

Characterization of Anisotropic emission of prompt fission neutrons for distinguishing radionuclides

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1. Introduction

In the center-of-mass (CM) frame of fission fragments created from fission events, prompt fission neutrons are generally emitted isotropically. However, when the velocity of the fission fragments is taken into account, the neutrons emitted in the laboratory system (LS) frame exhibit anisotropic characteristic [1]. In particular, it is known that the angle between emitted neutrons prone to occur at 180° and 0° rather than at 90° [2]. Furthermore, different fission isotopes produce different pairs of fission fragments, which in turn results in variations in the energies, the direction, and the number of neutrons emitted [3].

In this paper, we investigated whether fission anisotropy—degree of non-uniformity in the angular distribution between emitted neutrons—can be used to distinguish different spontaneous fission isotopes under varying conditions. Two detector configurations were considered: an idealized 4π coverage arrangement and a more practical setup consisting of 12 detectors positioned around the fission source. For each configuration, we calculated the fission anisotropy using the asymmetry factor and evaluated its effectiveness as a discriminating parameter for different spontaneous fission sources.

2. Methods and Results

In this section, we simulated fission anisotropy using GEometry ANd Tracking (GEANT4) Monte-Carlo simulation [4] in conjunction with the Fission Reaction Event Yield Algorithm (FREYA) model [5] for three spontaneously fissionable nuclides: ^{244}Cm , ^{252}Cf , and ^{240}Pu . GEANT4 was employed to model neutron transport from the fission source to the detectors, while the FREYA model provided realistic fission event generation using validated fission libraries. The asymmetry factor, defined in Equation (1), was evaluated under two detector configurations: (i) an idealized arrangement with full 4π coverage, and (ii) a practical setup with 12 detectors positioned around the source. The detector layout and source implementation used in the simulations are illustrated in Fig. 1.

$$\text{Asymmetry factor} = \frac{\text{Counts}_{180^\circ}}{\text{Counts}_{90^\circ}} \quad (1)$$

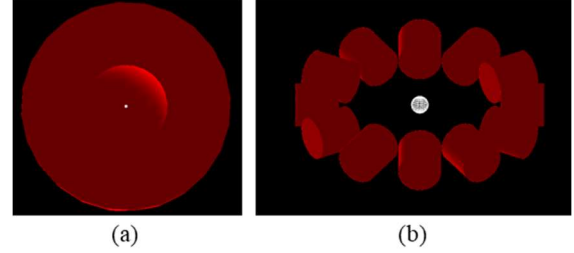


Fig 1. Detector configurations implemented in GEANT4 for anisotropy assessment: (a) full 4π coverage (b) 12-detector arrangement.

2.1. Idealized detector arrangement with full 4π coverage

For the ideal detector allocation with full 4π coverage shown in Fig. 1(a), we assumed a 30 cm-thick stilbene organic scintillator, sufficient to detect nearly all neutrons emitted from the fission source. With this thickness and coverage, this configuration represents the ideal case for observing fission anisotropy. A neutron detection event was defined as (n,p) reaction occurring in the scintillator, without modeling scintillation photon processes. The asymmetry factor was obtained for all angles between emitted neutron pairs. Moreover, fission anisotropy was calculated under varying recoil proton energy thresholds. The resulting anisotropy distributions for different fission sources are shown in Fig. 2, with corresponding asymmetry factors listed in Table 1. The results show that fission anisotropy is clearly distinguishable among different spontaneous fission isotopes and that the asymmetry factor increases with higher energy thresholds. This is because high-energy neutrons—selected by the threshold—originate from high-energy fission fragments. At these velocities, the neutron's contribution in the fragment's center-of-mass system is reduced, increasing the relative count ratio at 180° and 0° .

Table I: Asymmetry factors for different energy thresholds under ideal detector coverage.

