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Evaluation of Response Functions of 16"x16"x4" Large-sized NaI Scintillation Detector for Environmental Gamma-ray Survey

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Abstract

Response functions of the 16"x16"x4" - large sized NaI detector, which is mainly used for high sensitive gamma-ray survey in outdoor environment, have been calculated by using EGS4 code. The calculated results are compared with the measured data for standard gamma-ray sources to check their accuracy. Through the precise modeling of the detector structure in the calculation, the agreement between both results has been improved up to around ±15% relative deviation in ^{137}Cs source spectrum. Based on this calculation model, the directional response matrix consisting of 24 energy groups x256 pulse height bins has been prepared to unfold gamma ray spectra from the measured data. The unfolding results seem to be reasonable in a preliminary analysis on natural background gamma-ray spectra.

1 Introduction

Wide area and rapid survey for environmental nuclear radiation is often needed in health physics study[1], in the mineral resource search application[2] and/or sometimes in nuclear facility accidents[3]. For these purposes, a mobile radiation survey system based on a large volume NaI scintillation detector has already been developed and put to practical use. We have calculated response functions of a 16"x16"x4" large-sized NaI scintillation detector, which have not been established well, especially directional response functions, by using the EGS4 code and verified an accuracy of the calculated responses through comparison with experiments from the viewpoint of application to gamma-ray spectrum unfolding.

2 Detector Specification and Calculation Model

The NaI detector used, is commercially available type GPX-1024 (Exploranium G.S. Ltd.). As shown in Fig.1, it consists of four 4"x4"x16" NaI detector units arranged in parallel. Each NaI crystal is hermetically sealed in a 0.5mm thick stainless steel container and attached with a photomultiplier through an optical window (Fig. 2). The four components are packed into a ruggedized aluminum case with an effective thickness of 1.6mm, together with some thermal insulator and cushion materials.

In the EGS4 calculation, the detector structure was modeled as precisely as possible, except for photomultipliers, that is, in a combinatorial geometry consisting of four kinds of regions, NaI crystal, stainless steel cover, Aluminum case and air gap, as shown in Fig.3.

Twenty five points of incident gamma-ray energy were selected between 0.005 MeV and 3.0 MeV corresponding to the output signal gain of the detector system, while the pulse height distribution (or deposited energy distribution inside the detector) obtained from the calculation was divided into 256

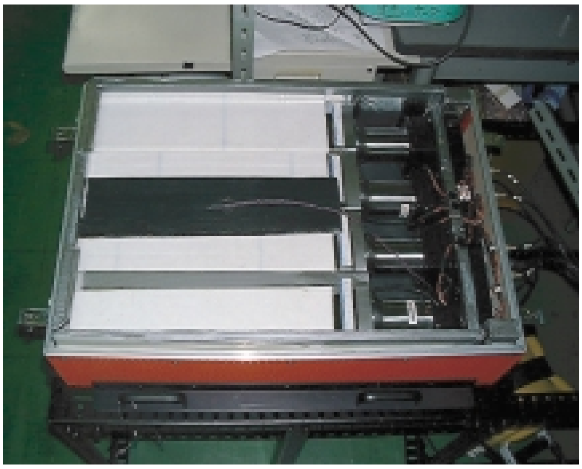

Figure 1: Appearance of GPX-1024.

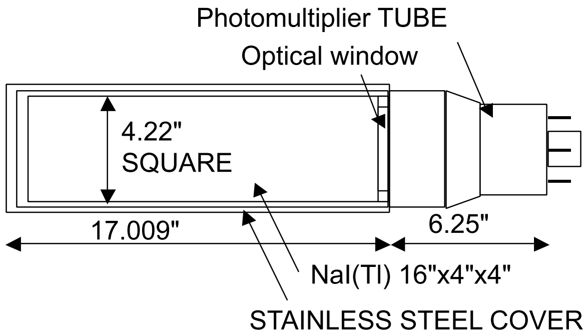

Figure 2: Cross sectional view of each NaI scintillator unit.

