Faculty of Science

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Study of the Spontaneous Fission of the ^{252}Cf isotope in Nuclear Track Emulsion

Thesis for

Ph.D. Degree of Physics in (Nuclear Physics)

By

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ABEER

ABSTRACT

A new mode of nuclear fission has been reported, called Collinear Cluster Tri-partition (CCT) which is very rare does not exceed the rate of occurrence of 0.2- 0.4% . The claim is based on indirect observation via missing-energy events, spontaneous fission of ^{252}Cf. The events were interpreted as perfectly collinear emission of three heavy fragments. 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.

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 and energies in a novel NTE are carried out. 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.

Summary

During this study,

Some rare types of fission were studied for the element californium 252, which is the ternary fission where the element splits into three different ions in more than one way, including:

1 - to exit the alpha with two heavy elements

2- That the element is divided into three closely related elements in the mass.

In this study and according to the available measurements and calculations, some properties of this fission were identified, including measuring the angles at which these elements exit, measuring the range, and from it measuring the energy of the alpha particle, and it was compared to some of the alpha particles that come out in other reactions, including the fission of carbon 12 when it is bombed with neutrons and also the fission of helium 8 into two alpha particles and the fission of boron 10 when it is also bombed with neutrons and another comes out of the aminium-241. It was found from the study that the alpha that comes out of californium during triple fission is the largest in the range and the highest in energy.

Also, calibration was done using some heavy elements with different cards, such as xenon 132 and krypton 86, 84 in order to be a guide for those who study these rare interactions, as it is known to everyone that more than 90% of fission for this element leads to obtaining only two elements, which is called binary fission Less than 1% of this type of fission occurs, which generates three elements. Also, some modern computer programs have been used, such as root, which is used in calculations and drawing, as well as a popular drawing program called Image G. It is a program that accurately copies, scans and scans samples and also performs some simple measurements by programming it on these measurements and the use of these programs also was one of the objectives of the study to find a way to deal with samples in an easier and faster way and at the end of the study we will have obtained some properties that help in identifying This kind of fission.

Emulsion samples are one of the techniques that are used in studying some of the properties of nuclear effects, as they record these effects and keep them for long periods and it is considered one of the advantages of emulsification, but in the end, like any technique, it cannot measure everything about these effects. Each technology has advantages and disadvantages and it is unable to identify These ions that come out from the fission products, but he can accurately measure the angles at which these nuclear effects come out, as well as their lengths and range, and thus the energies, which helps to classify these effects.

Also, the problem of small amounts of data was overcome by scanning a large number of samples using computer programs, which greatly saved much time that is used to collect this data.

1.1 INTRODUCTION

Science aims to provide us with a better understanding of the world that we live in. A scientific model that is commonly used for this purpose is particle physics, in which everything around us is composed of particles. Physicists try to classify the particles by their most fundamental constituents, the elementary particles, and a tradition that dates back to the ancient Greeks. The atom was long thought to be the most elementary particles, until the discovery of the nucleus, which itself was later found to be composed of the nucleons (protons and neutrons).

The list goes on, and today we know of a number of elementary particles, with the most recent addition being the Higgs boson. Everything that we observe is a consequence of processes involving the interactions between the particles and the different states that they can exist in. Which of the processes and states are allowed is governed by symmetries and conservation laws. Processes are classified into different categories of physics, mainly based on which interactions are involved. Nuclear fission for example, is governed by the nuclear and the Coulomb interaction between the nucleons. In the nuclear fission process, heavy nuclei split into several smaller charged fragments. The tightest bound [1, 2] system is known to be ^{62}Ni. As more nucleons are added to make heavier nuclei, the average binding energy per added nucleon decreases. Eventually the system seeks a more energetically favorable shape by deforming. At some point, the deformation becomes so severe that the repulsive Coulomb force overcomes the attractive nuclear force, and the system breaks up (scissions). Fission can either occur spontaneously, or be induced by nuclear reactions. To better understand nuclear fission, thousands of experimental and theoretical studies have been carried out since its discovery 75 years ago [3, 4, 5].

Like the nuclear interaction however, nuclear fission still proves to be a great mystery in many aspects. The nuclear fission process usually produces two charged fragments, in which case it is called binary fission. Once every few hundred fissions however, a third light charged fragment is formed as well, in a process known as ternary fission. Ternary fission was initially of great interest since the additional fragment, known as the ternary particle, was expected to carry vital information about the scission configuration, possibly being able to unravel some of the mysteries of the fission reaction mechanism. Detailed investigation showed that in 90% of the case, the third fragment was an alpha particle (^{4}He), in 9% a heavier helium or hydrogen, and in less than 1% a particle with charge $Z > 2$, with rapidly decreasing yields for higher Z and mass A [6]. The heaviest particles found in for example ^{235}U (n_{th},f) is ^{22}O with yields of $3{\cdot}10^{-9}$ [7]. For ternary particles with a size comparable to the other two fragments, called true ternary fission, only upper limits of the yield exist in low- energy fission, of roughly 10^{-10} [8, 9]. In 2010 claims of experimental observation of ternary $^{34-36}Si$ and ^{48}Ca from the reactions ^{235}U (n_{th},f) and ^{252}Cf(sf), respectively, were published [10]. A surprisingly high yield of about 0.5% per fission was reported, which is even higher than the ternary alpha yield, contradicting what has been generally accepted since the 1940s. More surprising, however, was the fact that almost the exact same yield was reported in two completely different fission channels, and for two very different ternary particles, with widely varying charges and masses. The decay was dubbed “Collinear Cluster Tri-partition”(CCT), since it was argued that all three fragments were emitted perfectly collinear along the same fission axis, and that its discovery had eluded previous experiments since two of the fragments look like a sum event to a detector.

1.2 Nuclear Fission

Heavy nuclei are known to split into smaller charged fragments in a process known as nuclear fission. The process is mainly a consequence of the gradual decrease in average binding energy per nucleon, those nuclei heavier than ^{62}Ni experience [1, 2]. Breaking up these heavy nuclear systems liberates large amounts of energy, of roughly 200 MeV. This energy mainly goes into kinetic and excitation energy of the resulting fragments, and partly into the emission of mostly neutrons and gamma radiation. Although very exo-energetic, the process is usually prevented by a potential barrier. Some systems can transcend this barrier spontaneously via tunneling, while others have to be excited, for example by nuclear reactions. Fission usually proceeds into two charged fragments, in which case it is called binary fission. The formation of three charged fragments is called ternary fission, and occurs once every few hundred binary fissions, with the third particle in 99% of the cases being a hydrogen or helium isotope. This thesis investigates the existence of a special kind of ternary fission, called Collinear Cluster Tripartition (CCT), in the channels ^{252}Cf(sf). In CCT, all three fragments are of comparable size and emitted perfectly collinear along the fission axis. This section starts by discussing briefly the theoretical models used in general nuclear physics, how they are applied to binary fission, and ends with experimental results. A more thorough investigation of the properties of ternary fission will then be discussed, with the conclusion.

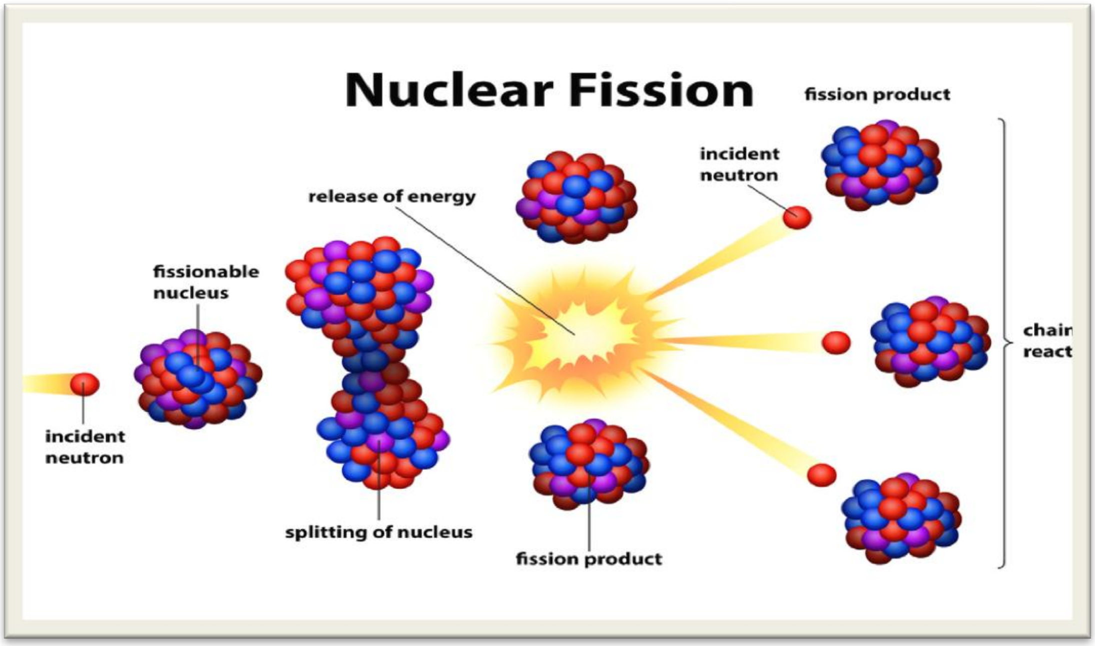

Fig 1.1 Nuclear fission

1.2.1 Nuclear Fission types

In nuclear physics and nuclear chemistry, **nuclear fission** is a nuclear reaction or a radioactive decay process in which the nucleus of an atom splits into two or more smaller, lighter nuclei. Nuclear fission of heavy elements was discovered on December 17, 1938 by German Otto Hahn and his assistant Fritz Strassmann, and explained theoretically in January 1939 by Lise Meitner and her nephew Otto Robert Frisch. Frisch named the process by analogy with biological fission of living cells. For heavy nuclides, it is an exothermic reaction which can release large amounts of energy both as electromagnetic radiation and as kinetic energy of the fragments (heating the bulk material where fission takes place). Like nuclear fusion, in order for fission to produce energy, the total binding energy of the resulting elements must have a greater binding energy than that of the starting element.

Fission is a form of nuclear transmutation because the resulting fragments are not the same element as the original atom. The two (or more) nuclei produced are most often of comparable but slightly different sizes, typically with a mass ratio of products of about 3 to 2, for common fissile isotopes [3,4]. Most fissions are binary fissions (producing two charged fragments), but occasionally (2 to 4 times per 1000 events), three positively charged fragments are produced, in a ternary fission. The smallest of these fragments in ternary processes ranges in size from a proton to an argon nucleus.

Apart from fission induced by a neutron, Spontaneous fission was discovered in 1940 by Flyorov, Petrzhak, and Kurchatov [5] in Moscow, when they confirmed that, without bombardment by neutrons, the fission rate of uranium was indeed negligible, as predicted by Niels Bohr; it was not The unpredictable composition of the products (which vary in a broad probabilistic and somewhat chaotic manner) distinguishes fission from purely quantum tunneling processes such as proton emission, alpha decay, and cluster decay, which give the same products each time. Nuclear fission produces energy for nuclear power and drives the explosion of nuclear weapons. Both uses are possible because certain substances called nuclear fuels undergo fission when struck by fission neutrons, and in turn emit neutrons when they break apart. This makes a self-sustaining nuclear chain reaction possible, releasing energy at a controlled rate in a nuclear reactor or at a very rapid, uncontrolled rate in a nuclear weapon [5].

The amount of free energy contained in nuclear fuel is millions of times the amount of free energy contained in a similar mass of chemical fuel such as gasoline, making nuclear fission a very dense source of energy. The products of nuclear fission, however, are on average far more radioactive than the heavy elements which are normally fission as fuel, and remain so for significant amounts of time, giving rise to a nuclear waste problem.

Concerns over nuclear waste accumulation and over the destructive potential of nuclear weapons are a counterbalance to the peaceful desire to use fission as an energy source.

The types of fission can be limited to the following points:

1- Binary fission
2- Ternary fission- true ternary fission
3- Quaternary fission

1.2.2 The Liquid Drop Model

Experimental indication of nuclear fission was found in 1938 by Hahn and Strassmann [6,7]. It was later interpreted by Meitner and Frisch [8], who explained the process qualitatively within the framework of the Liquid Drop Model (LDM). The LDM uses a macroscopic treatment of the nucleus as a uniformly charged liquid drop. The model was used to predict nuclear binding energies and Q-values (net energy liberated), making it possible to discern which decay modes and nuclear reactions are allowed. The LDM could also explain many of the gross features of the nucleus, like the valley of stability in the chart of nuclides. Bohr and Wheeler [2,3] further developed this explanation and applied it to nuclear fission, introducing terms like fissility and the fission barrier. The fissile is a representation of the competition between the repulsive and attractive forces between the nucleons. It is mathematically defined as the ratio of the Coulomb to surface energy in a nucleus $EC/2ES \propto Z^2/A$, and measures the tendency of the system to fission.

The fission barrier is defined as the potential energy effective along the most favorable deformation path to fission of a compound system. The barrier can be illustrated by plotting the deformation energy as a function of deformation (see Fig.1. 2). The ground state lies in a potential well delimited by the fission barrier. If a nucleus manages to get past the barrier and reach a sufficiently high deformation, it scissions. If the barrier is thin enough, the state might tunnel through it, in which case the system is said to be unstable against spontaneous fission. By adding excitation energy, fission of a heavy nucleus can be induced. The height and width of the fission barrier decreases with increased Fissile.

1.2.3 Spontaneous Fission of ^{252}Cf

Spontaneous fission is a process in which a single heavy nucleus splits into two or more smaller fragments without any external influence. The process occurs mainly in heavy nuclei and is the direct result of competition between the attractive nuclear force, which holds nucleons in the nuclei, and the Coulomb repulsion which drive the protons apart. For light nuclei, the strong nuclear force is easily able to overcome the Coulomb force. However, since the Coulomb force is repulsive, with more and more protons inside, the nucleus becomes more instable. The energy to hold a ^{252}Cf nucleus together, the binding energy, is approximately the difference between the measured mass of ^{252}Cf and the total mass of 98 protons and 154 neutrons, which is approximately 1800 MeV. The binary fission of ^{252}Cf is able to liberate ~200 MeV of nuclear energy and is therefore an energetically feasible means of de-excitation. Despite spontaneous fission, α decay is the predominately-favored decay mechanism for most heavy nuclei. The α decay process liberates ≈ 6 MeV of internal energy. Alpha decay is favored because the Coulomb barrier opposing the binary fission of ^{252}Cf into two 126 in nuclei is around

$$V(SF) = 1/4\pi\varepsilon_\circ Z_1 Z_2 e^2/(R_1 + R_2) \approx 275MeV \quad (1)$$

Assuming that the nuclear radius R = 1.25A1/3 fm, whereas the Coulomb barrier for the production of an α particle and a ^{248}Cm nucleus is V (α) ≈ 35MeV.

Right after the splitting of the parent nucleus, the primary fission fragments evaporate some number of neutrons, on the average of four for spontaneous fission of ^{252}Cf [11].

These secondary fragments are usually in very excited states and promptly emit γ-rays. The first two stages occur very quickly, with most neutrons evaporated in 10^{-20} to 10^{-15} seconds. When neutron emission becomes energetically impossible, the process of γ-ray decay takes over. At this stage, the fragments are referred to as secondary fragments and the γ rays which they emit are known as prompt γ rays. The emission of these prompt γ-rays eventually leads to a ground-state whose lifetime (∼ second) is far greater than the time-scale of the fission process and is relatively considered to be stable. The radioactive secondary fragments subsequently undergo a series of β decays and these continue until the fragments transform themselves into more stable nuclei The production region of spontaneous fission consists of two distinct areas either side of the exceptional stable doubly-magic ^{132}Sn nucleus. Each binary fission event of ^{252}Cf therefore yield complimentary pairs of one heavy and one light fragment. Since individual protons are not emitted as fission fragments, the same pairs of isotopes are always produced together: ^{40}Zr with $^{\mathbf{58}}$Ce, ^{42}Mo with ^{56}Ba, $^{\mathbf{44}}$Ru with $^{\mathbf{54}}$Xe etc. Consequently, γ-rays emitted from each pair will be in coincidence with each other.

