Gamma Sensitivity of Pressurized Drift Tubes

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Abstract

Using a set of commonly used radioactive sources, the efficiency of pressurized drift tubes (PDT) for gammas with energy from 5.9 keV up to 1.3 MeV have been measured. The PDT was made of aluminum and filled with Ar, $15\%CO_2$ and $2.5\% iC_4H_{10}$ gas mixture at 3 atm. The measured efficiency is compared with results of calculations in the frame of our simple model as well as with that of the Monte Carlo simulation using GEANT code. The results of our calculations are in agreement with experimental data, while GEANT simulation tends to gives lower efficiencis in the energy range of $E_\gamma > 200$ keV. The average efficiency of the PDT in the field of ATLAS gamma background is about 0.45%.

Introduction

The ATLAS muon detectors /1/ will operate at substantial neutron and gamma background (about 100 Hz/cm^2). While the main sources of the neutron background are hadronic and electromagnetic showers in the detector materials caused by secondary particles from primary interaction, the main sources of the gamma background are neutrons themselves. Neutrons produce photons (mainly via the radiation capture (n,γ) reaction) with energies between 10 eV and 10 MeV. The low-energy gammas are absorbed just near the production point by the detector material and the resulting energy spectrum of gammas is harder and looks like the one presented in fig.1 /2/. The simulation of radiation background for ATLAS /3/ and for the analogous detector of the SSC have shown that the gamma-quantum fluence is only 1.5$\div$4 times lower than the neutron fluence. If the muon detector efficiency for neutrons is one order of magnitude lower than the γ-detection efficiency, the background rate of detectors would be determined by photons. So the knowledge of the γ-detection spectral sensitivity of muon detectors is vital for correct estimation of the muon system performance.

One of the options of the ATLAS muon system detector is Pressurized Drift Tubes (PDT). Recently we have studied the spectral sensitivity of the aluminum PDT for neutrons using a neutron beam from the JINR pulse neutron source IBR-30/5/. In the present we show the results of measurements of the γ-detection efficiency of the aluminum PDT in the energy range from 6 keV up to 1.3 MeV.

The first measurements of the spectral γ-detection efficiency of such type detectors were carried out in 1950 for Geiger-Muller counters using different radioactive isotopes/6/. For the counter with 0.77 g/cm^2 bismuth cathodes filled with Ar (9 cm Hg) and ethyl alcohol (1 cm Hg) mixture it was found that the absorption of the gamma rays in the gas mixture can generally be neglected. The gamma quantum is detected if it is absorbed in the counter wall and ejects an electron into the sensitive volume of the counter. The efficiency essentially depends on where the photon passes through the counter and has two peaks near the walls of the counter. An average efficiency upon photon energy and varies between 0.7 to 2%.

Recently the sensitivity of iron, aluminum and mylar PDT to gammas from Co^{60} (1.33 and 1.17 keV) source was measured in the frame of GEM R&D/2/. The measured efficiencies were approximately 1%, which is in good agreement with GEANT simulation. Some discrepancies were pointed out only for mylar PDT.

Experimental Set-Up.

The PDT efficiency for gamma-rays of different energies was measured by irradiation of the detector with collimated gamma-rays from radioactive sources. The activities of the sources were known within 1%. The schematic description of the experimental set-up is shown in fig.2. The PDT was an aluminum tube 30 cm long, 30 mm in diameter and of 0.5 mm thick wall. The signal electrode was made of a 100 μm Cu-Be wire. The tube was filled with Ar + 15%CO_2 + 2.5%iC_4H_{10} gas mixture at 3 atm.

The photon flux was collimated by lead blocks so that the irradiated area was about 9 cm^2. The signals from the PDT were amplified and fed into the discriminator. The PDT was operated in the limited streamer mode and the threshold was set to 13.5 μA. The pulse width after discriminator was 1 μs in order to prevent counting of the afterpulses.

The tube efficiency was calculated as follows: $\varepsilon = 4\pi \frac{N-N_{BackGr}}{n\ \Delta t\ \Omega\ A}$, where N and N_{BackGr} are the numbers of PDT counts with and without radioactive source during the Δt measurement time, n is the effective number of gammas emitted by the source per decay, Ω is the solid angle subtended by the PDT, A is the gamma-source activity.

In order to investigate the possible influence on the results of gammas scattered into the counter by collimator, the count rate versus the collimator width was measured. The results are shown in fig.3. The PDT rate is proportional to the slit width and the influence of an interaction of the photons in the collimator walls is inessential.

To check our results the PDT efficiency for Co^{60} photons was also measured by the $\gamma - \gamma$ coincidence method. The second photon was detected by a scintillating counter (see fig.2). The scintillator was a polystyrene based $120 \times 110 \times 8mm^3$ rectangular bulk. The results of both methods are in good agreement with each other.

Efficiency Simulation.

