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THE RESPONSE OF THE HIGH-RESOLUTION HIGH-ENERGY PHOTON SPECTROMETER I

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Abstract

We investigated the response of the High-resolution High-energy photon Spectrometer (HHS) using standard γ sources and the ^{27}Al(p,γ)^{28}Si reaction. We report results of EGS4 simulations of peak efficiencies and response functions of a Twin Ge detector that is a main component of the HHS. The response of the HHS to γ rays from the (p,γ) reaction is also reported.

1 Introduction

The high-resolution high-energy photon spectrometer (HHS) has been developed [1] for high energy γ-ray spectroscopy which plays a key role in precision measurements of photoabsorption cross sections and neutron capture cross sections. The latter cross sections for minor actinides (Np, Am, Cm) and long-lived fission products (^{79}Se, ^{93}Zr, ^{99}Tc, ^{107}Pd, ^{129}I, ^{126}Sn, ^{135}Cs), provide fundamental information on transmutation of nuclear waste. The high energy γ ray spectroscopy ideally requires a thorough understanding of the response of the HHS to discrete γ rays in a wide energy range from 100 keV to 10 MeV. Experimental peak efficiencies and response functions of germanium detectors were previously investigated by means of Monte Carlo simulations [2, 3, 4]. Although these studies show that the overall response of a germanium detector of single-crystal is well reproduced by a Monte Carlo simulation, a lot of improvements are clearly necessary for the purpose of high-energy γ ray spectroscopy. It was recently pointed out that an EGS4 simulation based on the factory information on a P-type high-purity Ge detector overestimates peak efficiencies, where the discrepancy was attributed to the thickness of the dead layer [4].

Based on the preceding study [5], we have initiated a systematic study of the response of the HHS consisting of two large-volume Ge crystals (Twin Ge) surrounded by a BGO anti-Compton shield. Toward a thorough understanding of the response of the HHS for the spectroscopic purpose, we first measured peak efficiencies and response functions of the Twin Ge detector using standard γ sources and then the response of the HHS to 10.7 MeV γ rays from the ^{27}Al(p,γ)^{28}Si reaction as well as to standard γ sources. We report results of these measurements in comparison with EGS4 simulations.

2 Experimental Method

2.1 HHS and Twin Ge

Figure 1(a) and 1(b) depict the HHS and the Twin Ge detector, respectively. The Twin Ge detector consists of two N-type closed-ended coaxial crystals with the sensitive volumes of 335 cm^3 (79.6 mm in diameter and 69.8 mm in length) and 333 cm^3 (79.5 mm in diameter and 70.0 mm in length), respectively. The two crystals are encased in an inner aluminum container (thickness ≤ 1 mm) and enclosed in an outer aluminum container (thickness ≤ 1 mm, 105 mm in diameter and 200 mm in length) with the distance 5 mm apart from each other and 28 mm from the endcap. No information on the dead layer and the electrode is available on the specification sheet.

2.2 Measurements with the standard sources

Peak efficiencies of the Twin Ge detector were measured with the standard sources of ^{60}Co, ^{133}Ba, and ^{152}Eu at the distances of 300 mm and 1000 mm. No collimator was used. Response functions of the Twin Ge detector to the ^{60}Co source were also measured. The procedure of the response function measurement is illustrated in Fig. 2. Four sets of data were taken; Data01 and Data02 were taken with and without the ^{60}Co, respectively; After mounting two 50 mm-thick lead blocks in front of the Twin Ge detector, Data 03 and Data04 were taken again with and without the ^{60}Co, respectively. γ rays entering the Twin Ge are composed of the direct ^{60}Co component (A), the ^{60}Co component reflected by surrounding materials (floor, walls *etc*) (B), the room foreground (C), and the room backgound (D). Subtracting Data02 from Data01 gives a sum of the direct and reflected ^{60}Co components (A + B), while subtrating Data04 from Data03 the reflected component (B). The direct ^{60}Co component was obtained from the difference between the resultant two sets of data.

