Pulse-Height-Spectrum Distortion in Xenon Gaseous Detectors for Soft X Rays: Experimental Results

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Abstract

The results of an experimental determination of the pulse-height distortion in soft x-ray spectra in gaseous xenon detectors are presented. The study confirms previous Monte Carlo simulation results and emphasizes the importance of the electric field in the drift region in reducing spectral degradation while the effect of a strong magnetic field in the same region is shown to be neglegible.

I. INTRODUCTION

Xenon-filled gas proportional scintillation counters (GPSC) play an important role in the detection of x rays in many applications such as x-ray astronomy [1,2] and energy dispersive x-ray fluorescence analysis (EDXRF) [3,4]. GPSCs are structurally simple room temperature detectors with high detection efficiency, large window area, high counting rate capability and good energy resolution (a factor of ~2 better than proportional counters). These characteristics make GPSCs competitive with other radiation detectors in many applications. For energies below 2-3 keV, GPSC's energy resolution can even be better than cryogenic solid state detectors (HPGe and Si(Li)) when sensitive areas of several cm^2 are required.

For soft x rays, however, the pulse-height spectra of a GPSC may exhibit distortions represented by a significant low-energy tail (a departure from the gaussian shape output in the low amplitude region), eventually accompanied by a small shift in the peak position, as first observed by Inoue *et al.* with a xenon GPSC [5]. These authors have explained the observed x-ray energy dependence of the distortion effect in terms of a loss of primary electrons during drift and diffusion of the primary electron cloud towards the GPSC scintillation region.

A recent detailed Monte Carlo simulation study of the absorption of x rays in gaseous xenon predicted important spectra distortions which translated into a low-energy tail [6,7], and proved that this tail effect could be associated with the loss of primary electrons to the detector entrance window. Furthermore, the Monte Carlo calculation was able to relate this kind of distortion to low x-ray penetration depth in the gas, and showed that the effect was very sensitive to the electric field in the absorption/drift region. Monte Carlo calculations also predicted detectable shifts in the peak position as well. However, these were clearly ascribable to discontinuities in energy linearity near the absorption edges of the filling xenon gas [7,8], and not to primary electron loss to the window, as claimed in Inoue *et al.* [5] for similar conditions.

In the present work we have carried out experimental confirmation of the Monte Carlo calculated results on the distortion of pulse-height distributions for soft x rays in the 1 to 4.5 keV energy range. The effect of increasing the electric field in the absorption/drift region, as well as the effect of a strong magnetic field, were also investigated.

II. EXPERIMENTAL SETUP

The detector used in this experimental study of the degradation of soft x-ray energy spectra was a xenon-filled GPSC operated at 780 torr, shown in fig.1 [4]. The detector's entrance window was a 3.5μm thick, 20-mm diameter, aluminized Mylar film, externally supported by a stainless steel grid. The electric field in the 1-cm scintillation region was maintained at 4.5 $Vcm^{-1}torr^{-1}$ for all measurements.

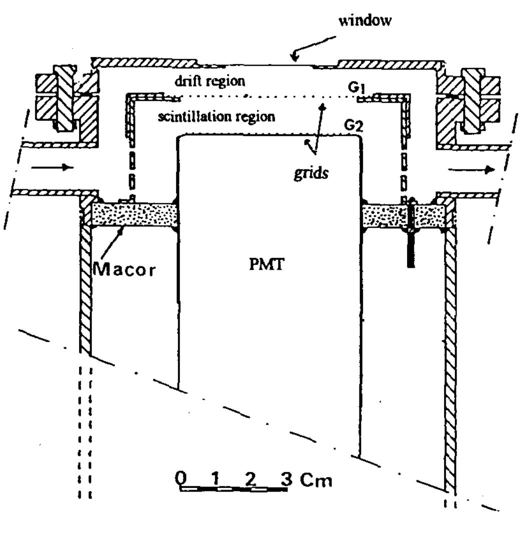

Fig.1- GPSC schematic.

To study the effect of the electric field, the depth of the absorption/drift region was kept constant at 7 mm. The scintillation light was collected by an EMI-D676 photomultiplier. In this configuration, the energy resolution of the system for a 2-mm, collimated 5.9 keV x-ray beam was 8.8 %.

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For the study of the effect of an applied magnetic field, a permanent ring magnet (Nd-Fe-B, 19.0x6.5x10.0 mm) was positioned over the detector entrance window, and the drift-region depth was increased to 40 mm to reduce the effect of the magnetic field on the PMT. The PMT, in this case, was an EMI-9956QB. Additional magnetic-field reduction was provided by a Conetics cylindrical shield around the PMT. The Conetics shield was also used to support the grid G1. The energy resolution for a 6-mm, collimated 5.9 keV x-ray beam was 11.5 % in the absence of the magnetic field, and 12.9 % when it was applied.