For better understanding of the role of different processes causing photon detection in a PDT, the calculations in the frame of a simple model were carried out. The contribution of pair production can be neglected because the role of this process is only dominate when photon energies are more than 10 MeV. Thereby we included photoeffect and Comton scatering only. In fig.4 the PDT cross-section and the trajectory of a photon passing through PDT at distance l from its axis are shown. It was supposed that if an electron produced by interaction of a photon with the tube reaches the gas volume, it will be registered with 100% efficiency. It was also supposed that electrons produced within the tube wall move straight and their path length is determined by their initial energy and equal to the mean electron range in aluminum /6/. Then one can calculate the contribution of the photon absorption within the tube wall to the total γ-detection efficency as follows:

$$\varepsilon(E_\gamma) = \int_0^R \frac{dl}{R} \int_0^d dx \frac{e^{-\frac{x}{\lambda}}}{\lambda} \int_0^{\frac{\pi}{2}} \frac{d\theta}{\pi/2} \int_0^{2\pi} d\phi \frac{\sin\phi}{2\pi} \frac{\frac{d\sigma}{d\Omega}}{\sigma_{tot}} f(\phi,\theta,x,E_e,l),$$

where E_γ is the energy of the incident photon , x is the distance passed by the photon within the wall before absorption (see fig.4), d is the wall thickness on the photon way, E_e is the energy of the produced electron, λ is the mean range of the photon corresponding to Compton scattering or photoeffect cross-sections. The function f is equal to 1 if the electron emitted at polar θ and azimuthal ϕ angles reaches the tube gas volume, and is equal to zero otherwise. The values of the total σ_{tot} and differential $\frac{d\sigma}{d\Omega}$ cross-sections of photoeffect and Compton scattering were taken from /7,8/.

The contribution of the photon absorption in the gas to the PDT efficiency was calculated as follows: $\varepsilon = (1 - e^{-\frac{d}{\lambda_{wall}}})e^{-\frac{D}{\lambda_{gas}}}$, where D is the part of the photon trajectory within the gas volume, λ_{wall} and λ_{gas} are the photon mean ranges in the detector wall and in the gas mixture respectively.

The results of calculations are shown in fig.5 along with the results of GEANT simulation. In GEANT simulation it was also supposed that a photon is detected if an electron is emitted into gas volume. GEANT cuts for minimum electron and photon energies were set at 10 keV.

The energy dependence of the PDT γ-detection efficiency has two features: a narrow peak at 20 keV and a wide maximum near 1 MeV. The tube efficiency near the low energy peak is completely determined by photoabsorption in gas mixture and is proportional to the gas pressure. The efficiency magnitude and the shape of the left slope of the peak are determined by the PDT wall thickness. due to γ-absorbtion in the tube wall. The right slope of the peak is due to the decrease in the photoeffect cross-section.

For photon energies more than 200 keV the PDT efficiency is mainly defined by Compton scattering in the tube wall. The efficiency increases up to 1.5% at 1 MeV and then slightly decreases. In the low-energy peak range the GEANT results are in good agreement with our model while at higher energies they are lower by a factor of two.

Results.

During the measurements 9 radioactive isotopes were used as sources of gamma-rays. Principal characteristics of these sources are presented in Table 1.

Table 1.

Source	Co^{60}	Zn^{65}	Mn^{54}	Cs^{137}	Na^{22}	Ba^{133}	Am^{241}	Co^{57}	Fe^{55}
Energy, keV	1332 1173	1115	834	662	511 1275	280-380 80 33	60 14-20	130 14	5.9
Emission, %	100 100	50.7	100	85	180 100	97 32.8 124	36 39	96.2 9.6	27.7
Max.energy of e^-, keV	310	-	-	514	-	-	-	-	-
Activity, kBq	81.7	4.0	5.7	106	42	81.2	94.5	4.2	10^6

For this measurements only Mn^{54}, Zn^{65} and Fe^{55} are sources of pure monoenergetic photons. The other isotopes have γ's with different energies and moreover some isotopes decay via β-decays. Therefore in each case it was required to separate contributions of photons of different energies. For example, fig.6 shows the dependence of the PDT count rate on gas pressure for Co^{60}, Am^{241} and Ba^{133}. In the case of Co^{60} the count rate practically does not depends on pressure. It means that the PDT efficiency for Co^{60} photons is completely due to Compton scattering in the tube wall. On the other hand, the efficiency strongly depends on pressure if the PDT is irradiated by Am^{241} or Ba^{133}. This behaviour indicats that the detaction mechanism governed by photoeffect in the gas of the PDT. Moreover the extrapolation of these dependencies to zero pressure shows that the efficiency for gammas from Am^{241} is only proportional to the gas pressure while in the case of Ba^{133} the efficiency contains some constant contribution from photon interaction with tube wall.

Co^{60} This source emits in one decay two photons with rather close energies. Therefore the measured efficiency was attributed to their mean energy 1253 keV. Electrons emitted by Co^{60} have maximal energy 314 keV and cannot reach the PDT sensitive volume because their range in aluminum is only 0.4 mm /6/.

Cs^{137} Apart from 661.5 keV photons the Cs^{137} source also emits electrons with maximal energy of 514 keV, whose range in aluminum is 1 mm. Therefore additional aluminum filters were placed between the tube and the radioactive source. The photon absorption in the filter was taken into account by extrapolating the results of measurements to filter of zero thickness.

