Eur. Phys. J. A **27**, s01, 201–204 (2006)
DOI: 10.1140/epja/i2006-08-031-8

EPJ A direct
electronic only

Study of fission fragments produced by ^{14}N + ^{235}U reaction

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Received: 8 July 2005 /
Published online: 8 March 2006 –

Abstract. This work was performed to understand the structure of neutron-rich fission fragments around the 130 mass region. A thin ^{235}U target was bombarded by a ^{14}N beam with 10 MeV/A from the Separated Sector Cyclotron at the iThemba Laboratory for Accelerator Based Sciences, Cape Town, South Africa. The main goal was to detect and identify fission fragments and to obtain their mass distribution by using solar cell detectors in the AFRODITE (African Omnipurpose Detector for Innovative Techniques and Experiments) spectrometer. The X-rays emitted from fission fragments were detected by LEP (Low Energy Photon) detectors and γ-rays emitted from excited states of the fission fragments were detected by CLOVER detectors in the spectrometer.

PACS. 25.70.Jj Fusion and fusion-fission reactions – 21.10.Gv Mass and neutron distributions

1 Introduction

The studies for heavy-ion–induced fusion-fission reaction have attracted a great deal of attention in recent years due to the expansion of the knowledge and understanding of the structure of neutron-rich fission fragments. There are two mechanisms of the fusion-fission reaction when bombarding a heavy target with a high-energy beam well above the Coulomb barrier: low-energetic fission and deep-inelastic processes. Asymmetric fission as a result of the former mechanism is a process dominated by shell effects and the heavy fragment is a neutron-excessive nucleus having approximately 50 protons and 82 neutrons. Since the beam energy is well above the Coulomb barrier, a few nucleons are evaporated and the mass of the fragments is shifted towards the line of stability. Thus, the interplay between the target-projectile combination and the variation of the projectile energy provides a possibility of moving the centroid of the fragment mass distribution throughout the (N, Z)-plane and accessing nuclei which cannot be produced in spontaneous fission or through symmetric fission [1,2]. Therefore, other reaction mechanisms needed to be utilized in these cases.

In a previous study, Yu *et al.* [3] investigated the reaction ^{12}C + ^{238}U at 20 MeV/A and demonstrated that with the increase of the beam energy deep-inelastic processes begin to compete with fusion-fission reactions for which, the asymmetric fission channel is open when using actinide targets.

Recently, in the low-energy proton-induced fission of actinides, it has also been demonstrated that there exist at least two independent deformation paths for fission process; one leads to a symmetrically elongated scission configuration, and the other leads to a compact scission configuration with reflection asymmetry [4].

In this work, we present an experiment to investigate nuclei around the 130 mass region utilizing the ^{14}N + ^{235}U reaction at 10 MeV/A. In order to obtain the fragment mass distribution directly from the reaction given above, a thin target and solar cell array have to be used. This arrangement will also give opportunity to correct Doppler shift due to the fission fragments decaying in flight as well as direct fragment identification.

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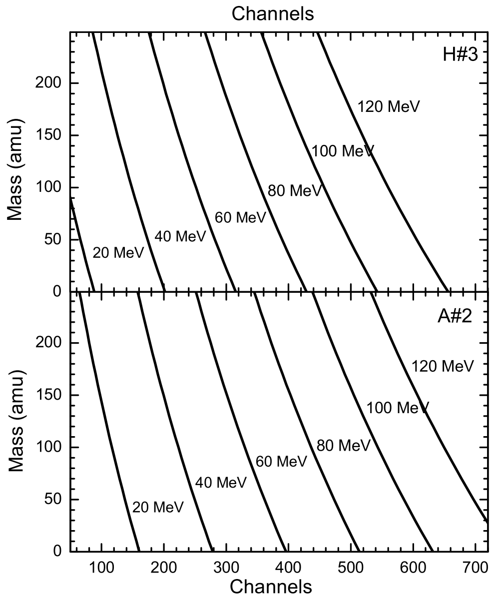

Fig. 1. The Channel-Energy-Mass dependency obtained for the H3 and A2 solar cell detectors.

