FISSION OF SWIFT HEAVY IONS AND PARTICLE EVAPORATION IN NUCLEAR TRACK DETECTORS

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TO

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CERTIFICATE I

This is to certify that the thesis entitled **"FISSION OF SWIFT HEAVY IONS AND PARTICLE EVAPORATION IN NUCLEAR TRACK DETECTORS"** *submitted by Mr. Jolly Raju for the Degree of Doctor of Philosophy of the North-Eastern Hill University, Shillong, INDIA, embodies the records of original investigations carried out by him under my supervision. He has been duly registered and the thesis presented is worthy of being considered for the award of Ph.D. This work has not been submitted elsewhere for a degree.*

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CERTIFICATE II

This is is to certify that Mr. Jolly Raju has satisfactorily completed the following Pre-Ph.D. courses.

	Courses	Grades
1.	Basic German Language	O
2.	Numerical Methods with applications to computer programming.	O
3.	Applications of Nuclear and Radiochemistry.	A
4.	Solid State Chemistry.	A

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

CHAPTER I

INTRODUCTION

Solid State Nuclear Track Detectors commonly abbreviated as SSNTDs have been applied **[1,2,3]** in a wide spectrum of scientific and technical fields. The utility of this versatile technique ranges from nuclear science and engineering to cosmic ray astrophysics and from geology, archeology and sub-oceanic geophysics to lunar science and meteorites **[4,5,6]**. Right from the development of this track technique, its versatility has been exploited in anthropology **[7]**, geochronology **[8]**, environmental sciences **[9]**, space research **[10]**, superfluidity **[11,12]**, lithography **[13]**, dosimetry **[14]**, medical research **[15]**, study of heavy ion nuclear reactions **[16-19]**, multifragmentation of the projectile **[20, 21, 22]**, particle identification **[23, 24]**, search for magnetic monopoles **[25, 26]**, discovery of super heavy elements **[27]**, exotic decay modes of heavy nuclei **[28,29]**.

This has been possible due to certain advantageous features of these track detectors such as the easy availability, inexpensive and a large choice of detectors ranging from organic polymers to inorganic crystals. At times the detectors are available naturally at the site of interest. The inherent characteristics of these detectors are that they have excellent resolution for mass, charge and energy **[30]** within the boundaries of experimental errors.

The technique too does not require heavy budget equipments. Besides these, the detectors carry a permanent record of the radiation damage to which they were exposed. Moreover the detectors can withstand a large dose of lighter particles and low ionizing radiation.

During the past few years measurement of energy-loss of heavy ions in different elemental and complex media using nuclear track technique has been carried out **[31,32]**. The involvement was also in the characterisation and calibration **[33,34]** of different track detectors for a purposeful utility of these detectors in different fields. Different studies to explore more on the track formation mechanism were also carried out **[35,36,37]**. For the mentioned studies confinement was to the linear tracks i.e the enlarged damage trails of the trajectories of energetic heavy ions in the detector matrix created by chemical processing.

Fig. I.1 is a photomicrograph of a fork-like event in CR-39 irradiated to ^{238}U ions of 15.2 MeV/u. In 1988 Dwivedi et.al. **[38]** reported the observation of fork – like events in CR-39 irradiated to ^{238}U ions of 1.6 GeV. A photomicrograph of two events from their report is shown in **Fig. I.2**. As the different experiments in CR-39, Makrofol-E, Cellulose Nitrate and Mica irradiated to ^{208}Pb, ^{209}Bi and ^{238}U were in progress, similar fork like events were encountered. Fork-like events with a third prong of comparatively shorter length have been observed at the point of bifurcation (fission) for ^{238}U in CR-39 (**Fig. I.3**). Having observed such fork like events a few fundamental querries, which needed explanations were : (i) Definitely the scission of the projectile takes place in the forward hemisphere but is there a possibilty of fusion with the nuclei of the atoms constituting the detector matrix, (ii) A suitable reason for the existence of the third prong. The probable answers to these querries can be sought after determining the masses in the exit channels, the angular distributions of the fragments, Q-Value of the reactions, the relative velocity of fragments and total opening angle in the laboratory and center of mass systems.

