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Multiplicity distribution of prompt gamma rays in spontaneous ternary fission of ^{252}Cf

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Abstract. The first and the second moments of the multiplicity distribution of prompt gamma rays in spontaneous ternary fission of ^{252}Cf have been measured by the multiple coincidence technique. While both these moments were found to be nearly independent of the energy of the light charged particle accompanying the fission fragments, the width of the multiplicity distribution was larger than that in the case of normal binary fission by about 20%.

Keywords. Spontaneous ternary fission of ^{252}Cf; prompt gamma ray multiplicity distribution; multiple coincidence technique.

1. Introduction

It is known that once in few hundred binary fissions, a light charged particle (LCP) accompanies the two fission fragments. A study of the characteristics of this mode of fission (ternary fission) is expected to provide useful information not only on the mechanism of charged particle emission in fission but also on the fission process itself. Comparison of binary and ternary fission characteristics have been made in the past as regards fragment mass, kinetic energy distributions, neutron and gamma emissions, etc. (Halpern 1971, Feather 1969). From a study of neutron and gamma ray emission in binary and ternary fission, it is known that the excitation energy of the fragments is on the average less in ternary fission than in binary fission. However, detailed investigation on many aspects of neutron and gamma ray emission in ternary fission is lacking. Some measurements have even yielded conflicting results. For example, in a measurement of the average number of gamma rays per ternary fission, $\bar{\eta}$, Adamov *et al* (1967) found that $\bar{\eta}$ is nearly independent of the energy of LCP, whereas the results of Ajitanand (1969) show a sharp increase in $\bar{\eta}$ for $E_{LCP} > 17$ MeV. In the present work we have carried out measurements of the first and second moments of the prompt gamma ray multiplicity distribution in spontaneous ternary fission of ^{252}Cf by means of multiple coincidence technique. The measurements were carried out as a function of the energy of the LCP.

2. Experimental method and results

Figure 1 shows a schematic diagram of the experimental set up. The ^{252}Cf source and the LCP detector were mounted inside an evacuated chamber. A thin aluminium

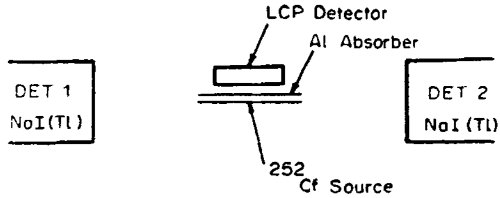

Figure 1. Schematic diagram of the experimental assembly.

absorber of about 8 mg/cm^2 thickness was used to stop the fission fragments and the natural alpha particles from the ^{252}Cf source. Two NaI(Tl) detectors of $2'' \times 2''$ dimension were placed at about 10 cm each from the source to detect the prompt fission gamma rays. After suitable electronic processing of the pulses, coincidences were taken between the LCP detector pulse and each of the two gamma detectors to give gates corresponding to double coincidence events and all the three detectors to give gates corresponding to triple coincidence events. The spectrum of the LCP detector pulses was recorded in the first quadrant of a 1024 channel analyser and routed to 2nd, 3rd and 4th quadrants by means of the coincidence gates. Thus the 2nd and 3rd quadrants contained the LCP energy spectra corresponding to coincidences between the alpha detector pulse and pulse from either one of the gamma detectors ($\alpha-\gamma_1$, $\alpha-\gamma_2$) and the 4th quadrant contained the alpha energy spectrum for triple coincidence events ($\alpha-\gamma_1-\gamma_2$).

From the counts in each channel in the four quadrants, the average number and the width of the multiplicity distribution of gamma rays were obtained in the following manner.