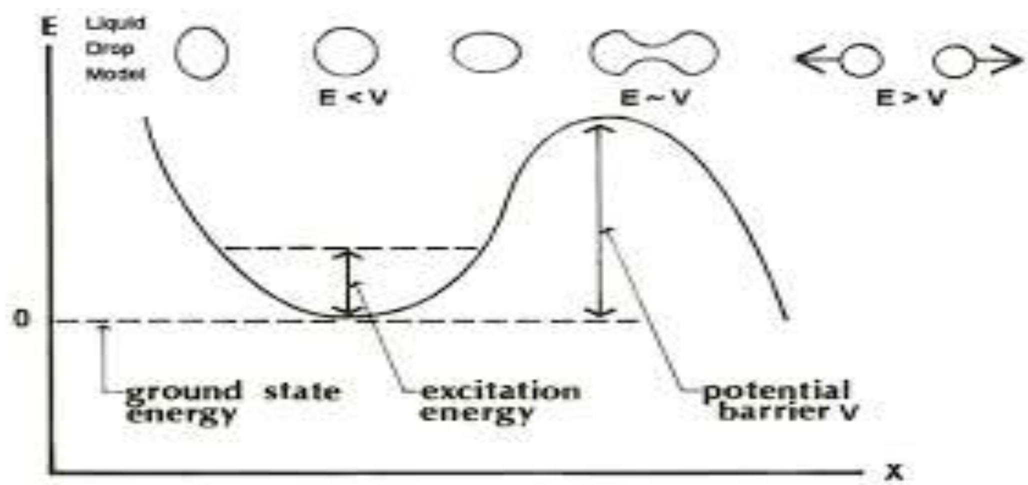

Fig. 1.2 Deformation energy as a function of deformation. The ground state lies in the well delimited by a potential barrier, the height of which is called the fission barrier. Corresponding shapes are shown qualitatively above the curve.

1.2.4 Ternary fission

Nuclear fission is usually a binary process, in the sense that two charged particles (the primary fragments) are formed from the fissioning nucleus. The possibility of ternary fission, in which three fragments are created, was proposed in 1941[12]. In 1946 it was found experimentally from tracks in nuclear emulsions photographs (see Fig 1. 3), and was confirmed in 1947 from measurements with ionization chambers[13]. Analysis of the tracks showed that two of the fragments are emitted with similar angles and masses as the light fragment (LF) and heavy fragment (HF) of binary fission. The third fragment, called the ternary particle (TP), is much lighter and emitted under roughly right angles to the fission axis. Due to this similarity, ternary fission is also known as light charged particle (LCP) accompanied fission.

Ternary fission occurs once every 250–500 fissions for the actinides and it occurs 25% more often in spontaneous fission than in fission of the same system induced by thermal neutron capture. Although rare, ternary fission is still of interest since it:

1. Serves as a probe of the nuclear fission mechanism, yielding information about the configuration and dynamics at scission.
2. Produces tritium, helium and hydrogen in nuclear reactors, and thus of interest to the nuclear industry.

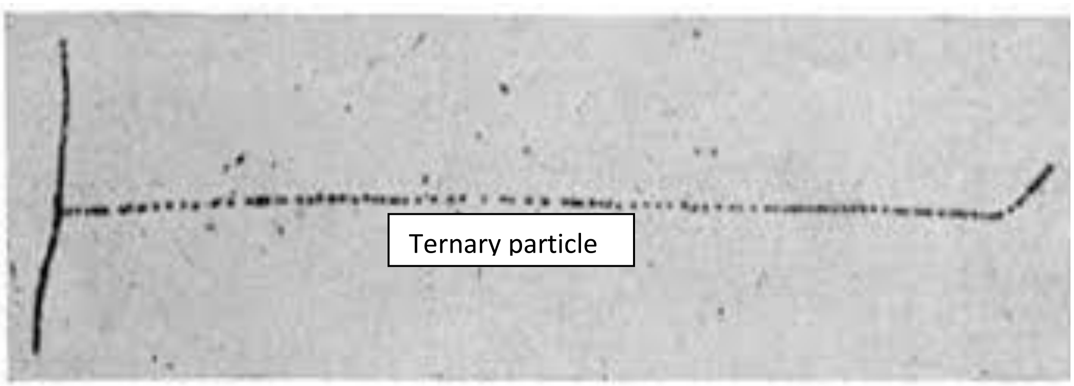

Fig1.3 Nuclear emulsion tracks of three fission fragments, marking the first experimental evidence of ternary fission. (Adapted from San-Tsiang et al.[31].)

1.2.5 Ternary fission theoretical models

Ternary fission is three-body decay, thus offering more degrees of freedom and a larger phase space than binary fission. As a result, the theoretical models of binary fission are insufficient at describing the physics of ternary fission. For example, the prerequisites of the liquid drop model and the shell-model are not met, since the surface to volume ratio is too large. The scission point model of Wilkins et al. [3,4] and the random neck rupture model of Brosa et al.[11] both fail to account for the formation of a ternary particle. There are numerous ternary fission models that account for this and several other aspects. A consistent model that combines all major aspects is however yet to be formulated, or one that can reproduce from first principle the energy distribution and individual yields of the ternary particles. A few key features of generally accepted models will now be presented. Reviews of individual theoretical models can be found in Wagemans [12], K¨oster , and in B¨orner, G¨onnenwein, and Zimmer[13]. Most models are based on the premise that the ratio of ternary to binary events is governed by a factor exp(−EC/T), where EC is seen as the energy cost of emitting a ternary particle, and T parameter describing how easily scission configurations that are energetically unfavorable can be accessed. The models use different geometrical configurations at scission, and interpret the parameter T differently (basically arguing if it represents a "nuclear temperature" or not). The geometrical parameters differ slightly between the models, and they are obtained by doing trajectory calculations which are fitted to experimental results. Most models agree on how ternary fission is formed. The fissioning system is deformed into an elongated prolate shape as it makes it saddle-to-scission transition. As the system is deformed, the shape becomes unstable, and a ternary particle is formed between a light and a heavy fragment as a result of two random neck ruptures.

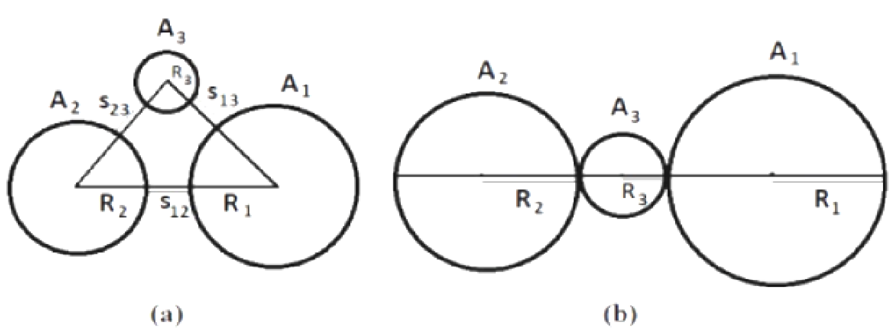

Fig.1.4 Generalization of most ternary fission models scission configuration

1.2.6 True ternary fission and collinear cluster tri-partition

Theories have long suggested the existence of so-called true ternary fission, in which all three fragments have a similar mass. Experimentally, only upper limits exist in low-energy fission [8, 9], of less than 10^{-8} to 10^{-11} events per fission. These experiments were designed to search for ternary particles emitted with angles $0^\circ < \theta < 180^\circ$ relative to the light fragment direction. A publication [14] from the FOBOS collaboration argued that these experiments could have failed to detect true ternary fission events if the three particles were emitted perfectly collinear, along the same fission axis. Such a configuration was dubbed Collinear Cluster Tri-partition (CCT). In practice such decay is more diffcult to detect, since two fragments entering a detector collinearly could be detected as a sum event that is interpreted as a single heavy fragment. In 2010, the FOBOS collaboration reported the observation of CCT with ternary particles of masses A > 30 and high yields of about 0.5% per fission in both $^{235}U(n_{th},f)$ and $^{252}Cf(sf)$ [10]. Since then, several theoretical papers have tried to explain the observation [12, 13, 14, 15], but the experimental results themselves are yet to be verified independently. An experiment with a similar setup reported a non-observation of CCT in 1999[16].

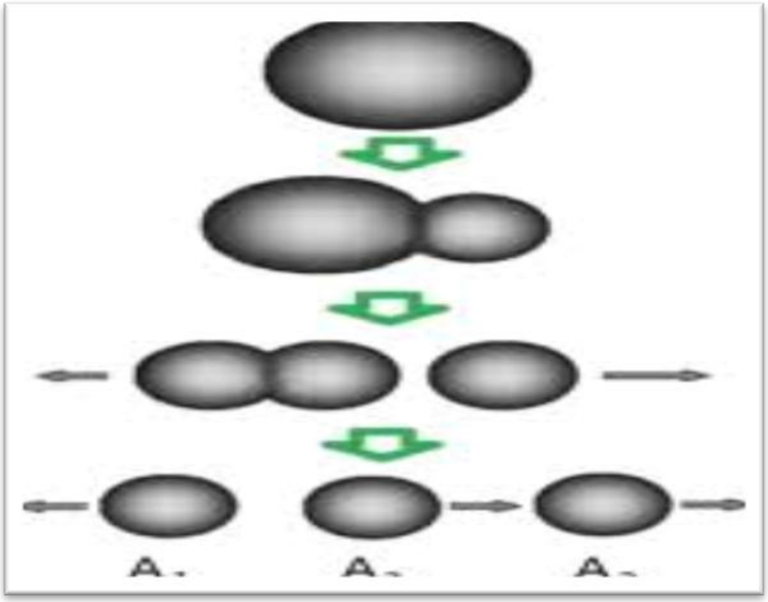

Fig 1.5 true ternary fission

1.3 Rare modes in the spontaneous fission of ^{252}Cf

Californium 252 a man-made trans-uranic element, having an alpha-particle half life of 2.2 Yr. undergoes spontaneous fission. Approximately one fission occurs per 38 α particles, [17, 18] and the material is therefore well suited to an investigation of the possibility of rare modes of spontaneous fission. Two rare fission modes have been established in one the emitted particle, is long range and uniquely α- particle, in the other, short range particles, apparently light elements appear to be emitted in the process which comparable masses.

Observation of quaternary fission of californium was claimed in the emulsion plates.

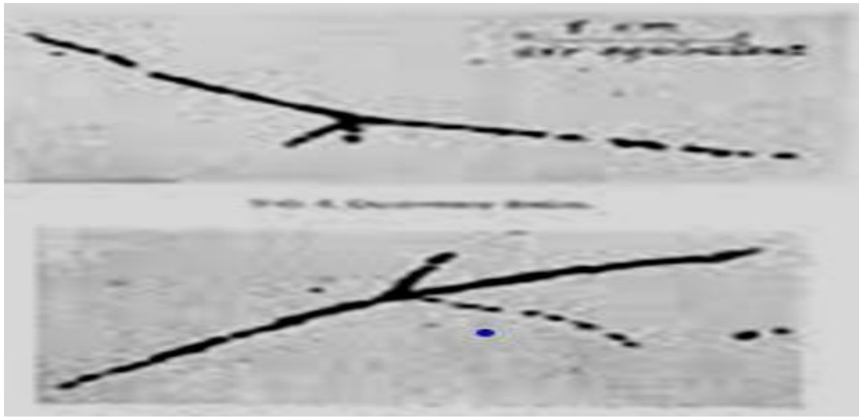

Fig 1.5 quaternary fission example in ^{252}Cf

1.4 ^{135}Xe production from ^{252}Cf

The presence of ^{135}Xe is often used as an indicator that fission has occurred, ^{135}Xe is a good indicator that fission has occurred and is a valuable isotope used to help enforce the Comprehensive Test Ban Treaty. Due to its rather short half life and minimal commercial interest, there are few ways that ^{135}Xe can be purchased. Currently, calibration standards can be purchased from the University of Texas1. These standards are made by the neutron irradiation of stable Xe gas. As such they contain significant quantities of Xe carrier. Readily available carrier-free standards of this isotope with other radioactive xenon isotopes would be very useful for calibrating collection and analytical techniques. ^{135}Xe can be produced in the fissioning of actinide isotopes, or by neutron capture on ^{134}Xe. Since the neutron capture cross section of ^{134}Xe is only about 265 milli-barns, neutron capture is a low yield, though useful, production route. ^{135}Xe has a half life (t½) of 9.14 hr; its cumulative yields from both thermal and fast neutron fission of ^{235}U and ^{239}Pu are 6.54%, 5.67% and 7.61 %, 6.18%, respectively. Its build-up is significant in clad reactor fuel. This buildup is the cause of "Xe poisoning" in nuclear reactors since it continues to increase once fission has stopped due to the 6.57 hr half-life of the parent ^{135}I. ^{135}Xe also has one of the highest thermal neutron capture cross-sections of any isotope (approximately 2.6 x 106 b) and neutron capture reactions over longer irradiation times significantly deplete the ^{135}Xe isotope. ^{135}Xe could be best produced in a high flux reactor or a fast reactor where ^{135}Xe neutron absorption cross sections are negligible. ^{135}Xe is also produced by spontaneous fission of ^{252}Cf.

^{252}Cf has a spontaneous fission rate of about 6 x 10^{11} s^{1} g^{-1}. The cumulative yield of ^{135}Xe from the spontaneous fission of ^{252}Cf is 4.19%; and the competing neutron capture reaction that depletes ^{135}Xe in thermal reactor systems is negligible because the neutron capture cross section is low for fast fission neutrons. At the INL, scientists have previously transported fission products from an electroplated ^{252}Cf thin source for the measurement of nuclear data of short-lived fission products using a technique called He-Jet collection2 .

The thin film of californium provided a near 2-Pi geometry; that coupled with the thinness of the film maximized fission product release into the “jet” atmosphere. A nickel foil was used to segregate high energy ejected fission products that are not stopped in the foil from the ^{252}Cf particles that ablate from the surface of the Cf film due to fission. A slow helium purge loaded with NaCl aerosols was used to transport fission fragments. In order to validate the idea of fission product collection, an aluminum foil was placed over a 2.07 x 105 Bq (10.0 ng) ^{252}Cf source that was dried (not electroplated) and after 26 days, the Al foil was repetitively gamma-ray counted using an HPGe detector. The two peaks identified are from ^{135}Xe. As a next step, a 2 mg ^{252}Cf source (approximately 1200 fissions/second) was electroplated in order to study both the transmission of fission fragments through various foils and the capture of fission fragments [19].

1.5 Clusterization in Ternary Fission

1.5.1 Searching for New Ternary Decay

The observation of a new kind of ternary decay of low-excited heavy nuclei. This decay mode has been called by us "collinear cluster tri-partition" (CCT) in view of the observed features of the effect, that the decay partners fly apart almost collinearly and at least one of them has magic nucleon composition. CCT is observed together with conventional binary and ternary fission. It could be one of the rare fission modes, but at the moment this assumption is not an established fact. For instance, many years have passed between the experimental discovery of the heavy ion radioactivity and working out of a recognized theory of the process.

Nuclear fission, a process where a heavy nucleus decays into two fragments of intermediate mass (e.g. Ba + Kr) has been identified by Hahn and Strassmann in 1938. It was discovered by chemical analysis while irradiating natural Uranium with thermal neutrons [20]. Shortly afterwards Petrzhak and Flerov [21] observed spontaneous fission of the ^{238}u isotope. The energy release in the fission process was immediately calculated by all leading physicists at that time to be very large, typically 200-205 MeV (e.g. Meitner and Frisch [22]). The large value is due to the larger binding energy per nucleon *(Es/ N)* in the mass range around mass $A = 54$ (iron, EB/ N = 8.2 MeV), as compared to the value at the end of the periodic table, *(E s / N* = 7.2 MeV). This fact could have been noticed four years before these discoveries, because of the existence of the liquid drop model and the nuclear mass formula of Bethe and Weizsacker [23].

However, the large collective motion through a large deformation (today called super-deformation) was considered to be unlikely Fission of heavy low-excited nuclei into three fragments of comparable masses, so called "true ternary fission", has been intensively investigated soon after the discovery of fission. Swiatecki [24] has shown within the framework of the liquid- drop model (LDM) that fission into three heavy fragments is energetically more favourable than binary fission for all nuclei with fisslity parameters $30.5 < Z^2/A < 43.3$. On the basis of a modified liquid-drop model that takes into account the finite range of the nuclear forces the macroscopic potential energy maps for symmetric systems of interest were calculated [25].

