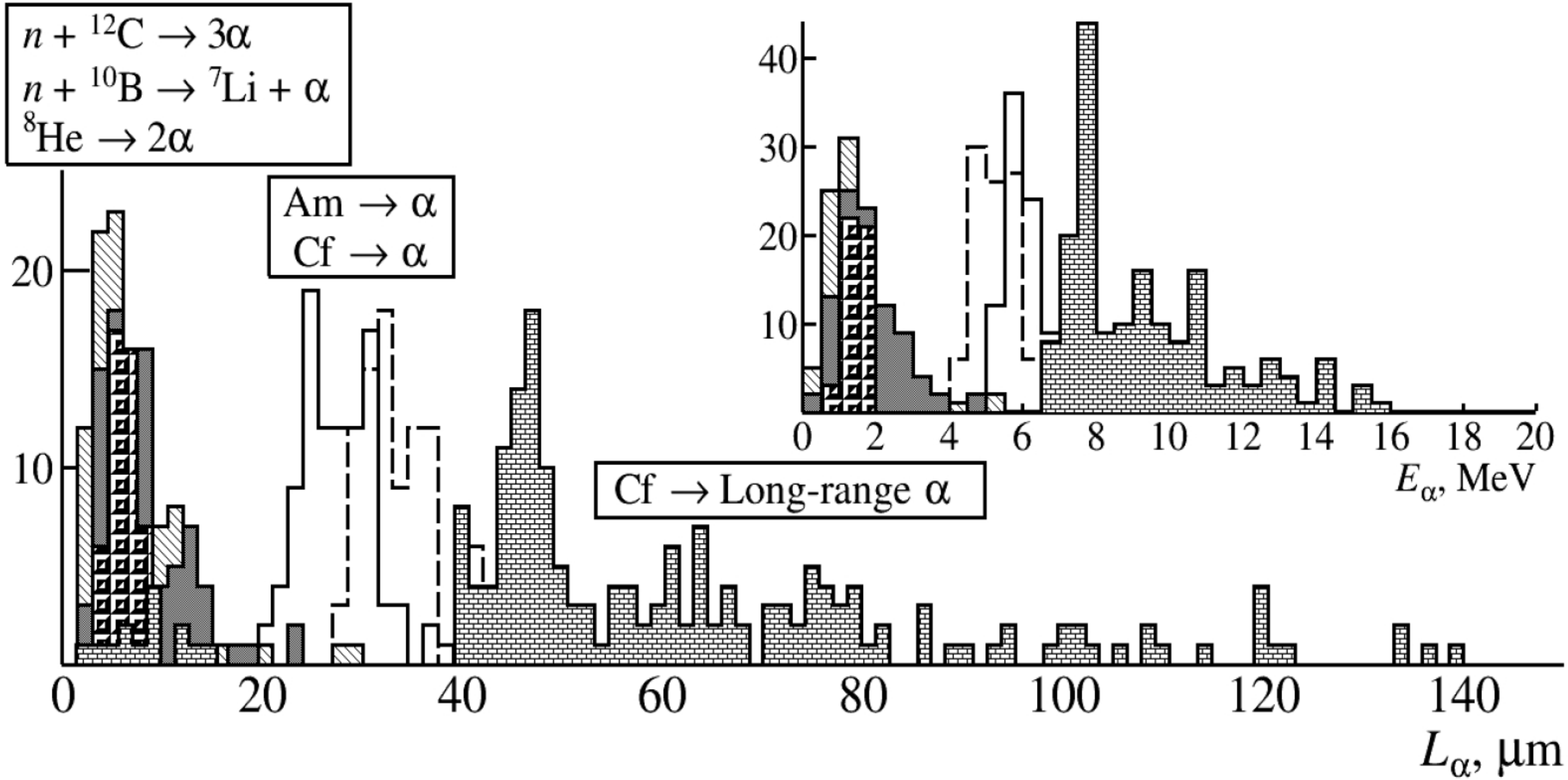
