ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E1-97-195

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EMISSION OF RELATIVISTIC HEAVY FRAGMENTS AT WIDE ANGLES

FROM THE INTERACTION OF 58 GeV ^{16}O IONS WITH THICK COPPER TARGET

Submitted to «Radiation Measurements»

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1997

1. INTRODUCTION

Heavy ion collisions at higher energies have been relatively less extensively explored. The interaction studies at relativistic energies at the distant collisions and quasi-elastic processes can be distinguished experimentally from more central collisions. More central high energy collision are much more violent than at lower energies [1]. Peripheral collisions at relativistic energies could provide snapshots of zero-point fluctuations induced in the ground state by different collective modes [2,3].

In the relativistic energy region the participant-spectator model is useful for peripheral collisions, and in the central collisions explosive events may appear. The heavy ion interactions in this energy range may enable scientists to search for the novel phenomena. There could be completely unknown phenomena taking place e.g. the production of anomalons or quark-gluon plasma [4-7]. So special models and mathematical techniques are needed to describe these reaction mechanisms.

A low energy ionizing particle passing through the SSNTD produces a large hole as compared to that at comparatively high energy. That is, the diameter of the damaged region can be correlated to the energy loss of the particle. The diametric distribution of the etched pits has been used to determine the energy distribution of the α-particles, recoil nuclei, fission fragments and reaction products of different energies and at different angles using different SSNTDs [8-10]. During the last two decades the hardware and software have been developed for microprocessor based systems for automatic scanning of SSNTDs. The use of microprocessor based image analysis system enables the applications of nuclear track detectors in experiments collecting large quantity of data, which were previously impossible [11-12].

Brandt & co-workers [13-16] studied the emission of projectile fragments emitted at relatively wide angles to the incident relativistic heavy ion beam. In their experiments a beam of 44 GeV ^{12}C was incident on a thick Cu target. Cu rings of different diameters were placed at different distances from the target. Using the radiochemical activation analysis technique they observed a very high partial cross section of ^{24}Na production (in Cu rings) by projectile fragments emitted at wide angles to the incident beam. To complement the results of the interactions of relativistic heavy ions incident on thick copper target they placed SSNTDs at different angles to study the projectile fragments [17-20]. In these experiments they studied relativistic projectile fragments of 44 GeV ^{12}C, 58 GeV ^{16}O and 69 GeV ^{19}F ions incident on a thick Cu target using CR-39 detector stacks placed at different angles, particularly at 20° to 30° with the direction of initial beam. They also studied the projectile fragments of these relativistic ions produced the interaction within CR-39 plastic track detectors stacks. The projectile fragments found at angle in between 20° to 30° with respect to the beam direction were justified to be relativistic fragments, resulting in the interaction of relativistic heavy ions with the Cu target [16, 20-22]. They also observed the „through-tracks“ in the detectors of the stack placed for the recording of projectile fragments and observed the decrease in the distribution of „through-tracks“ from 20° to 30° with respect to the beam axis [23]. Their method of track analysis was based on the track diameter measurements and most of the work was carried out with computerized automatic scanning systems.

In this paper relativistic fragments of the interaction of relativistic oxygen ions with thick copper target emitted at wide angle have been studied. Using the SSNT detection technique it has been concluded that heavy projectile fragments do scatter at wide angles with respect to the incident direction of incoming beam [18, 20]. The emission of „relativistic heavy fragments“ at wide angles in the nuclear interactions in relativistic energy range is no longer a controversial subject. In this paper the „through-tracks“ in various sheets of CR-39 have been observed using an automatic track analizing system (Zeiss, Oberkochen, Germany). With the help of spatial distribution of tracks with end points at different depths of detecktors stack, the emission of relativistic oxygen, nitrogen and carbon at angles 20° to 30° w.r.t. incident direction of 58 GeV ^{16}O ions beam interacting with copper target was studied.

