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Ternary particles of Z =1 to 4 emitted in spontaneous fission of ^{252}Cf

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This paper presents the results of ternary light charged particles from ^{252}Cf spontenous fission source. The method ΔE - E was applied to identify the particle by a position sensitive ΔE - E telescope.The specific energy loss (ΔE) was measured using the transmission type ΔE detector (thicknesses of 150 μm) ordered from the company Micron Semiconductors, while the residual energy (E) was measured by a Timepix detector with thicknesses of 600 μm . It was possible to measure partial-energy spectra of the various ternary particle types due to the thicknesses of Al foil (31 μm) and ΔE detector (150 μm) placed before E detector. The energy spectrum of protons was qualitatively different from the spectra of the other particles since protons from Al(n,p) and Si (n,p) reactions could contribute to the spectra.

Keywords: Ternary fission; ΔE - E method; Timepix pixel detector; ΔE detector; silicon detector

Introduction

Nuclear fission was discovered more than 80 years ago, but there is still no single theory that successfully explains all aspects of this process. Binary fission when the fissioning nucleus splits into two main fragments of approximately equal size is more studied, however, significant aspects of the physics of the process are manifested in fission into more fragments. It is also possible the nuclear splits not only into two but into three or four fragments [1-4]. In ternary fission, the nucleus is divided into two heavy fragments, with the emission of a light particle [4-6]. In addition to ternary fission, there is a rarer process called quaternary fission when the nucleus splits into four fragments. Two relatively light and two heavy fragments are observed in this fission process [4-6]. Studying these nuclear processes could give information about the mechanism of nuclear fission, so these particles carry information on statistic and dynamic properties of fissioning nuclei at the scission point [4, 7-9]. To study these processes, an experimental setup was assembled consisting of three position-sensitive ΔE - E semiconductor telescopes and a silicon detector. Measurements were done using ^{252}Cf spontaneous fission source and the preliminary results from only one telescope (telescope 2) were presented.

Experiment

A picture of the detection system are presented in Figure 1. It consists of thee ΔE - E telescopes and an array of Si detectors to register main fission fragments. The first and third telescope consisted of ΔE detector with 15 μm and Timepix with 300 μm thicknesses, while the second of ΔE detector with 150 μm and Timepix with 600 μm. Si detectors were ordinary PiN detectors with an area of 20x20 mm^2 and thicknesses of 300 μm. Thin detectors with an area of 10x10 mm^2 were used to measure ΔE measurements. Timepix pixel silicon detectors with an area of 14x14 mm^2 were used as E detectors so that they could provide information about the energy, coordinate and interaction time of particles with detector material. The signals coming from the telescopes were processed by standard analog and digital electronics. FITPix COMBO [10-12] electronic module was used to control and acquire signals from Timepix detectors. This module acquires signals from the backside electrode and pixel part of Timepix (both in parallel). Spectrig [10-12] device was used for controlling ΔE detectors and the acquisition of signals from them. It is controlled by IEAP spectrometry (software) [10-12]. Readout interface FITPix biases and controls the Timepix detector [10-12]. Pixelman software is developed user-friendly to control the interface [10-12]. A specially designed synchronization bus was used to synchronize the detection system. The bus was integrated into the FITPix COMBO device. The clock bus has also been designed to manage the trigger and busy signal to provide efficient filtering of unpaired events when performing coincidence measurements. Any combination of Timepix or Spectrig instruments (up to 32) can be connected to create a final measurement setup. The synchronization system is discussed in detail [10-11]. The trigger signal arising from simultaneous detection by detectors of the telescope ensured synchronization with the operation of the remaining detectors.

A thin ^{252}Cf spontaneous fission source was used in the measurements. The activity of the source was about 375 kBq. It has Al_2O_3 backing with a 60 mg/ cm^2 thicknesses and a diameter of 18 mm. The other side of the source was coated with a gold layer of less than 10 mg/cm^2. These characteristics of the source made main fission fragments emit into both side with energy loss of about 4 MeV. The source was in a round form with a diameter of 3.5 mm. The uniformity of the source was within 20%. The vacuum was maintained at <0.4 mBar inside