These maps demonstrate many important features of the potential energy landscape, including the heights and locations of the binary, ternary, and quaternary fission saddle points. In 1963 Strutinsky [26] has cal- culated the equilibrium shapes of the fissioning nucleus and has shown, that along with the ordinary configuration with one neck, there is the possibility of more complicated elongated configurations with two and even three necks, at the same time it was stressed, that such configurations are much less probable. Later Diehl and Greiner [27, 28] have shown a preference for probate over oblate saddle-point shapes for the fission of a nucleus into three fragments of similar size. Such pre-scission configurations could lead to almost collinear separation of the decay partners, at least in a sequential fission process. Actually the Coulomb interaction in the total potential energy is the smallest for linear arrangements of the three fragments. Ternary potential barriers as a function of the distance between the mass centers of the fragments were calculated in Ref. [29].

In the ternary fission path, the isomeric states corresponding to elongated and compact shapes were predicted for heavy systems. Investigating ternary fission of the system $^{235}U + ^{238}U$ the authors of [30] came to conclusion that binary fission is much more probable than ternary fission even among very heavy compound nuclei. The reasons for this are that the LDM potential for ternary fission turns out to be higher than that for binary fission at large deformations and that the formation and rupture of necks for binary fission occur much earlier in the fission process than for ternary fission. However, it was emphasized that very strong shell effects might also lead to earlier ternary neck formation during fission. Results demonstrating a decisive role of shell effects in the formation of the multi-body chain-like nuclear molecules were obtained by Poenaru et al. [31].

We want to refer as well on very recent theoretical articles, devoted to unusual ternary decays of heavy nuclei including CCT [32-35]. The authors analyze the potential energy of different pre-scission configurations leading to ternary decays, and the kinetic energies of the CCT partners [33] are calculated for a sequential decay process. These results, being strongly model dependent can be considered as only the first step in the description of the CCT process. On the experimental side there have been multiple attempts to find the true ternary fission in low energy fission by means of counting techniques and radiochemical studies. The schemes of the spectrometric experiments were based on the assumption of comparable angles between all three fragments emitted [36,37]. Masses of the fragments were calculated in this case based on experimental values of the energies and angles. Contradictory results have been obtained; these were treated as showing the absence of fission fragments in the vicinity of mass fifty both in binary and ternary fission [32]. The latest attempt to find very specific ternary decay mode similar to the CCT in ^{252}Cf nucleuses is reported in series of works [34, 38-40].

Spontaneous cold ternary decay showing the nuclei of ^{96}S r, ^{146} Ba and ^{10} Be in the exit channel was searched for. The experiment was carried out at the Gamma sphere and gamma-gamma coincidences were analyzed. At the first stage of the work the authors came to conclusion that ^{10}s e nucleus stays at rest after fission but later this conclusion was not confirmed. At the same time almost collinear ternary decays of excited heavy nuclear systems were known from the experiments in Refs. [41] at the early stage of our work. In the highly excited nuclear systems produced by the nucleus- nucleus collisions in the intermediate energy domain (20- 100 MeV/n) the binary fission remains an important exit channel. Nevertheless, the ternary, quaternary, quandary decay has been observed [42, 43]. The interpretation of this multi-fragment production is still elusive, but all the models put forward so far (dynamically induced density fluctuations, expansion of an initially compressed source, statistical decay and so on) are valid exclusively for hot nuclear matter at the excitations far beyond the region where shell effects manifest themselves.

As was mentioned above, at least one of the CCT products has magic nucleon composition. Shell effects give rise also to two well-known binary decay modes: namely, cluster radioactivity and cold fission. Evident and deep link between all three processes demands to remind briefly the main features of these binary decays. Cluster radioactivity as a rare spontaneous decay mode of heavy nuclei has been intensively studied in recent years. In this type of radioactivity any emitted nuclear species with masses heavier than $A = 4$ (α -particles) and lighter than A = 60 (fission fragments) are called "clusters". The heavy fragments are grouped in the vicinity of the double magic ^{208}Pb, and this allows speaking about the known domain of cluster decay as “lead radioactivity". This type of radioactivity is far from being unique. Many other combinations of daughter nuclei are allowed energetically to be emitted; they include the formation of the products of comparable masses. This process is known as cold fission. However, cluster radioactivity is a very rare process: the observed partial life times lie in the interval 10^{11} - 10^{27} s. This is corresponds to a branching ratio relative to 10^{-10} - 10^{-17} for those α -decays.

In a11 known cases, except for one, the products of cluster radioactivity are formed in their ground states. From this point of view cluster radioactivity is much closer to alpha-decay than to spontaneous fission, the process in which the both fragments are deformed and strongly excited. For this reason correct comparison of both processes can be done only if cold fission is meant because here the fragments are formed in their ground or low-lying excited states. However, cold spontaneous fission itself is studied even worse than cluster radioactivity. The question of what is the mechanism of cluster radioactivity and whether it resembles either a-decay or fission was widely discussed.

The authors of [44] made a survey of mass distributions of cold decays for a series of nuclei and drew some conclusions. Cold decays are distributed over the whole available range of masses. The phenomenon known today as "cluster radioactivity" is only a particular case of their more general family. It is not distinguished neither by L denature of its origin, nor by its probability in comparison with the other modes. One can speak about "lead", "tin" and "calcium" activities depending on L be vicinity of Z- and N-values to the corresponding magic numbers. The most wide- spread activity is the "tin" one due to the fact that the ratio 82/50 is close to the average *N* /Z ratio of the decaying parent nuclei (this provides on the average L be maximum Q-value). "Tin" activity d rifts from very asymmetric one in the parent mass region *A* ~ 150 to symmetric fission for ^{264}Fm. Another source of enhancement of the decay probability is the formation of fragments having prolate static deformations. Orientation of the big axis along the direction of movement results in lowering of Coulomb barrier and diminishing the path under it. As a result, the authors conclude that one cannot distinguish between cold fission and different types of cluster radioactivity. However, the dynamics of fragment formation in different parts of mass spectra can be different. Alpha-radioactivity and fission usually are described by completely different formalism reflecting a different physical picture of what happens, and these extremes are applied to the descript ion of cluster radioactivity.

Alpha-decay is considered to be a non-adiabatic process. It means a sudden formation of a cluster inside the mother nucleus which then makes attempts to penetrate the barrier. The fission- like process, on the contrary, is described as an adiabatic one. It includes the pre-scission phase where the matter now takes place and fragments are overlapping. Their final format ion happens only after the system goes through a sequence of geo metrical shapes whose parameterization is a pa11of the adopted Theo- recital approach. The existing data and theoretical calculations indicate that cluster (at least "lead") radioactivity and cold fission have different mechanisms, probable non-adiabatic and adiabatic correspondingly. The transition between both mechanisms takes place at the fragment masses in the vicinity *A*= 35.

We would like to emphasize, that at the early stage of our work the process of "true ternary fission" (fission of the nucleus into three fragments of comparable masses) was considered to be undiscovered for low excited heavy nuclei [45]. Another possible prototype--three body cluster radioactivity- was also unknown. The most closest process to the CCT phenomenon, at least cinematically, is the so called " polar emission" [46], but only very light ions (up to isotopes of Be) have been observed so far. In the analysis of the experiments devoted to the " polar emission", we came to the conclusion that typical CCT fragments could not be detected in the cited works [47]. In fact, *dE-E* telescopes (energy-loss, energy) were used to stop the fission fragments (FFs) in the dE-detector located on the path of the light charged particles (LCP) flying in the same direction (polar LCP). At the same time this detector must be thin enough to be trans parent for the LCP under study. The thickness of the dE-detectors, chosen as a com- promise, puts a boundary for the mass/charge of the LCP, which could be detected.

Bearing in mind both theoretical and experimental results mentioned above, we came to the conclusion, that collinear tri-partition of low-excited heavy nuclear systems would be a promising field of research. In our first experiments dedicated to this problem [48, 50] some indications of such processes were already observed. At least one of the decay products detected was a magic nucleus. By analogy with known cluster decay (or lead radioactivity), the process has been called "collinear cluster tri-partition" (CCT).

1.6 Purpose and scope of the thesis

Nuclear physics is an important field in many aspects. Without the nuclear reactions in the sun, there would be no life on earth. Nuclear fission provides our society with electricity, with steady and reliable neutron sources for probing the inner structure of matter, and with medical treatment and diagnostics, just to mention a few applications. Better knowledge of the nuclear fission mechanism is therefore required to better understand the world that we live in. This knowledge also has direct technical applications in society, and is essential for building safer and cleaner nuclear reactors. Just recently, several groups in the NEA (Nuclear Energy Agency) discussed how to reduce nuclear physics uncertainties in fission product yields to the sub-percent level. Therefore, verifying or refuting the 0.5% effect interpreted as CCT is very important in many aspects.

This thesis reports on 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 ^{252}Cf source was initiated. A planar event containing nothing but fragment triples were found and studied by using a computational method 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.

2.1. Introduction

Nuclear emulsion is considered one of the oldest ways to record the nuclear events resulting from the nuclear processes that occur inside the nucleus, as it has proven its efficiency in preserving these nuclear events and studying them, especially the products of the rare fission process.

In particle and nuclear physics, a **nuclear emulsion plate** is a photographic plate with a particularly thick emulsion layer and with a very uniform grain size. Like bubble chambers, cloud chambers, and wire chambers nuclear emulsion plates record the tracks of charged particles passing through. They are compact, have high density and produce a cumulative record, but have the disadvantage that the plates must be developed before the tracks can be observed.

Nuclear emulsions can be used to record and investigate fast charged particles like nucleons or mesons. After exposing and developing the plate, single particle tracks can be observed and measured using a microscope.

Using nuclear emulsions exposed on high mountains, Cecil Frank Powell and colleagues discovered the charged pion in 1947.[51] This discovery won them a Nobel Prize in Physics in 1950. [52, 53]

Nuclear photographic or nuclear Emulsion, radiation detector generally in the form of a glass plate thinly coated with a transparent medium containing a silver halide compound. Passage of charged subatomic particles is recorded in the emulsion in the same way that ordinary black and white photographic film records a picture. After photographic developing, a permanent record of the paths of the charged particles remains and may be observed through a microscope.

Radioactivity was discovered in 1896 by its effect on a photographic plate, and nuclear emulsions later played a pivotal role in cosmic ray research for example, in the discovery of the pion in 1947[54,55,56]. Emulsions continue to be useful in the study of the production and decay of short-lived particles produced in high energy particle physics experiments.

2.2. Nuclear Track Emulsion (NTE)

2.2.1. Tasks for Emulsion

Much of effort of modern experimental physics is devoted to bring within man's ken the invisible, inaudible, and otherwise unsensed world of atomic and subatomic processes[57].

Silver halide emulsion of the type used for registering the tracks of charged particles consists of about equal parts of volume of halide crystals, a few tenth of micron in diameter, and a matrix material which is chiefly gelatin, the gelatin is transparent with the microscope the paths of charged particles that penetrated the emulsion are visible as trails of minute silver grains under the microscope. A true three dimensional image of particles is produced of the paths, outlined by silver, literally exist in space.

2.2.2. General Description of (NTE)

The emulsion consist of an inorganic component, silver halide microcrystal, and usually about an equal volume of gel phase consisting mainly of gelatin with a variable quantity of water and small amounts of glycerol, sensitizer, and possibly other substances. The equilibrium water content depends on the relative humidity and temperature of the air in contact with the emulsion.

The silver halide is usually in the form of silver bromide crystals with small amount of iodine in the crystal lattice, but other types of silver halide emulsions can been used.

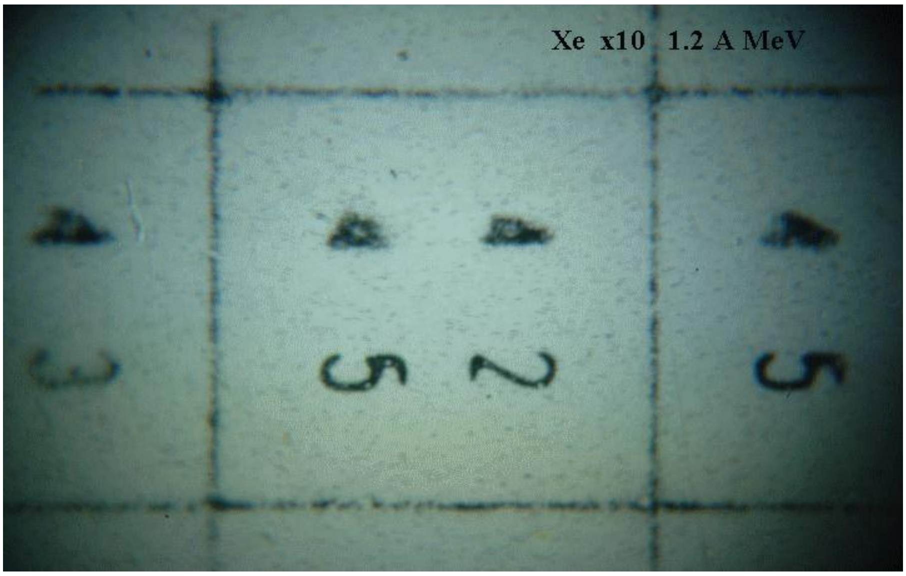

Fig. 2.1. Emulsion surface with numbers marks.

2.3 Experimental facilities

2.3.1 Exposure to ^{252}Cf source

In the present work, Surface exposures of NTE samples 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. ^{252}Cf isotope also undergoes a spontaneous fission to a pair or even triple of fragments with probabilities of 3%, and about 0.1%, respectively. only two ternary fission fragment can be observed on the exposure surface 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. [58,59,60]

In the present work we used a ^{252} **Cf** source activity 0.2806 μCi in june 2005from isotope product laboratory.

In figure 2.2 we can used the manual way to irradiate the NTE samples by moving the source from right to left side and then move down and repeat this step to finish the sample. Surface exposures of NTE samples started in department of radiation dosimetry (DRD) were performed.

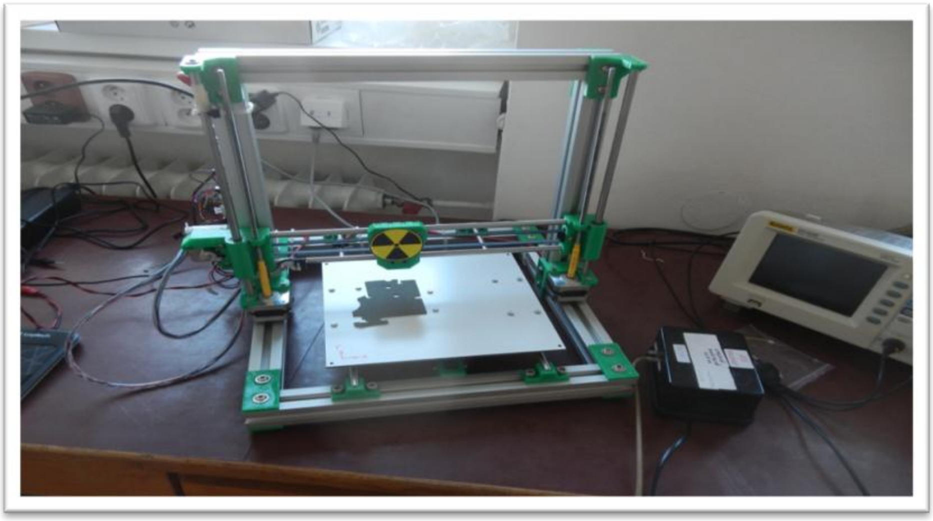

Fig.2.2 DSCN0897 irradiation tools used in irradiate the NET samples.

2.3.2 Observation tools

- **Area scanning microscope (HSP-100)**

The scanning microscope used in search the triple events from the fission and locates its position with a camera to take photos of the tracks.

This microscope in figure 2.3 can search a large area of the samples which can saves time and efforts. The camera can take a photos of tracks to hold it and can measured range of tracks from the photos by image J program.

Fig. 2.3. area scanning microscope (HSP 1000)

- **Along track microscope (KSM)**

This microscope is very useful in measuring the parameters such as range, depth and locate the track from its principles axes because this microscope is very accurate with accuracy about 0.1.

It can rotate with 360 degree which help us to measure the parameters easily and more accurate. Figure 2.4 show this microscope which is manufactured by the emulsion lap in the institute of nuclear research in Dubna.