2 Experiment

We used ^{14}N + ^{235}U reactions in order to produce fission fragments. The 140 MeV ^{14}N beam for these experiments was delivered by the Separated Sector Cyclotron at the iThemba Laboratory for Accelerator Based Sciences, Cape Town, South Africa. The ^{14}N projectile was chosen in order to somewhat enhance the production of odd-Z isotopes. The γ decay and the X-rays after the reaction were detected by the AFRODITE spectrometer, which consisted of seven Compton-suppressed CLOVER detectors and eight large-area LEPs detectors. This spectrometer is described in detail in ref. [5].

The reaction chamber had Mylar windows. All this allowed to have a detection limit for the X-rays as low as 8–10 keV. A thin 500 μg/cm^2 target of ^{235}U was used in the experiment. Solar cell detectors, positioned at forward angles, were operated together with the AFRODITE spectrometer, which allowed measurement of fragment–γ–X-ray coincidences.

3 Results

The response of solar cell detectors have to be calculated since the energy of incoming fragments from the fission is not exactly proportional to the deposited energy due to the Pulse Height Defects (PHD). Due to PHD, the energy of fission fragment, E, can be related to the signal observed by surface barrier semiconductor/solar cell detector used for the detection of heavy ions:

$$E = (a + a^{'}M)x + (b + b^{'}M), \qquad (1)$$

where, M is the mass of fragment, a, $a^{'}$, b and $b^{'}$ are the coefficients of the charged-particle detector used. These

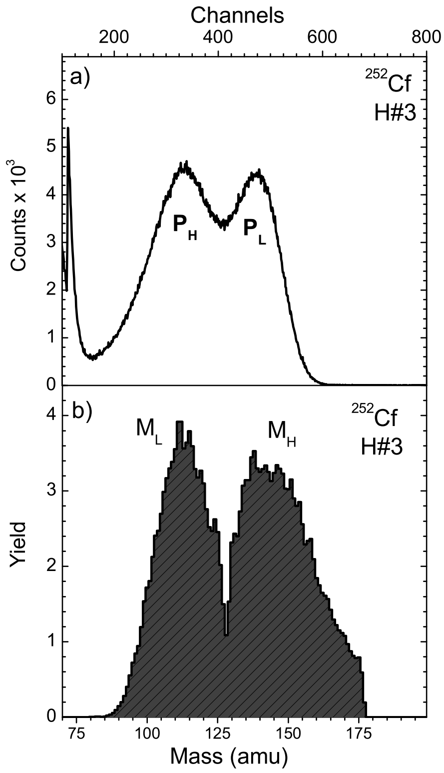

Fig. 2. a) The pulse height spectrum of ^{252}Cf obtained with the H3 solar cell detectors. b) The unfolded mass distribution of ^{252}Cf normalized to 200.

coefficients were determined by using Schmitt's Calibration Method described in [6]. In this calibration procedure, pulse height spectra of the fragments from ^{252}Cf spontaneous-fission source were obtained by using the solar cells. Then using the iterative processing algorithm suggested by Houry [7], the mass distributions of ^{252}Cf were obtained. The Energy-Channel-Mass dependency obtained for H3 and A2 solar cells are shown in fig. 1. In figs. 2a and 3a, the pulse height spectra and in figs. 2b and 3b, the unfolded mass distributions of ^{252}Cf are shown. In figs. 2b and 3b, the mass distributions were normalized to 200 and smoothed with using 3 channel averaged method. The calibration and unfolding results plotted in figs. 2 and 3 are based on average neutron multiplicity for each fragment [8] and the well-known ^{252}Cf mass distribution [9,10,11].

As can be easily seen, there are two prominent humps determined as

$\langle A_L \rangle$ = 108–109 amu and $\langle A_H \rangle$ = 144 amu in the mass distribution corresponding to the light and heavy fission fragments, respectively, are in good agreement with a literature values $\langle A_L \rangle = 108.9 \pm 0.5$ amu and $\langle A_H \rangle = 143.1 \pm 0.5$ within the experimental accuracy [9].