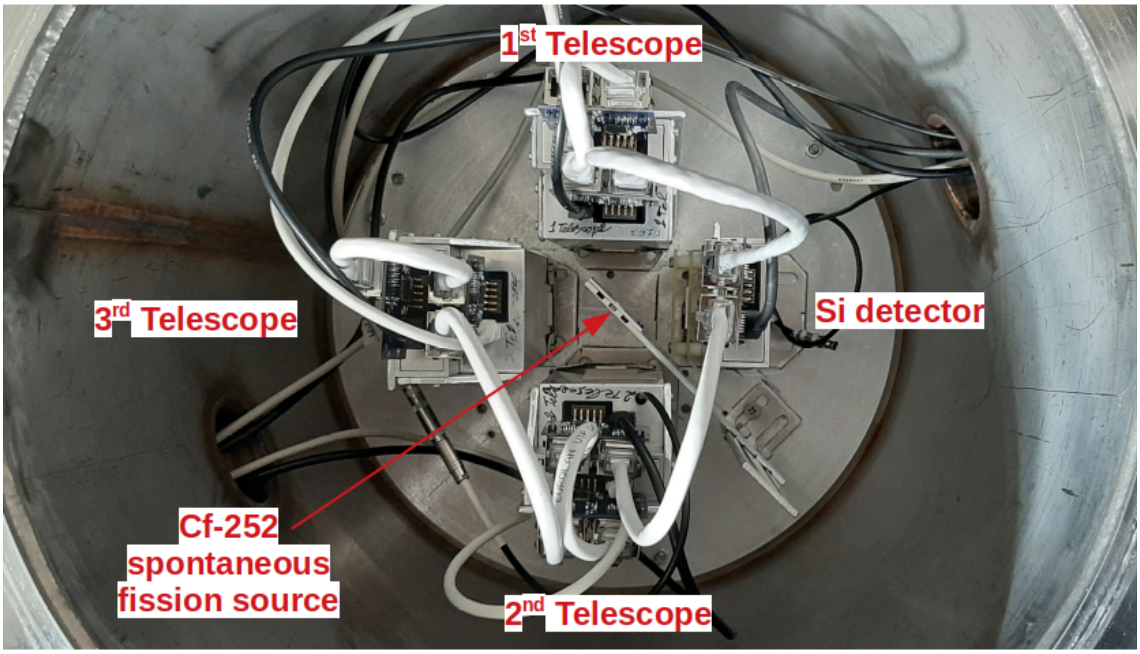

Figure 1. A picture of the detection system.

the vacuum chamber. Three telescopes and one E detector are oppositely placed at 5 cm from the source. An aluminum foil with 31 μm thicknesses was placed between the source and the detectors, which ensured the complete absorption of main fission fragments and alpha particles from the spontaneous alpha decay of ^{252}Cf (6.2 MeV). Thus, the detectors registered only particles from ternary fission. All information obtained about the registration of light particles was recorded sequentially on a PC for offline analysis.

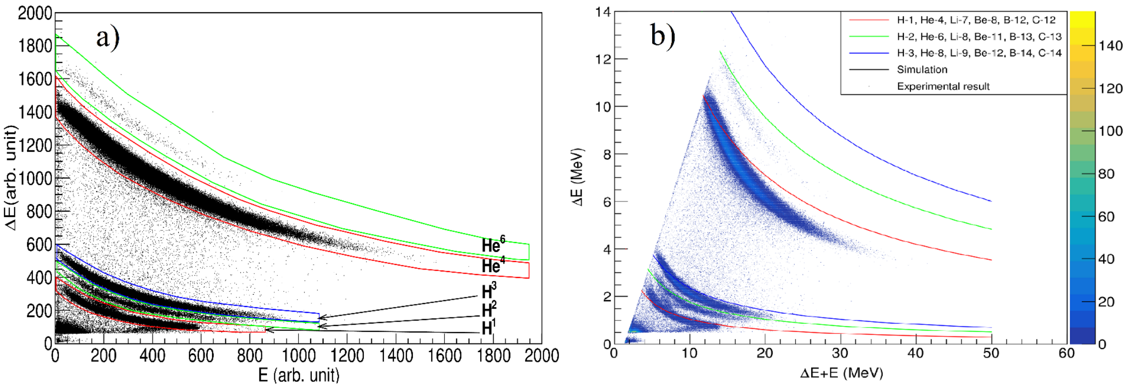

Figure 2. The experimental and simulated ΔE - E patterns from ternary LCPs. The contour lines define the identification windows used for the analysis. 31 μm thick Al foil was used for protecting the telescopes from being hit by fission fragments and the 6.2 MeV background alpha particles.

Results

Uncalibrated (a) and calibrated (b) ΔE - E spectra of ternary particles were shown in Figure 2. Simulation was carried out by SRIM [13] and the simulated spectrum was plotted on the calibrated ΔE - E spectrum in order to compare results. As shown in Figure 2 (b), there exist cut-off energies due to the thickness of Al foil and ΔE detector. It was registered that particles go through Al foil and ΔE detector and lose some part of energy in the E detector. It was ignored that events related to such particles completely lose their energy in the ΔE detector. The events did not allow identifying particles, so there was no information about E energy. As shown in Figure 2, the telescope allows identifying ternary particles from protons (H^1) to He^6. Telescope did not allow identifying isotopes heavier than He^6 due to the thickness of the ΔE detector and the limitation of the electronic system.