2. EXPERIMENTAL METHOD

Schematic representation of this experimental set up is shown in fig. 1. Four stacks of CR-39 detectors („Homolite“ Corporation, Wilmington, USA) have been used in this experiment. All the stacks were identical i.e. having (4×4) cm^2 cross sectional area and 10 cm length. A Cu disk, 1 cm thick and 2 cm in diameter, was exposed perpendicularly to a beam of ^{16}O ions with fluence of 1.5×10^9 # cm^2 and energy 58 GeV from SYNCHROPHASOTRON at the JINR, Dubna (Russia). In the present work two stacks, stack C and stack F (as shown in fig 1) have been analysed. There were 122 detectors (thickness of each detector ~ 0.82 mm) in each stack. At a distance of 11 cm under an angle of 25° with respect to beam direction we placed a 10 cm long CR-39 stack (F in Fig.19), in order to register the nuclear fragments emitted into the forward hemisphere. Another stack of CR-39 having the same dimensions, separated from the Cu-disk by 2 cm and parallel to the beam direction was exposed to the beam halo as shown in Fig.1. Since it is exposed to the projectile beam, it can be used to study the normal behavior of ^{16}O beam ion thereby providing a calibration of our detector stack.

After exposure the detectors of calibration stack (i.e. stack C in fig.1) were numbered as C1, C2, C3, ... C120, C121 and C122 while the detectors of forward stack (i.e. stack F) as F1, F2, F3, ... F120, F121 and F122. A few detectors from both the stacks were etched in 6 normal solution of sodium hydroxide (NaOH) at (70 ± 1)°C for different lengths of time followed by ultrasonic cleaning and drying diameter before carrying out the microscopic analysis. The observation of the track densities, diametric distributions, „through-tracks“ etc. were made for each etching interval. Some of these results have been previously published [20, 23] and some further results are being reported here.

Using an automatic system of recording etch-pit coordinates, a set of detectors mostly located uniformly along the entire length of the forward stack were scanned. The frequency of „through-tracks“ was measured as a function of depth in the stack. Earlier results were reported in Ref. [20].

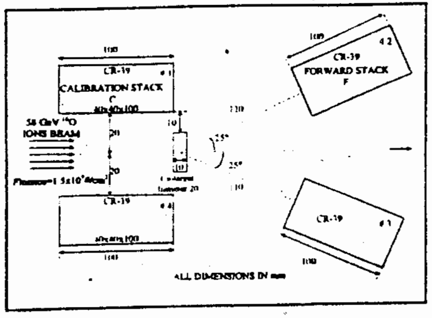

Fig.1: Schematic representation of the exposure geometry. The centrally located Cu target is perpendicularly irradiated with the beam of 58 GeV ^{16}O ions having a fluence 1.5 • 10^9 #/ cm^2 at the SYNCHROPHASOTRON, JINR, Dubna, Russia. There are 122 detectors in each stack. Thickness of each detectors is ~ 0.82 mm.

3.RESULTS AND DISCUSSION

The track density in some selected detectors of stack F was measured and is plotted as a function of depth in the stack as shown in Fig. 2. There is about 3-fold reduction in a track density within the first 5 mm of this stack (stack F) as shown in fig.2. This sudden decrease is obviously because of the presence of significant numbers of low energy particles which are quickly stopped in this stack (stack F). The tracks found in the detectors of the stack F after 5 mm are due to the energetic nuclear fragments having charge (Z < 8), emitted at an angle of 25° with respect to the incident beam, as result of interactions of 58 GeV ^{16}O ions with Cu target. [20]

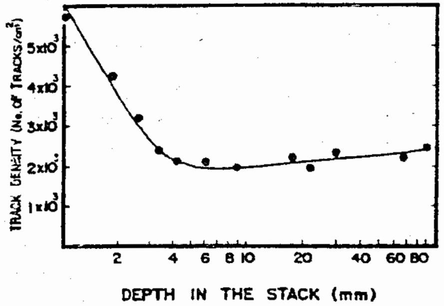

Fig.2 The variation of track density as a function of depth into the stack F.

From the chosen detectors, detector # 6 (F6), #24 (F24), #54 (F54) and #121 (F121) were etched under identical conditions for 20 hours. The diameter distributions measured manually are shown in Fig. 2 of Ref. [23]. The presence of distinct peaks at lower than (40 -

44) μm, indicate that the ions of charge lower than that of ^{16}O arrive at the stack which is placed at an angle of 25° with the beam direction. With the present statistics, it is not possible to isolate separate groups to be identified with individual charge states $Z < 8$. In the absence of a clear undestanding of the reaction process involved, it is difficult to estimate energies of these fragments as well. The only significant conclusion that can be drown from these limited observations was that the projectile fragments do scatter to angles which are considered large for incident beam of 58 GeV ^{16}O ions.

