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Monte Carlo calculation of response functions to gamma-ray point sources for a spherical NaI(Tl) detector

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ABSTRACT

Response functions of a 7.62 cm-diameter spherical NaI(Tl) detector to gamma-ray point sources in the energy range up to 1.5 MeV were calculated by means of the Monte Carlo method using PENELOPE-2006 (Salvat et al., 2006). The detector materials and dimensions were modeled realistically. The calculated response functions agreed well with the experimental spectra.

1. Introduction

Due to their superior detection efficiencies of gamma-rays and the relative simplicity of use without cryogenic devices, NaI(Tl) detectors in various shapes are widely used in the measurement of environmental radioactivity, low level radioactive waste, prompt gamma-ray neutron activation analysis and some nuclear physics experiments. The response characteristics of NaI(Tl) detectors to gamma-rays are essential in quantitative understanding or unfolding the spectrum. The response functions of NaI(Tl) detectors to mono-energetic gamma-rays can be measured (Heath, 1964) but they are limited to a few cases because of lack of mono-energetic gamma-ray sources. Instead, since as early as 1960s, many authors have recourse to the Monte Carlo method to calculate the response functions and efficiencies of NaI(Tl) detectors (Zerby and Moran, 1961; Berger and Seltzer, 1972; Saito and Moriuchi, 1981; Faddegon et al., 1991; Allison and Sanderson, 1998; Shi et al., 2002; Baré and Tondeur, 2011).

In the present study, we calculated the response functions of a 7.62 cm-diameter spherical NaI(Tl) detector to gamma-ray point sources in the energy range up to 1.5 MeV by means of the Monte Carlo technique using PENELOPE-2006 (Salvat et al., 2006). The calculation results were compared with experiments.

2. Simulation model

Based on the information given by the manufacturer, the material and dimension of the spherical NaI(Tl) detector were modeled precisely for the simulation (Fig. 1). An upper part of the 7.62 cm-diameter spherical NaI(Tl) crystal is cut and faced with 5 mm-thick cylindrical disk of NaI(Tl). The window of PM tube was modeled as being composed from glass. The outer diameter of the detector was measured. The material of the detector housing enclosing the spherical NaI(Tl) crystal was Al with the thickness given by the manufacturer equal to 0.8 mm. We assumed that the density of the MgO reflector was 2.5 g/cm^3 in the simulation model in accordance with the range 2–3 g/cm^3 suggested by the manufacturer.

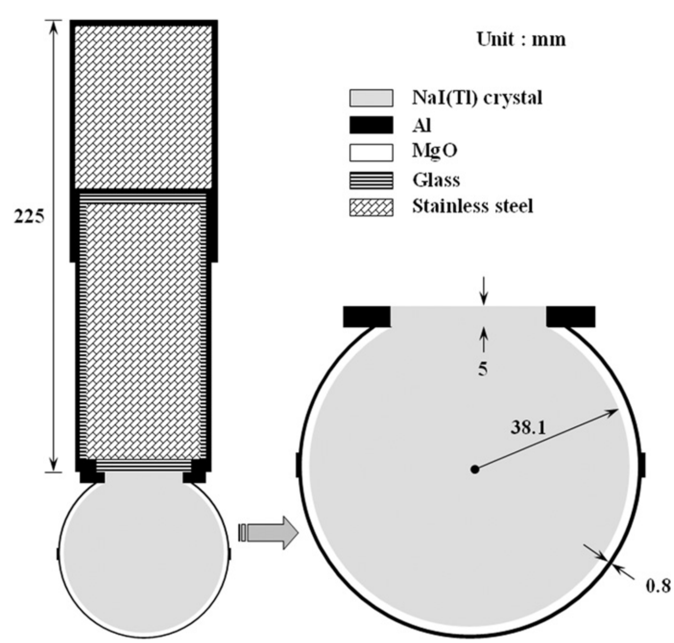

Fig. 1. Simulation geometry of the 7.62 cm-diameter spherical NaI(Tl) detector.

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The measured total weight of the detector was 1786 g. The weight given by the manufacturer for the detector head was 867 g, which was reasonable considering the estimated weight of 847 g from the crystal volume. From analyzing the information of all the components of the detector, the average density of the inner space of PM tube and base was figured out to be around 0.5 g/cm^3. The material of inner space of PM tube and base was modeled as stainless steel with uniform density of 0.5 g/cm^3. The choice of stainless steel was stemmed from the assumption that materials of electronic elements contained in the PM tube and base were mixture of metals, large portion of which was iron.

Table 1
Full energy peak efficiencies of the selected point sources located at 10 cm from the face of the 7.62 cm-diameter spherical NaI(Tl) detector. Discussion on the uncertainties of the measurement and the calculation is given in the text.