Solar cell detectors calibrated using the method given above were then used for detecting fission fragments from the ^{14}N + ^{235}U fusion-fission reaction. As has been already indicated above, all solar cell detectors are positioned in forward angles allowing only one of the two fis-

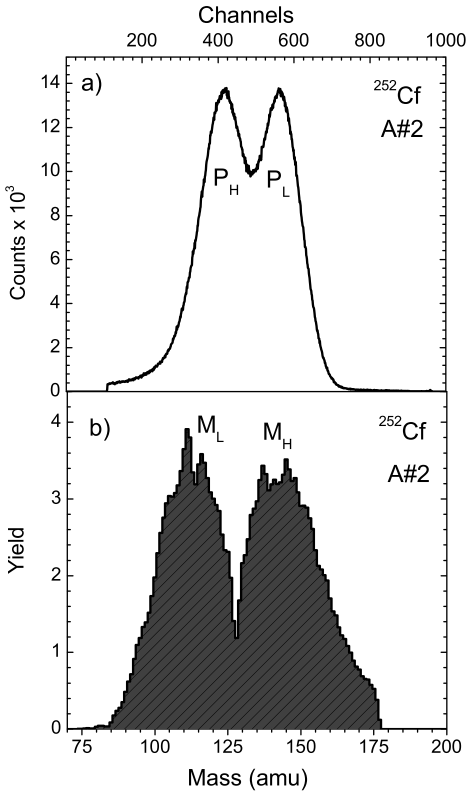

Fig. 3. a) The pulse height spectrum of ^{252}Cf obtained with the A2 solar cell detectors. b) The unfolded mass distribution of ^{252}Cf normalized to 200.

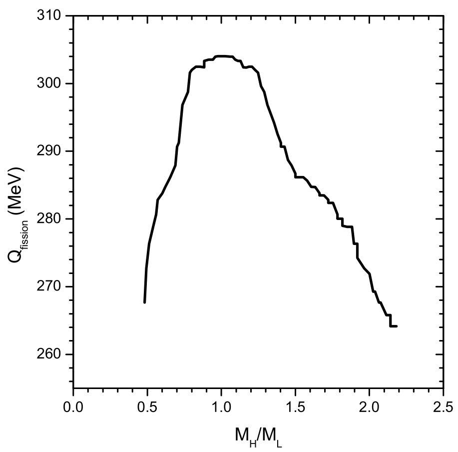

Fig. 4. The M_H/M_L dependency of $Q_{fission}$ calculated for the ^{245}Es fissioning nucleus.

sion fragments to be detectable. In order to determine the energy of the undetected complementary fragment, the total kinetic energy release from the fission and total excitation energy of the fragments have to be known. The total kinetic energy of fission fragments was taken from the Viola systematics [12] with mass asymmetry dependency [13], while fragment masses were taken from the Möller Mass Table [14] and then they were used to deter-

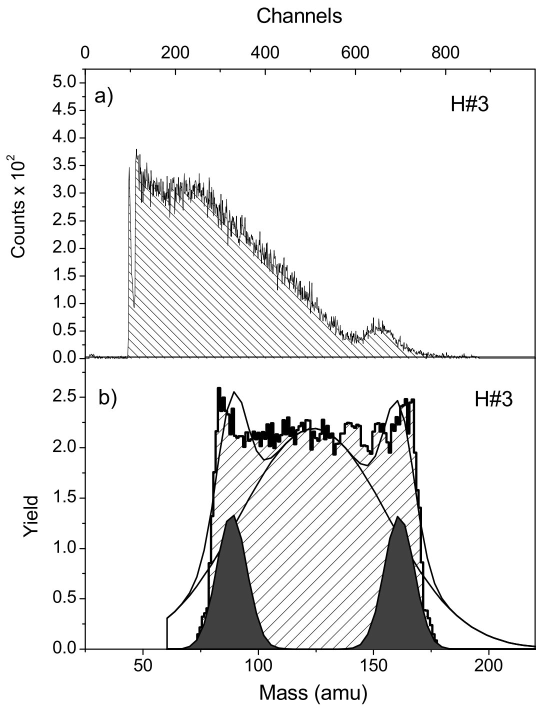

Fig. 5. a) The pulse height spectrum obtained with the H3 solar cell detector for the $^{14}N+^{235}U$ reaction. b) The fitted unfolded mass distribution of $^{14}N+^{235}U$ normalized to 200.