Fig .2.4 along track microscope

(KSM microscope)

Californium is a synthetic radioactive chemical element used in nuclear fusion. Californium is known to be one of the most expensive materials on the earth due to its cost

Californium-252, with its half-life of approximately 2.6 years, is a strong neutron emitter. It can be used to start up nuclear reactors and to treat cancer. The neutrons can pass through materials, and so californium-252 can be used to detect gold and silver, landmines in war zones, and bombs in luggage.[61,62]

2.4. Physical properties of Californium

Is a silvery white actinide metal with a melting point of 900 ± 30 °C (1,650 ± 50 °F) and an estimated boiling point of 1,745 K (1,470 °C; 2,680 °F). The pure metal is malleable and is easily cut with a razor blade.[63]

It is being used as a neutron source to identify gold and silver ores through a technique known as neutron activation. It is also being used in devices known as neutron moisture gauges that are used to find water and oil bearing layers in oil wells. A few compounds of californium have been produced and studied.

Californium is a radioactive chemical element with atomic number 98. The element was first synthesized in 1950 at the Lawrence Berkeley National Laboratory (then the University of California Radiation Laboratory), by bombarding curium with alpha particles (helium-4 ions). It is an actinide element, the sixth trans uranium element to be synthesized, and has the second highest atomic mass of all the elements that have been produced in amounts large enough to see with the unaided eye (after einsteinium).[64,65] The element was named after the university and the state of California.

In this work we used the image j program to study the photos of ^{252}Cf ternary fission.

2.5. Experiment

in this work calibration by alpha and heavy ions have done and make some measurements (range, energy, angles and depth of the track produced from ternary fission with two modes (long range alpha with two heavy ions – three heavy ions) which explained in details in chapter three.

Using C++ language, we make a program used in calculations and graph (ROOT program) showed in the appendix . in this experiment we cannot identify the fragments produced from the ternary fission by this technique but it is very useful in previous measurements and more accurate comparing to another techniques. There is no ultimate technique able to answer all questions.

Image J is a Java-based image processing program developed at the National Institutes of Health and the Laboratory for Optics and Computational Instrumentation (LOCI, University of Wisconsin).[66,67,68] Its first version, ImageJ 1.x, is developed in the public domain, while ImageJ2 and the related projects SciJava, ImgLib2, and SCIFIO are licensed with a permissive BSD-2 license. ImageJ was designed with an open architecture that provides extensibility via Java plugins and recordable macros.[69] Custom acquisition, analysis and processing plugins can be developed using ImageJ's built-in editor and a Java compiler. User-written plugins make it possible to solve many image processing and analysis problems.[70]

3.1. Introduction

Nuclear track emulsion (NTE) retains the status of a universal and inexpensive detector in spite of the fact that half a century passed since its development. With unsurpassed spatial resolution NTE provides complete observation of tracks starting from fission fragments and down to relativistic particles [71-73]. 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 sampling of hundreds of tracks which presents as a rule only a tiny fraction 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 the possibility of a collinear cluster tri-partition [74]. The existence of this phenomenon could be established in the observation of such a type of ternary fission of heavy nuclei in which a lighter fragment is emitted in the direction of one of the heavy fragments.

Despite distinct observability of fission fragments they cannot be 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 [75, 76].

A large-scale NTE scanning is suggested to be performed on the microscope HSP-1000 [77] of the Department of radiation dosimetry (DRD) of Nuclear Physics Institute. The use of the NTE resolution will be full if the microscope will be adapted to operate with lenses of the highest magnification. DevelOn 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

3.2. Calibration by α-particles

Production of NTE of the BR-2 type possessing sensitivity to relativistic particles lasted in Moscow for four decades and ended about ten years ago. The interest in its further application stimulated the production of NTE has started in the MICRON workshop that is part of the company "Slavich" (Pereslavl Zalessky) [78]. At present, samples are produced by NTE layers of thickness of 50 to 200 μm on glass substrates. Verification of the reproduced NTE in exposures to relativistic particles confirmed that it is similar to the BR-2 NTE. It was decided to demonstrate that NTE is competitive in experiments involving measurements of α-particle and heavy ion tracks on a KSM microscope with a 90× objective.

Correlation of α-particle triples were studied in disintegrations of carbon nuclei of NTE composition by 14.1 MeV neutrons [79]. When measuring decays of ^{8}He nuclei implanted in NTE the possibilities of α-spectrometry were verified [80-82]. The angular correlations of ^{7}Li and ^{4}He nuclei produced in disintegrations of boron nuclei by thermal neutrons n_{th} were studied in boron enriched NTE [83]. In this case a mean ^{7}Li range (at RMS) is equal to 3.1 ± 0.3 (0.8) μm at a mean thickness of 0.73 ± 0.02 (0.05) μm, and the ^{4}He one is 5.5 ± 0.5 (1.1) μm and 0.53 ± 0.01 (0.04) μm, respectively. In this series of exposures the angular resolution of NTE was confirmed to be perfect by expected physical effects which are manifested in the distributions of the opening angles distributions of the products of the studied reactions.

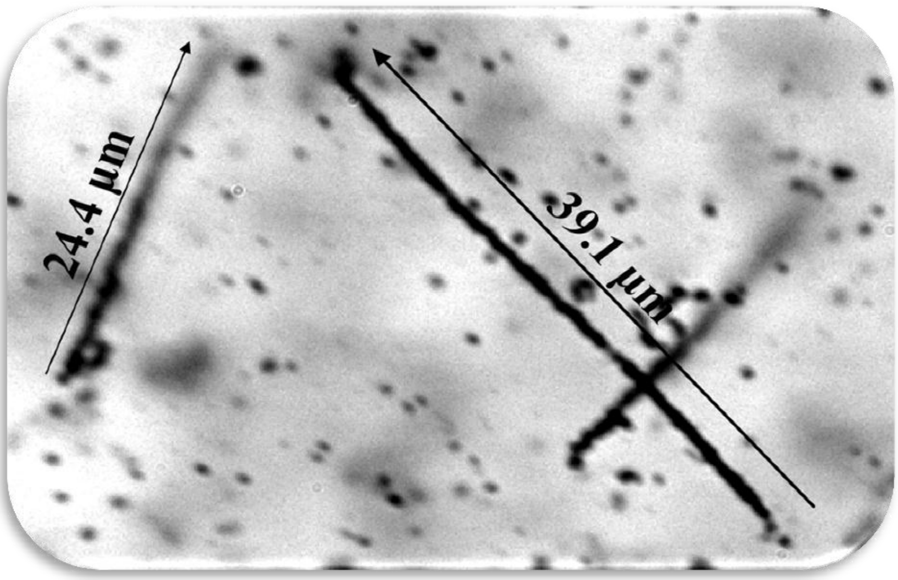

Fig.3.1. long range alpha track

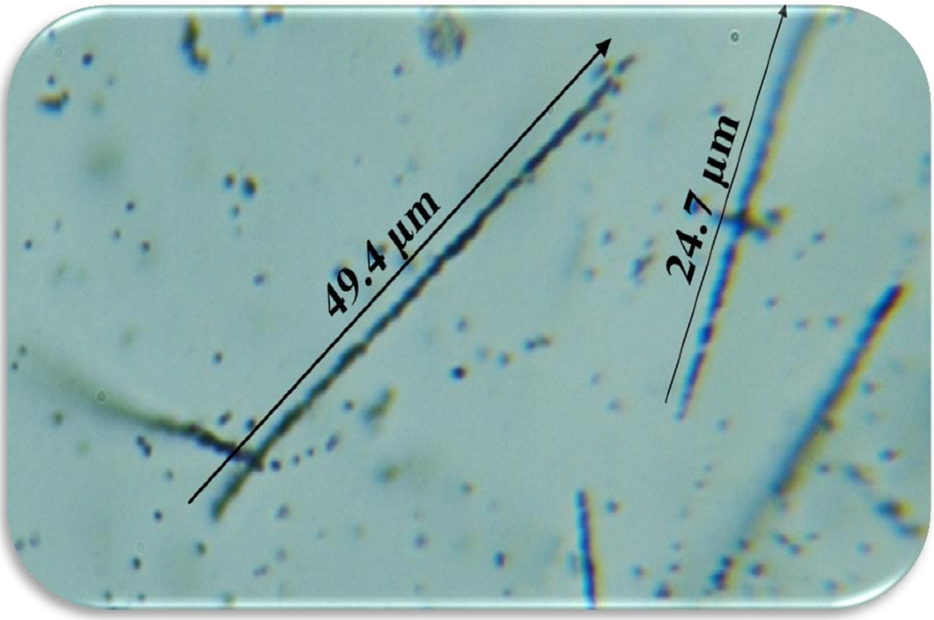

Fig.3.2. alpha track in emulsion plates with its ranges.

Most likely the ^{252}Cf isotope decays by emission of a sequential α-particle triple of energy of 5-6 MeV, the tracks of which mainly populate an exposed sample. 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.

In the case of a surface exposure there should not be observed more than two ternary fission fragments as the third one is emitted source 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. Fig.3.3 summarizes the measured α-particle ranges in the exposures listed above as well as their energy values calculated in the SRIM model [84]. Average values of ranges and energy are given in Table 1

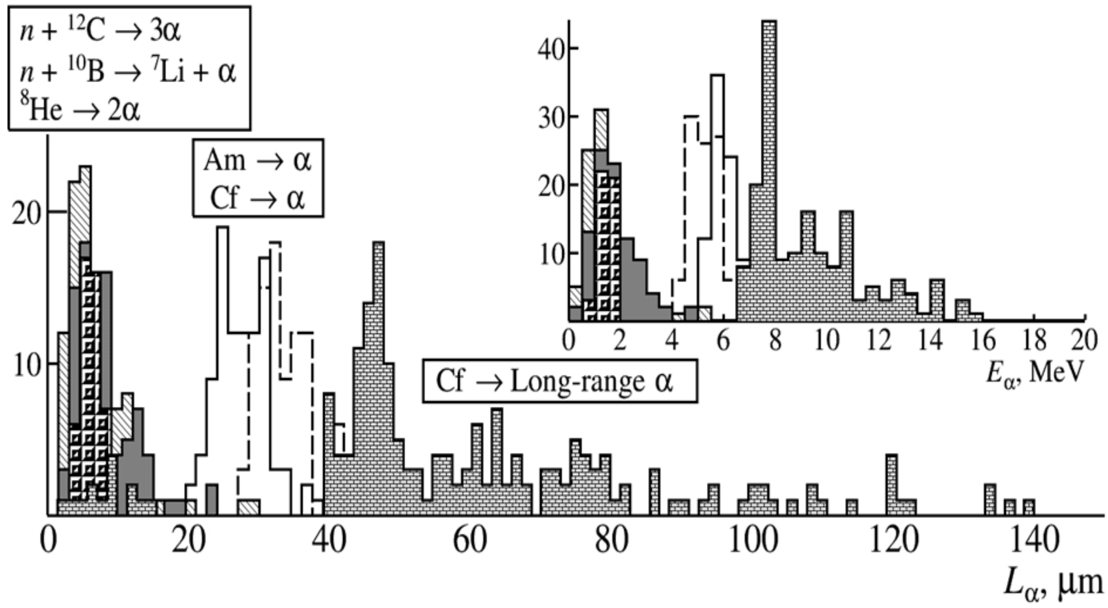

Fig.3.3. Distributions of α-particle ranges: n(14.1 MeV) + 12C → 3α (obliquely-shaded), 8He→ 2α (gray), nth + 10B → 7Li + α (black dot), Cf α (solid), Am α (dotted histogram), Cf long-range α (brick-shaded); the inset: corresponding of α-particle energy estimated via spline-interpolation of range-energy calculations in the SRIM model.

Table.1. Average values of ranges and energy of α-particles in the studied reactions and decays; values in parentheses are the RMS.

Reaction or Decay	Average Range, μm	Average Energy, MeV
n (14.1 MeV) + $^{12}C \rightarrow 3\alpha$	5.8 ± 0.2 (3.3)	1.9 ± 0.05 (0.9)
^{8}He (2β) → 2α	7.4 ± 0.2 (3.8)	1.7 ± 0.03 (0.8)
$n_{th} + {}^{10}B \rightarrow {}^{7}Li + \alpha$	5.5 ± 0.5 (1.1)	1.4 ± 0.5 (0.3)
$^{241}Am \rightarrow \alpha$	27.7 ± 0.4 (4.2)	4.9 ± 0.04 (0.4)
$^{252}Cf \rightarrow \alpha$	33.4 ± 0.6 (3.6)	5.3 ± 0.05 (0.5)
^{252}Cf → Long-range α	77.1 ± 4.6 (46.1)	10.3 ± 0.4 (3.8)

Table. 2. Mean values of ion ranges; values of RMS are in parentheses.

^{84}Kr (3 A MeV)	34.4 ± 0.3 (2.4)
$^{124}Xe^{+25}$ (1.2 A MeV)	20 ± 0.1 (1.0)
$^{86}Kr^{+17}$ (1.2 A MeV)	17 ± 0.2 (1.0)
^{252}Cf → three fragments	5.1 ± 0.3 (2.0)
^{252}Cf → 2 fragment+ long range alpha	9.1 ± 0.3(0.6) 13.1 ± 0.6 (1.1)

3.3. Calibration by heavy ions

NTE samples were exposed in the Flerov Laboratory of Nuclear Reactions, JINR at the IC-100 cyclotron to 1.2 *A* MeV $^{86}Kr^{+17}$ and $^{124}Xe^{+26}$ ions and at the U-400M cyclotron to 3 *A* MeV ^{86}Kr ions [85]. The exposures were performed under vacuum conditions of the accelerators and also without a light protective paper. Fixing of the samples in the exposure chambers was performed at a light which is ordinary for a photo lab. For track observation the samples were installed with a significant inclination with the respect to the beam directions. Track densities in NTE reached 10^6 nuclei per cm^2 for a few seconds of the sample exposures. Fig.3.4 shows the range distribution of no scattered ions. Their average values are presented in Table 2. These data provide guidelines for further NTE calibrations into smaller energy values that are typical for heavy nucleus fissions.

Range can be calculated from this relation:

$$L = \sqrt{(x^2 + y^2 + z^2)} - \Delta z \qquad (1)$$

Where Δz is shrinkage factor which can calculate from:

$$\Delta z = \text{thickness} / Z_{up} - Z_{down} \qquad (2)$$

We can calculate the opening angle between every two fragment from:

$$\text{Opening angel} = \cos\,(xy.yx / |x|.|y|\,) \qquad (3)$$

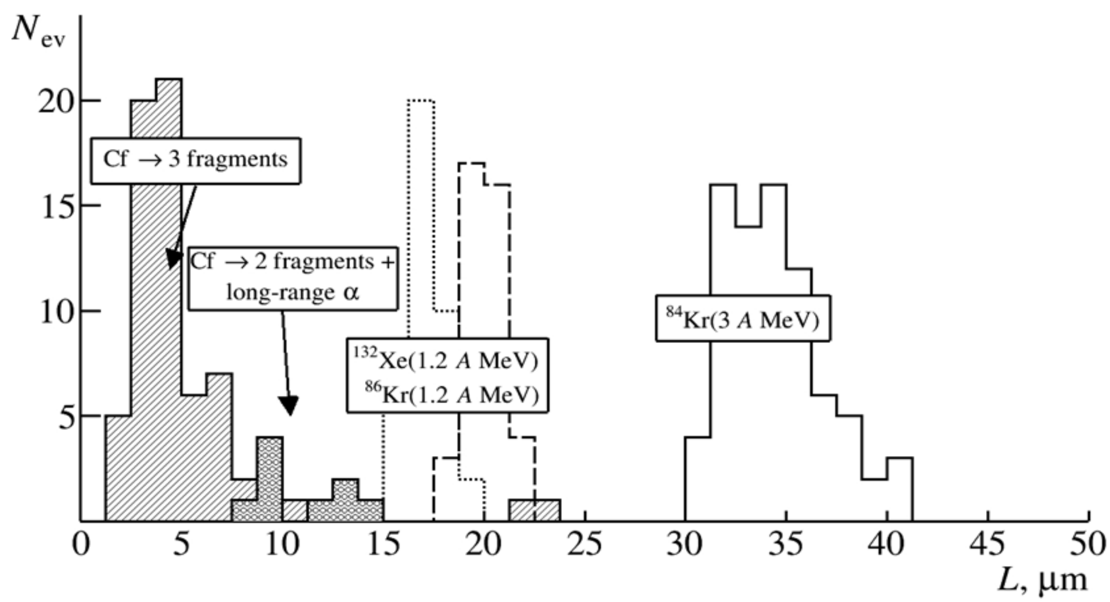

Fig.3.4.Distributions of ranges of ions 86Kr, 132Xe, 84Kr and in decays Cf → 3 fragments and Cf → 2 fragments + long-range α.