Na^{22} In one decay the Na^{22} source ejects two 511 keV photons and one photon with energy 1275 keV, which is very close to average energy of Co^{60} photons. This have allowed determination of the efficiency for 511 keV photons using the measured efficiency for Co^{60}.

Co^{57} Co^{57} emits X-rays with energy of 14.4 keV in addition to 122.1 and 136.5 keV photons. Although the probability of X-rays emission is 10 times less than that of gamma emission, the PDT efficiency for 14 keV X-rays is 25 times higher than that for 130 keV photons (fig.5). The main contribution to the PDT efficiency in this case is given by X-rays. To obtain the correct PDT efficiency at 14 keV the contribution from 130 keV photons was subtracted supposing that efficiency to this photons is equal to the calculated value.

Am^{241} As in the case of Co^{57}, the main contribution to the PDT efficiency for Am^{241} is given by L(Np) X-rays with energy between 14 and 20 keV rather than 60 keV photons. The efficiency value was corrected by subtraction of a calculated contribution of 60 keV photons. Am^{241} also emits 5.5 MeV α-particles, but they cannot influence the results of measurements because of their too short range.

Ba^{133} Ba^{133} produces the most complicated gamma spectrum. It emits 33 and 80 keV photons whose detection probability is proportional to the gas pressure. Also Ba^{133} emits photons with energies in the range of $280 \div 380$ keV where the PDT efficiency does not depend on the gas pressure. The contributions of gammas with different energies were separated using the pressure dependence of tube count rate. The efficiency at 350 keV mean energy was obtained by extrapolating the results of the measurements to "zero" pressure. To find the efficiency at 33 keV the contribution of the 80 keV photons was subtracted as in the cases of Am^{241} and Co^{57}.

The measured values of the PDT efficiency at different photon energies are presented in fig.7. One can see that in the whole energy range they are in good agreement with the results of our simple model. At the same time the GEANT results are by a factor of two lower than the experimental values within the $0.3 \div 1.2$ MeV energy range.

Summary.

The sensitivity of aluminum PDT filled with Ar + 15%CO_2 + 2.5%iC_4H_{10} gas mixture at 3 atm to gamma-rays have been measured using a set of standard radioactive isotopes whose activities were known with 1% precision. The results were verified for the Co^{60} source by the $\gamma - \gamma$ coincidence method.

In order to elucidate the role of different processes that cause photon detection we have calculated the PDT efficiency in the frames of a model based on assumption that the photon will be detected if it produces an electron reaching the PDT sensitive volume. Results of the calculation are in good agreement with the experimental data. At the same time the results of GEANT simulation agreed with the experimental data only at low energies. At gamma energies $E_{\gamma} > 200$ keV GEANT gives systematically lower efficiency values than the experimental data.

At photons energies more than 200 keV the Compton scattering in tube wall gives the main contribution to the PDT quantum efficiency. The role of photoabsorption at this energies is negligible . Below 100 keV the photoabsorption in argon is the main mechanism for gamma detection. The PDT efficiency reaches 6% at 18 keV. The photons with energy below 10 keV cannot pass through the tube wall and the energy of produced electrons is to low to reach the gas volume.

Based on the results for PDT sensitivity to gammas an average PDT efficiency for ATLAS photon background have been calculated. The mean efficiency is determined to be 0.45 %. Comparing the PDT efficiency for photons and for neutrons /5/ one can conclude that the photons contribution to the PDT occupancy is by a factor of two more than that of neutrons.