Let $C_1(i)$, $C_2(i)$, $C_3(i)$ and $C_4(i)$ denote the counts in the four quadrants as a function of channel number i. The sum, $C(i) = C_1(i) + C_2(i) + C_3(i) + C_4(i)$ is the total number of alpha particles detected in channel i. Then

$$\frac{C_2(i)}{C(i)} = \sum_n [1 - (1 - \Omega_1)^n]\, P_n(i) \tag{1}$$

$$\frac{C_3(i)}{C(i)} = \sum_n [1 - (1 - \Omega_2)^n]\, P_n(i) \tag{2}$$

and

$$\frac{C_4(i)}{C(i)} = \sum_n [1 - (1 - \Omega_1)^n - (1-\Omega_2)^n + (1-\Omega_1-\Omega_2)^n]\, P_n(i) \tag{3}$$

where Ω_1, Ω_2 are the detection efficiencies of the gamma ray detectors including the solid angle factors and $P_n(i)$ is the probability of emission of n gamma rays per ternary fission for channel number i. For the present geometry, the detection efficiencies Ω_1 and Ω_2 are of the order of 3%. It is, therefore, reasonable to assume that the probability of more than one gamma ray entering the same detector in the same event is negligibly small and one obtains the following simple relations for the coincidence counting rates,

$$\frac{C_2(i)}{C(i)} = \bar{n}(i)\,\Omega_1 \tag{4}$$

$$\frac{C_3(i)}{C(i)} = \bar{n}(i)\,\Omega_2 \tag{5}$$

and

$$\frac{C_4(i)}{C(i)} = \overline{n(i)\,[n(i)-1]}\,\Omega_1\,\Omega_2 \tag{6}$$

The bars over the quantities represent the average taken over the entire multiplicity distribution $P_n(i)$.

Eliminating the unknown solid angle factors Ω_1 and Ω_2 from eqs (4)-(6), the values of the second moment $\overline{n^2}(i)$ can be obtained by knowing the values of $\bar{n}(i)$. The value of $\bar{n}$, the average number of gamma rays in ternary fission is known to be 1·16 times less than in binary fission (Ajitanand 1969) and the average number of gamma rays per fission in binary fission is known to be 10·3 (Johansson and Kleinheinz 1966). Normalizing the average of the relative values of $n(i)$ to this number, it is possible to obtain the absolute values of $\bar{n}(i)$ as a funtion of channel number i. $\overline{n^2}(i)$ is obtained from the relation:

$$\frac{C_4(i)\times C(i)}{C_2(i)\times C_3(i)} = \frac{\overline{n(i)\,[n(i)-1]}}{[\bar{n}(i)]^2} = \frac{\overline{n^2}(i)-\bar{n}(i)}{[\bar{n}(i)]^2} \tag{7}$$

The width of the distribution, σ is related to $\overline{n^2}$ by the relation $\sigma^2(i)=\overline{n^2}(i)-\bar{n}^2(i)$, assuming a Gaussian shape (Ramamurthy *et al* 1977). Finally the channel numbers were converted to energies from known calibration to obtain the variation of $\bar{n}$ and σ as a function of LCP energy. We have so far not considered the effect of the fission neutrons which also get detected in the NaI(Tl) detectors. In the present geometry, taking into account the known angular correlation between the direction of emission of the LCP and of the fragments, and the relative detection efficiency of the NaI(Tl) detectors to neutrons and gamma rays, it was estimated that the contribution of the fission neutrons relative to the gamma rays in NaI(Tl) detectors is about 8%. Assuming an approximate value of 0·5 for the ratio of the width to the mean of the prompt neutron multiplicity distribution in fission, the neglect of the neutron contribution in eqs (4)-(6), leads to an underestimate of the width of the gamma ray multiplicity distribution by about 5-6%. This effect has, however, not been included in the results presented in this paper because of the uncertainties in the above estimates for the lack of precise experimental information on the neutron multiplicity distribution in ternary fission.