3.1 "Through-Tracks"

The track etch velocity depends on the ionisation power (directly proportional to the Z/β of the incident ion) of the ion producing the damage trail in the dielectric track detector. Futhermore, as the velocity of ionizing particle is increased, its power to ionize the atoms or molecules of the detector material is decreased. Therefore, a solid state nuclear track detector needs a long etching time for the relevation of a through hole track to see the path of the ion producing the etchable damage trail. The etching of the detector for a long time changes the shape of the track on the detector, so the parameters of the tracks like diameters, cone angles etc. can not be determined accurately. Therefore, a short etching time is feasible for the accurate estimation of the properties like masses, charge etc. of the particles producing the tracks in the detector. At short etching time the impact of a high energy charged particle on an SSNTD can only be revealed on the front and back surface of the detector. In such circumstances a particle is said to have passed through the detector if some parameters, like diameter cone angle etc. of the track are comparable on the entering and exiting surfaces of the detector. In present studies the detectors stack F (as shown in Fig. 1) has been placed at 25° with the initial direction of the projectile beam in order to observe the wide angle emission of nuclear fragments produced in the reaction ^{16}O + ^{nat}Cu. The average thickness of a detector in stack F was ~ 0.82 mm. As the stack F is not normally incident for every fragment ensuing from the target as a result of ^{16}O ion interactions with copper, therefore observing through an optical microscope (normal to the plane of the detector) the tracks formed by the particle on front side of the detector can not be found exactly at the same position as on back side of the same detector. It has been calculated that a fragment which passes through the detector can exit within a circular range of (0-174) μm with respect to the normal to the entering position on the detector. In the present work the tracks found on the back side of a detector with diameters same as on the front side within the above mentioned circular range are correlated and are named as "through-holes". The wide angle emission of projectile fragments in relativistic heavy ions collisions is supported by the presence of so-called "through-tracks" in the forward stack F. A "through" track is defined as an etch-pit which has correlated co-ordinates with respect to all preceding detector foils. Thus it represents the distance penetrated by a nuclear fragment in the forward stack. Using an automatic system of recording etch-pit coordinates, a set of detectors mostly located uniformly along the entire length of the forward stack have been scanned. The frequency of "through-tracks" has been measured as function of depth into the stack F which has been shown in fig.3. The rapid decrease of number of "through-tracks" within the first few detectors of the stack can be neglected because these are due to the particles which are certainly non-relativistic. However a rather smooth decrease of the number of "through-tracks" between the depth of the stack from 30 mm to 50 mm is expected for relativistic particles slowly absorbed within the stack F. The change of the slope of the number of "through-tracks" at the detector number about 80 is interesting. Presently, we can give no interpretation for this phenomenon.

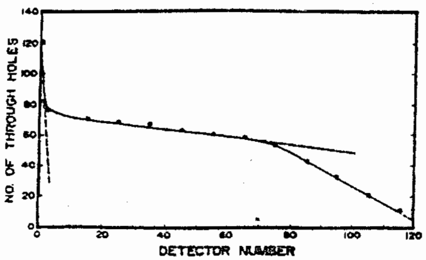

Fig.3 The decrease of "through-tracks" starting in the first detector and ending in a given detector of stack F.

3.2. Spatial Distribution of "Through-tracks"

The detector for which the "through-tracks" were measured as shown in Fig.3 have been analysed again for further confirmation. A computer controlled automatic scanning system (Zeiss, Oberkochen, Germany) has been employed to "trace" the etched damaged trails in the respective detectors. The spatial distribution of tracks with end points at various depth in the stack F have been recorded. To observe the spatial distribution of "through-tracks", (4 × 4) cm² area of each detector, has been scanned. The spatial distribution of "through-tracks" which disappeared at different depths in the stack F have been shown in fig.4 (a,b,c,d). Fig 4(a) shows the spatial distribution of tracks stopped within detector # F1 and F5. After calibration it has been concluded that these "through-tracks" are due to light particles having charge < 6. From detector #F6 to F119 the spatial distribution of "through-tracks" has been obtained in three steps as shown in fig. 4 (b,c,d). Three types of different track diameters have been observed stopping at different depths into the stack F. Different symbols corresponds to different groups of diameters associated with particles making "through-tracks" as shown in fig.4 (b,c,d). A preliminary calibration indicates that these track diameters corresponds to relativistic particles having Z = 6, 7, 8 as shown in fig.4 (b,c,d). According to the classification open circles correspond to oxygen ions, filled circles correspond to carbon ions and filled squares correspond to nitrogen ions.