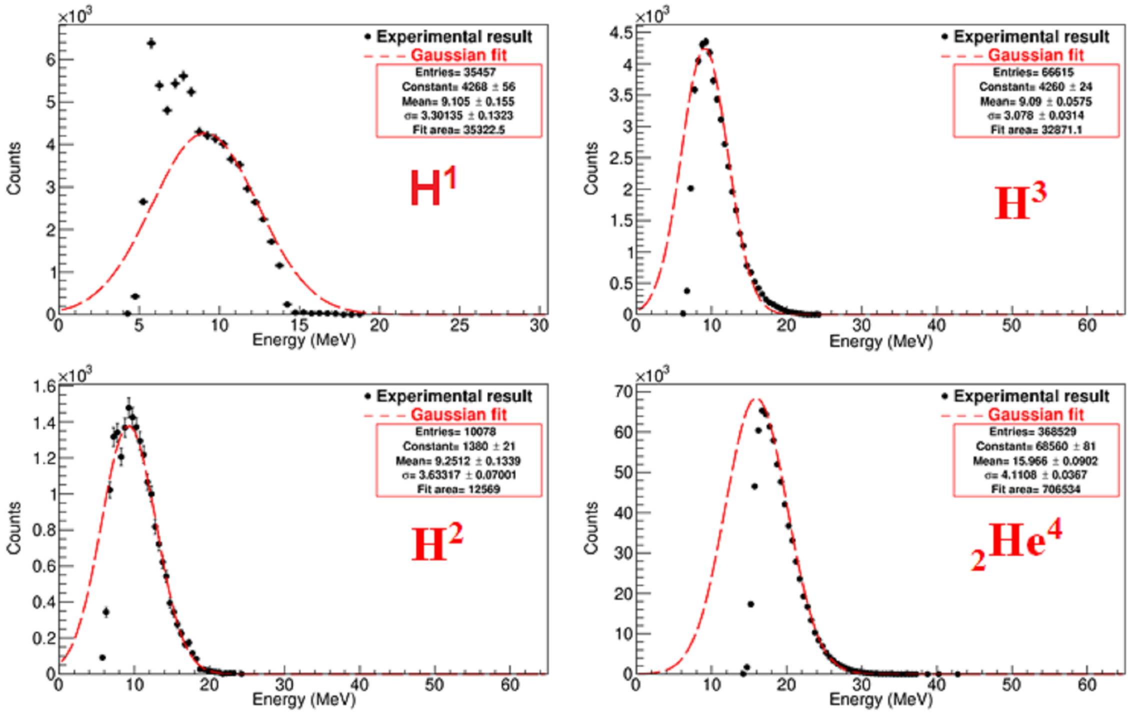

Figure 3. Energy spectra of ternary particles from ^{252}Cf spontaneous fission source, measured at different detection thresholds.

One must take into account the energy losses of different particles in Al foil in order to correct energy spectra. For these purposes, we used the cut method as shown in Figure 2 (a). A specially written program in ROOT [14] was used to utilize cut and SRIM information to recover energy spectra. For H^1 isotopes, cut-off energies were observed on both sides of the spectra due to the thickness of the telescope and Al foil. The thickness of the telescope was not enough to stop H^1 particles. Figure 3 presents the energy spectra of the ternary particles.

The spectra were fitted by the Gaussian function in order to determine the energies and FWHMs (2.35*σ) of ternary particles. The table presents the results obtained in the experiment. A comparison of the results with the literature is shown in Table 1, too. As shown in Table 1, the experimentally observed energies of ternary particles are in good agreement with the results of other authors within errors.

Table 1.
Summary of data obtained from the spontaneous ternary fission of ^{252}Cf.

Ternary particles	Measured energy range, MeV	Energy, MeV	Sigma, MeV	Energy, MeV [Ref.]
H^1	5 - 14.5 MeV	9.11 (0.16)	3.30 (0.13)	9.0±2.0[15] 7.8±0.8 [16]
H^2	6.5 - 25 MeV	9.25 (0.14)	3.63 (0.07)	7.0±2.0[15] 8.0±0.5[16]
H^3	7 - 25 MeV	9.09 (0.58)	3.08 (0.03)	7.8±0.1[5] 8.0±1[15] 8.0±0.3[16] 9.0[17]
He^4	16.5 - 40 MeV	15.97 (0.09)	4.11 (0.04)	15.7±0.1[5] 15.7±0.2[6] 15.7±0.2[17]

Conclusion

Ternary particles of Z=1 to 4 from spontaneous fission source ^{252}Cf were studied using the ΔE - E position-sensitive charged particle telescopes consisting of transmission type ΔE detector (150 μm) and hybrid pixel detector - Timepix (600 μm). The telescope was able to identify ternary particles starting from H^1 to He^6. Studied energy ranges of ternary particles were different due to the thickness of the telescope and using shielding Al foil. The energy spectra of H^1, H^2, H^3 and He^4 were found to have maxima at 9.10 $\pm$ 0.16, 9.25 $\pm$ 0.13, 9.09 $\pm$ 0.06, 15.97 $\pm$ 0.09 MeV and sigma of 3.30 $\pm$ 0.13, 3.63 $\pm$ 0.07, 3.08 $\pm$ 0.03, 4.11 $\pm$ 0.03 MeV, respectively. These results coincide well with the results of other authors. Utilizing the fact that energy spectra of H isotopes exhibit the most probable energy of about 9.0 MeV with a sigma of about 3.3 MeV, one might expect the release mechanism of these particles to be the same.

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