Dependence of gamma spectra from a CsI(Tl) scintillator on the quantum efficiency of the coupled photodetector: A GEANT4-based study

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Introduction

The matching of emission spectra of scintillators with spectral response curves of photodetectors plays one of the most critical roles in determining the energy resolution obtainable from scintillator based gamma spectrometers. In this study, GEANT4-based simulation is performed for a $2''\phi \times 2''$ L cylindrical CsI(Tl) crystal coupled to a $2''\phi$ photodetector. Transport of incident gamma photons in the crystal is followed up by generation and transport of optical photons up to the surface of the photodetector. Optical photons reaching this surface are detected with a probability equal to the detection efficiency (η) defined for the surface. Therefore, η is same as the conventionally defined quantum efficiency, which represents the conversion probability of optical photons to photoelectrons at the surface of the photodetector. Gamma spectra are generated via simulation from the number of optical photons (n_{ph}) detected at the photodetector surface in each primary gamma ray event. The spectra generated for different values of η are analysed and compared.

Simulation

The simulated geometry is presented in Fig. 1. The whole assembly was placed in air and subjected to a divergent beam of gamma photons originating from a point placed on the cylinder axis at 300 mm on the left of the front surface and entirely covering this surface. The beam consisted of photons with an energy-mixture of 32 keV (6%), 36 keV (1%) and 662 keV (85%) (typical of ^{137}Cs-decay).

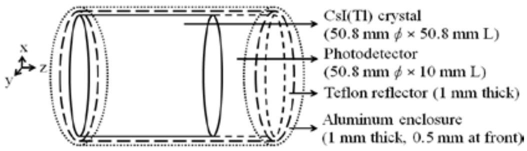

Fig.1 The simulated geometry (not to scale)

It is to be mentioned that only the surface parameters of the photodetector control n_{ph}, and, therefore, the arbitrary length (i.e. 10 mm) taken for it does not affect the simulation results. The simulation parameters are summarized in Table 1.

After scoring n_{ph} for each gamma ray event, the same was converted into pulse height by using the equation

$$Pulse\ height\ (V) = \frac{n_{ph} \times e \times G}{C} \quad (1)$$

where,e = electronic charge= 1.602×10^{-19} C.

All simulations were performed for 7×10^4 primaries. A pulse-height histogram was generated by tallying the pulse height values on an event-by-event basis.

Results and Discussion

In [1], we have reported the experimental validation of the simulation model when CsI(Tl) is coupled to Hamamatsu R1306 photomultiplier tube (PMT) with η = 0.05. Simulated spectrum for η = 0.8267 (typical of Hamamatsu S3590-08 photodiode) was also presented and compared with that for η = 0.05 in [1]. Simulated spectra are generated here for several additional values of η. The variation of energy resolution (R) of the 662-keV peak and the corresponding peak pulse height (PPH) are shown as functions of η in Fig.2.

The best-fit curve between R and η is given by,

$$R = 1.66872 + \frac{1.02041}{\sqrt{\eta}} \quad (2)$$

Table 1: Simulation parameters

Parameter (Unit)	Value
Doping concentration (at%)	0.15 of Tl w.r.t. Cs
Densities(g/cm^3)	4.51 (CsI(Tl)), 2.2 (Teflon)
Scintillation emission spectrum	Implemented as a function of photon energy as experimentally measured, peaking at nearly 540 nm
Refractive indices	1.79 (CsI(Tl)), 1.35 (Teflon), 1.00 (Air)
Optical photon absorption length (m)	5
Mie scattering length (m)	5000
Absolute light yield (photons/MeV)	65000
Resolution-scale	1.0
Decay time (ns)	700 (57%), 3500 (43%)
Birks' constant (mm/MeV)	1.52×10^{-3}
Surfaces: **1.**CsI(Tl)-Teflon (dielectric-dielectric) **2.** CsI(Tl)-photodetector (dielectric-metal) (Model used: UNIFIED)	**Type:** ground-front-painted (1), polished (2) **Reflection type:** Lambertian (1), Specular Lobe (2) **Reflectivity:** 0.98 (1), 0.00 (2) **Roughness:** 0˚ (1), 0˚ (2) **Detecting efficiency:** 0.00 (1), varied, see Fig. 2 (2)
Photodetector gain, G	2.7×10^5 (typical of Hamamatsu R1306 PMT)
Overall circuit capacitance, C (nF)	1.0 (arbitrary)

It is known that $R \propto 1/\sqrt{n_{ph}}$.On the other hand, as, $n_{ph} \propto \eta$, the result presented in (2) is justified.

The equation of the best-fit straight line between *PPH* and η is,

$$PPH(V) = 1.5041 \times \eta - 2.47152 \times 10^{-4} \quad (3)$$

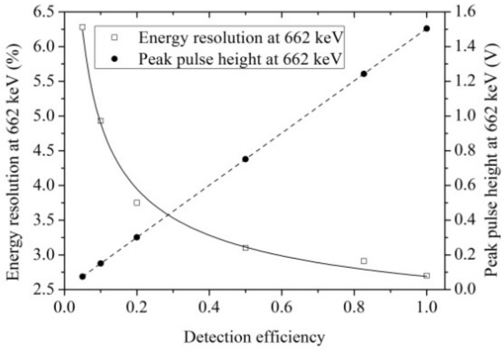

Fig. 2 Energy resolution of the 662-keV peak and its corresponding pulse height as functions of detection efficiency of the photodetector

This result may be explained on the basis of the fact that $PPH \propto n_{ph}$, and, also, $n_{ph} \propto \eta$.

The improvement of *R* and increase of *PPH* with increase in η indicate that the better matching of emission spectrum of CsI(Tl) with spectral response of silicon-based photodetectors, and, consequently, higher values of η, can significantly improve the quality of gamma spectra when CsI(Tl) is coupled with such photodetector, as opposed to the case when CsI(Tl) is coupled to PMTs with typical bialkali photocathodes.

It is worth a mention that the values of *PPH* in Fig. 2 are calculated based on Eq. (1), where the values of *G* and *C* are arbitrary. Hence the values of *PPH* are subject to change in practical cases based on the actual values of *G* and *C* of the scintillator/photodetector configuration.

Conclusion

Monte Carlo simulation with optical photon transport is carried out for a CsI(Tl) scintillator coupled to a photodetector. Effects of variation of detection efficiency of the photodetector on the pulse height spectra are quantitatively analysed. It is observed that energy resolution improves as the inverse of the square root of detection efficiency, whereas pulse height increases linearly with the same. Although reported for CsI(Tl), the methodology can also be applied for other scintillators when their respective properties are substituted.

References

[1] Mitra P. *et al.*, IEEE Trans. Nucl. Sci. **66** (7), 1870-1878 (2019)