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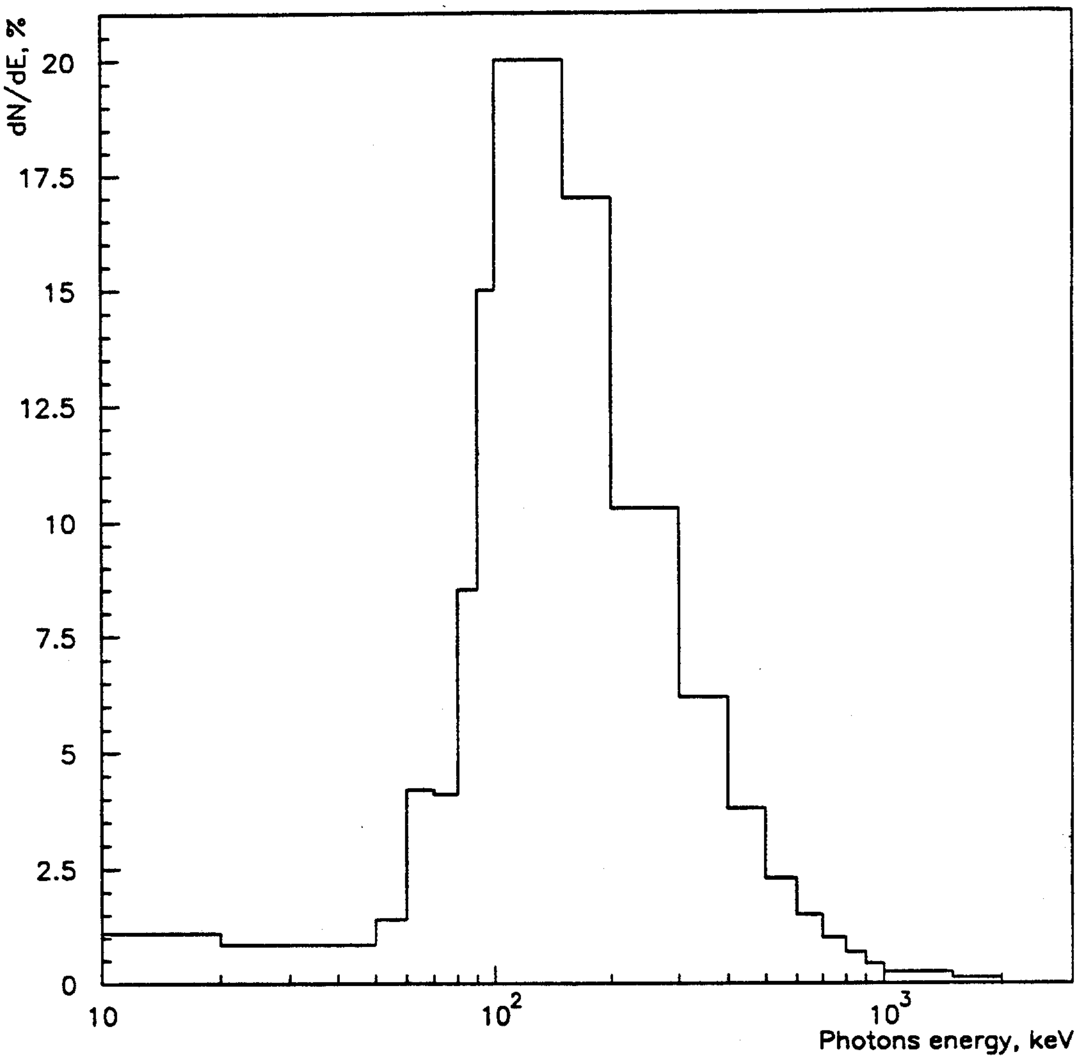