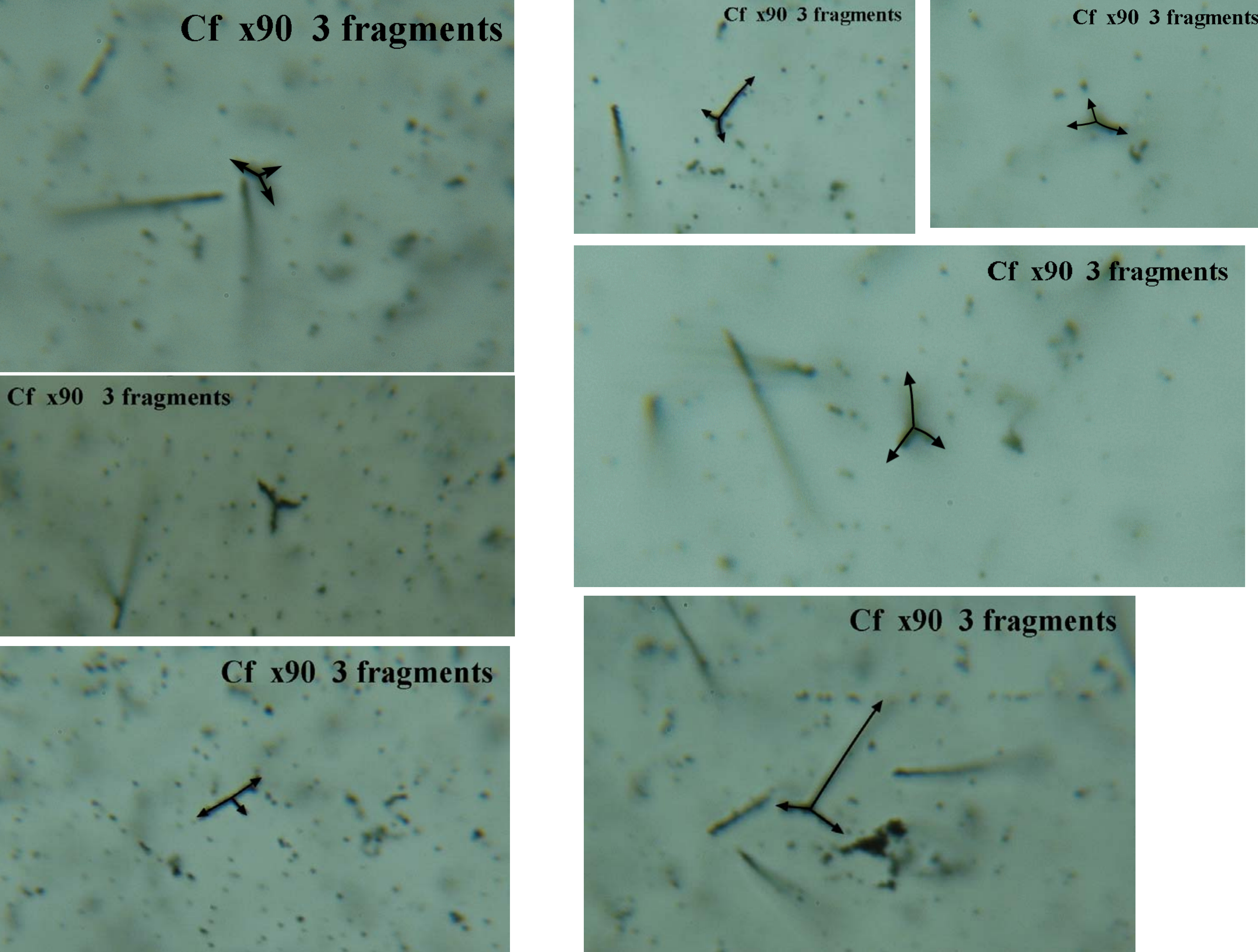


