Nucleus-Nucleus coherent bremsstrahlung in ^{252}Cf spontaneous fission

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Introduction

The nature of high energy γ-ray spectra emitted in the spontaneous fission of ^{252}Cf for energies above 10 MeV has been one of the fundamental problems of nuclear fission physics. The yield of the γ-ray in the energy range of 10 - 20 MeV is mainly associated with direct excitation of the giant dipole resonance from the daughter nuclei arising in the fission process. The shape of γ-ray spectra in this energy range (10-20 MeV) obtained from the different experiments are reasonably close to each other. [1, 2, 3, 4]. However, for energies above 20 MeV, both experimental data and theoretical calculations are contradictory. In one experiment, the yield of γ rays with such a high energy was not detected, and only an upper bound was determined [3] while in three other experiments, the energy spectrum was measured above 20 MeV [1, 4, 5]. The yield of γ rays with energies 20-120 MeV is theoretically attributed to the coherent bremsstrahlung of the accelerating fission fragments in coulomb field and depends on the acceleration mechanism (instantaneous, pure Coulomb [1, 3], quantum-mechanical corrections for the effect of the tunneling of fragments through the potential barrier [3]). The calculations in different models differ by several orders of magnitude. The discrepancy in experimental and theoretical situations of coherent bremsstrahlung from nuclear fission requires further investigation. For this reason, an extensive experiment was carried out using ^{252}Cf source to investigate the photon emission accompanying the spontaneous fission at Variable Energy Cyclotron Centre (VECC), Kolkata.

Experiment

High energy γ-rays from the spontaneous fission of ^{252}Cf is detected in coincidence with the low energy discrete γ-rays emitted from the decay of excited fission fragments in order to establish a correlation (photons/fission) between the high energy γ-rays and the fission process. The high energy γ-rays were measured using the LAMBDA array [6] and the prompt γ-rays with multiplicity detector [7]. Four small BaF_2 detectors (3.5 x 3.5 x 5 cm^3) were placed as close as possible to the source to determine the start signal for each event. The LAMBDA array arranged in a 7 x 7 matrix was kept at a distance of 35 cm from the source. Time of flight measurement distinguished the γ-rays from neutrons while long/short gate technique was applied to reject the pile up events. Data were collected in this γ-γ coincidence mode for 450 hours.

At the photon energies E_γ > 25 MeV, cosmic ray showers are major source of background therefore extreme precaution was taken to obtain the experimental data free from cosmic impurity. Lead bricks surrounding the multiplicity filter and the LAMBDA array were used as passive protection shield from cosmic γ-rays. Large area plastic scintillator pads (pedals) were used as active shielding that surrounded the LAMBDA array as well as the multiplicity filter to reject the cosmic muons. Further, the cosmic pile up events were rejected using our cluster summing technique [6] in which the energy deposit in each element was required to satisfy the adequate gating employed by the pulse shape discrimination gate and the sharp prompt time gate. Finally, the random coincidence events were rejected by subtracting the background spectrum which was also collected for 450 hours without the fission source in an identical configuration.

Result

The data points in Fig. 1 shows the γ-ray spectrum obtained from the fission of ^{252}Cf in γ-γ mode. Photons having energy > 20 MeV is observed in this experiment. The solid curve represents the CASCADE calculation [8] folded with our detector response. The calculation includes the fission process with friction and GDR γ emission on the path from the saddle to scission, as well as from the fission fragments. The experimental data matches remarkably well with the theoretical calculation in the GDR region.

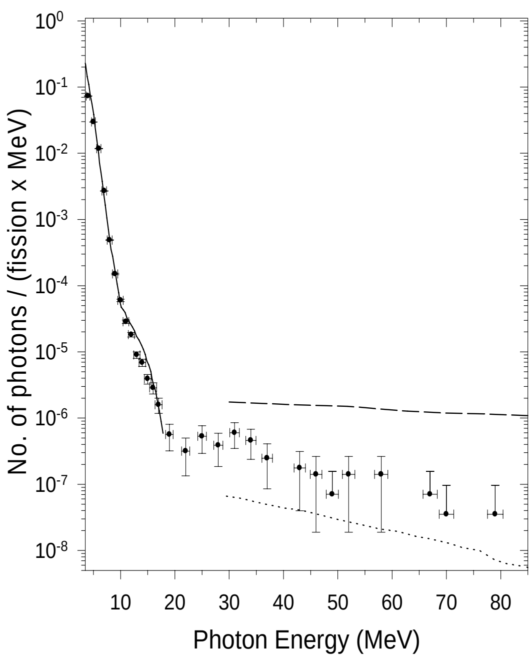

Fig.1. The points represent the high energy spectrum obtained in this experiment. The dotted line corresponds to the coulomb acceleration model for bremsstrahlung yield and the dashed line represents the sudden approximation model [3].

An interesting feature in the spectrum is that the CASCADE calculation falls rapidly after 20 MeV while the data at higher energies shows a completely different trend. The spectrum clearly indicates that the phenomenon below and above 20 MeV are completely different in origin. The most stringent theoretical calculation on the probability of the emission of γ-rays due to the mechanism of the coherent bremsstrahlung of fission fragments of ^{252}Cf has been performed by Luke et al.[3]. The dotted line represents the coulomb acceleration model of fission fragment and the dashed line corresponds to a sudden acceleration calculation of the bremsstrahlung radiation, in which the fission fragments achieve their asymptotic velocity instantaneously. The measured cross-section is in somewhat close agreement with the coulomb model calculation done by Luke [3]. The experimental data above 20 MeV can be described by an exponentially decreasing curve with slope parameter E_0 = 20 MeV. The upper limit for the component > 20 MeV measured in this experiment is 6 x 10^{-7} γ/(fission MeV). The angular correlation between the fission fragments and the high energy γ-rays could not be ascertained in this case, since the prompt γ-rays are emitted roughly isotropically from the fission system.

A detailed theoretical calculation is underway to understand the experimental results and the prediction of estimated yield of these photons. The results will be presented during the conference.

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