Figure 1: Expected spectrum of background photons

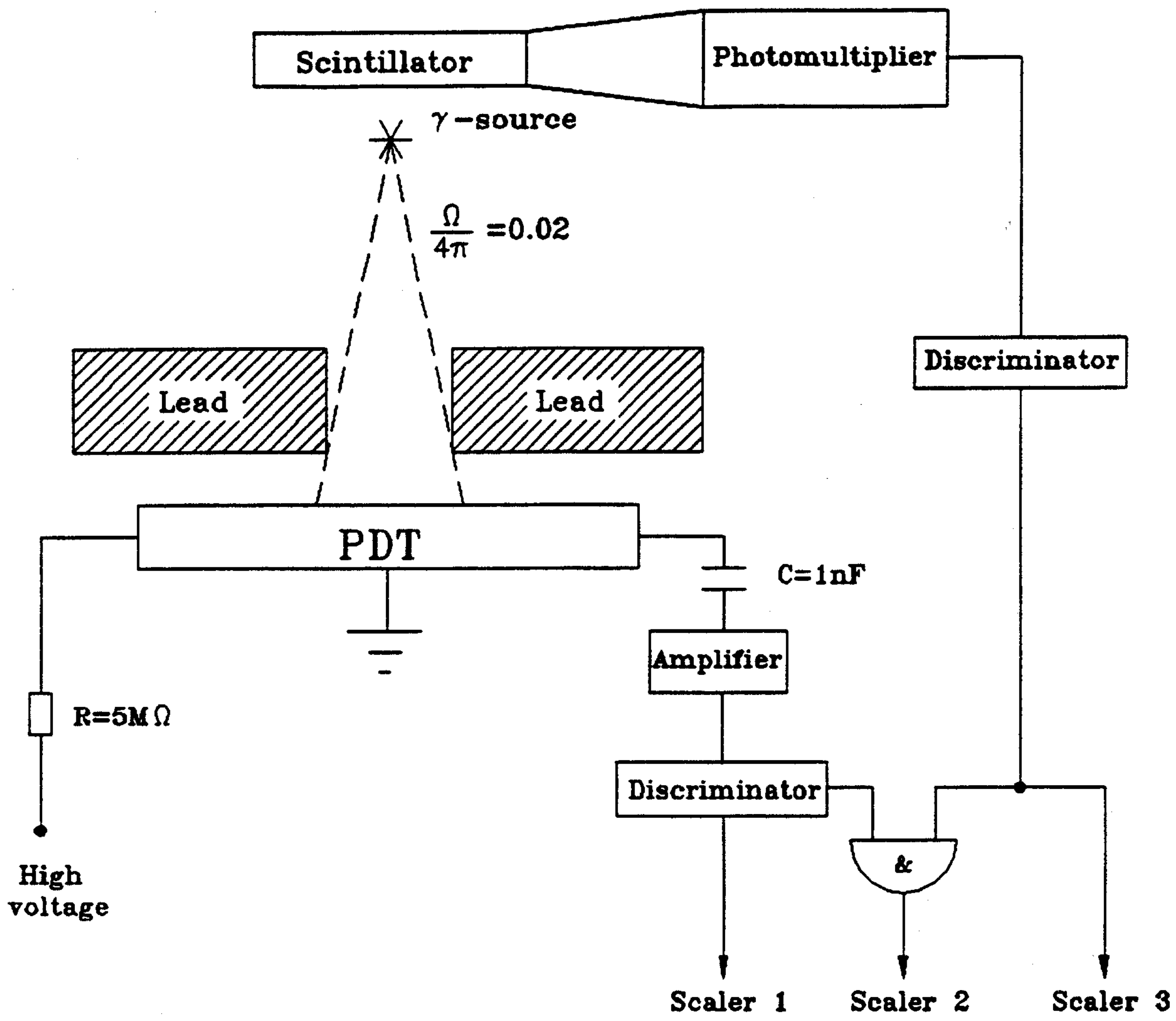

Figure 2: Schematic description of the experiental set-up