Fig. 1. Distributions of α-particle ranges: n(14.1 MeV) + ${}^{12}C \to 3\alpha$ (obliquely-shaded), ${}^{8}He \to 2\alpha$ (gray), $n_{th} + {}^{10}B \to {}^{7}Li + \alpha$ (black dot), Cf → α (solid), Am → α (dotted histogram), Cf → long-range α (brick-shaded); the inset: corresponding of α-particle energy estimated via spline-interpolation of range-energy calculations in the SRIM model.


Cf x90 3 fragments
Cf x90 3 fragments
Cf x90 3 fragments
Cf x90 3 fragments
Cf x90 3 fragments
Cf x90 3 fragments
Cf x90 3 fragments

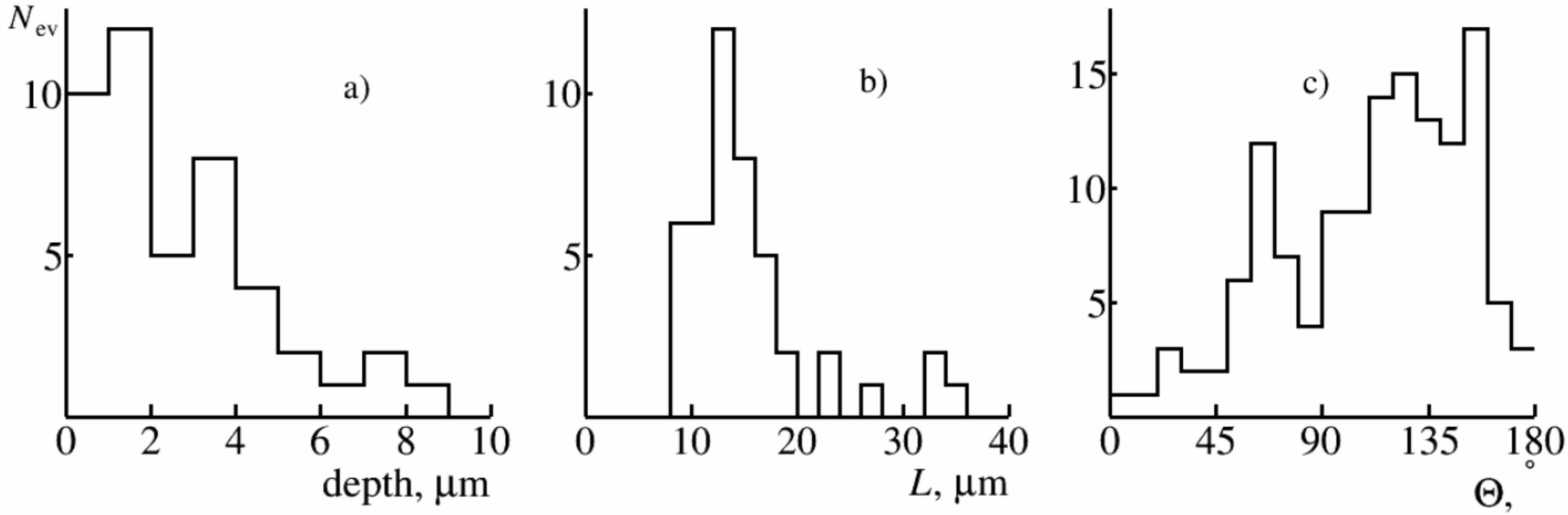
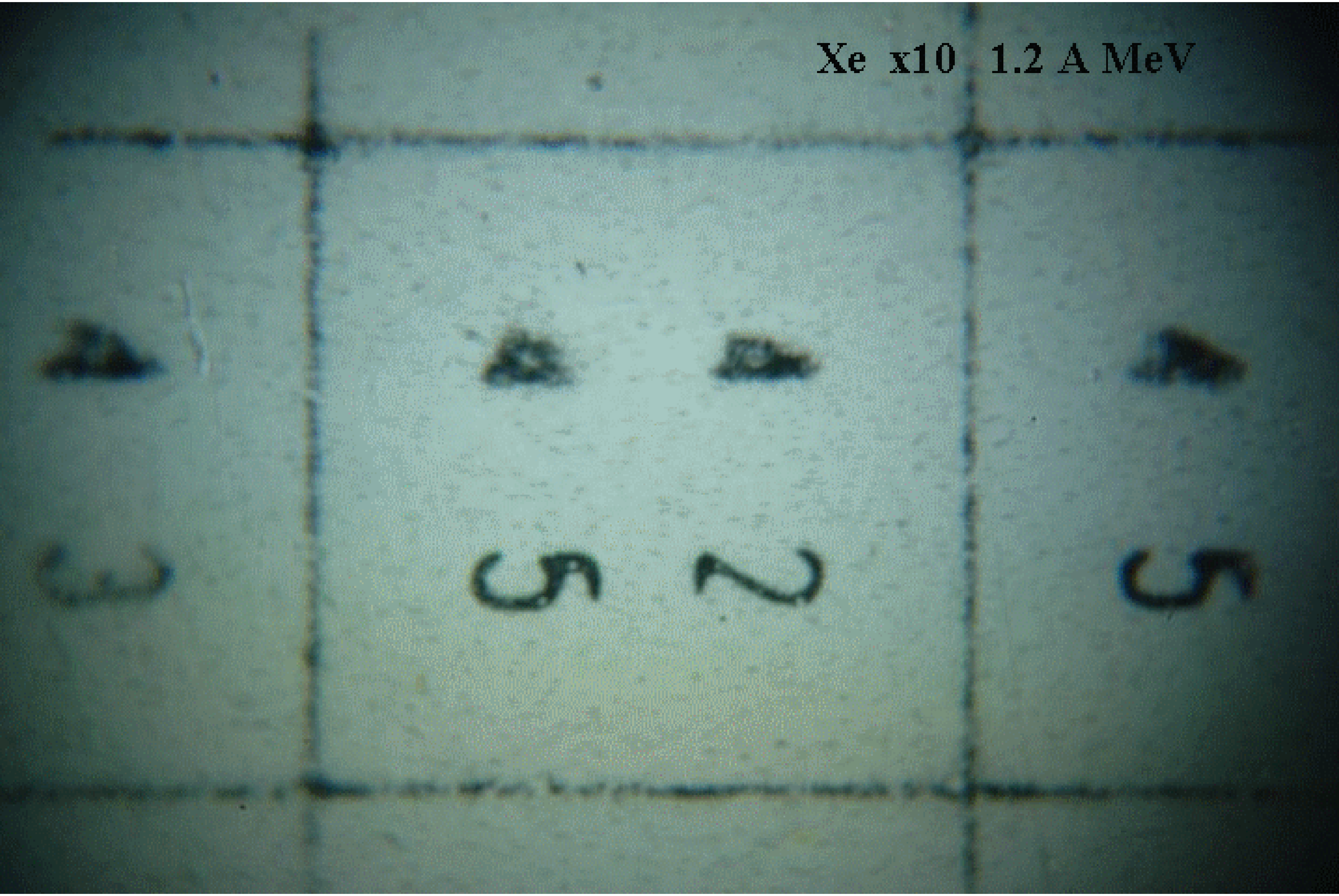
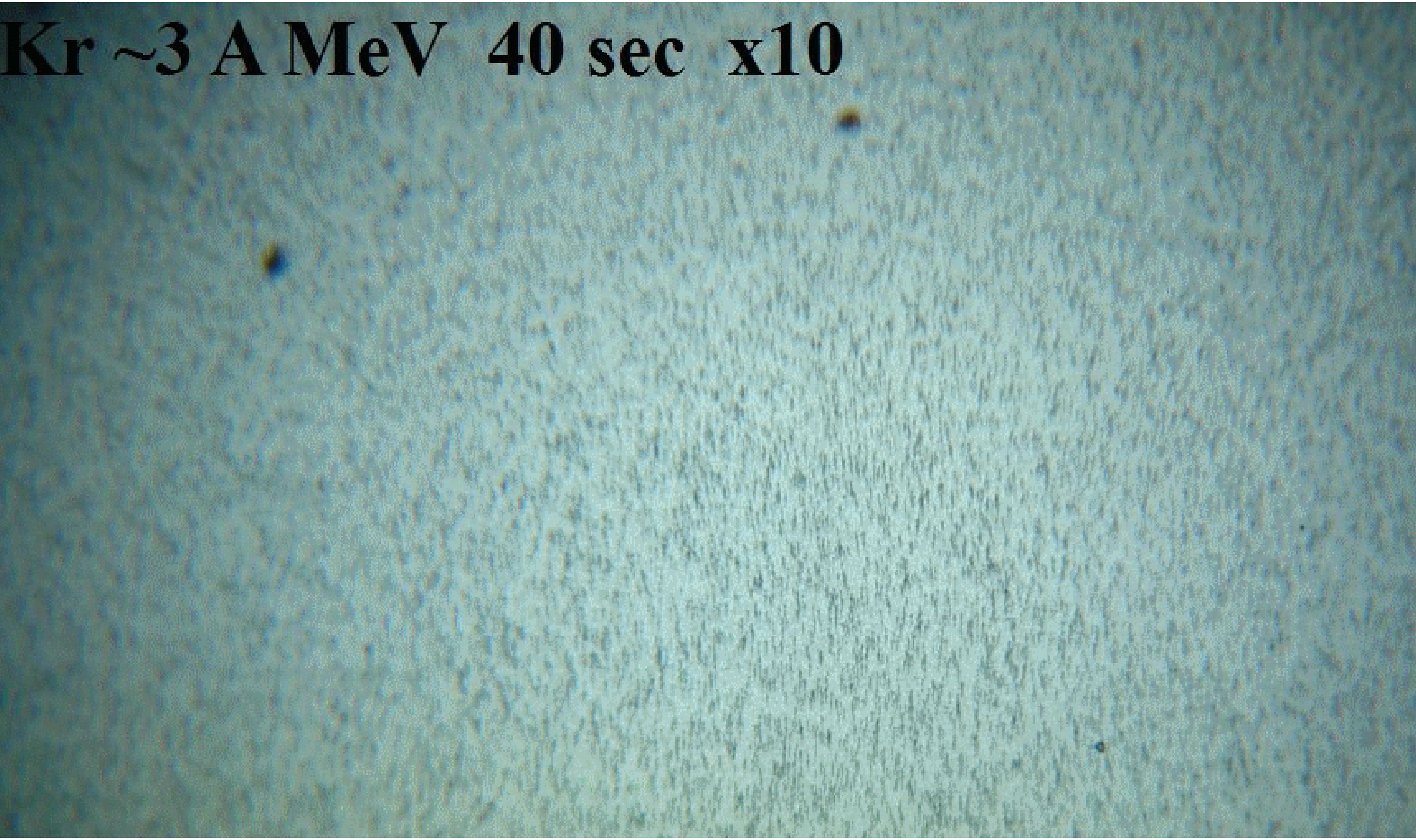