The x-ray energies studied, from ~1.2 to ~4.5 keV, were the fluorescence K lines of Mg (1245 eV), Al (1487 eV), Si (1740 eV), S (2307 eV), Cl (2622 eV), Ca (3690 eV) and Ti (4508 eV) samples.

III. Results and Discussion

For each x-ray energy, a series of increasing electric fields in the drift region was used, in the pressure reduced electric field E/p interval 0.1 to 1 $Vcm^{-1}torr^{-1}$ (1 $Vcm^{-1}torr^{-1}$ is the threshold for secondary scintillation [9,10]). As an example, the spectra obtained for the highest and the lowest drift electric fields for two different x-ray energies E_x are shown in figs.2 and 3 (K lines of Mg and Al, absorption lenghts d_x of 296 and 428 μm respectively, at 780 torr).

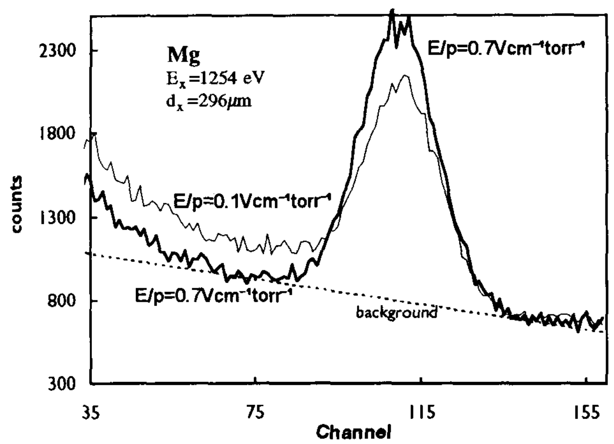

Fig.2 - 1254eV x-ray spectra for E/p = 0.1 and 0.7 $Vcm^{-1}torr^{-1}$.

In each figure, an enhanced low-energy tail associated with a decrease in the area under the peak is observed as a function of the applied electric field, the enhancement being greatest for the lowest electric field. This effect can be attributed to the loss of electrons to the entrance window, as established by the Monte Carlo calculations. In addition, no shift in peak position was observed when the electric field was varied, also consistent with the results of the Monte Carlo simulation (see fig.2 or fig.3).

The likely source for the shift in peak position described in Inoue *et al.* [5], which was there claimed to be related to electron losses to the window during diffusion, can possibly be attributed to a reduction in secondary scintillation collection related to solid angle effects in the conditions of their experiment.

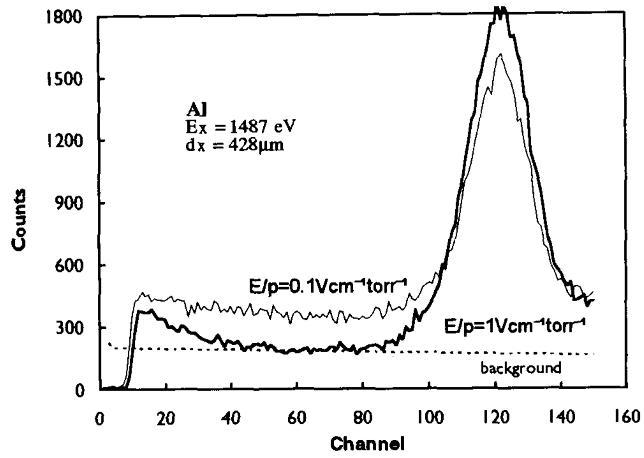

Fig.3 - 1487 eV x-ray spectra for E/p= 0.1 and 1 $Vcm^{-1}torr^{-1}$.

In the x-ray energies studied, the area under the low-energy tail decreases as the x-ray energy increases (i.e. as the absorption length increases). For example, for the titanium K line at 4508 eV, the area under the low-energy tail is small even for the lowest value of drift field studied (~5 % of the total area)

To characterize the distortion in each spectrum, for both Monte Carlo [6] and experimental studies, a distortion parameter Q was defined as the ratio between the area T under the tail below the spectrum corresponding to a full electron collection (the reference spectrum $\mathcal{R}$) and the spectra total area A

$$Q = \frac{T}{A} \tag{1}$$

However, the reference spectrum $\mathcal{R}$ cannot be obtained experimentally, as electron losses to the window will always occur for the x-ray energies studied and for all reduced drift fields used (< 1 $Vcm^{-1}torr^{-1}$ as stated above). Therefore, in this experimental study Q was taken as (see fig.4)