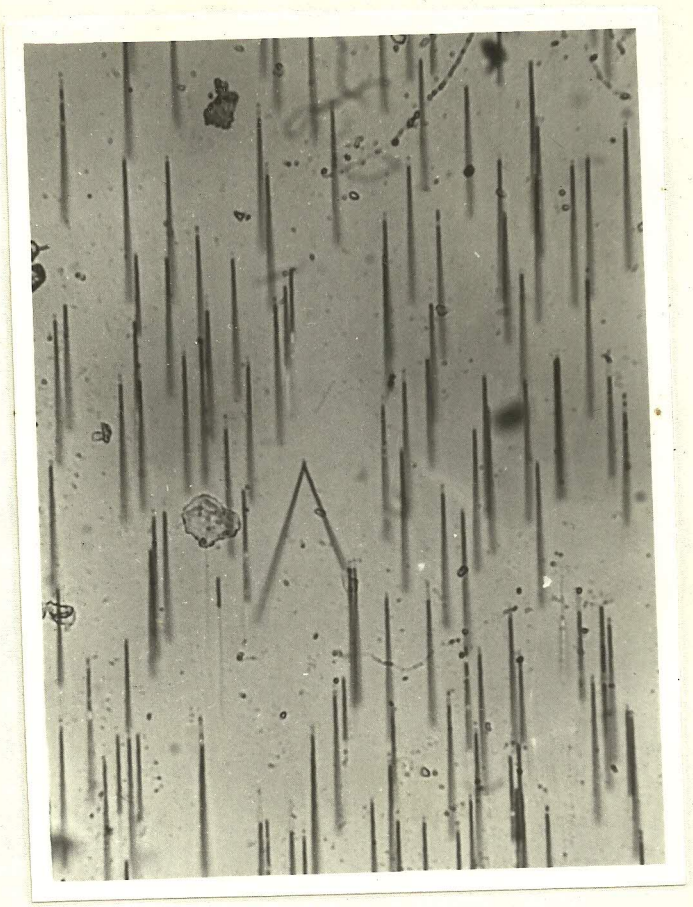

Fig. I.1 A photomicrograph of a fork-like event in CR-39 irradiated to 15.2 MeV/u ^{238}U.

Fig. I.2 A photomicrograph; two events from Dwivedi and Fiedler **[38]** in CR-39 irradiated to 16.3 MeV/u ^{238}U ions.