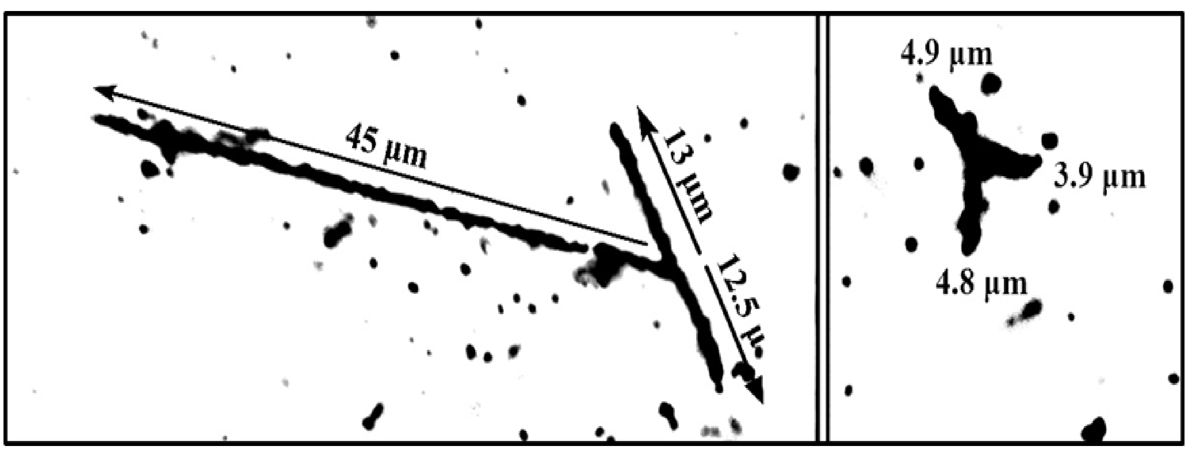

Fig. 3.5. Examples of observed events of ternary fission; track lengths are specified. Left photo: long-range α-particle (long arrow), fragment (middle arrow). Right photo: three fully observed fragment tracks.

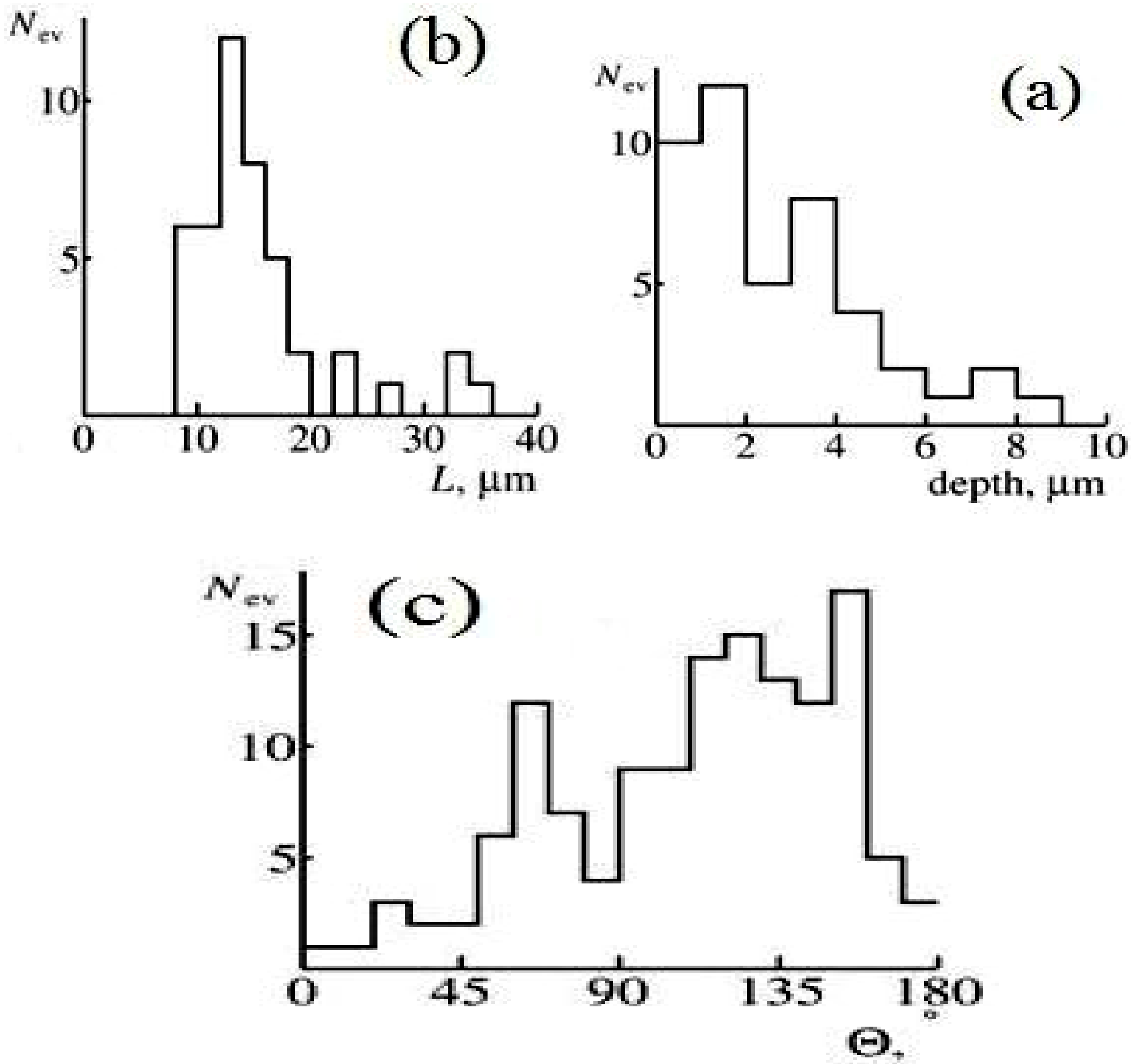

Fig. 3.6. Distributions for the ^{252}Cf fissions of vertices into three fragments over depth in NTE layer (a) total ranges of three fragments (b) and opening angles between fragments (c).

Deth can be calculated from that relation:

$$\text{Depth (dip)} = (Z_{up}\text{-}Z_{ver}) \,.\, \Delta z \quad (4)$$

The obvious equation used to calculate the dipping of ternary tracks.

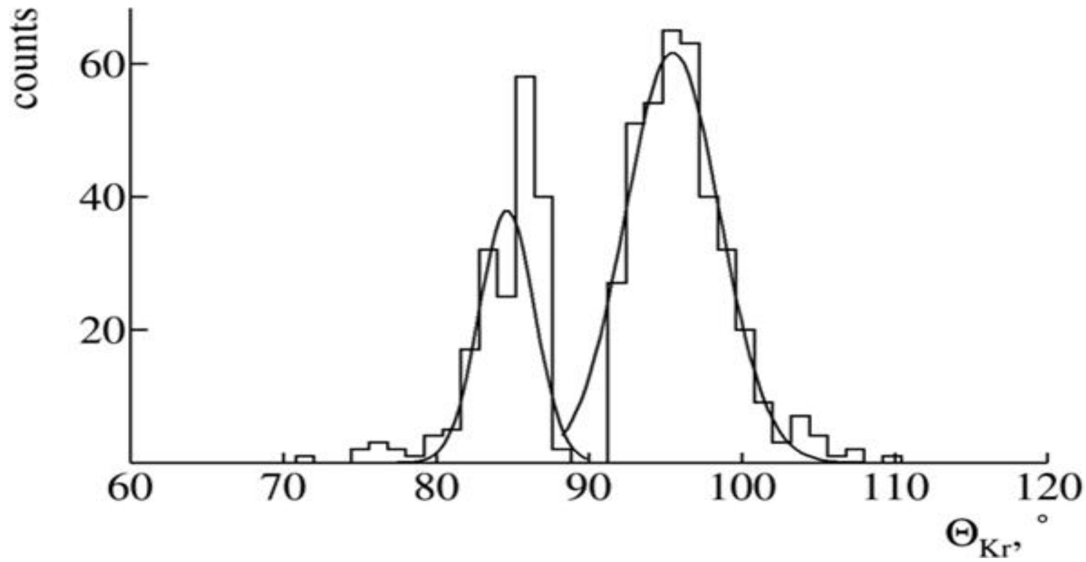

Figure 3.7.Distribution over planar angles of 3 A MeV ^{84}Kr ions.

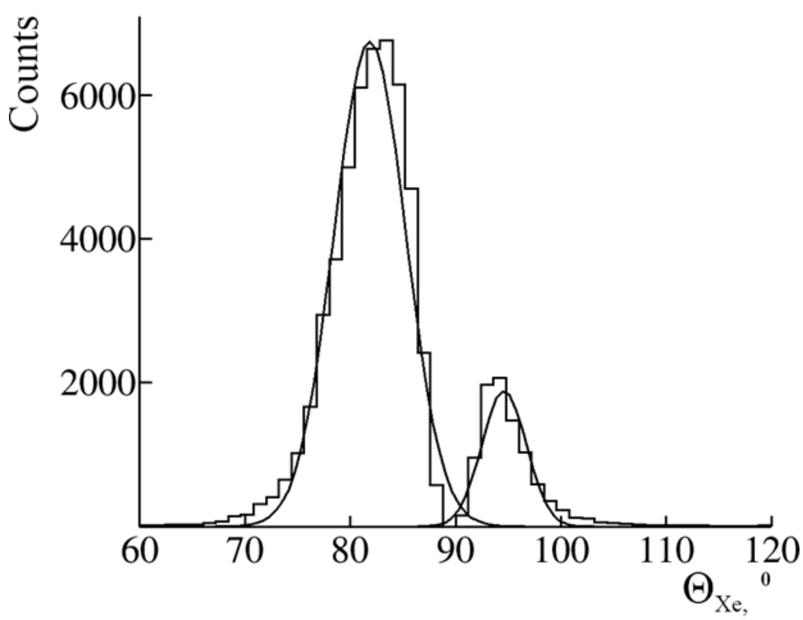

Fig. 3.8. Distribution over planar angles of 1.2 A MeV ^{132}Xe ions.

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 events are found consisting of a pair of fragments and a long-range α-particles and triples as well as consisting only of fragments. Their examples are given in Fig.3.5 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 a track triple its decay point should be dipped to a depth not less than a typical track thickness. Fig.3.6 (a) shows the distribution of vertices of ^{252}Cf fissions into three fragments over NTE layer depth which has an average value of 1.8 ± 0.2 μm (RMS equal to 1.4 μm). Perhaps this effect is due to the binding of ^{252}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 23 events of a true ternary fission, i. e., not containing α-particles the fragment ranges (Fig.3.5, right photo) are measured. Comparison of the mean values in Table 2 indicates that the average energy of fission fragments is of the order 400 *A* keV. However, this is a very rough estimate. Calibration of the ranges of heavy ions should be promoted substantially below 1 *A* MeV in controllable conditions provided by accelerators. Effective criteria for a fission into heavy fragments is their total range (Fig.3. 6(b)), which has an average value of 15.3 ± 1.4 μm when RMS 6.4 μm.

In addition, the opening angles between the fragments are measured in these events (Fig.3.6 (c)); their distribution is characterized by a mean value 116 ± 5^0 when RMS 36^0.

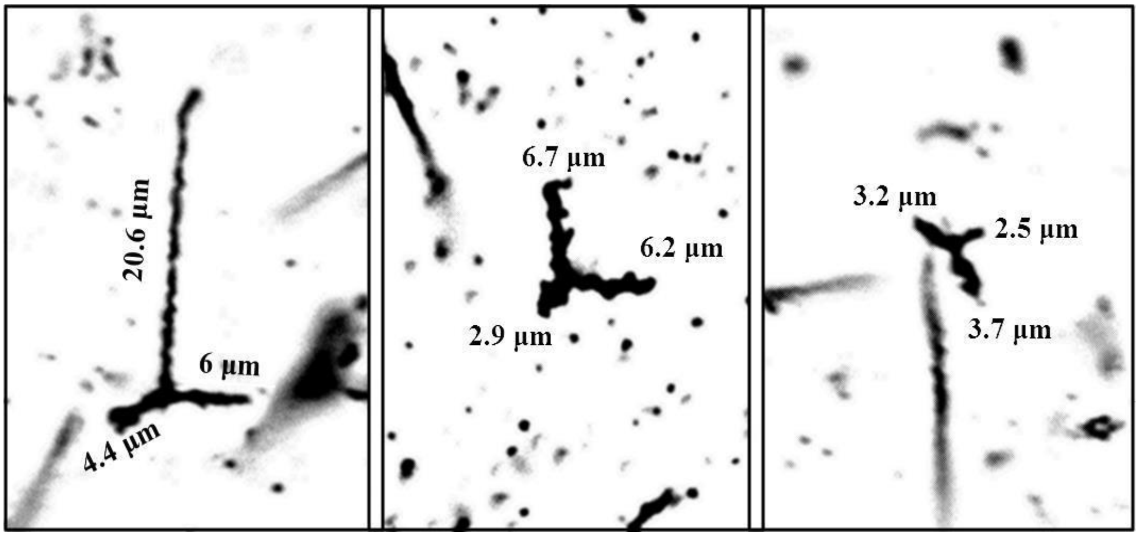

Fig. 3.9 . Examples of observed events of ternary fission; track lengths are specified. Left photo: long-range α-particle (long arrow), fragment (middle arrow). Mid and right photo: three fragment tracks.

3.4. Steps and experience of automatic measurements

The initial experience of a computer analysis of heavy ion tracks in NTE is obtained using the Image program [86], available online and a close-up of the NTE sample exposed at an angle of 45^0 to the $^{132}Xe^{+26}$ beam. Stages of such an analysis are shown in Fig 3.11. initial close-up shot via a NIKON camera D70 with 60× objective, track image findings, description of them as ellipses as well as determination of ion ranges in the computer (93 tracks) and manual analyses of non-scattered tracks (40 tracks). At coincidence of average ranges in a computer and manual analysis (19.1 ± 0.3 μm and 20 ± 0.2 μm, respectively) in the first case RMS is substantially greater (2.9 ± 0.2 μm and 1.0 ± 0.1 μm, respectively).

Often ion tracks entered in NTE are ending with bends or "forks" due to scattering on Ag and Br nuclei (fig 3.10). For example, in the case of ^{86}Kr scatterings an average range to scattering points was 7.7 ± 0.2 μm at RMS 1.8 μm which corresponds to an average energy at scattering of 250 ± 10 keV at RMS 100 keV. Residual tracks of scattered ions have a range 5.5 ± 0.3 μm at RMS 3 μm. It is impossible to attribute secondary tracks to an original ion and ion recoil target after scattering.

Since only tracks of non-scattered ions have been taken for the manual analysis, such a sampling has provided the perfect range resolution.

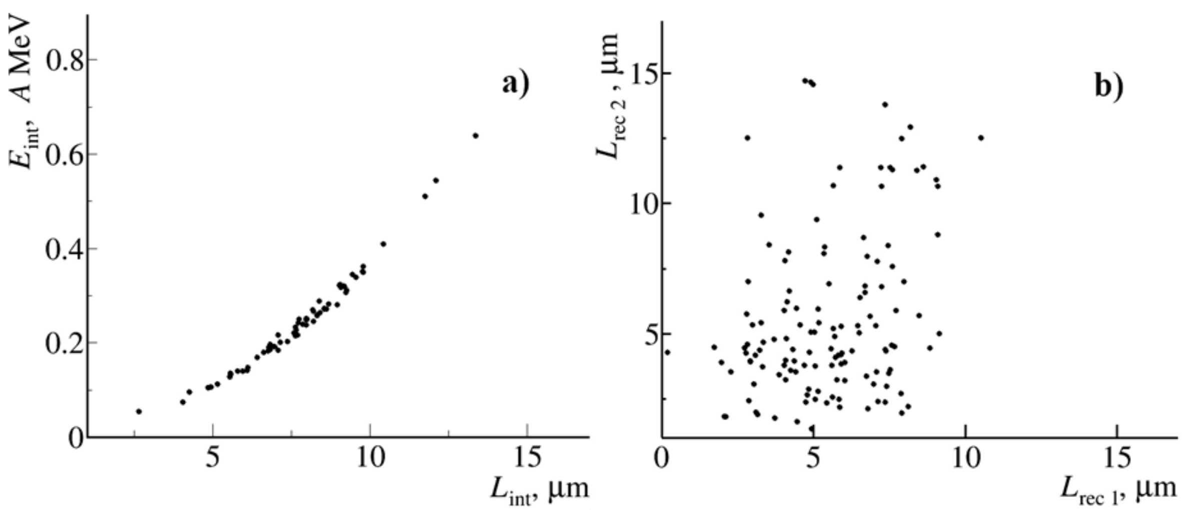

Fig. 3.10. (a) Ranges of ions to scattering points Lint and energy Eint in them by the SRIM model; (b) ranges of recoil ions Lrec1 and Lrec2.