3. Results and discussion

Figure 2 shows a plot of the measured mean and the standard devation of the prompt gamma ray multiplicity distribution in ternary fission as a function of the energy of the LCP. Also shown in the same figure is the measured energy distribution of the LCP. It is seen that the mean number of gamma rays per fission $\bar{n}$ is nearly inde-

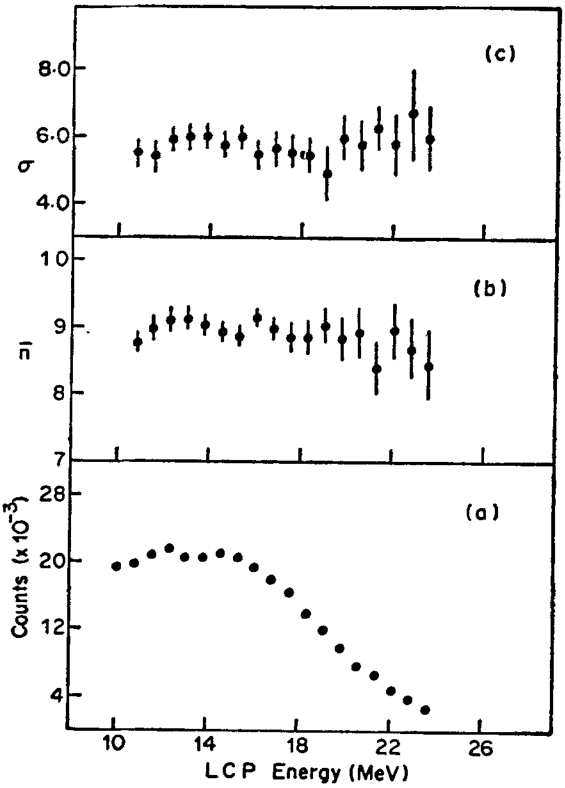

Figure 2. (a) Energy spectrum of the LCP; (b) Variation of $\bar{n}$ with energy of LCP; (c) Variation of σ of the multiplicity distribution with energy of LCP.

pendent of the energy of the LCP within the experimental errors. This result is in agreement with the earlier result of Adamov *et al* (1967) for the case of spontaneous ternary fission of ^{244}Cm, but is in contradiction to the results of Ajitanand (1969), who found that $\bar{n}$ increases sharply beyond LCP energy of about 17 MeV. It can also be seen from figure 2 that the width of the multiplicity distribution σ is nearly independent of the LCP energy. However, the absolute magnitude of σ averaged over the energy of the LCP is significantly larger than the corresponding valueof $4{\cdot}2 \pm 0{\cdot}4$ in the case of binary fission obtained by Ramamurthy *et al* (1977). A simple interpretation of this result is as follows: Gamma rays are emitted following neutron emission during the deexcitation of the excited fission fragments and takes place both in statistical and cascade manner, depending on the spin distribution of the fragments. It has been shown earlier (Ramamurthy *et al* 1977) that the width of the multiplicity distribution is related to the spin distribution of the fragments and a smaller average spin gives rise to a wider multiplicity distribution and vice versa. The present results, therefore, imply that the spin distribution of the fragments in ternary fission has a smaller average value than in binary fission. One possible reason for this reduction in the average spin of the fragments in ternary fission is that the average distance between the fragments at scission is larger in ternary fission than in binary fission, as has been brought out by trajectory calculations (Halpern 1971, Choudhury and Ramamurthy 1975). The near independence of σ with respect to the energy of the LCP suggests that there is no correlation between the point of LCP emission with respect to one of the fragment centres in the scission configuration which decides mainly the final energy of LCP and the distance between the nascent fission fragments. This absence of correlation has indeed been noticed in earlier trajectory calculation of Choudhury (1976). This is an important feature in which the trajectory calculation of Choudhury (1976) differs from other trajectory calculations, where it is usually assumed that the LCP is emitted at the coulomb potential energy minimum along the line joining the nascent fragments and, therefore, there is a correlation between the distance of the point of emission of LCP from one of the fragment centres and the interfragment distance. The present experiment has thus provided an important experimental information that can differentiate between the assumptions and emission mechanisms underlying the various trajectory calculations.

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