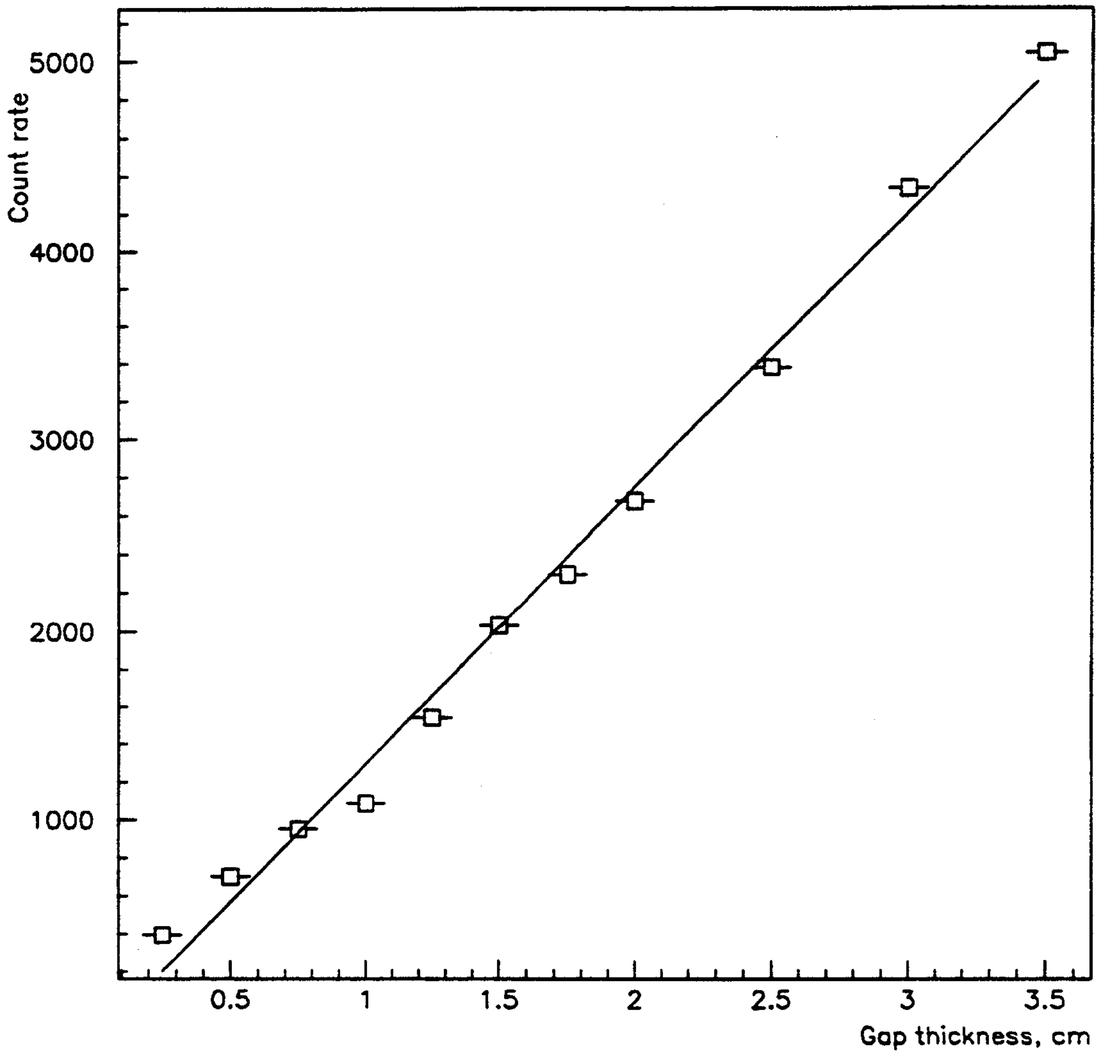

Figure 3: PDT count rate versus collimator width

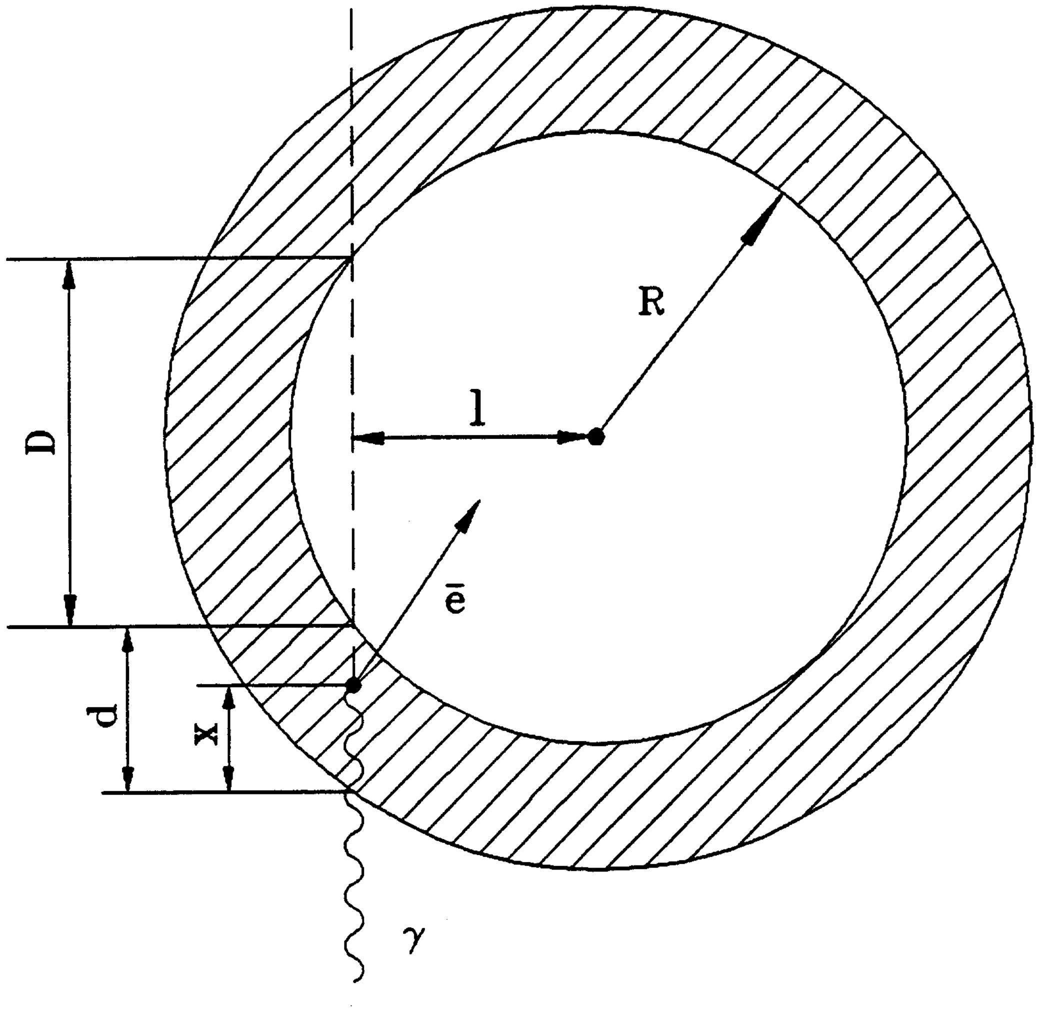

Figure 4: Cross-section of PDT