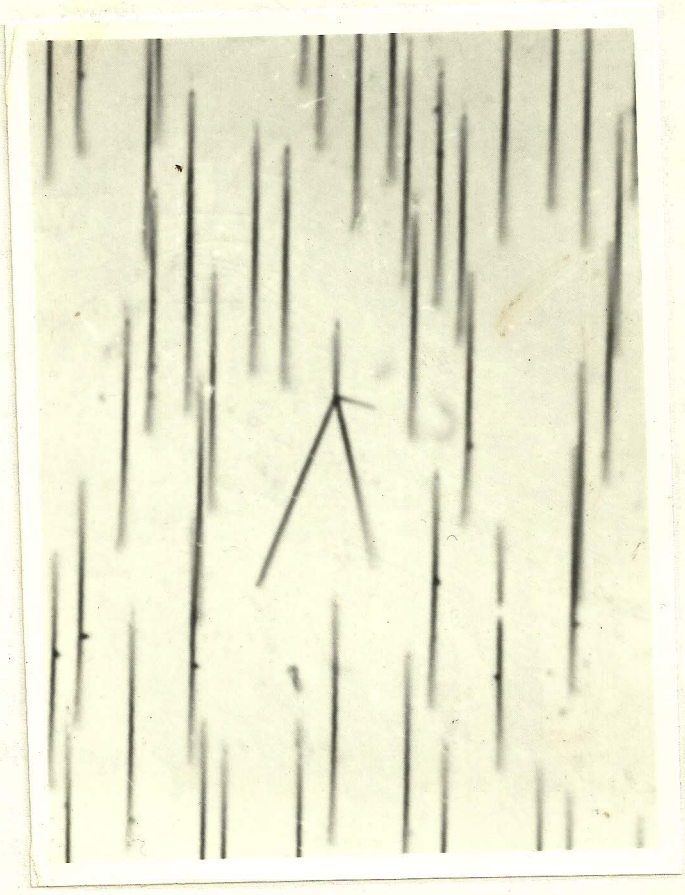

Fig. I.3 A photomicrograph of a fork−like event with the third prong at the point of scission in CR-39. The CR-39 was irradiated to 16.4 MeV/u ^{238}U ions.

On the way to seek the answers to the querries by determining different kinematic variables of the events few barriers too were encounterd. They are:
(i) Deriving the real values of different parameters of the prongs from the microscopically observed projected images. The different parameters of the events to be derived are the real lengths of the prongs, the real opening angles with respect to the beam direction and the energy of the projectile at the scission point.

(ii) Analysing each event in terms of the masses of the fragments in the exit channels and other kinematic variables such as the Q-value of the reaction, relative velocity of the fragments, opening angle in the laboratory and centre of mass systems.

(iii) Developing a systematic approach to study the third prongs in terms their actual track lengths and distribution around the axis considered along the trajectory of the projectile.

In an attempt to search the solutions for the above querries along with overcoming the barriers, a 4π geometry technique has been developed for the analysis of these fork-like events. It consists of a geometrical approach followed by computational analysis. The geometrical part takes care of the first barrier while the computational part tackles the second. A systematic approach has been developed to analyze the third prongs in terms of their true track lengths, direction of existence and also the angle with respect to the beam direction. This technique is advantageous over other techniques of radiation measurement as each individual event is registered as a permanent record in the detector matrix. Hence multiple measurements of the same event can be carried out even after few years of its occurence. It also offers the recording of spatially distributed particles in 4π geometry unlike any other conventional 2π detection system.

A description of the subsequent chapters are as follows:

(i) **Chapter II** deals with the theoretical aspects of analysis of the events: geometrical approach followed by computational. In section II.1 the geometrical aspect of the event is discussed where the derivations of different real parameters of an event from the projected parameters have been accomplished. Section II.2 deals with the methods to construct range-energy calibrations needed to calculate pre-fission energy of the projectiles. In section II.3, the logic and the functions of the program 'TRANSCORD' developed for the first step of analysis are described. The second step of analysis done with the help of the application program 'HIFISS' is explained in section II.4 along with the logic used. The trivialities involved in the computation of different kinematical variables along with the mathematical equations used for the purpose are discussed in this chapter. The systematic steps undertaken to study the third prongs have also been explained.

(ii) **Chapter III** contains an account on the systematic procedure undertaken to study these events. At the very beginning the criteria of selecting the detctors to carry out the present kind of study is discussed. Thereafter, preparation of detectors and their irradiations to specific projectiles are described in detail. In section III.3 the chemical processing of the detectors in suitable chemical reagents have been dealt with and in the next section an account on the observation and scanning of the processed detectors is given where the measurement of different parameters of an event are discussed along with the determination of energy of the projectile, the track density and detector calibrations. This chapter is concluded by a detail account on the error analysis.

(iii) **Chapter IV** contains a systematic account of the experimental results and related discussions under the following sub-heads: statistics of events, differential and total cross-sections, total mass of fragments, the Q-Values of the nuclear reactions, relative velocity of fragments, the opening angle in the laboratory and centre of mass systems and the results obtained from the

systematic analysis carried out on the third prongs.

(iv) and finally in **chapter V** the significant results of the present investigation are highlighted. A brief description on the potentialities and scopes of this track technique is presented for some future applications.

(v) The source codes of the programs 'TRANSCORD' and 'HIFISS' are given in the appendices A and B respectively.