Figure 2. Distributions for the ^{252}Cf fissions into three fragments over depth in NTE layer (a), amount ranges of three fragments (b) and opening angles between fragments (c).


Xe x10 1.2 A MeV


Kr ~3 A MeV 40 sec x10

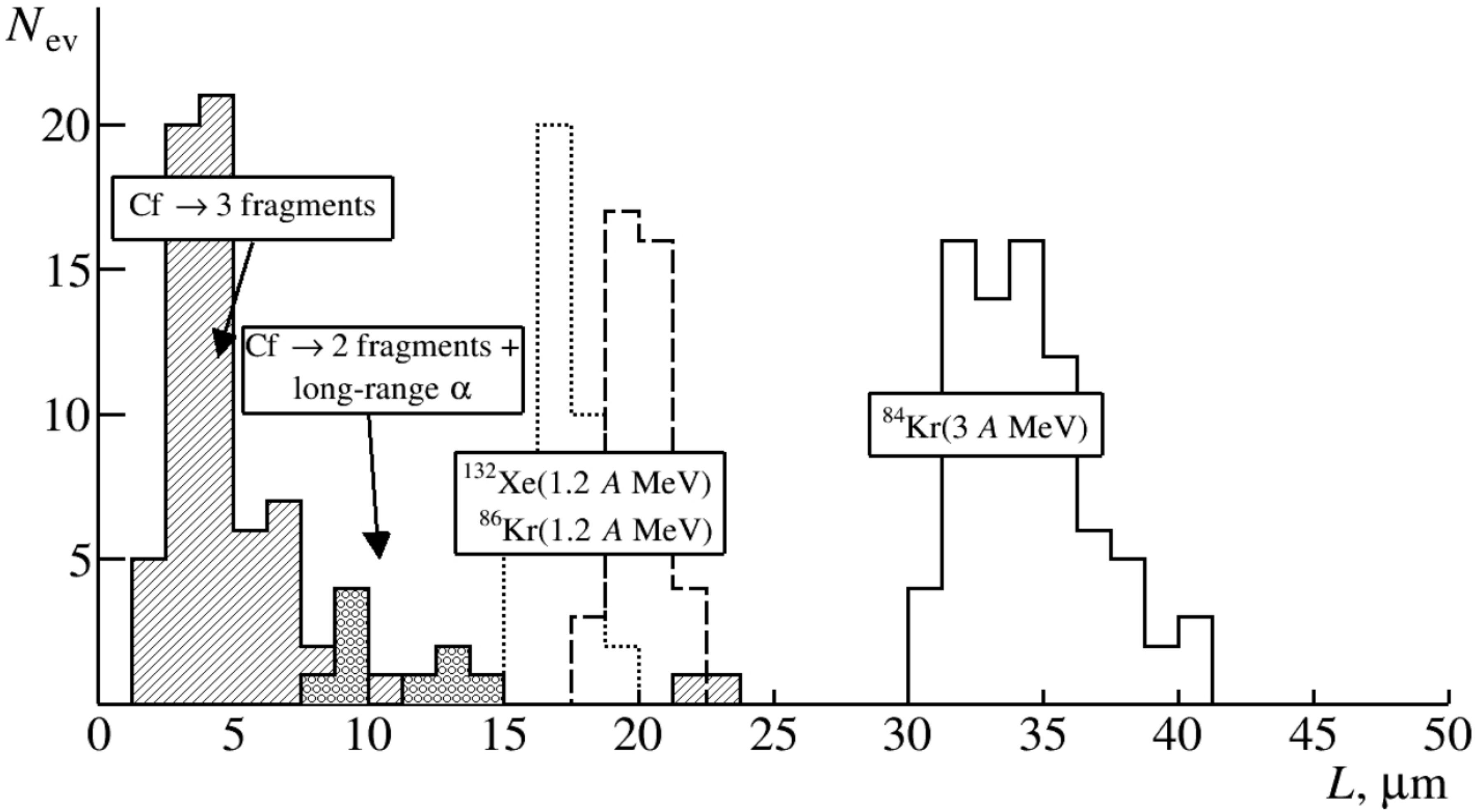


Fig. 2. Distributions of ranges of ions ^{86}Kr, ^{132}Xe, ^{84}Kr and in decays Cf → 3 fragments and Cf → 2 fragments + long-range α.