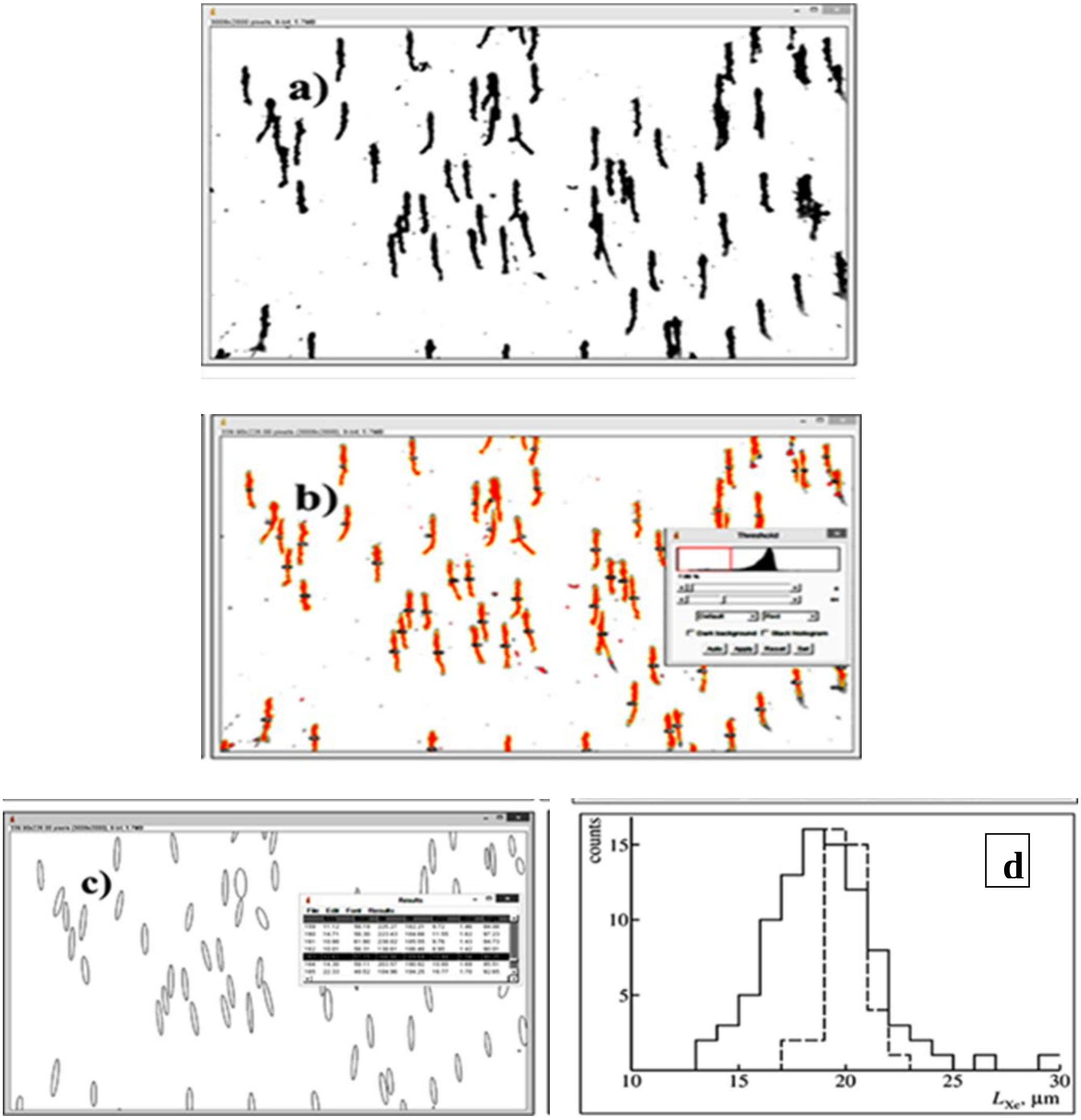

Fig. 3.11. Stages of computer analysis: initial close-up (a), finding of track images (b), description of them as ellipses (c) and ion range distribution in computer (solid line) and manual (dashed line) analysis (d).

These previous figure shows the steps of automatic measurements by using image j program after calibration and drawing by root program.

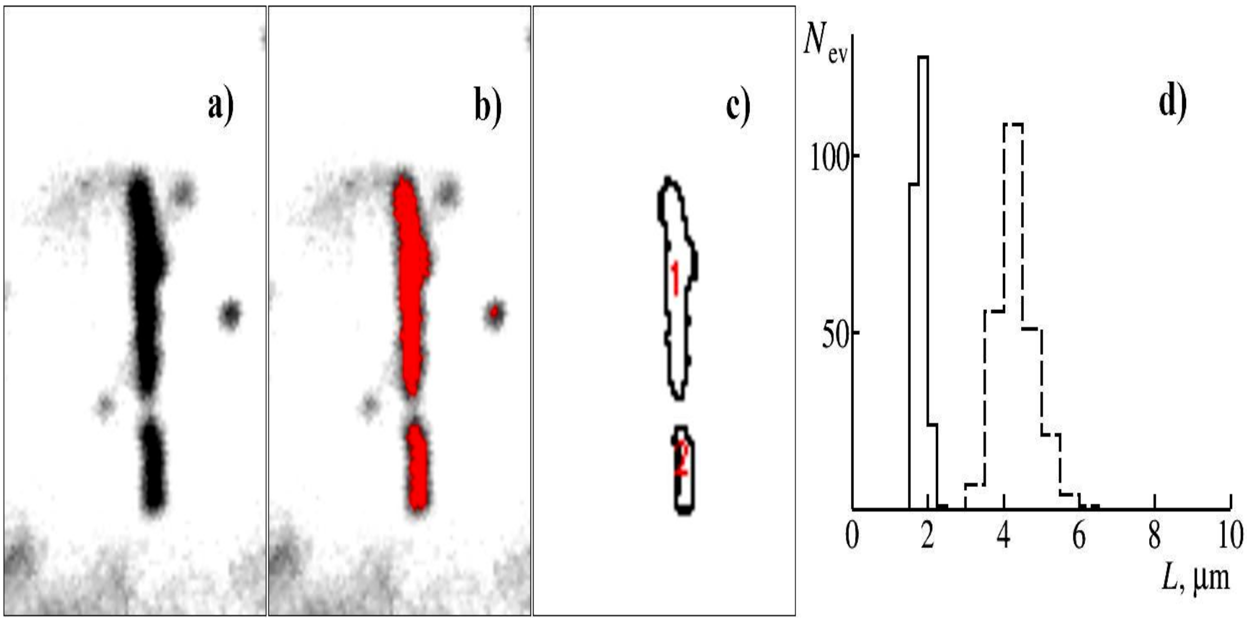

Fig. 3.12. Example of disintegration of boron nucleus by thermal neutron to the Li and He nth (a) and steps of image recognition via the Image program (a-c). Distribution of mean range of Li (solid line) and He (dotted line) (d).

Thus, the methodology prerequisites are established for transition to an automatic analysis on the discussed subject. The HSP-1000 microscope of DRD manufactured by "Seiko Precision" is unique scientific equipment at the European level. It is equipped with a high-resolution linear sensor, which allows up to 50 times higher speed of image acquisition compared to conventional CCD cameras. A full image of the sample is restored when continuous shooting from a relatively small number of long chains. Fully automatic digitization provides more easily and fast image analysis. This microscope with a 20 objective is used for the analysis of solid-state track detectors. In order to use the NTE resolution completely it is necessary to apply an oil immersed 60 objective. The HSP-1000 microscope is now being replenished in a corresponding way.

Recently, the microscope HSP-1000 with a lens 20 was used to scan a large area of NTE exposed to 1.2 A MeV Xe^{+26} ions at a 450 inclination. An analysis by orders of magnitude beyond a man possibility is carried out on an array of 225 frames of 2500 2000 pixels. The program ImageJ has found 60,000 tracks on an area of 1.4 cm^2 and determined their lengths and planar angles Θ_{Xe} in an ellipse approximation (Fig.3.8). The distribution of lengths is described by a Gaussian function with a parameter of 1.0 μm corresponding to the manual measurements. Statistics Θ_{Xe} is divided into two groups differing of 130 in the average values. These groups Θ_{Xe} are described by Gaussian functions with parameters of 3.4◦ and 2.0◦. Apparently, Θ_{Xe} splitting is caused by a change of a magnetic rigidity of approximately 20% fraction of ions extracted from the accelerator IC-100 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.

discussed exposures and videos based on them are available on the BECQUEREL project website[87].

3.5. Exposure to ^{252}Cf and Measurement

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.3.6(a) shows the distribution of vertices of ^{252}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 ^{252}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. Eff ective criteria for a fission into three heavy fragments is their amount range (Fig. 3.6(b), 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. 3.6(c). Their distribution is characterized by a mean value 111 ± 3◦ when RMS 39◦.

3.6. Experimental Examination of Ternary Fission in NTE.

Nuclear emulsion 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 NTE. Ternary fission of ^{235}U induced by thermal neutrons was discovered using NTE that was soaked with a chemical compound enriched in this isotope [88]. Spontaneous fission of ^{252}Cf introduced into NTE has been studied for quite a while [89,90]. The ratio of probabilities of ternary and binary fission is yet to be determined. The collinear ternary fission hypothesis has been proposed recently [91, 92]. 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 NTE.

The NTE 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 NTE was stimulated by its production at the MICRON division of Slavich (Pereslavl-Zalessky) [93].

The samples used in the present study were fabricated by coating glass substrates with a ~100-μm-thick NTE layer. The NTE 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 NTE area irradiated by a ^{252}Cf source with a suitable density of tracks of α-particles and spontaneous fission fragments [93]. This proposal may be developed further to include the use of NTE samples enriched in ^{235}U and irradiated with thermal neutrons. The findings made at the preliminary stage of NTE irradiation are reported below.

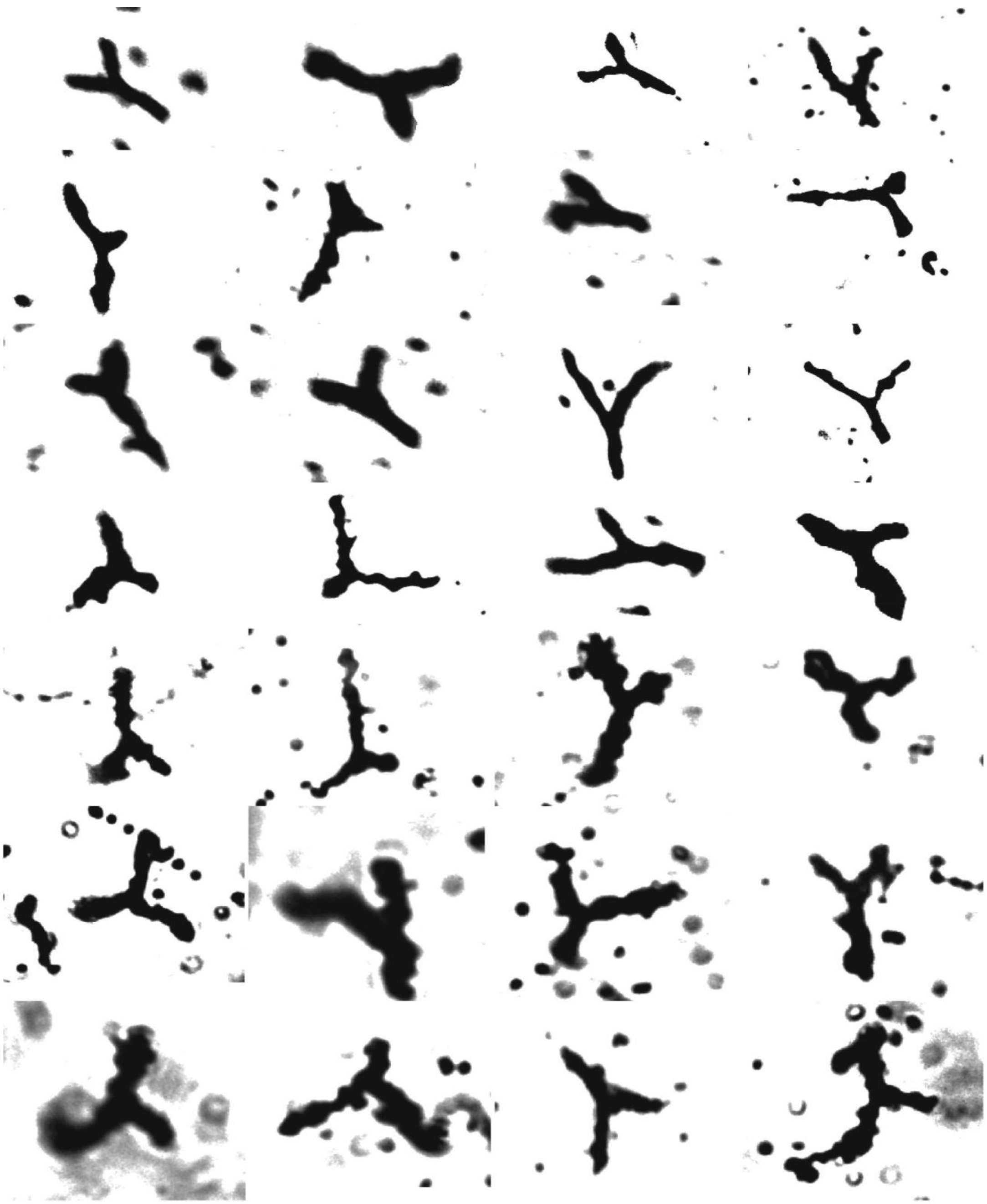

Fig. 3.13. Examples of observed ternary fission events.

Unfortunately, the quality of presented images does not reproduce fairly the level of detail of actual observations. The remark ability 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 3.13 shows the distribution of 96 vertices of ^{252}Cf fission into three fragments over the NTE layer thickness. The mean value is 4.1 ± 0.2 μm (RMS 2.5 μm).

The surface shielding of the source with the initial thickness of deposited gold of 50μg/cm^2 (according to certificate) apparently did not prevent this penetration. Track lengths Lfr of all fragments were measured in 96 found ternary fission events (Fig. 3.15, left panel). The mean value of Lfr 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 NTE should be extended below 1 A MeV. The opening angles of fragments were measured in these events (Fig.3. 15, 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.3.16, 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.3. 16, 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 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. Macro photographs of the discovered events, which are archived at the BECQUEREL project site [94], 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) [94]. This microscope is used to perform trial scanning (at 20X magnification) of considerable areas of NTE irradiated by the californium source. In order to utilize the NTE resolution fully, the microscope is being fitted with a 60X lens immersed in oil. In general, the present study, which was aimed at reintroducing NTE into nuclear experiments based on advanced microscopy techniques, may be used as a reference in solving a variety of problems.

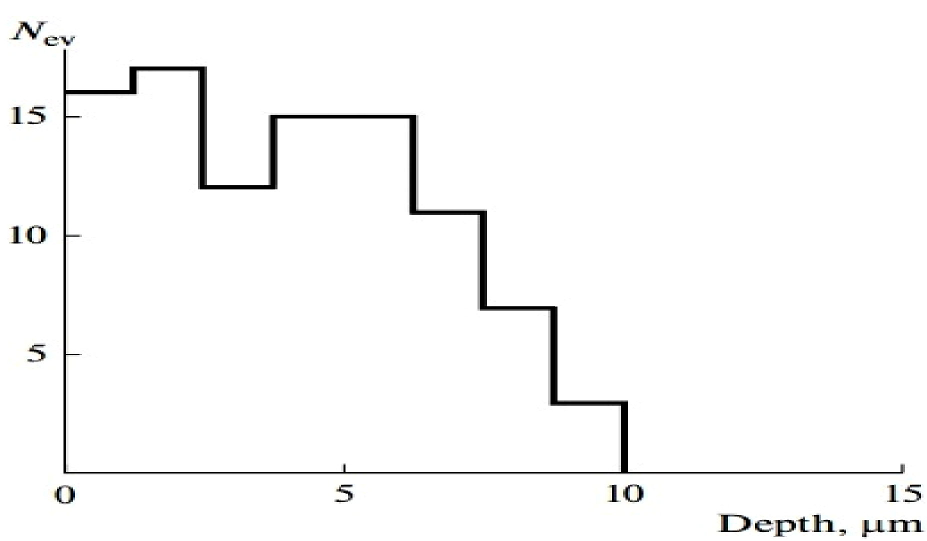

Fig. 3.14. Distribution of ternary ^{252}Cf fission events over the NET layer thickness.