channels adjusting to the function of the Multi-channel analyzer. The above energy range includes major gamma-rays produced from natural radioactive isotopes. This 25x256 response matrix was prepared for a uniform parallel-beam gamma-ray incidence perpendicular to the 16"x16" detector surface as a reference and also checked on the dependence of the gamma-ray beam incident angle to the detector surface. In addition, some response functions for an isotropic point source were calculated to compare with an experiment for standard gamma-ray sources, which were broadened to reproduce the measured results of photoelectric peaks, according to an energy resolution (Gaussian) function with an energy dependent relative FWHM (Full Width at Half Maximum),

$$R = \frac{\sqrt{\alpha + \beta E}}{E}, \tag{1}$$

where E is the gamma-ray energy and the parameters α and β are experimentally determined.

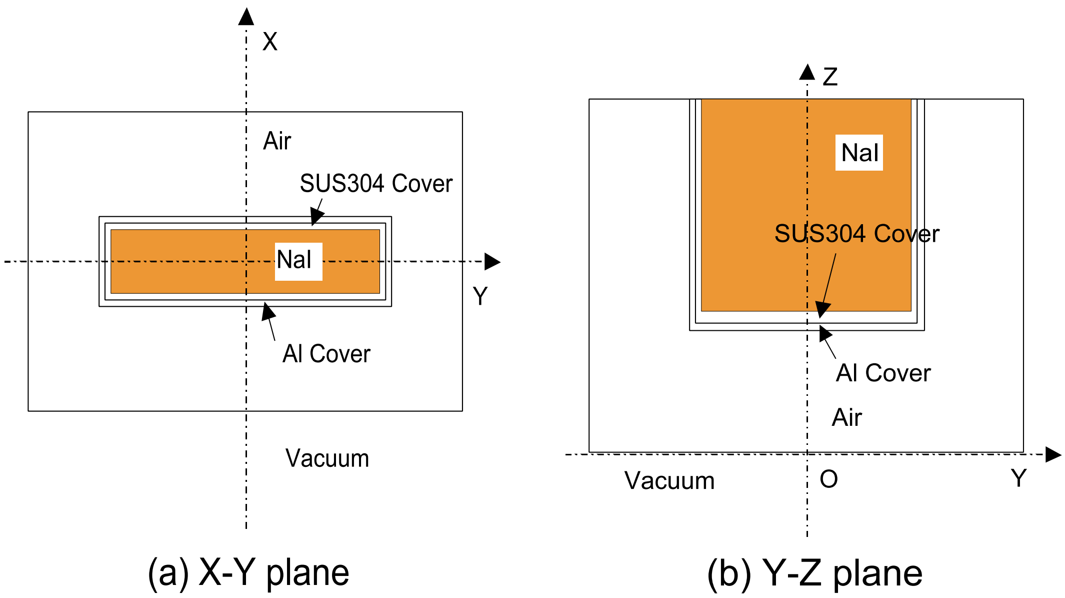

Figure 3: Geometry for EGS4 calculation.

3 Results and Discussion

For standard gamma-ray sources such as ^{137}Cs and ^{60}Co, the directional response functions were measured and compared with the calculated results. Fig. 4 shows an experimental arrangement to measure the response function for a point source placed just above the 16"x16" detector surface, that is, in the 0 degree incidence of gamma-rays. Fig. 5 gives an example of comparison results between experiment and calculation for a ^{137}Cs(662 keV) gamma-ray source in the arrangement of Fig. 4. By making the detector modeling more precise step by step, an agreement between both results has reached up to within $\pm 15\%$ relative deviation in the whole energy range. Fig. 6 illustrates another example of experimental arrangements to measure the response function in the just side (or 90 degree) incidence of gamma-rays. For this arrangement, the calculated response was also compared with the measured one, as shown in Fig. 7, where good agreement is found in the energy range of a photoelectric peak and compton continuum for the ^{137}Cs gamma-ray spectrum, while the discrepancy in the lower energy region would be mainly due to the contribution of gamma-rays scattered from the experimental room floor.