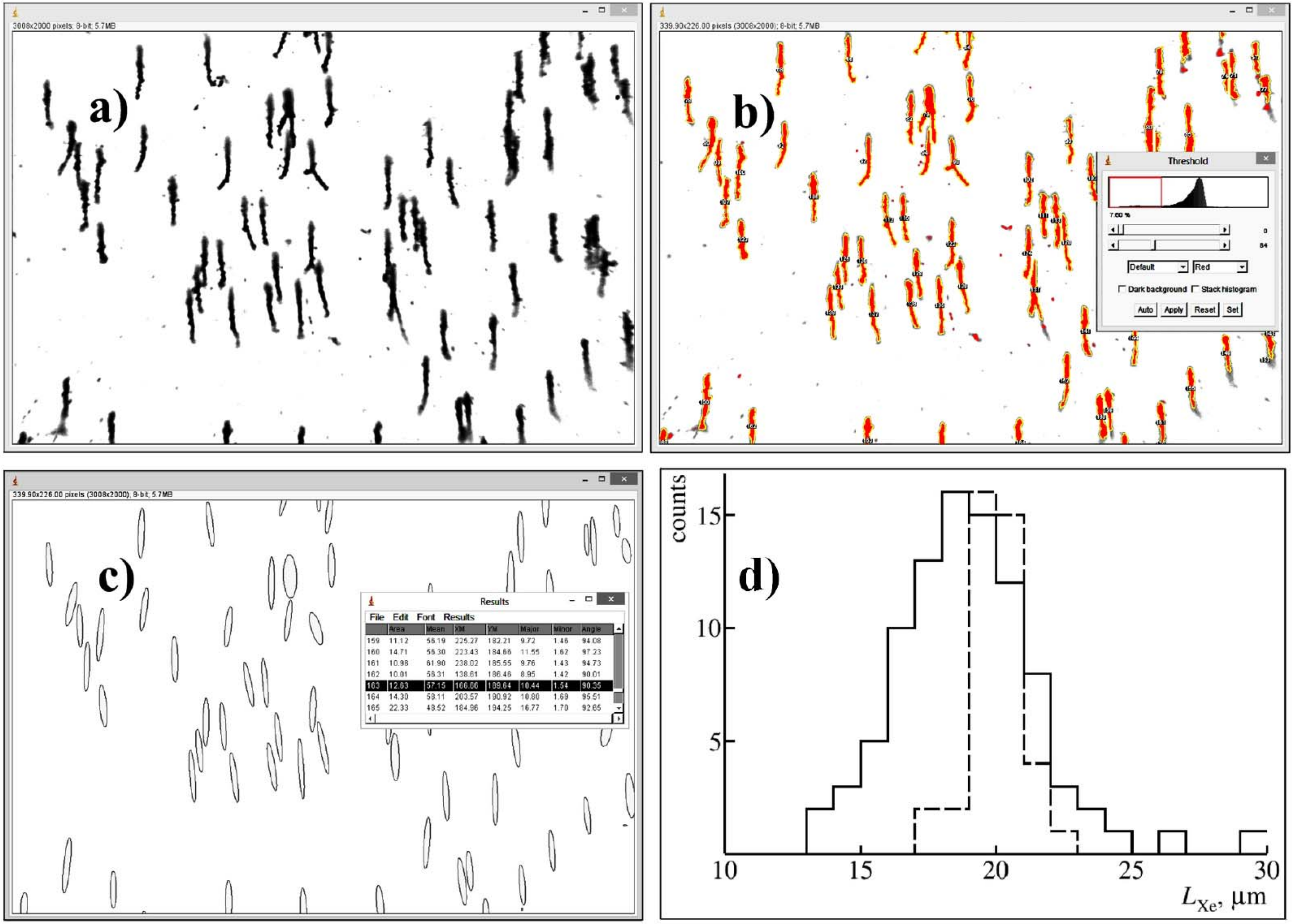


Fig. 5. Stages of computer analysis: (a) initial close-up, (b) finding of track images, (c) description of them as ellipses and (d) ion range distribution in computer (solid line) and manual (dashed line) analysis.

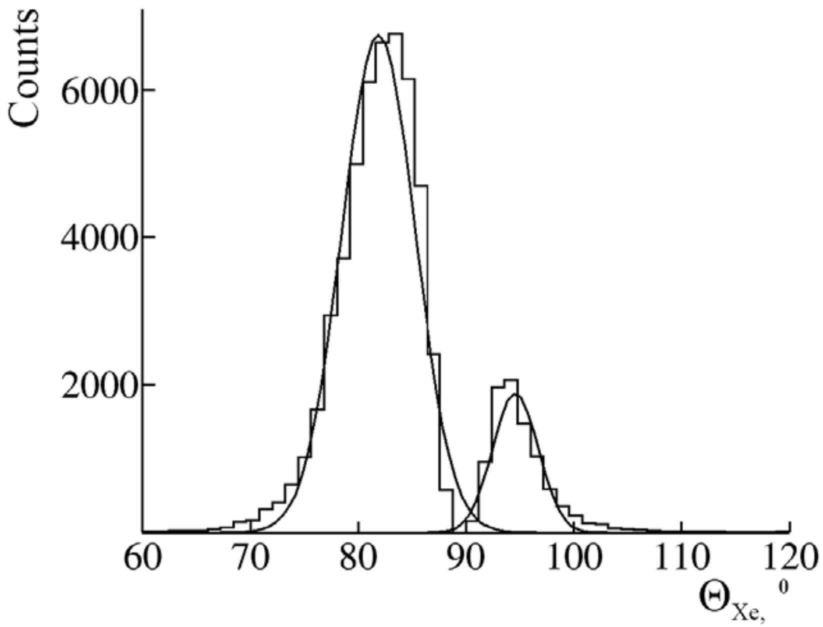


Fig. 7. Distribution over planar angles of 1.2 *A* MeV ^{132}Xe ions.