In Fig 5 area distribution of "through-tracks" dissappearing within 60mm of the stack F have been shown. Three types of "through-tracks" have been observed. They are not centered at edges, but they are well distributed over the area, just as one can expect it for tracks starting at the Cu target (as shown in the exposure geometry, Fig.1). A decrease of "through-tracks" corresponding to open circles and filled circles, open squares going from 20° to 30° with respect to the incoming beam axis has been observed.

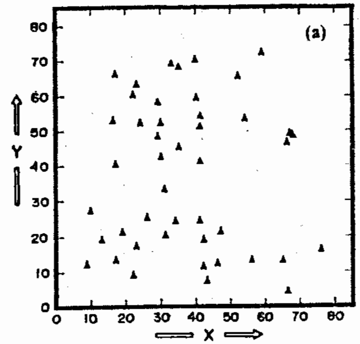

Fig.4(a) Spatial distribution of "through-tracks" stopped within detector #F1 and F5. These tracks are due to light particle having Z<6. The coordinates of the axis are arbitary.

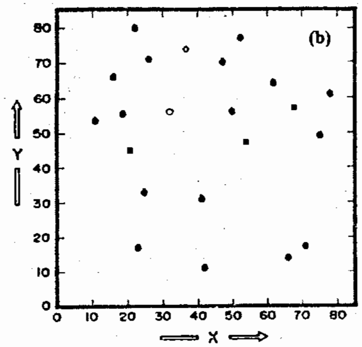

Fig.4(b) Spatial distribution of "through-tracks" disappeard between detector #F6 and #F70. Open circles correspond to oxigen ions, filled circles correspond to carbon ions and filled squares correspond to nitrogen ions. The coordinates of the axis are arbitary.

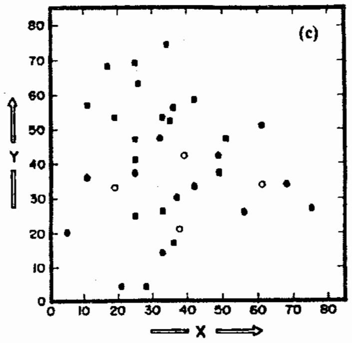

Fig 4(c) Fig.4(a) Spatial distribution of "through-tracks" disappeard between detector #F71 and F106. Open circles correspond to oxigen ions, filled circles correspond to carbon ions and filled squares correspond to nitrogen ions. The coordinates of the axis are arbitary.

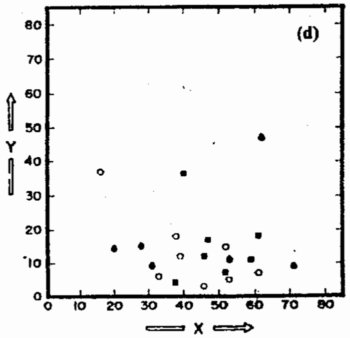

Fig.4(d) Spatial distribution of "through-tracks" disappeard between detector #F107 and #F119. Open circles correspond to oxigen ions, filled circles correspond to carbon ions and filled squares correspond to nitrogen ions. The coordinates of the axis are arbitary.

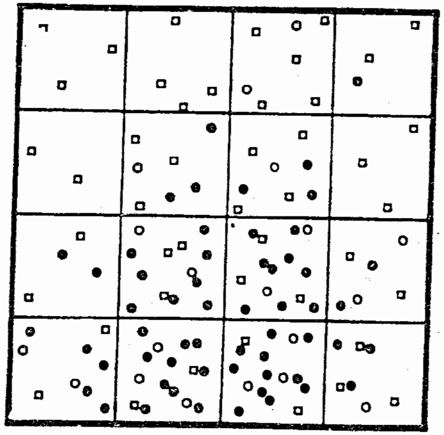

Fig.5. The area distribution of the "through-tracks" (as shown in fig.2) stopped within approximately 60 mm depth into the stack F. The area is of a size of (4×4) cm^2. The track density decreases with increasing angle, given the angle with respect to the insident beam axis. The filled circles correspond to oxigen ions, open circles correspond to carbon ions and open squares correspond to nitrogen ions. The botton of this figure corresponds to 20°, the top to 30° with respect to the beam direction.