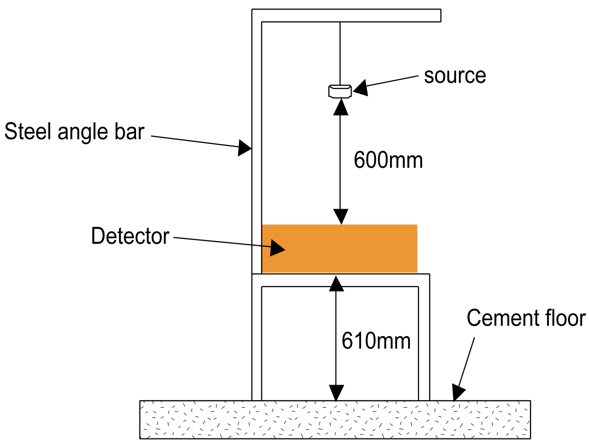

Figure 4: Experimental arrangement for the 0 degree gamma-ray incidence.

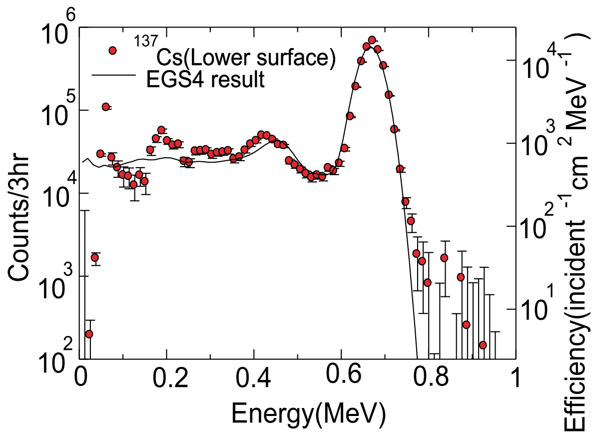

Figure 5: Comparison between experiment and calculation in the 0 degree incidence of ^{137}Cs gamma-ray.

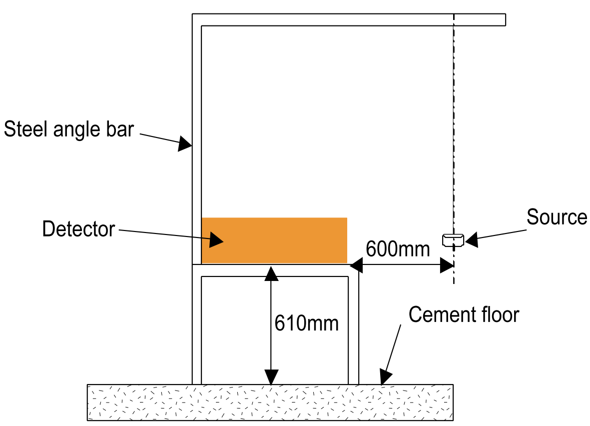

Figure 6: Experimental arrangement for the 90 degree gamma-ray incidence.

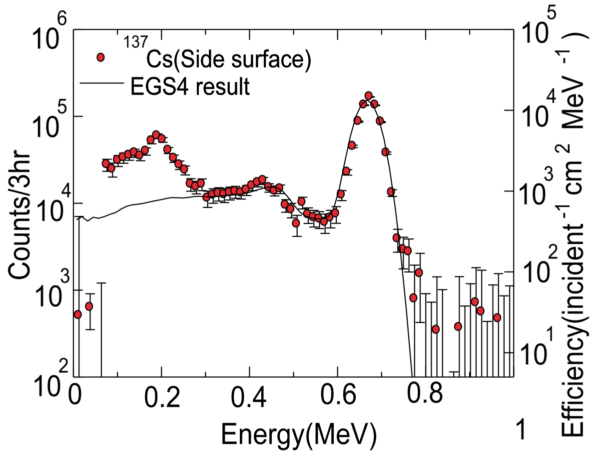

Figure 7: Comparison between experiment and calculation in the 90 degree incidence of ^{137}Cs gamma-ray.