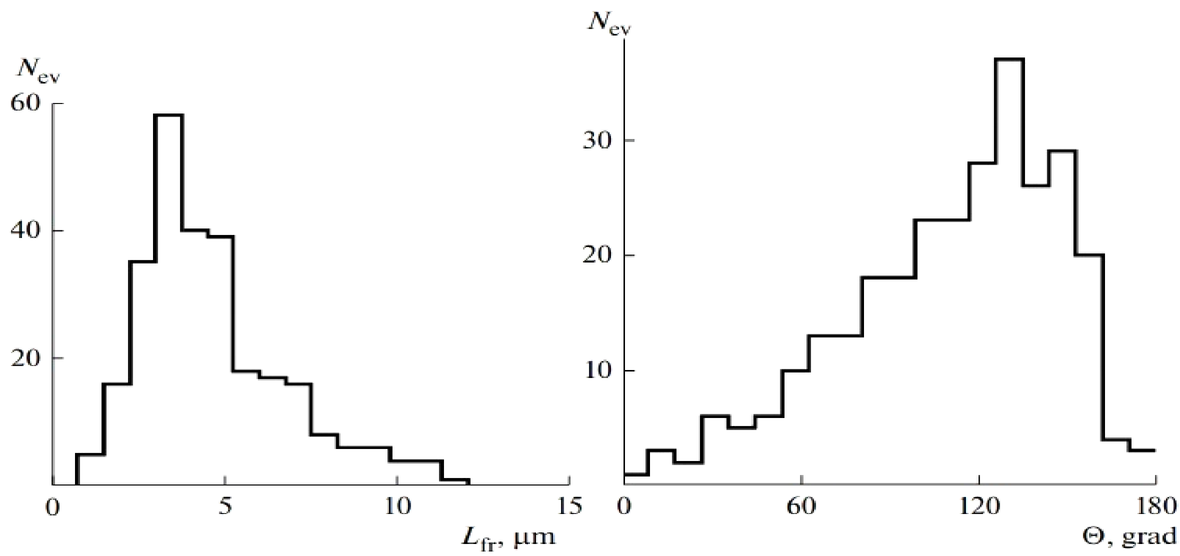

Fig. 3.15. Distribution of ternary [252]Cf fission events as a function of the fragment range Lfr (left) and opening angle Θ (right).

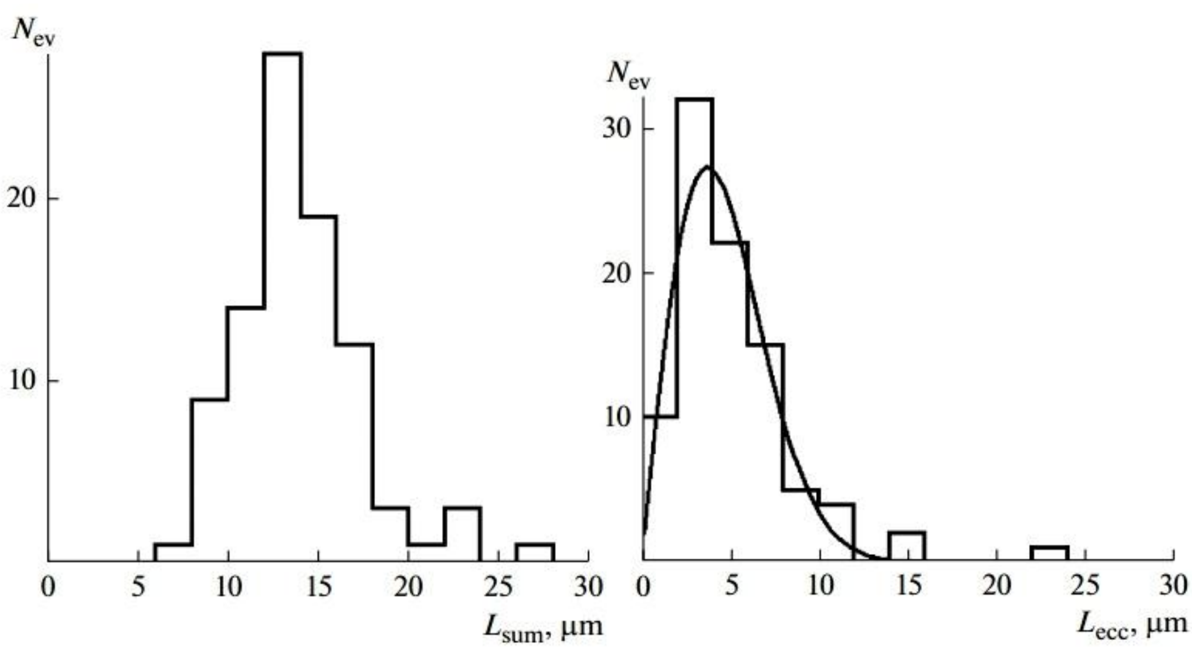

Fig. 3.16. Distribution of ternary 252Cf fission events as a function of the total track length of fragment triples L_{sum} (left) and the length of the total range vector L_{ecc} (right).

3.7 ^{8}Be in CCT

Search for the collinear cluster tri-partition (CCT) of fissionable nuclei is among current challenges (reviewed in [126]). Such a process is assumed to proceed through sequential binary fissions via formation of an intermediate state composed of two resulting fragments. Such a state is considered existing long enough with the respect to the fission time scale to be considered as a kind of a nuclear molecule.

Decaying sequentially it could lead to alignment emission directions of the three fragment along the common axis. Therefore, there are obvious diffculties in separating pairs of fragments moving in the same direction. Orientation toward the ternary fission involving sufficiently long-lived isotope ^{8}Be allows one to overcome this diffculty. ^{8}Be emission in spontaneous decays ^{252}Cf established recently [95] supports this idea. It is worth noting that the ^{8}Be emission mimics 2α particle radioactivity.

In general, unbound configurations of lightest nuclei (α, t) originated from decays of light nuclei exited above relevant thresholds aren't excluded in the ternary fission. The unstable ^{8}Be nucleus is considered as a loose bond of α - particles whose centers are a separated by a distance of about the- α particle size. So, it would be too little to refer it to exotic nuclei. Due to its size over deformation axis comparable to a heavy nucleus one ^{8}Be can be considered as an important participant among heavier fission fragments (Figure 3.14).

Besides, ^{8}Be could serve as a temporary covalent bond in an emerging ensemble. A ^{8}Be accompanied fission can proceed like 4-body instantaneous decay or sequential one when ^{8}Be is kept by one of heavier fragments while the other one drifts away. The second option leads to the CCT pattern. Both scenarios seem intriguing and their interplay is possible. Thus, experimental examination of the pattern of the ternary fission involving ^{8}Be is an inspiring goal.

Regarding the current status of the NTE technique the following can be noted. Being developed more than half a century ago it remains a status of a universal and cost-efficient detector. BR-2 type NTE with an unsurpassed observation beginning from fission fragments up to relativistic particles. In the last decade, the NTE technique is actively applied in the BECQUEREL experiment [95] at the JINR Nuclotron allowing studying of light nuclei including radioactive ones nuclei at their relativistic dissociation. Unstable nuclei ^{8} Be and ^{9}B were identified by invariant masses of their decay products in the cases of the isotopes ^{10}B and ^{10,11}C . Meaning of the last fact is as follows. As is known, nucleosynthesis chains involving ^{8} Be and ^{9}B are suppressed due to an absence of the bound ground states. Nevertheless, this circumstance does not prevent the substantial structural contribution of ^{8} Be and ^{9}B. Therefore, it cannot be ruled out that they can serve as transient states persisting in the bound nuclei.

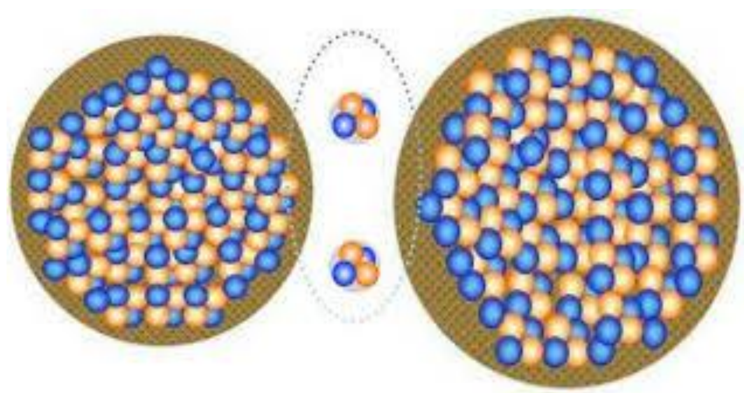

Fig.3.17 Scenario of ternary fission of heavy nucleus involving ^{8} Be.

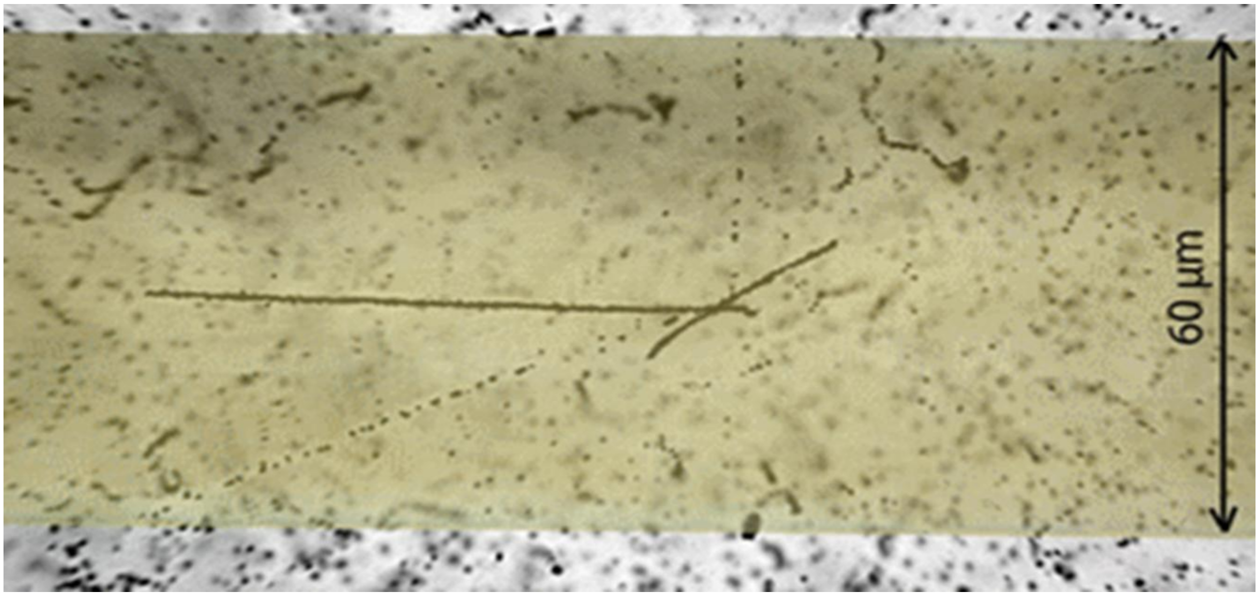

Fig.3.18 Mosaic macro photograph of "hammer-like" decay of the ^{8}He nucleus stopped in the nuclear track emulsion (horizontal track). The decay results in a pair of relativistic electrons (dotted tracks) and a pair of α particles (oppositely directed short tracks).