2.3 ^{27}Al(p,γ)^{28}Si reaction

The response of the HHS to γ rays from the ^{27}Al(p,γ)^{28}Si reaction was measured at Tokyo Institute of Technology. A beam of 1 MeV protons from the pelletron accelerator of the Research Laboratory for Nuclear Reactors was used to irradiate an aluminum foil mounted onto a stainless-steel plate which was water-cooled during the irradiation. γ rays passed through a tapered hole with the diameter 3 mm in the front face and 12 mm in the back face of a 150 mm-thick lead block placed at 250 mm from the target and impinged on the Twin Ge detector of the HHS mounted at the distance of 650 mm. Also measured was the response of the HHS to the standard γ-ray sources (^{60}Co and ^{137}Cs) in the same set-up, where the sources were mounted onto the front face of the lead collimator.

3 Results and EGS4 simulations

3.1 Peak efficiency of the Twin Ge

Figure 3 shows peak efficiencies of the Twin Ge detector measured with the standard γ sources. Results of Monte Carlo simulations with the EGS4 code [6] are also shown in the figure; the dashed lines and solid lines represent results with input parameters of the specification sheet and results with optimized parameters, respectively. Due to a lack of the factory information, the dead layers was assumed to be 700 μm thick for the inner n^+ contact and 0.3 μm thick for the outer p^+ contact [7]. The present EGS4 simulation with the nominal parameters of the specification sheet confirms the result of Ref. [4], that is, the overestimation of peak efficiencies. In the optimization of the EGS4 simulation, the Ge sensitive volume was reduced in such a way that the radius of the Ge crystal was decreased by 1.7 mm. Further, the thickness of the entrance Al window was increased to be 3 mm (2 mm increase) to account for the behavior of the peak efficiency at low energies.

3.2 Response function of the Twin Ge

Experimental response functions of the Twin Ge detector to the ^{60}Co source are shown by the dashed lines. Results of the EGS4 simulation with the optimized parameters are also shown by the solid lines, where the detector resolution is taken into account. Although the EGS4 simulation reproduces the response functions as well as the peak efficiencies, there remain some discrepancies between the data and the simulation at lowest energies, where the data exhibit excessive counts with large uncertainties though not shown in the figure. The discrepancy is most likely because the reflected ^{60}Co component is not subtracted perfectly. It is visible in the response function with good statistics (Fig. 4(b)) that the full-energy peaks are characterized by low-energy tails. The tailing can be attributed to imperfect charge collection in some regions of the detector [7], which is not included in the present EGS4 simulation. This feature should be studied further.

3.3 Response of the HHS

Figure 5(a) and 5(b) show response functions of the HHS to 10.7 MeV γ rays from the ^{27}Al(p,γ)^{28}Si reaction with the BGO anti-coincidence on and off, respectively. One can see in Fig. 5(a) that the Compton component is drastically reduced by the BGO anti-coincidence shield. It is to be noted that the full-energy peak is accompanied by a low-energy tail. A preliminary result of the EGS4 simulation shows that this tail originates from forward scattering of 10.7 MeV γ rays as passing through the collimator.

4 Conclusion

The response of the high-resolution high-energy photon spectrometer (HHS) was investigated within the framework of the EGS4 simulation. The peak efficiency and the response function of the Twin Ge detector which is a main component of the HHS were well reproduced by reducing the sensitive volume by 8.3 % from the nominal volume found in the specification sheet. The response of the HHS to 10.7 MeV γ rays was also measured. EGS4 simulations are in progress toward a best understanding of the response of the HHS. The cause for the tails of the full-energy peaks, which emerged for the 1.33 MeV and 1.17 MeV γ rays without a collimator and for the 10.7 MeV γ rays with the collimator, respectively, should be pursued. The former tail must be characteristic of the Twin Ge detector itself, while the latter tail is the forward scattering effect associated with the lead collimator.

