Measurement of prompt emission energy spectrum of gamma-rays and neutrons in spontaneous fission of ^{252}Cf

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Introduction

Prompt gamma-rays contribute considerably to the fission heat in a reactor core, whereas prompt neutrons are responsible for maintaining a chain reaction. In recent years, there has been a renaissance in the accurate measurement of prompt fission gamma ray spectrum (PFGS) primarily due to the requirement of precise data for innovative designs of Gen-IV reactor cores [1]. The precision with which their characteristics are known is, of course, important for both safety reasons and economy. Apart from the technological aspects, there are also indications that, prompt fission gamma-rays reveal detailed information about the dynamics of the fission process, particularly, the partitioning of energy in fission [2]. With the advent of advanced scintillation detectors such as Lanthanum halides, it is now possible to unravel more intricate details present in the prompt emission spectrum in fission [1,2]. In this regard, we have measured the prompt emission spectrum of gamma-rays and neutrons from the spontaneous fission of ^{252}Cf.

Experiment

The fission fragments were detected using an ionization chamber with circular electrodes of 4.5 cm diameter each, separated by a 3 mm teflon spacer. The chamber was operated in air with an operating voltage ~ +500 V applied to the anode while the cathode, where the ^{252}Cf source was mounted, was grounded. The energy loss signal obtained due to the ionization produced by the fragments was further processed to provide trigger to the data acquisition system. A threshold value is set using a constant fraction discriminator to cut-off the noise. It was found that the fission pulses were much above the noise and also above those produced by the alpha particles from the ^{252}Cf source. The pulse height spectrum of fission fragments is shown in Fig.1

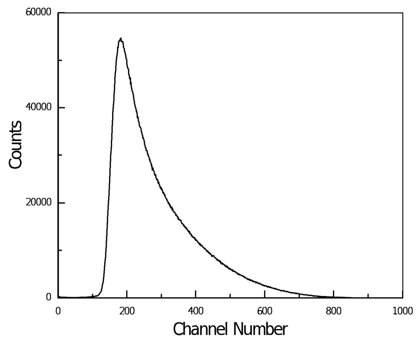

Fig.1: Pulse height spectrum of Fission Fragments.

The prompt neutrons were detected by a 5”x2” liquid scintillator detector kept at a distance of 87 cm from the source. The prompt gamma rays were detected by 3.5” long face to face and 8” thick hexagonal BaF_2 detector and a 3” dia and 6” long cylindrical $LaBr_3$(Ce) detector each kept at 18 cm from the source. A -ve voltage of 1400 was applied to the neutron detector while voltages of -1600 V and -900 V were applied to the BaF_2 and $LaBr_3$ detectors. An MPD-4 (Mesytec) module was used to obtain the pulse shape discrimination in the neutron detector. The time-of-flight spectrum was recorded using an individual start-stop TDC while all the analog signals were acquired through an 8 channel ADC. The neutron detector threshold was adjusted to be around 33 keVee. Calibrations of the BaF_2 as well as $LaBr_3$ were performed using ^{152}Eu, ^{137}Cs and Am-Be sources. The energy resolution obtained at 0.662 MeV was 22.27% and 5.004% for BaF_2 and $LaBr_3$ respectively. The prompt fission energy spectrum obtained using $LaBr_3$ detector is shown in Fig 2. This spectrum was obtained after correcting the background for the same duration and approximately the same number of fission triggers. While recording the background the ^{252}Cf source was heavily shielded with Lead to ensure that the fission gamma rays are not directly reaching the $LaBr_3$ detector. The intrinsic activity of $LaBr_3$ at 1.43 MeV was clearly visible in the background measurement.

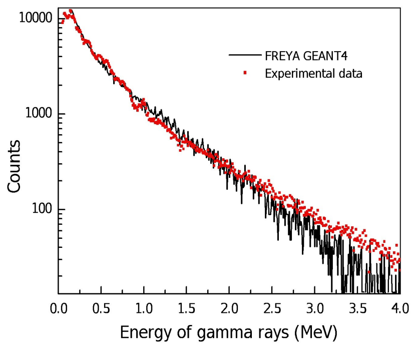

Fig.2: Prompt gamma ray spectra obtained using Lanthanum Bromide

From Fig. 2, it can be seen that the high resolution spectrum obtained using $LaBr_3$ shows distinct structures particularly at energies below 1 MeV. We have performed the Monte Carlo simulation of the prompt fission emission spectrum using GEANT4 10.01 [4] with the incorporation of FREYA (Fission Reaction Event Yield Algorithm) [5]. FREYA enables the emission of completely correlated fission secondaries from individual realizations of fission processes on an event-by-event basis for several isotopes including ^{252}Cf. For the present simulation 10^4 spontaneous fission events were considered and emission spectrum was obtained. The result of simulation is shown in Fig 2 (thick black curve). Unfolding of the measured spectrum to the emission spectrum is being performed using the response matrix of the detector. Monte Carlo simulations have also been carried out for energies ranging from 0.05 MeV to 12 MeV in steps of 0.05 MeV using GEANT4 10.01 to obtain the response matrix.

As regards the neutrons, the time of flight spectrum obtained after calibration was converted to the energy spectrum after correcting for the efficiency [3] and is shown in Fig 3. The energy spectrum was fitted with Watt spectrum which yielded a temperature T = 1.065 MeV.

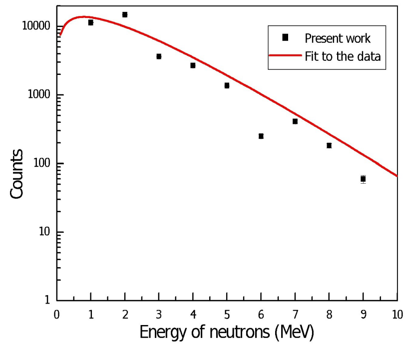

Fig.3: Energy spectrum of neutrons obtained from spontaneous fission of ^{252}Cf

Summary

Prompt fission gamma spectra were obtained using $LaBr_3$ and BaF_2 detectors and prompt neutron spectra was obtained using liquid scintillator detector in coincidence with fission using a gaseous ionization chamber. Analysis of the gamma energy spectrum obtained using the $LaBr_3$ detector reveals fine structure at low energy region. But no such structure was observed in case of Barium Fluoride detector because of its poorer resolution. Time of Flight measurement results into a Maxwellian distribution of emitted neutrons with a temperature of the emitting system to be of the order of 1.065 MeV. Scattering of neutrons from surroundings also contribute to the neutron spectrum. Detailed analysis is in progress and further results will be presented during the symposium.

References

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