Unfolding the prompt gamma ray spectra measured by a Lanthanum Bromide detector using GRAVEL method

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Introduction

In recent years, there has been renewed interest in the accurate measurement of prompt fission gamma ray spectrum (PFGS) of actinides primarily due to the requirement of precise data for Gen-IV reactor systems. It is also noted that prompt fission gamma-rays reveal detailed information about the dynamics of the fission process, particularly, energy partitioning in fission [1]. With advanced scintillation detectors based on Lanthanum and Cerium Halides, accurate determination of PFGS characteristics is now possible. This paper describes the application of GRAVEL method for unfolding the prompt fission gamma energy spectra in the spontaneous fission of ^{252}Cf measured using a Lanthanum Bromide detector.

Experimental set-up

A ^{252}Cf source mounted on the cathode of a small ionization chamber covering 2π solid angle for fission fragments and operating in air was used to create fission trigger [2]. The anode and the cathode of 4.5 cm diameter each were placed 3 mm apart using a Teflon insulator ring. A positive voltage of 500V was applied to the anode. At 18 cm from the source, a 3” dia and 6” long cylindrical $LaBr_3$(Ce) detector was kept which was used to detect the gamma rays. A negative voltage of 900V was applied to the $LaBr_3$ detector. The signals from the $LaBr_3$ detector were processed using a spectroscopy amplifier which was then passed to an ADC which was triggered by a Master Gate which opened only when fission occurred. Besides the $LaBr_3$ signal, the pulse height spectrum of the fission detector was also recorded in another channel of the ADC.

Response matrix of the detector

The response matrix for the $LaBr_3$ detector was obtained using the Monte Carlo simulation kit GEANT4 version 10.1 [3]. All electromagnetic phenomena have been included (E.M. Standard) and the simulations were carried out at each energy step for 1 million histories each. Based on the experimentally observed resolution, an energy binning of 0.02 MeV was found to be sufficient for generating the response matrix.

GRAVEL algorithm

The response function of the detector M, the gamma energy spectra C and the differential pulse height spectrum Y are related as:

$$Y_k = \sum_l M_{kl} C_l \qquad \text{…....................(1)}$$

where Y_k (k=1,2,...,u) is the count that is recorded in channel number u, C_l (l=1,2,...,v) is the number of gamma emitted by the source in the energy interval v and M_{kl} is the response matrix for the detector which couples the *u*th pulse height interval with the *v*th energy interval. The deconvoluted spectra can be represented discretely as:

$$C_l^{a+1} = C_l^a \exp\left(\frac{\sum_k Z_{kl}^a \ln\left(\frac{Y_k}{\sum_{l'} M_{kl'} C_{l'}^a} \right)}{\sum_k Z_{kl}^a} \right) \qquad \text{----(2)}$$

where Z_{kl} is a weight factor given as:

$$Z_{kl}^a = \frac{M_{kl} C_l^a}{\sum_{l'} M_{kl'} C_{l'}^a} \frac{Y_k^2}{b_k^2} \qquad \text{--------------(3)}$$

where b_k is the error in the measurement, which is the square root of Y_k. C_l^a is the gamma emitted after *a*th iteration in the *l*th energy interval[4]. A constant input spectrum C^0 is used to start the iteration. In our present work, the iteration is stopped when χ^2 per degree of freedom reaches a saturation value.

$$\frac{\chi^2}{u} = \frac{1}{u}\sum_k \frac{\left(\sum_l M_{kl} C_l - Y_k\right)^2}{b_k^2} \quad \text{------(4)}$$

Results

Fig.1.shows the background subtracted measured spectrum obtained from a ^{60}Co source (black curve) and its emission spectrum (red curve) obtained by applying GRAVEL method. The photopeak efficiency of the $LaBr_3$ detector is 29.72% at 1.173 MeV and 24.76% at 1.333 MeV.

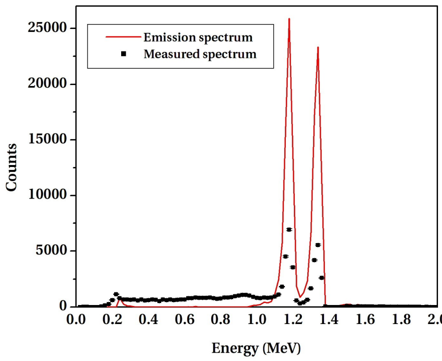

Fig.1. Background subtracted measured spectrum of ^{60}Co obtained using the $LaBr_3$ detector and its emission spectrum obtained by GRAVEL method

Now we apply the GRAVEL algorithm to the gamma spectrum produced by the spontaneous fission of ^{252}Cf. Fission with and without shielding the ^{252}Cf source were recorded. The background is subtracted from the original spectrum and the measured spectrum is obtained as shown in Fig.2. Original emission spectrum is produced by unfolding the measured spectrum using GRAVEL algorithm. The obtained spectrum shows fluctuations in the low energy range. Previous experimental data of Verbinski et al show similar structures [5] as shown in Fig.3.

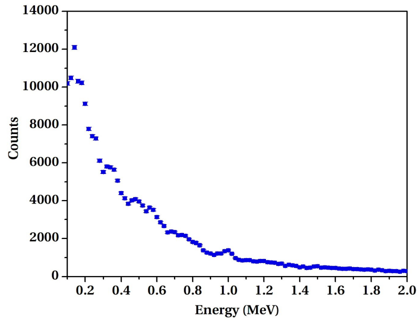

Fig.2. Backgroud subtracted measured spectrum of ^{252}Cf obtained using the $LaBr_3$ detector

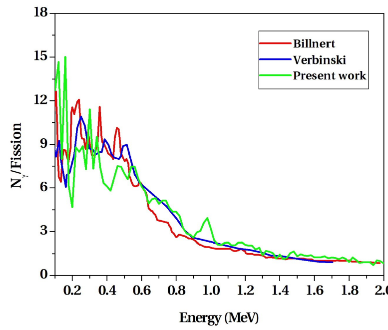

Fig.3. Emission spectrum of ^{252}Cf obtained using GRAVEL algorithm and compared with existing data.

Identical fluctuations but with much better resolution is obtained by Billnert et al. using $LaBr_3$ and $CeBr_3$ detectors. Hence, we can apply this present method of unfolding the gamma spectra to the measured spectra of all other actinides. Although the amount of emitted gamma is comparable for all the three cases, but the fine structures do not match exactly. Hence, further improvement in the code is possible.

References

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