and trajectory of a passing photon

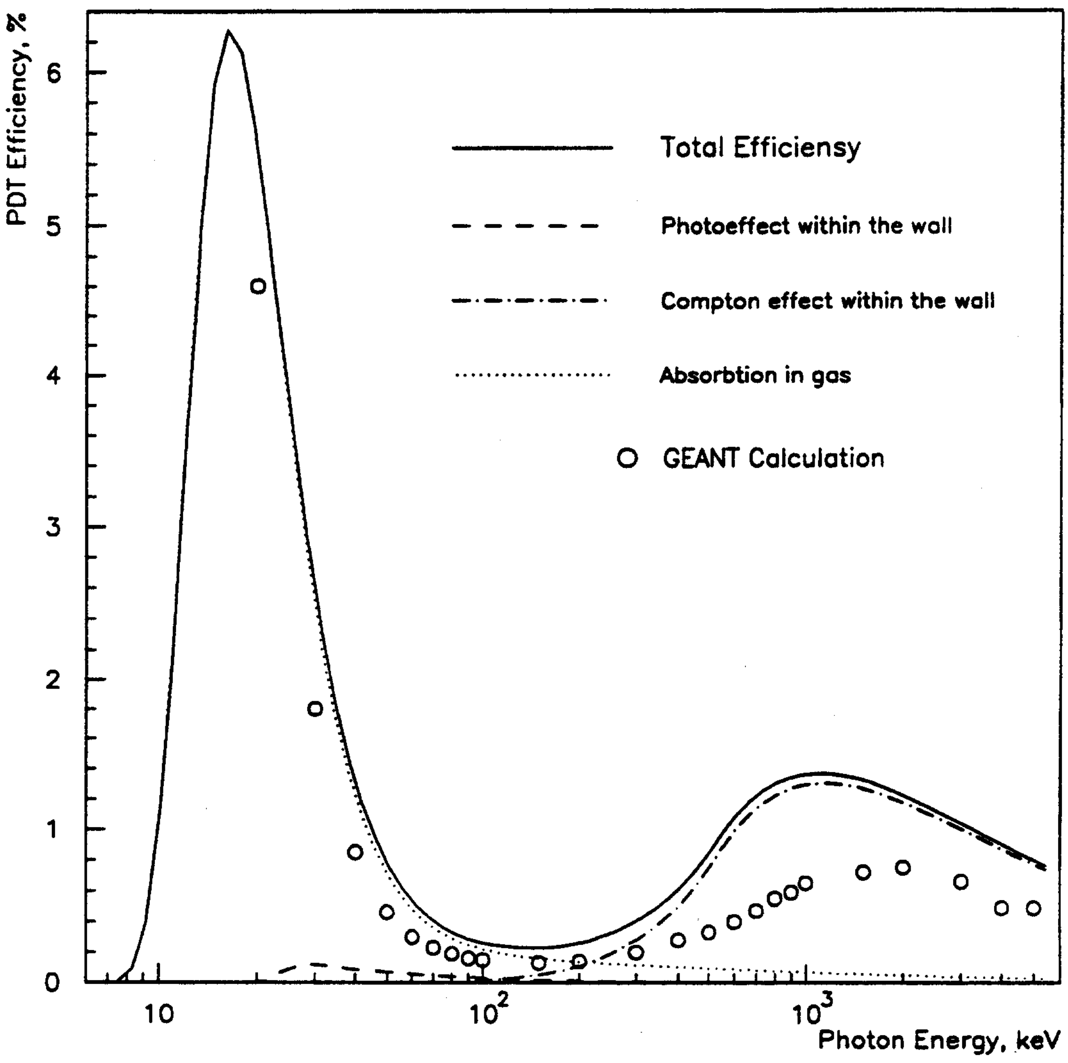

Figure 5: Calculated quantum efficiency of the PDT as a function of photon energy