4. CONCLUSIONS

The density of the tracks at different depths into the stack F has been measured. A sudden decrease in the track density within first 5 mm of stack F has been observed. This decrease is due to the reaction products having low energy and they are quickly stopping within first few detectors of the stack F. There is no effect of these low energy particles beyond the depth of 5 mm because the track density is approximately uniform in the range of 5 mm to 10 mm as shown in fig.2. The tracks found in the region beyond 5 mm depth into the stack F are due to relativistic nuclear fragments having Z<8.

The diametric distribution of "through-tracks" can help to estimate the charges of the nuclear species producing these tracks. After calibration it has been concluded that the "through-tracks" disappearing within a depth of 6 mm into the stack F are due to the particles having charge numbers less than 6.

Three types of "through-tracks" with different diameters have been observed which are due to the particles stopped beyond the depth of 6 mm. After calibration it has been confirmed that these diameters of "through-tracks" are produced by the relativistic C, N and O particles.

The area distribution of the "through-tracks" which stopped within a depth of 60 mm in the stack F shows, that these tracks are well distributed over the detector area just as it is expected from the exposure geometry. A decrease of "through-tracks" has also been observed going from 20° to 30° with respect to incident beam of (58 GeV) ^{16}O ions.

The authors want to thank the operating crew at the Synchrophasotron of the Laboratory of High Energies, JINR (Dubna, Russia) for the irradiations and Academician A.M.Baldin as well as Professors A.I.Malakhov, I.B.Issinsky and A.D.Kovalenko for their continued support of this work.

The authors thank Prof. Yu.A.Panebratsev, Drs. S.S.Shimansky and Yu.S.Averichev for their support in carrying out the irradiations of the targets at the F3 focus of the DISK installation.

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Received by Publishing Department
on June 19, 1997.

Шахзад М.И. и др. E1-97-195

Эмиссия релятивистских тяжелых фрагментов в широком угловом интервале при взаимодействии пионов ^{16}O с энергией 58 ГэВ с толстой медной мишенью

Фрагментация релятивистских ядер исследовалась в гибридных экспериментах с использованием методов ядерной спектроскопии и твердотельных трековых детекторов. Тяжелые фрагменты, образующиеся во взаимодействиях ядер ^{16}O с энергией 58 ГэВ с медной мишенью, изучались с помощью комплексной сборки ядерных трековых детекторов CR-39, которая помещалась под углом 25 ° к направлению бомбардирующего пучка.

При «прослеживании» протравленных треков в детекторах на сканирующей системе, управляемой ЭВМ, были обнаружены тяжелые продукты реакций, образующие основные отверстия в слоях детекторов CR-39, а также измерено пространственное распределение треков, которые оканчиваются на разных глубинах детекторов.

С учетом калибровки сделано заключение, что эти сквозные треки образуются релятивистскими фрагментами O, N, и C, генерируемыми при взаимодействиях ядер ^{16}O (58 ГэВ) с толстой медной мишенью. Установлено, что дифференциальные угловые сечения уменьшаются с увеличением угла к направлению первичного пучка и с ростом заряда продуктов ядерных реакций.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1997

Shahzad M.I. et al. E1-97-195

Emission of Relativistic Heavy Fragments at Wide Angles from the Interaction of 58 GeV ^{16}O Ions with Thick Copper Target

Relativistic projectile fragmentation has been studied with the help of hybrid experiments using radiochemical and track detection methods. The heavy fragments produced in the interaction of 58 GeV ^{16}O with thick copper target have been studied using thick stacks of CR-39 nuclear track detectors placed at 25 ° with respect to the direction of incoming beam. A computer controlled automatic scanning system was employed to «trace» the etched damaged trails in respective detectors of the CR-39 stack. The heavy reaction products producing «through-tracks» in various sheets of CR-39 detectors were observed. The spatial distribution of tracks with end points at various depths have been recorded. After calibration it has been concluded that these «through-tracks» are due to relativistic O, N and C. The fragments are emitted from the interaction of 58 GeV ^{16}O ions with thick copper target. The differential angular cross section was found to decrease with increasing angle with respect to the incident beam direction and with increasing charge of the reaction products.

The investigation has been performed at the Laboratory of High Energies, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna, 1997