Source	Photon energy (MeV)	Measured	Simulated
^{137}Cs	0.6617	$(6.84\pm0.11)\times10^{-3}$	$(6.65\pm0.33)\times10^{-3}$
^{60}Co	1.1732	$(4.16\pm0.10)\times10^{-3}$	$(4.03\pm0.20)\times10^{-3}$
	1.3325	$(3.69\pm0.08)\times10^{-3}$	$(3.59\pm0.18)\times10^{-3}$

3. Simulation parameters

In PENELOPE, photons are traced using the conventional detailed method. Electrons and positrons are transported by means of a mixed procedure, which was denoted as 'Class 2' simulation scheme by Berger (1963). The simulation parameters of PENELOPE governing electron and positron transport are E_{abs}, W_{cc}, $C1$ and $C2$ (Salvat et al., 2006). E_{abs} is the lower energy limit of the electron transport. The cutoff energy for hard inelastic collision is W_{cc}. We set $E_{abs}=W_{cc}=10$ keV, i.e., bremsstrahlung photons with energy greater than 10 keV were considered. $C1$ is the average angular deflection and $C2$ is the maximum average fractional energy loss between the consecutive hard elastic events. $C1$ and $C2$ are allowed from 0 (detailed simulation) to 0.2. We chose the fastest option, $C1=C2=0.2$ because the parameters $C1$ and $C2$ gave negligible effect to the simulation results.

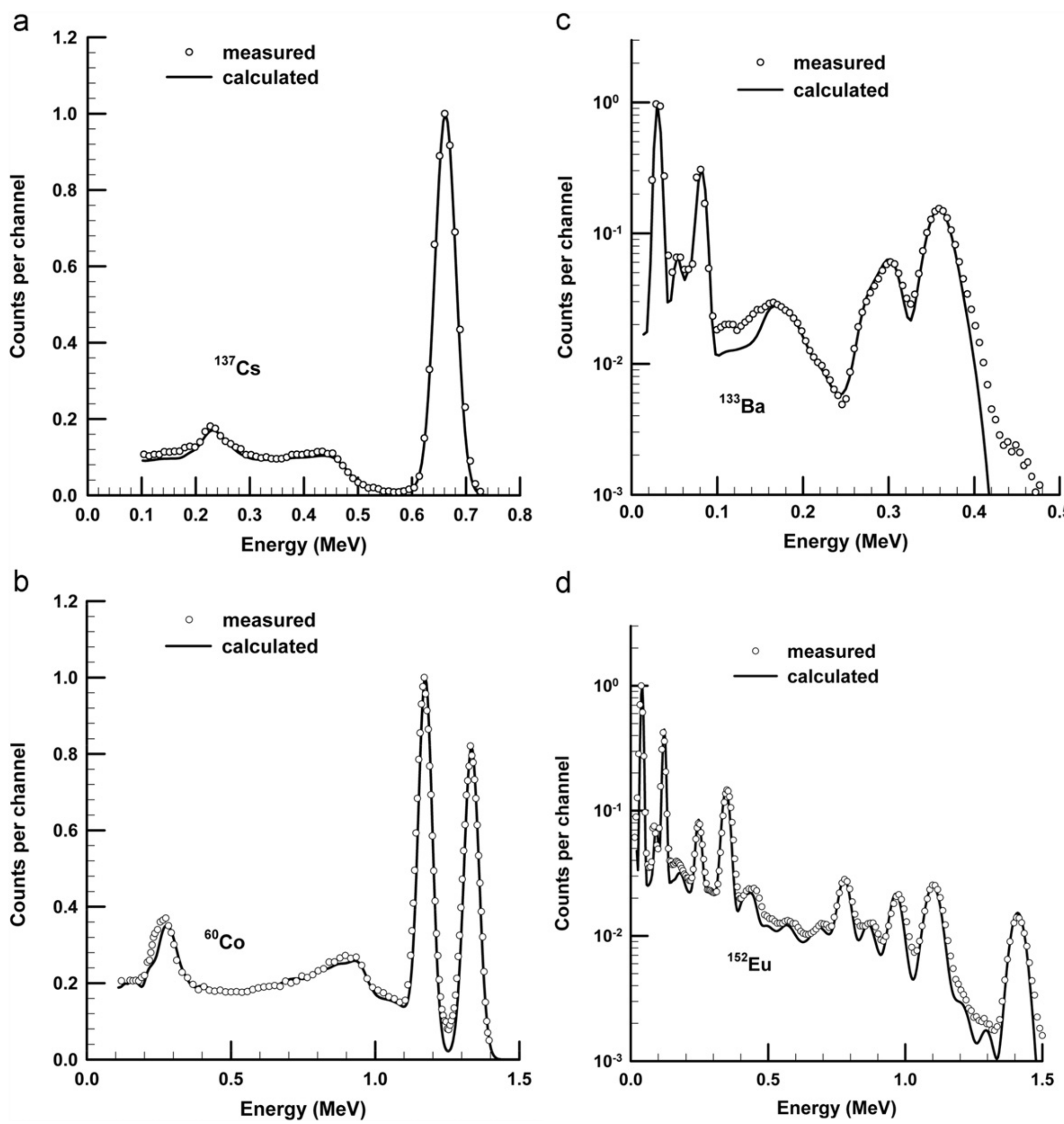

Fig. 2. Calculated response functions of the spherical NaI(Tl) detector for the point sources placed on the center axis of the detector at 10 cm from the detector face. ^{137}Cs (a), ^{60}Co (b), ^{133}Ba (c) and ^{152}Eu (d).