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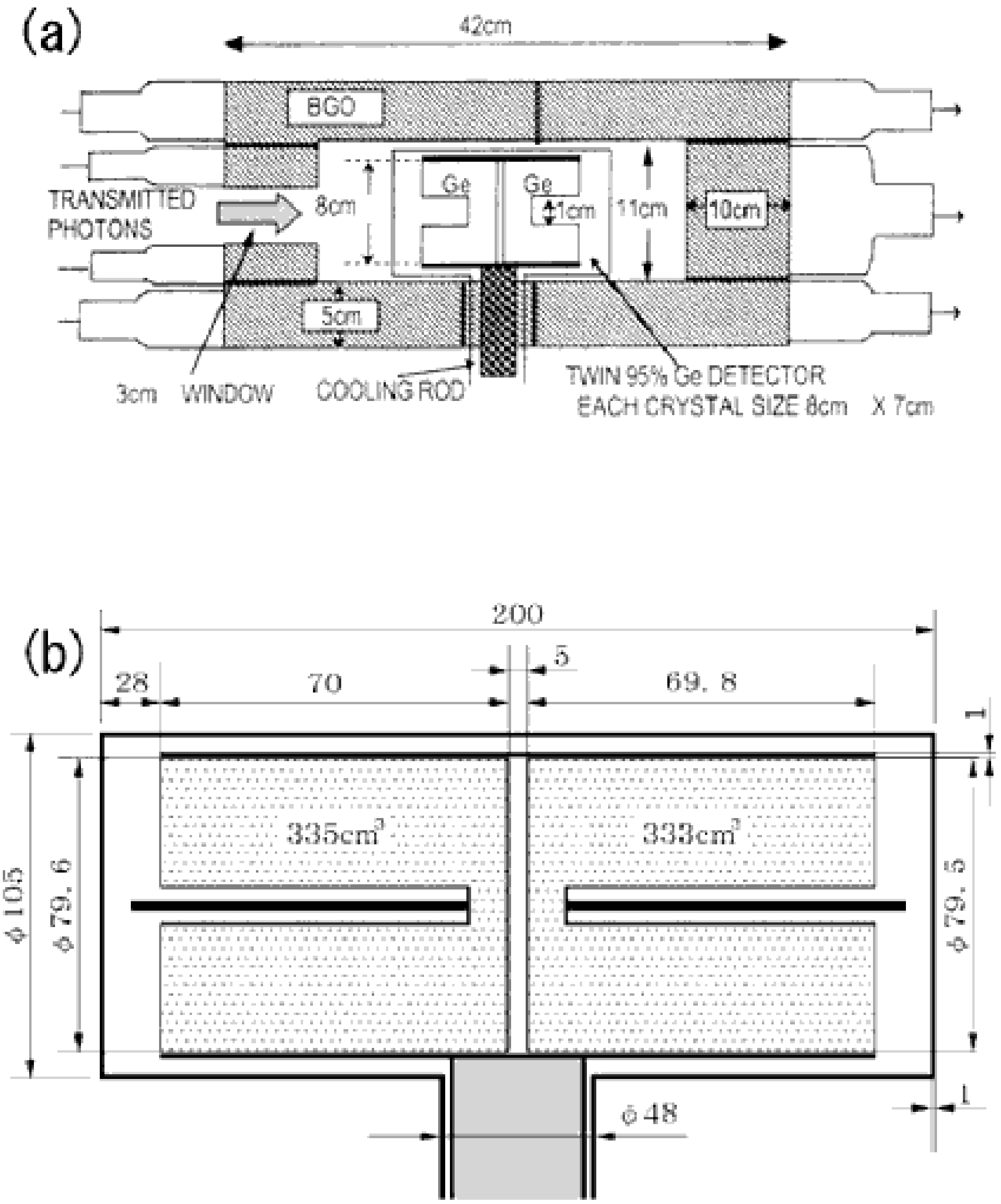

Figure 1: The High-resolution High-energy photon Spectrometer (HHS) (a) and the Twin Ge detector (b).