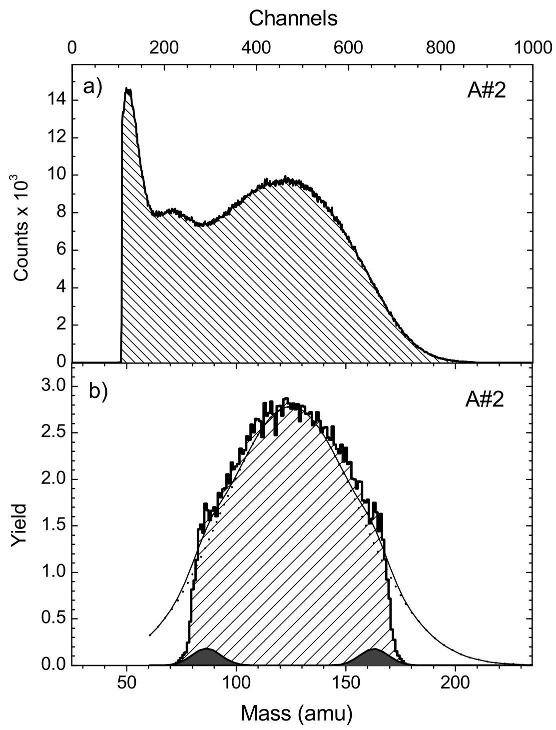

Fig. 6. a) The pulse height spectrum obtained with the A2 solar cell detector for the $^{14}N+^{235}U$ reaction. b) The fitted unfolded mass distribution of $^{14}N+^{235}U$ normalized to 200.

mine the maximum reaction energy as a function of the mass ratio M_H/M_L, where M_H and M_L are the mass of the heavy and the light fragment, respectively. Figure 4 shows the fission Q-value dependency on the M_H/M_L ratio for ^{245}Es assuming that the number of pre-fission neutron evaporation $\nu_{pre} = 3.69$. The average number of neutrons evaporated ν_{pre} and ν_{post} were taken from ref. [15].

The pulse height spectra of the fission fragments are shown in figs. 5a, 6a and the unfolded mass distributions of the fission products are shown in figs. 5b, 6b. The unfolded mass distributions were obtained with the same method mentioned above using the iterative processing algorithm of Houry [7].

4 Conclusion

The mass distributions obtained from solar cell detectors for ^{14}N + ^{235}U reactions in figs. 5b and 6b were subjected to further investigation by fitting the whole mass distributions to sum of three Gaussian functions. The masses of fragments formed in the area are in the range of 75–180 amu. The thick solid curve in figs. 5b and 6b is the results of the fit assuming that there are one dominant symmetric and two asymmetric components. These Gaussians are centered around 124 amu with $\sigma = 57$ (for the A2 solar cell) and $\sigma = 64$ (for the H3 solar cell) for the symmetric and around 87 amu and 162 amu with $\sigma = 13$ for both the asymmetric components. In figs. 5b and 6b, the dark grey Gaussian-like distributions can be attributed to the shell closures, which have been observed in ref. [16] and ref. [17].

It can be concluded that the asymmetric channel could be opened, hence the neutron-rich nuclei heavier than those produced in the spontaneous fission could be obtained [18,19,20]. It could also be concluded that by employing solar cells in the array improves the mass selectivity by direct fragment identification.

This work was supported by the Research Fund of the University of Istanbul, Project numbers UP-12/040199 and UP-8/270598.

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