$$Q = \frac{T' + T_0}{A} \tag{2}$$

where T′ is the tail area of the current spectrum above the highest E/p spectrum (lowest losses) and T_0 is the tail area of this spectrum above the hypothetical reference $\mathcal{R}$. As again T_0/A cannot be deduced from the experimental results, it was assumed that the small distortion it represents is similar, for each x-ray energy, to the corresponding value Q_0^{MC} calculated by the Monte Carlo simulation in [6]. The experimentally deduced distortion parameter Q was therefore computed as

$$Q = \frac{T'}{A} + \frac{T_0}{A} \sim \frac{T'}{A} + Q_0^{MC} \qquad (3)$$

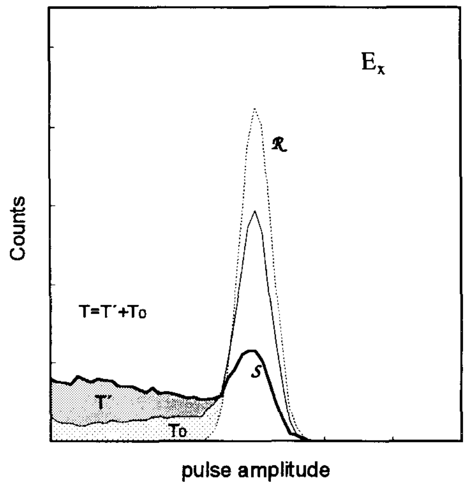

Fig.4 - Distortion parameter Q for spectrum S is $Q = (T'+T_0)/A$.

In fig.5 we compare the distortion parameter Q calculated by Monte Carlo simulation with the experimental values obtained through eq.(3). Fig.5 shows that the two groups of results exhibit a very similar behaviour with increasing electric field (note that the behaviour of each experimental curve is not affected by the additive term Q_0^{MC} introduced in eq.(3) which stands only a reference point for each curve).

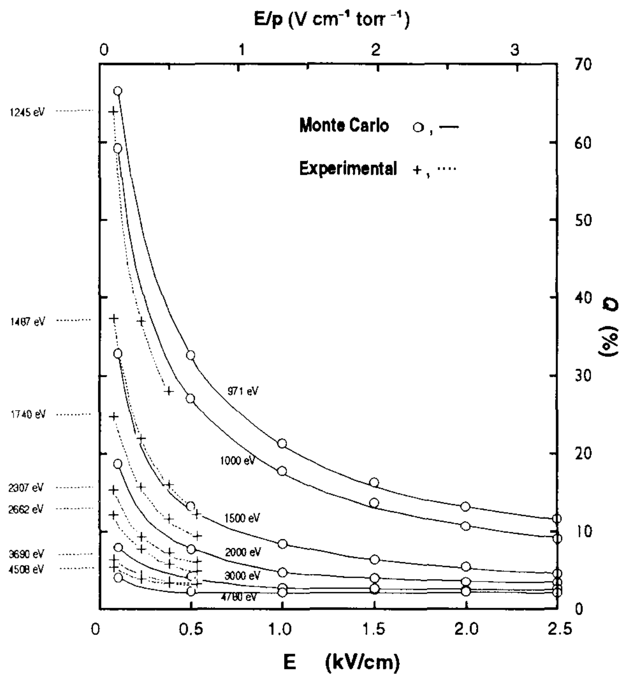

Fig. 5 - Monte Carlo calculated (—o—) and experimental (···+···) distortion parameter Q for different x-ray energies absorbed in xenon.

The Q curves shown in fig.5 (each curve characterizes an x-ray energy E_x), exhibit a systematic decrease with the increase in the drift field E, and it is clear that a judicious choice of the intensity of the electric field applied in the drift region of a conventional GPSC can significantly improve the collection of electrons, and consequently optimize its performance. It should be noted that E/p ~ 1 Vcm^{-1}torr^{-1}is the highest electric field that can be applied in the drift region without jeopardizing the performance of a xenon filled gas proportional scintillation counter, as this E/p value is the threshold for secondary scintillation in xenon. Taking the curve for $E_x = 1487$ eV as an example, it can be seen that for a reduced drift field E/p = 0.1 Vcm^{-1}torr^{-1} Q will reach ~35%, while for E/p = 0.3 Vcm^{-1}torr^{-1} Q is ~ 20%, and for E/p = 0.7 Vcm^{-1}torr^{-1} Q ~ 10%.

While distortion is not significant for the higher x-ray energies and for all drift electric fields (E_x above ~3 keV, lower lying curves in fig.5), important electron losses can never be avoided for x-ray energies lower than ~1.5 keV. In fact, for $E_x < 1.5$ keV, Q never reaches a value under ~10% even for the highest drift field (E/p = 1 Vcm^{-1}torr^{-1}).