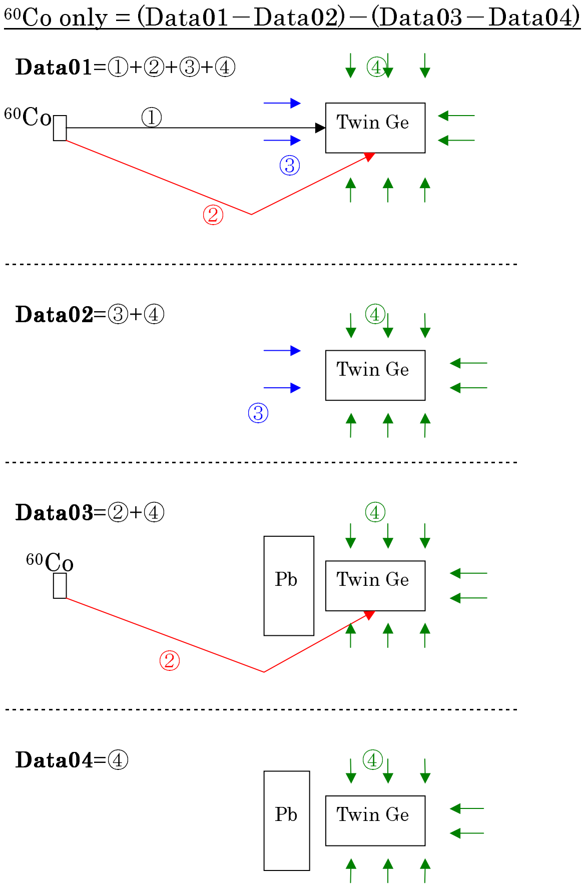

Figure 2: Procedure of the response function measurements for the Twin Ge detector and the data manipulation.

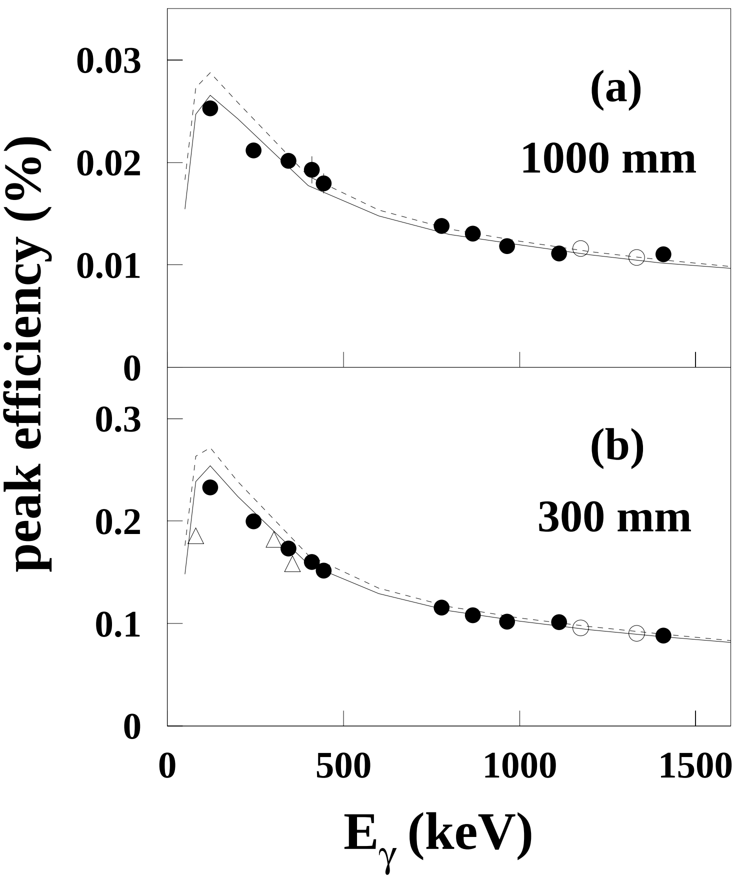

Figure 3: Peak efficiencies of the Twin Ge detector at 1000 mm (a) and 300 mm (b) from the point sources measured without a collimator. The open circles are data for ^{60}Co, the solid circles for ^{152}Eu, and the open triangles for ^{133}Ba.

