Nuclear Instruments and Methods in Physics Research A 619 (2010) 186–189

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Calculation of responses and analysis of experimental data for a silicon gamma spectrometer

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ARTICLE INFO

Available online 10 November 2009

Keywords:
Silicon detector for gamma
Gamma spectrometry
Detector response
Monte Carlo simulation
Unfolding

ABSTRACT

A silicon detector developed for gamma ray spectrometry (intended for measurement in the mixed neutron gamma fields, e.g. in reactor physics) was tested for the photon energy interval up to 10 MeV. The responses of this spectrometric system were simulated using a Monte Carlo method (MCNPX code), and the response matrix was calculated. Unfolding techniques for reconstructing incident photon spectra were tested, and a method based on the Scofield–Gold iterative solution of the corresponding matrix equation was applied. The applicability of such an approach to spectrometry data processing and spectral analysis is demonstrated, an example of the results is presented, and possible future improvements and optimizations are discussed.

1. Introduction

The silicon detectors of different types are widely used in many areas of experimental physics, medicine, technology, etc., for the spectrometry, imaging, positioning and detection purposes. Application of silicon detectors for X and gamma ray spectrometry is usually limited to region of lower energies due to silicon low density and also low Z_{eff}. Aim of the presented work was to test application of the large volume silicon detector for higher energy region (up to 10 MeV) using suitable method of spectrometry data processing and analysis. The motivation for developing and testing this system using Si detector was its relatively low sensitivity and higher radiation tolerance (e.g. in comparison with HPGe detector) to neutrons. These features make this Si detector promising for gamma spectrometry in mixed neutron gamma fields, e.g. in reactor physics. Another advantage of the system with Si detector is its lower sensitivity to gamma, which enables measurements in fields with higher photon fluence rates.

2. Description of the detector

A cylindrically-shaped silicon detector (Si(Li), sensitive volume 8.8 cm^3 (approx. diam. $3.74 \times 0.8\,\text{cm}^2$), has been developed at the Institute for Physico-Technical Problems, Dubna, Russia [1]. The detector is installed in a measuring probe coupled with a preamplifier. A schematic view of the detector design is presented in Fig. 1. Limiting factors for gamma spectrometry in the higher energy photon fields are low density and low Z_{eff} mentioned above, relatively small volume and disc shape with relatively small thickness. All measurements and determination of detector parameters and spectrometric characteristics were carried out in the NRI Rez [7]. The preferred direction for measurement in the energy range from 3 to 10 MeV is from detector side because of higher effective thickness. Due to the absence of full absorption peaks (for energies up to about 0.5–1 MeV), the energy calibration has to be performed from other structures in the experimental spectra, i.e. Compton edges (CE) and double escape peaks (DE), when the single escape peaks are very low and are practically invisible in the measured spectra. An example of a spectrum (with marked calibration points) used for calibration is shown in Fig. 2. The *R*-squared value of linear regression of the energy calibration data ($R^2 > 0.995$) shows very good linearity of the detector response.

The detector resolution can be determined from identifiable peaks, and by an analysis of the shape of the Compton edges in the calibration spectra, and it depends on the operating conditions (voltage, signal processing). The energy dependence of the resolution (for standard operating conditions) is shown in Fig. 3, including the fit of the experimental data by the function $r(E) = 8.99 * (661.6/E)^{0.599}$ [%, keV].

3. Simulating the detector response

A detailed geometrical model of the detector and the full detection system (without preamplifier electronics) was

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doi:10.1016/j.nima.2009.10.180

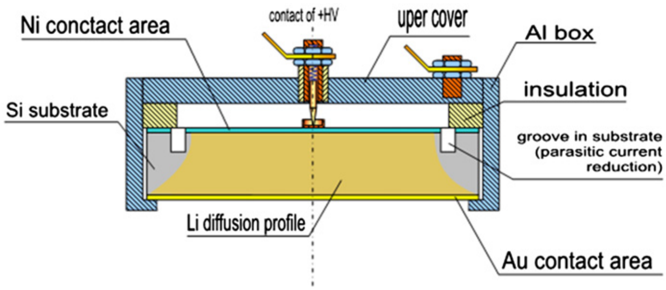

Fig. 1. Schematic view of detector design.

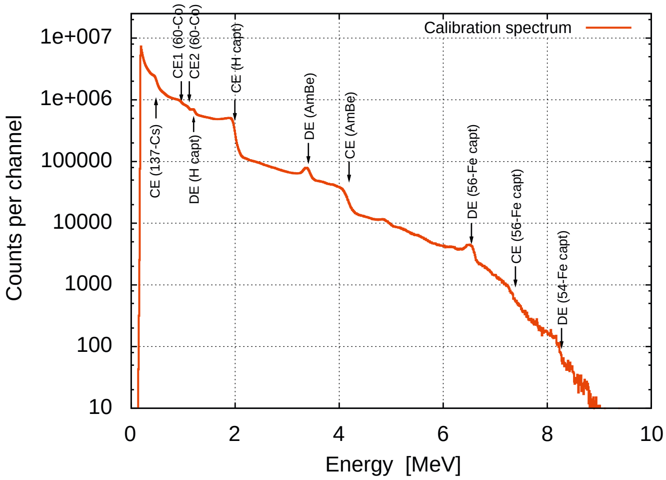

Fig. 2. Spectrum of mixed sources/fields used for calibration (arrows indicate the calibration energies).