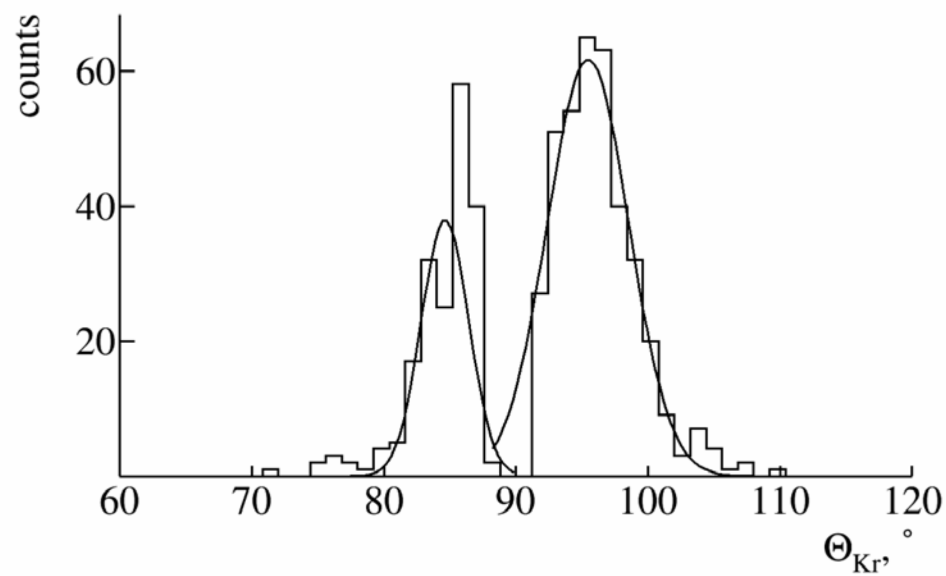


Figure 2. Distribution over planar angles of 3 *A* MeV ^{84}Kr ions.

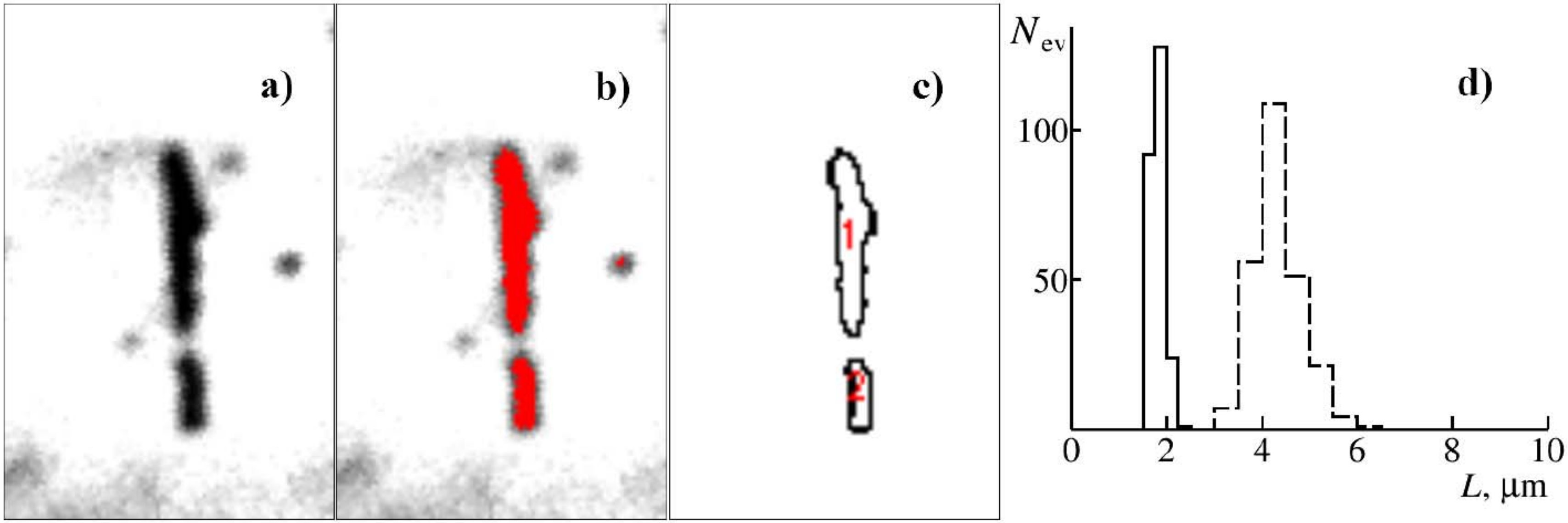


Figure 3. Example of disintegration of boron nucleus by thermal neutron to the Li and He n_{th} (a) and steps of image recognition via the ImageJ program (a-c). Distribution of mean range of Li (solid line) and He (dotted line) (d).

Conclusions

The stated task of analyzing extremely rare events of the ternary fission is reduced to finding planar triples of nuclear fragments. Beginning at a common vertex and being randomly directed their tracks should have an extent of from 1 to 10 μm. 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.