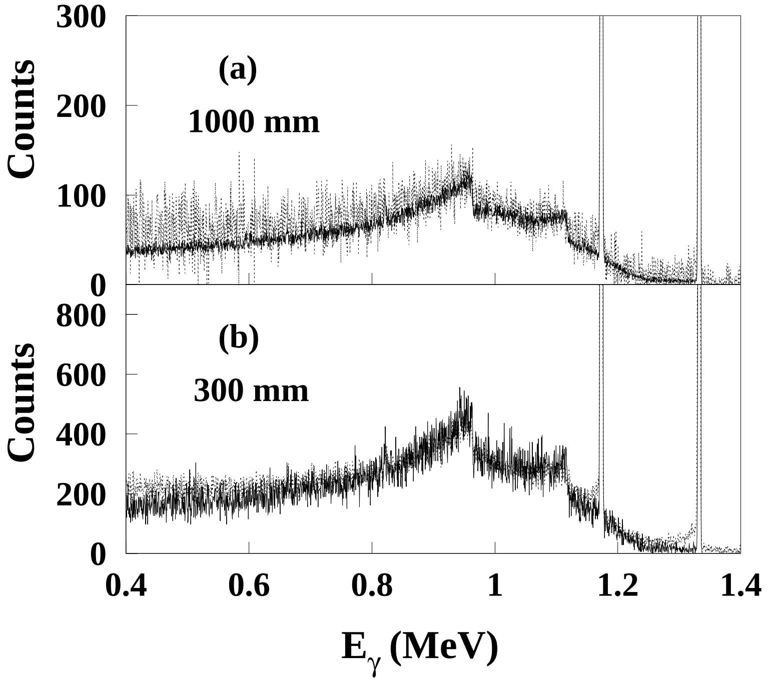

Figure 4: Response functions of the Twin Ge detector at 1000 mm (a) and 300 mm (b) from the ^{60}Co source measured without a collimator.

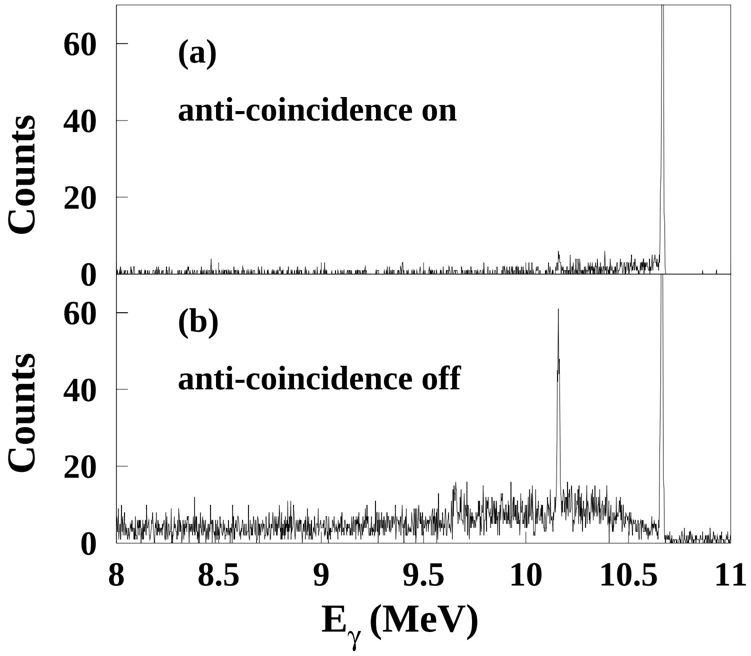

Figure 5: Response functions of the HHS for 10.7 MeV γ rays from the ^{27}Al(p,γ)^{28}Si reaction measured with a collimator.