In an attempt to further improve the performance of GPSCs for soft x rays, we have also studied the effect of a strong magnetic field in the absorption region. The effect of the magnetic field on electron trajectories could, in principle, increase the number of electron collisions for those electrons that spiral towards the window. This, in turn, would result in an increased loss in electron energy and a reduction in the probability of capture by the window. For this purpose, a permanent magnet (Nd-Fe-B maximum field intensity 0.2 T)

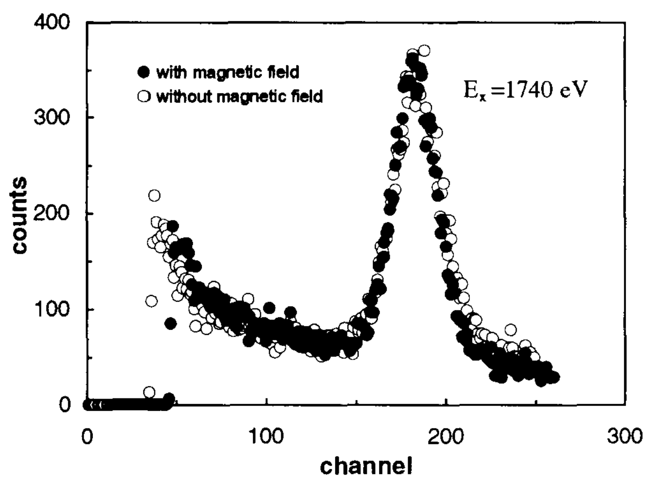

Fig.6 - Si K line (E_x=1740 eV) energy spectra obtained with and without the application of a strong magnetic field in the GPSC drift region.

was placed over the entrance window. Fig.6 presents the Si K line (1740 eV) spectra obtained with and without the influence of the magnetic field in the GPSC's drift region.

From this example, it is clear that a magnetic field of that intensity has no visible effect in reducing the observed distortion in soft x-ray energy spectra. Stronger magnetic fields are expected to be efficient, but the photomultiplier would certainly be affected in the present GPSC's design .

IV. CONCLUSIONS

Experimental results on the influence of the electric field applied to the drift region of a GPSC in reducing the distortion effects observed in soft x-ray energy spectra have been presented in this work. These results were found to be in very good agreement with previous Monte Carlo calculations [6]. The observed distortions in pulse-height distributions are attributed to electron loss to the detector entrance window that result from low-energy x rays that interact with xenon at shallow depths beneath the window. To characterize the distortion effects, a parameter Q has been defined as the tail to total area ratio. The Q results of a systematic study are summarized in fig.5, and allow the choice of the best experimental working conditions for GPSC applications. However, for $E_x < 1.5$ keV a value lower than 10% for Q is never achieved, even for the highest drift fields.

The effect of a weak magnetic field applied to the drift region in minimizing the distortion effect was also experimentally assessed and found to be negligible.

Acknowledgements

Support is acknowledged from JNICT (Junta Nacional de Investigação Científica e Tecnológica) through project STRDA/P/CEN/422/92.

We thank Dr. R. E. Morgado (LANL, USA) for helpful suggestions.

REFERENCES

[1] A.Peacock, B.G.Taylor, N.White,T.Courvoisier and G.Manzo, *IEEE Trans. Nucl. Sci.* NS-32 (1985) 108.

[2] D.F.Anderson, T.T.Hamilton, W.H.Ku and R. Novick, *Nucl. Instrum. Meth.* 163 (1969) 125.

[3] D.A. Goganov, A.A.Schultz and B.V.Elkind,. *Instrum. Exp. Techn. (URSS)* 27 (1984) 478.

[4] J.M.F. dos Santos, A.C.S.S.Bento and C.A.N.Conde, *X-Ray Spectrom.* 22 (1993)328.

[5] H.Inoue, K.Koyama, M.Matsuoka, T.Ohashi, Y.Tanaka, and H.Tsunemi, *Nucl. Instrum. Meth.* 1573 (1978) 295.

[6] T.H.V.T.Dias, F.P.Santos, A.D.Stauffer and C.A.N.Conde, *Phys. Rev.* A46 (1992) 237.

[7] F.P.Santos, T.H.V.T.Dias, A.D.Stauffer and C.A.N.Conde, *Nucl. Instrum. Meth.* A307 (1991) 347.

[8] T.H.V.T.Dias, F.P.Santos, A.D.Stauffer and C.A.N.Conde, Phys. Rev. A48 (1993) 2887.

[9] F.P.Santos, T.H.V.T.Dias, A.D.Stauffer and C.A.N.Conde, J. Phys. D: Appl. Phys. 27 (1994) 42.

[10] F.Favata, A.Smith, M. Bavdaz,T.Z.Kowalski, *Nucl. Instrum. Meth.* A294 (1990) 356.