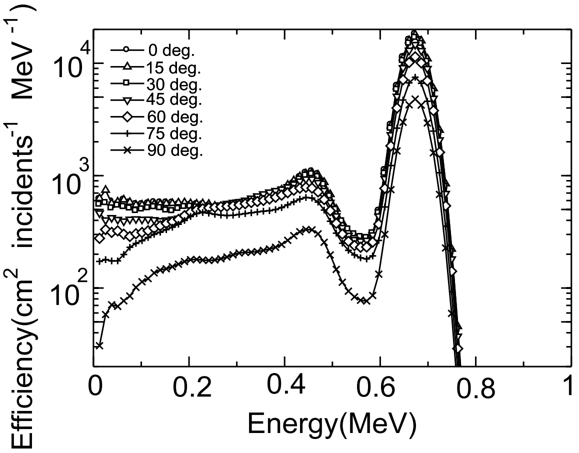

Figure 8: Comparison of calculated directional response functions.

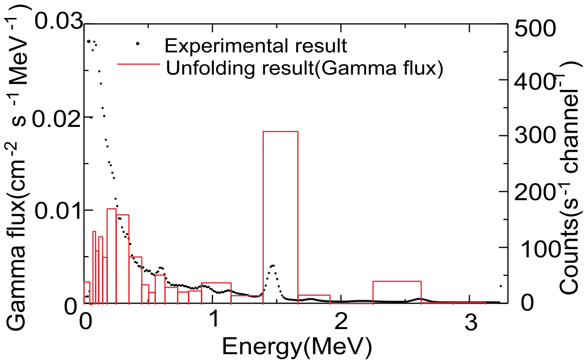

Figure 9: Preliminary unfolding result of natural background gamma-ray spectrum.

Fig. 8 shows a comparison of calculated directional responses corresponding to the incident angle of uniform parallel-beam gamma-rays from 0 to 90 degrees. It is found that the directionality of response functions is clearly appeared in the lower energy parts of pulse height distribution. This means that the directional response functions of the present system should be precisely evaluated and adequately applied to derive (or unfold) gamma-ray spectrum from measured data by considering the directionality of gamma-ray fields of interest. Fig. 9 demonstrates a preliminary result of natural background gamma-ray spectrum, which was derived from the measured data of environmental gamma-rays through an analysis combining the present response matrix with a simple unfolding method 'SAND-II'. The unfolded spectrum seems to be reasonable, where natural radioactive isotope sources such as ^{40}K (1.461MeV), ^{214}Bi (1.765MeV), ^{208}Tl (2.615MeV) are clearly observed and separated as gamma-ray peaks[4, 5].

4 Conclusion

We have calculated directional response functions and/or response matrices for a 16"x16"x4" - large sized NaI detector by using the EGS4 code and checked their accuracy by comparing with the measured responses for standard gamma-ray sources. The comparison results have shown that the calculated responses could agree with the measured ones within $\pm 15\%$ relative deviation(corresponding to $\sim 3\sigma$) in ^{137}Cs source spectrum through the precise detector modeling in the calculation.

It has been also pointed out that the directional response functions should be precisely evaluated and adequately applied to derive accurate gamma-ray spectra from measured data. For this purpose, the EGS4 code is a powerful tool and will be used to make more detailed response matrices for our NaI system.

References

[1] L. Travis et al., *Nucl. Instr. and Meth. in Physics Research A* **422**(1999)144-147.

[2] M. Cruz et al, *Fuel* **77, No.13**(1998)1427-1430.

[3] ICRU Report 53 1994.

[4] K. Saito, S. Moriuchi, *JAERI 1306*pp.6-7(1987).

[5] S. Minato, *JCAC* **32**(1998)5.