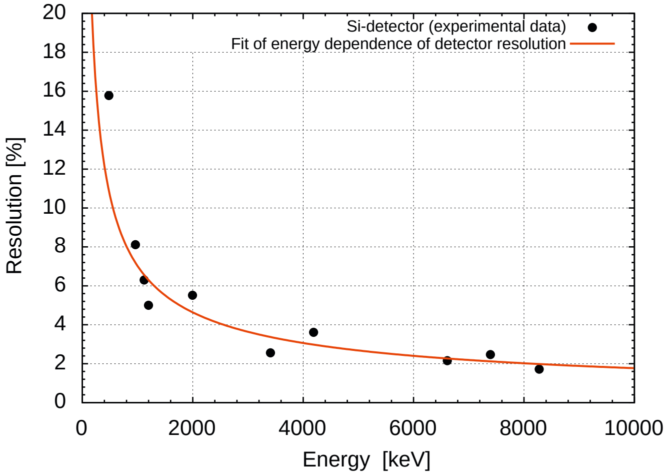

Fig. 3. Energy dependence of detector resolution.

described for MCNPX code (see a 3D view, Fig. 4). Various source/beam positions were simulated. For detector parameter measurements and calibration, two basic point source positions were selected: 5 and 40 cm from the centre of the detector active volume on the cylindrical axis of symmetry (“front position”) and on the axis perpendicular to the previous position (“side position”). The energy deposition spectra were simulated using tally F8 (pulse height tally). An example of the calculated energy deposition spectra for the source front position at distance 40 cm and set of energies 0.5 and 1.02–10.02 MeV (energy step 1 MeV) is shown in Fig. 5. Using convolution of the calculated energy deposition spectra with the detector resolution function (a Gaussian function is assumed, and a fit of the energy dependence of the detector resolution—see Fig. 3), we can

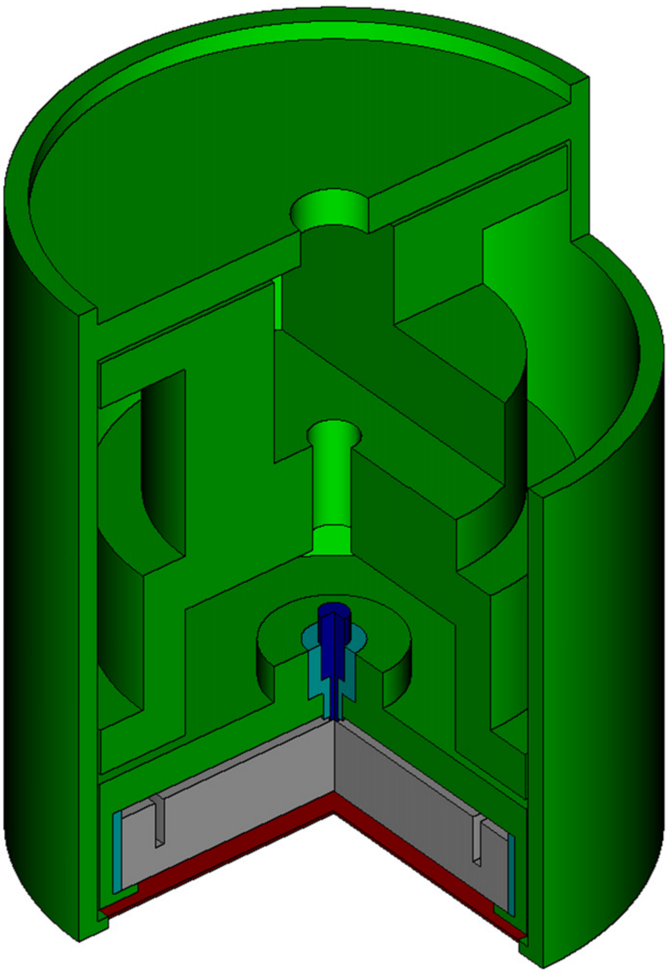

Fig. 4. A 3D view of a geometrical model of the detection system used for MCNPX simulations.

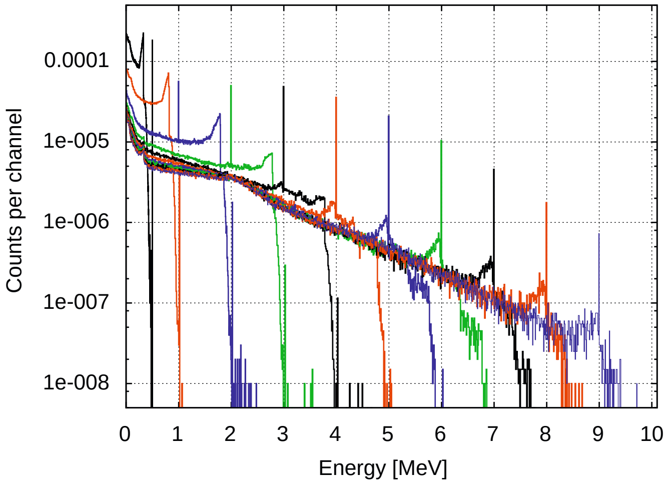

Fig. 5. Example of calculated energy deposition spectra, energies 0.5 and 1.02–10.02 MeV with energy step 1 MeV (Si-detector with housing, point source in front position, distance 40 cm).