Energy Threshold	^{252}Cf	^{244}Cm	^{240}Pu
N/A	1.18	1.27	1.41
0.5 MeV	1.20	1.30	1.45
1.0 MeV	1.25	1.38	1.59
1.5 MeV	1.33	1.52	1.80

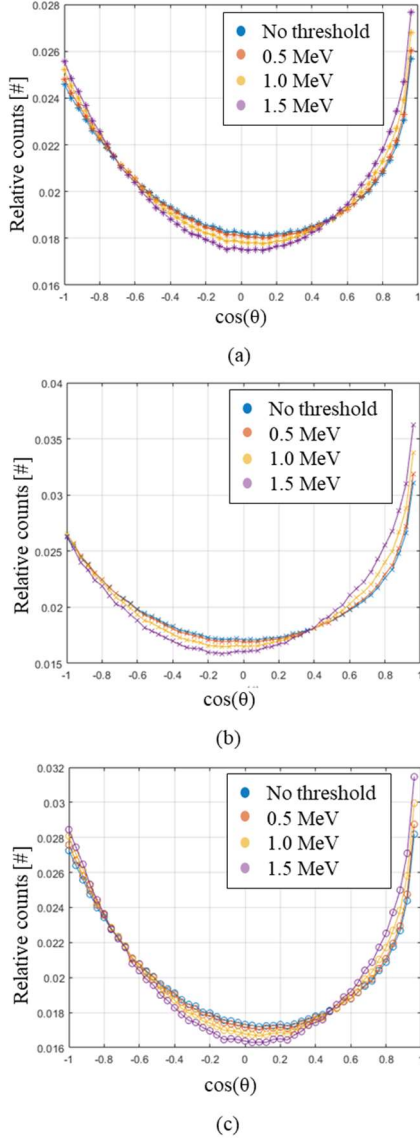


Fig 2. Fission anisotropy distributions at varying recoil proton energy thresholds under ideal detector coverage: (a) ^{252}Cf (b) ^{244}Cm (c) ^{240}Pu .

2.2. Practical 12-detector arrangement

For the realistic 12-detector arrangement shown in Fig. 1(b), we replicated the detector configuration used in the University of Michigan experiment [6]. Like the ideal case, fission anisotropy was evaluated for varying recoil proton energy thresholds. The resulting distributions, shown in Fig. 3, differ significantly from those in Fig. 2. This is because the neutron detection efficiency for multiple detectors is obtained by multiplying the single-detector efficiency for each detector, resulting in an exponential decrease with the number of detectors. When cross-talk events are removed, the observed anisotropy becomes closer to the ideal case.

In this configuration, the asymmetry factors are smaller than in the ideal case, indicating that neutron emission appears more isotropic for a realistic detector

layout. Additionally, coincidence events at 30° are more frequent than in the ideal case. This is attributed to cross-talk, where a neutron scattered from one detector subsequently triggers a nearby detector. Still, as shown in Table 2, it was shown that applying an energy threshold increases asymmetry factor, despite it being lower than ideal cases.

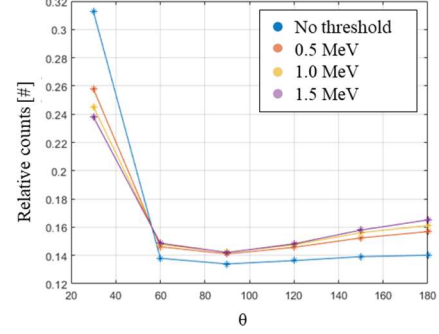


Fig 3. Fission anisotropy distributions for ^{252}Cf with energy thresholds under practical 12-detector arrangement.

Table I: Asymmetry factors for different energy thresholds under practical 12-detector arrangement.

Energy Threshold	^{252}Cf	^{244}Cm	^{240}Pu
N/A	1.04	1.12	1.14
0.5 MeV	1.08	1.19	1.22
1.0 MeV	1.13	1.25	1.30
1.5 MeV	1.16	1.32	1.37

3. Conclusions

We assessed the fission anisotropy qualitatively through asymmetry factor for distinguishing ^{244}Cm , ^{252}Cf , and ^{240}Pu under ideal and practical detector setups. With ideal 4π coverage, anisotropy was clearly isotope-dependent and increased with higher recoil proton energy thresholds due to high neutron detection efficiency of detectors.

In the practical 12-detector arrangement, anisotropy was reduced and appeared more isotropic because of lower detection efficiency and cross-talk, though some source-specific trends comparably diminished. These results indicate that fission anisotropy can support spontaneous fission source identification, with performance strongly affected by detector geometry and cross-talk suppression.

Acknowledgments

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