3.8 Appendix

Program used in calculations and graph by C++ (ROOT)

```
 #include "Riostream.h"
      #include "stdio.h"
      #include "math.h"
      #include "vector.h"

 gROOT->Reset();
 gStyle->SetOptStat(0);
  gStyle->SetOptStat(112211);
 gStyle->SetOptTitle(0);
 // gStyle->SetOptFit(111);
 gStyle->SetLineWidth(3);
 gStyle->SetLineColor(1);
 gStyle->SetFillColor(0);


ifstream in;
in.open("all_in_one.txt");

struct Pv{
Float_t x;
Float_t y;
Float_t        z;
Int_t   ls;
};
/////////////////////////////////////////////


 Int_t name, type, n, Ldup, Lver, Ltr;
 Float_t thiknesst, zdown, zup, xt, zt, zs, yt, Dipping, openang0, openang1,
openang2;
 Float_t zver, xver, yver, xvp=0, yvp=0, zvp=0, rangeV, dZ;
        vector<Pv>v;
```

```
 TH1F *h11 = new TH1F("h11","openang",20,0,180);
TH1F *h21 = new TH1F("h21","Dipping",20,0,10);
TH1F *h4  = new TH1F("h4","range",20,0,40);
TH1F *h2  = new TH1F("h2","range",15,0,10);

 h11->StatOverflows(kTRUE);
 h21->StatOverflows(kTRUE);
 h4->StatOverflows(kTRUE);
 h2->StatOverflows(kTRUE);


        while (!in.eof())
        {

 in>>name>>n;
 // cout<<name<<endl;
 in.ignore(1024, '\n');
 if(!in.good())break;
 // cout<<name<<"          "<<n<<endl;
 in>>thiknesst>>Ldup;
 in.ignore(1024, '\n');
 if(!in.good())break;
 // cout<<thiknesst<<"  "<<Ldup<<endl;
 in>>zdown>>zup;
 in.ignore(1024, '\n');
 if(!in.good())break;
 // cout<<zdown<<" "<<zup<<endl;
 in>>Lver;
 in.ignore(1024, '\n');
 if(!in.good())break;
 // cout<<Lver<<endl;
 in>>xver>>zver>>zup>>yver;
 in.ignore(1024, '\n');
 if(!in.good())break;
//  cout<<xver<<"  "<<zver<<"  "<<zup<<"  "<<yver<<endl;
   dZ=thiknesst/abs(zup-zdown);
   Dipping = (zup-zver)*(thiknesst/abs(zup-zdown));
```

```
      // cout<<zup-zver<<endl;
      // cout<<zver*(thiknesst/abs(zup-zdown))<<endl;
          // cout<<Dipping<<endl;

          h21->Fill(Dipping);

for(Int_t i=0;i<n;i++)
{

         in>>type>>Ltr;
         in.ignore(1024, '\n');
         if(!in.good())break;
         //cout<<type<<"  "<<Ltr<<endl;
         in>>xt>>zt>>zs>>yt;
         in.ignore(1024, '\n');
         if(!in.good())break;
         //cout<<xt<<"  "<<zt<<"  "<<zs<<"  "<<yt<<endl;

         xvp=(xver-xt);
         yvp=(yver-yt);
         zvp=(zver-zt)*dZ;

        Pv tmp;
  tmp.x=xvp;
  tmp.y=yvp;
  tmp.z=zvp;
  tmp.ls=type;
  v.push_back(tmp);


   rangeV=abs(sqrt(xvp*xvp+yvp*yvp+zvp*zvp));
         if(rangeV<10.) h2->Fill(rangeV);
  // if(name==174111) cout<<rangeV<<endl;

  // totalR[i]=range;

      // if(range<20)          //h11->Fill(rangeV);
```

```
        // cout<<name<<" "<<xvp<<"    "<<yvp<<"    "<<zvp<<"    "<<rangeV<<"
        "<<endl;
}
openang0=(180./3.14159)*acos(((v[0].x*v[1].x)+v[0].y*v[1].y+v[0].z*v[1].z)/(sqrt(
v[0].x*v[0].x+v[0].y*v[0].y+v[0].z*v[0].z)*sqrt(v[1].x*v[1].x+v[1].y*v[1].y+v[1].z
*v[1].z)));
openang1=(180./3.14159)*acos(((v[0].x*v[2].x)+v[0].y*v[2].y+v[0].z*v[2].z)/(sqrt(
v[0].x*v[0].x+v[0].y*v[0].y+v[0].z*v[0].z)*sqrt(v[2].x*v[2].x+v[2].y*v[2].y+v[2].z
*v[2].z)));
openang2=(180./3.14159)*acos(((v[2].x*v[1].x)+v[2].y*v[1].y+v[2].z*v[1].z)/(sqrt(
v[2].x*v[2].x+v[2].y*v[2].y+v[2].z*v[2].z)*sqrt(v[1].x*v[1].x+v[1].y*v[1].y+v[1].z
*v[1].z)));

rangeV0=abs(sqrt(v[0].x*v[0].x+v[0].y*v[0].y+v[0].z*v[0].z));
rangeV1=abs(sqrt(v[1].x*v[1].x+v[1].y*v[1].y+v[1].z*v[1].z));
rangeV2=abs(sqrt(v[2].x*v[2].x+v[2].y*v[2].y+v[2].z*v[2].z));
if(name==174111) cout<<openang0<<endl;
// cout<<name<<" "<<v[0].ls<<" "<<v[1].ls<<"    "<<openang0<<endl;
// cout<<name<<" "<<v[0].ls<<" "<<v[2].ls<<"    "<<openang1<<endl;
// cout<<name<<" "<<v[2].ls<<" "<<v[1].ls<<"    "<<openang2<<endl;

        h4->Fill(rangeV0+rangeV1+rangeV2);
   // total=totalR[0]+totalR[1]+totalR[2];
 h11->Fill(openang0);
 h11->Fill(openang1);
 h11->Fill(openang2);
 // if(range<20) h11->Fill(total);
  v.clear();
  }

in.close();
   TCanvas *c2 = new TCanvas("c2", "c2",265,249,600,400);
          c2->Range(0,0,1,1);
          c2->SetFillColor(0);
          c2->SetBorderMode(0);
          c2->SetBorderSize(1);
          c2->SetTopMargin(0.06643356);
          c2->SetBottomMargin(0.1346154);
```

```
      c2->SetFrameLineColor(0);
      c2->SetFrameBorderMode(0);

    h2->GetXaxis()->SetTitle("#font[12]{L}, #mum");
    h2->GetXaxis()->SetNdivisions(5);
    h2->GetXaxis()->SetLabelFont(132);
    h2->GetXaxis()->SetLabelSize(0.08);
    h2->GetXaxis()->SetTickLength(0.03);
    h2->GetXaxis()->SetTitleFont(132);
    h2->GetXaxis()->SetTitleSize(0.08);
    h2->GetYaxis()->SetNdivisions(5);
    h2->GetYaxis()->SetLabelFont(132);
    h2->GetYaxis()->SetLabelSize(0.08);
    h2->GetYaxis()->SetTickLength(0.02);
    h2->GetYaxis()->SetTitleOffset(0.8);
    h2->GetYaxis()->SetTitleFont(132);
    h2->GetYaxis()->SetTitleSize(0.08);
    h2->SetMinimum(0.001);
    h2->SetLineWidth(3);
    h2->SetLineColor(1);
    h2->Draw();
  tex = new TLatex(-1.418972,9.289599,"N_{#font[132]{ev}}");
  tex->SetTextFont(12);
  tex->SetTextSize(0.06851661);
  tex->SetLineWidth(2);
  tex->Draw();

 TCanvas *c1 = new TCanvas("c1", "c1",265,249,1394,475);
      c1->Range(0,0,1,1);
      c1->SetFillColor(0);
      c1->SetBorderMode(0);
      c1->SetBorderSize(1);
      c1->SetTopMargin(0.06643356);
      c1->SetBottomMargin(0.1346154);
      c1->SetFrameLineColor(0);
      c1->SetFrameBorderMode(0);

// ------------>Primitives in pad: c1_1
```

```
TPad *c1_1 = new TPad("c1_1",
"c1_1",0.0007194245,0.01118568,0.3143885,0.9910515);
c1_1->Draw();
c1_1->cd();
c1_1->Range(-1.499061,-1.825708,11.27767,7.989174);
c1_1->SetFillColor(0);
c1_1->SetBorderMode(0);
c1_1->SetBorderSize(1);
c1_1->SetLeftMargin(0.1173274);
c1_1->SetTopMargin(0.06512807);
c1_1->SetBottomMargin(0.1861161);
c1_1->SetFrameLineColor(0);
c1_1->SetFrameBorderMode(0);
c1_1->SetFrameLineColor(0);
c1_1->SetFrameBorderMode(0);

    h21->GetXaxis()->SetTitle("depth, #mum");
    h21->GetXaxis()->SetNdivisions(5);
    h21->GetXaxis()->SetLabelFont(132);
    h21->GetXaxis()->SetLabelSize(0.08);
    h21->GetXaxis()->SetTickLength(0.03);
    h21->GetXaxis()->SetTitleFont(132);
    h21->GetXaxis()->SetTitleSize(0.08);
    h21->GetYaxis()->SetNdivisions(5);
    h21->GetYaxis()->SetLabelFont(132);
    h21->GetYaxis()->SetLabelSize(0.08);
    h21->GetYaxis()->SetTickLength(0.02);
    h21->GetYaxis()->SetTitleOffset(0.8);
    h21->GetYaxis()->SetTitleFont(132);
    h21->GetYaxis()->SetTitleSize(0.08);
    h21->SetMinimum(0.001);
    h21->SetLineWidth(3);
    h21->SetLineColor(1);
    h21->Draw();
tex = new TLatex(-1.418972,9.289599,"N_{#font[132]{ev}}");
tex->SetTextFont(12);
tex->SetTextSize(0.06851661);
tex->SetLineWidth(2);
```

```
   tex->Draw();

         tex = new TLatex(6.7,7.7,"a)");
   tex->SetTextFont(132);
   tex->SetTextSize(0.06851661);
   tex->SetLineWidth(3);
   tex->Draw();

    c1_1->Modified();
    c1->cd();

// ------------>Primitives in pad: c1_2
   c1_2 = new TPad("c1_2", "c1_2",0.3007194,0.01118568,0.6136691,0.9910515);
   c1_2->Draw();
   c1_2->cd();
   c1_2->Range(-4.497183,-3.130685,33.83302,13.69583);
   c1_2->SetFillColor(0);
   c1_2->SetBorderMode(0);
   c1_2->SetBorderSize(1);
   c1_2->SetLeftMargin(0.1173274);
   c1_2->SetTopMargin(0.06512807);
   c1_2->SetBottomMargin(0.1861161);
   c1_2->SetFrameLineColor(0);
   c1_2->SetFrameBorderMode(0);
   c1_2->SetFrameLineColor(0);
   c1_2->SetFrameBorderMode(0);

         h4->GetXaxis()->SetTitle("#font[12]{L}, #mum");
         h4->GetXaxis()->SetNdivisions(5);
         h4->GetXaxis()->SetLabelFont(132);
         h4->GetXaxis()->SetLabelSize(0.08);
         h4->GetXaxis()->SetTickLength(0.03);
         h4->GetXaxis()->SetTitleFont(132);
         h4->GetXaxis()->SetTitleSize(0.08);
         h4->GetYaxis()->SetNdivisions(5);
         h4->GetYaxis()->SetLabelFont(132);
         h4->GetYaxis()->SetLabelSize(0.08);
         h4->GetYaxis()->SetTickLength(0.02);
```

```
        h4->GetYaxis()->SetTitleOffset(0.8);
        h4->GetYaxis()->SetTitleFont(132);
        h4->GetYaxis()->SetTitleSize(0.08);
        h4->SetMinimum(0.001);
        h4->SetLineWidth(3);
        h4->SetLineColor(1);
        h4->Draw();
               tex = new TLatex(25.7,10.7,"b)");
   tex->SetTextFont(132);
   tex->SetTextSize(0.06851661);
   tex->SetLineWidth(3);
   tex->Draw();
    c1_2->Modified();
    c1->cd();

// ------------>Primitives in pad: c1_3
   c1_3 = new TPad("c1_3", "c1_3",0.6035971,0.01118568,0.9172662,0.9910515);
   c1_3->Draw();
   c1_3->cd();
   c1_3->Range(-26.9831,-4.435663,202.9981,19.40248);
   c1_3->SetFillColor(0);
   c1_3->SetBorderMode(0);
   c1_3->SetBorderSize(1);
   c1_3->SetLeftMargin(0.1173274);
   c1_3->SetTopMargin(0.06512807);
   c1_3->SetBottomMargin(0.1861161);
   c1_3->SetFrameLineColor(0);
   c1_3->SetFrameBorderMode(0);
   c1_3->SetFrameLineColor(0);
   c1_3->SetFrameBorderMode(0);

    h11->GetXaxis()->SetTitle("#Theta, ^{#circ}");
        h11->GetXaxis()->SetNdivisions(5);
        h11->GetXaxis()->SetLabelFont(132);
        h11->GetXaxis()->SetLabelSize(0.08);
        h11->GetXaxis()->SetTickLength(0.03);
        h11->GetXaxis()->SetTitleFont(132);
        h11->GetXaxis()->SetTitleSize(0.08);
```

```
        h11->GetYaxis()->SetNdivisions(5);
        h11->GetYaxis()->SetLabelFont(132);
        h11->GetYaxis()->SetLabelSize(0.08);
        h11->GetYaxis()->SetTickLength(0.02);
        h11->GetYaxis()->SetTitleOffset(0.8);
        h11->GetYaxis()->SetTitleFont(132);
        h11->GetYaxis()->SetTitleSize(0.08);
        h11->SetMinimum(0.001);
        h11->SetLineWidth(3);
        h11->SetLineColor(1);
        h11->Draw();
                tex = new TLatex(84.7,14.7,"c)");
  tex->SetTextFont(132);
  tex->SetTextSize(0.06851661);
  tex->SetLineWidth(3);
  tex->Draw();
   c1->cd();
   c1->Modified();
   c1->cd();
   c1->SetSelected(c1);
}
```

CONCLUSION

During this study, the following was done:

- First, a comparison between the range and energy of the alpha that comes out from the ternary fission with the range and energy of the alpha that comes out from some important reactions, including the decomposition of ^{12} C using thermal neutron, the decay of ^{8} He, the decay of ^{10} B, also the ^{241}Am and also the alpha that comes out as a result of the dissolution of ^{252}Cf and it was proved that the alpha from triple fission is the highest in range and energy.
- Another comparison has also been made between range of the heavy nuclei coming out of the nucleus of ^{252}Cf in the ternary fission with some known heavy nuclei that often come out from the products of normal fission, such as $^{\text{١٢٤}}$Xe , ^{84} Kr and ^{86} Kr with different energies.
- During this study, some new programs were used in this field, which were very useful in saving time and effort, such as a program IMAGE J and ROOT.
- Angle distributions were made for the fully three ions that come out of this spontaneous fission, which helps visualize a scenario around this fission occurrence.
- Measurement of length,range and dipping of these three ions to can make a classification of these tracks into light and heavy ions.

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الملخص العربى

تعتبر عينات الاستحلاب من اسهل وارخص الطرق لدراسه العمليات النوويه المختلفه وذلك عن طريق دراسه الاثار النوويه التى تحدث داخل هذه العينات ويتم تحضير العينات كيميائيا فى المعمل من ماده بروميد الفضه وجلاتين كماده شفافه وبعض العناصر الاخرى التى تكون عجينه يتم فردها على شرائح من الزجاج وتحفظ تحت درجات حراره معينه لاتزيد عن ٣٠ درجه مئويه حتى لاتفسد من درجات الحراره العاليه وتتميز هذه العينات بسهوله التعامل معها وحفظها وتحتفظ هذه العينات لفتره طويله بهذه الاثار النوويه لفتره طويله وتعتبر هذه الميزه من اهم المميزات التى تتميز بها هذه العينات حيث يمكن الرجوع اليها فى اى وقت.

وتم فى خلال هذه الدراسه دراسه بعض الانواع النادره من الانشطار لعنصر الكاليفورنيوم ٢٥٢ وهو الانشطار الثلاثى حيث ينشطر العنصر الى ثلاث ايونات مختلفه باكثر من طريقه منها

١- ان يخرج الالفا ومعها اثنين من العناصر الثقيله

٢- ان ينقسم العنصر الى ثلاث عناصر متقاربه فى الكتله

وفى هذه الدراسه وحسب القياسات المتاحه والحسابات تم التعرف على بعض الخواص لهذا الانشطار منها قياس الزوايا التى تخرج بها هذه العناصر وقياس المدى ومنه قياس الطاقه لجسيم الالفا وتمت مقارنته ببعض جسيمات الالفا التى تخرج فى تفاعلات اخرى منها انشطار الكربون ١٢ عندما يتم قذفه بالنيترونات وايضا انشطار الهيليوم ٨ الى جسيمين الفا وانشطار البورون ١٠عندما يتم قذفه ايضا بالنيترونات واخرى تخرج من الاميني‍ثيوم ٢٤١ واتضح من الدراسه ان الفا التى تخرج من الكاليفورنيوم اثناء الانشطار الثلاثى هى اكبرهم فى المدى واعلاهم فى الطاقه.

الملخص العربى

وايضا تم عمل معايره باستخدام بعض العناصر الثقيله بطاقات مختلفه مثل الزينون ١٣٢ والكريبتون٨٦ ، ٨٤ حتى تكون مرشد لمن يقوم بدراسه هذه التفاعلات النادره حيث انه من المعلوم لدى الجميع ان اكثر من ٩٠% من الانشطار لهذا العنصر يؤدى الى الحصول على عنصرين فقط الذى يسمى الانشطار الثنائى واقل من ١% يحدث هذا النوع من الانشطار الذى يولد ثلاث عناصر.وايضا تم استخدام بعض برامج الكمبيوتر الحديثه مثل الروت الذى يستخدم فى الحسابات والرسم وايضا برنامج رسم شهير يسمى ايمدج جى.

وهو برنامج يقوم بتصوير العينات ومسحها ومسحها مسحا دقيقا وايضا يقوم ببعض القياسات البسيطه من خلال برمجته على هذه القياسات واستخدام هذه البرامج ايضا كان من اهداف الدراسه لايجاد طريقه للتعامل مع العينات بطريقه اسهل واسرع وفى نهايه الدراسه نكون قد حصلنا على بعض الخواص التى تساعد فى التعرف على هذا النوع من الانشطار.

يعتبر عينات المستحلب احدى التقنيات التى تستخدم فى دراسه بعض خواص الاثار النوويه حيث انها تسجل تلك الاثار وتحتفظ بها لفترات طويله وتعتبر احدى مميزات الاستحلاب ولكنه فى النهايه مثل اى تقنيه لايستطيع ان يقيس كل شىء عن هذه الاثار فلكل تقنيه مميزات وعيوب ومن عيوبه انه لايستطيع التعرف على هذه الايونات التى تخرج من نواتج الانشطار ولكنه يستطيع ان يقيس بكل دقه الزوايا التى تخرج بها هذه الاثار النوويه وايضا اطوالها والمدى الخاص بها وبالتالى الطاقات مما يساعد على تصنيف هذه الاثار.

وايضا تم التغلب على مشكله كميات البيانات الصغيره عن طريق مسح عدد كبير من العينات باستخدام برامج الكمبيوتر التى وفرت بشكل كبير الوقت الكثير الذى يستغل فى تجميع هذه البيانات.

الموجز العربى

تم ملاحظه نوع جديد من الانشطار النووى والتعرف عليه من خلال التعاون مع فريق فوبوس بمعهد الدراسات النوويه بروسيا يسمى التكتلات الثلاثيه او الانشطار الثلاثى.والذى قام على الملاحظه غير المباشره عن الطاقه المفقوده والتلقائيه لعنصر الكاليفورنيوم ٢٥٢ لينتقل الى ثلاث ايونات ثقيله او ايونيين ثقيلين وواحد خفيف هو الالفا من خلال عمليه الانشطار. نظريا يصعب الشرح من خلال النماذج النوويه المختلفه ولكن عمليا توجد هذه الانشطارات بنسب تصل الى ٠.٥ % . تطبيقات عينات المستحلب النووى كبيره جدا وباستخدام الميكروسكوب للبحث عن هذا النوع من الانشطارات الثلاثيه المنزرعه داخل العينات يم عمل معايره لجسيمات الفا من خلال قياسات المدى والطاقه ومقارنتها ببعض الاخرى التى تخرج من تفاعلات مختلفه مثل الالفا التى تخرج نتيجه اضمحلال الكربون ١٢ واضمحلال البورون ١٠ باستخدام النيترونات وايضا اضمحلال الهيليوم ٨ واضمحلال الامينيثيوم ٢٤١ واضا الالفا التى تخرج من الكاليفورنيوم ٢٥٢. وتم ايضا عمل معايره باستخدام ايونات ثقيله مثل الكريبتون والزينون بطاقات مختلفه وعمل توزيعات لزوايا هذه الايونات ودراستها وباستخدام بعض برامج الكمبيوتر التى توفر الوقت والمجهود وتكمل العمل البشرى.