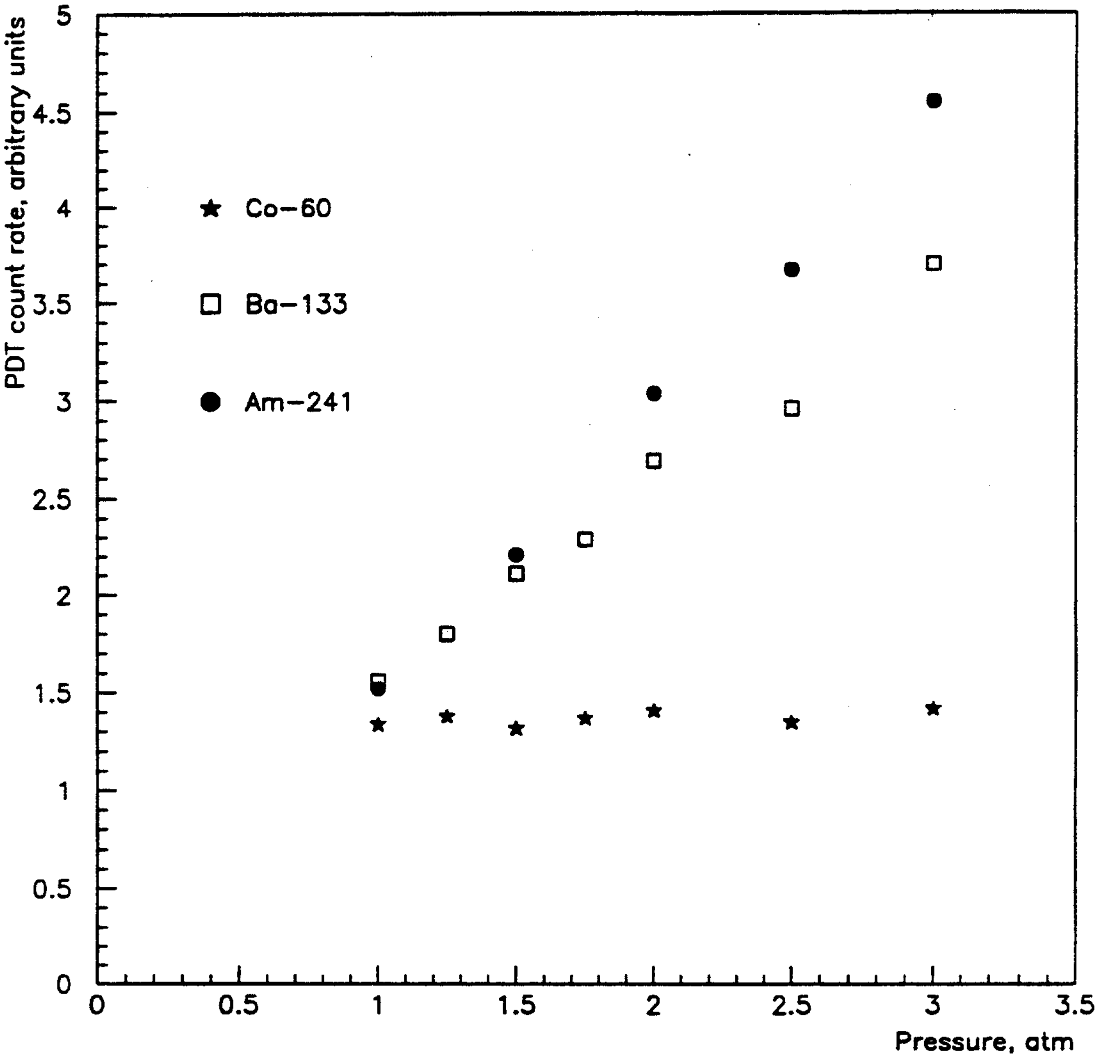

Figure 6: The PDT count rate versus gas pressure

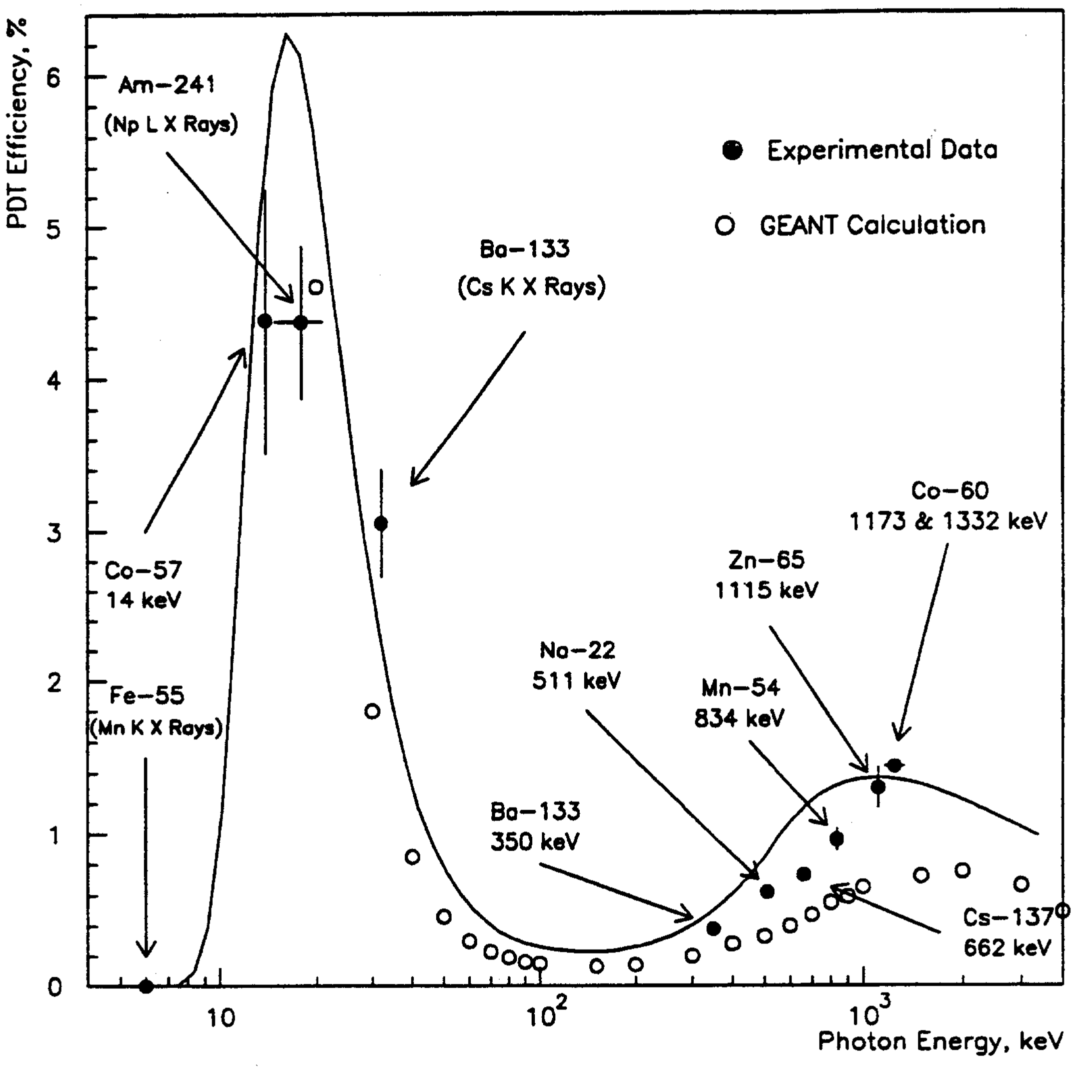

Figure 7: The PDT efficiency versus photon energy