THE ENERGY RESOLUTION AND WINDOW AREA CAPABILITIES
OF THE GAS PROPORTIONAL SCINTILLATION COUNTER

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Abstract

The behaviour of xenon and argon-xenon gas proportional scintillation counters is considered. For X-rays, ranges of window area are defined showing competition with semiconductor detectors. Data for primary scintillation of X-rays and alpha particles are included. Relative efficiencies of tetraphenylbutadiene, p-terphenyl, diphenyl-stilbene, sodium salicylate and p-quaterphenyl were measured.

Introduction

The gas proportional scintillation counter is essentially a gaseous device where scintillations are generated, its light output being controlable by application of suitable electric fields. The main lines of research are summarized by P. E. Thiess and G.H. Miley[1], most of the work done till now being on nuclear physics applications, as a detector, both in low and high radiation fields.

As a detector, the scintillation is generated by an ionizing particle and essentially two main components are considered in the corresponding light flash: the primary scintillation due to the deexcitation of the medium following the interaction of the particle being detected; and the secondary scintillation corresponding to the light emitted during the migration of the secondary electrons under electric fields. Both the primary and the secondary components have been studied for a wide range of gas mixtures[1]. In particular, for X-ray detection, probably the best way to study the main statistical factors relevant to the behaviour of the gas proportional scintillation counter, the energy resolution and counting rate capabilities associated with the secondary component have been considered[2,3,4,5].

The window area is also an important parameter. Provided that a reasonable degree of localization is attained for the region where the secondary light is produced, and because the electronic noise and detector capacitance play no role on the behaviour of the gas proportional scintillation counter, it is expected that large window areas can be used without deterioration of the resolution[2,3].

The gas proportional scintillation counter may compete with the semiconductor X-ray detectors as far as energy resolution is concerned, if the window area parameter is taken into account. Criteria related to system resolution and detector area, for cooled silicon X-ray detectors were analised by R. S. Frankel and D. W. Aitken[6] and areas till about 500mm^2 may be very useful. It was then decided to study the variation of the resolution with window area for the gas proportional scintillation counter on the same region of window areas.

Another important parameter relevant for the energy resolution of the gas proportional scintillation counter is the light output of the detector per unit of energy, under conditions of no charge multiplication; and this is essentially determined by the nature of the wavelength shifters used and the gas filling. Concerning the primary scintillation an extensive study was made by J.A. Northrop and J. C. Gursky[7] and pure xenon and mixtures of neon--50% xenon and helium-10% xenon have the greatest light output, when diphenylstilbene and a glass window photomultiplier tube are used. But when one tries to choose a mixture for gas proportional scintillation counters the available data concerning light outputs are scantier, the main reason being that most of the studies have been made in conditions of charge multiplication, which means that they are not a valid indication of the amount of secondary light per electron. Under conditions of charge multiplication pure xenon, helium-10% xenon, and argon-5% xenon seem to be the best scintillators on the ultraviolet region[8,9]; if the visible and infrared regions are included then mixtures of Ne-He, Ne-Ar, Ne-O_2, He-N_2, He-O_2, Ar-N_2 and pure helium and argon are also very good scintillators[1]. In view of previous experience of the authors and the available data, xenon and argon-5% xenon were used as filling gases and the ultraviolet emission was detected through the use of wavelength shifters and quartz window photomultipliers, EMI 9656QR.

Again most of the available data for wavelength shifters efficiencies concern either the primary scintillation or the scintillation on conditions of charge multiplication. Then a previous study[10] of p-terphenyl, sodium salicylate and p-quaterphenyl, as wavelength shifters for xenon proportional scintillation counters under conditions of no charge multiplication, is continued using 1,1,4,4, tetraphenylbutadiene and 4,4' diphenylstilbene.

Experimental techniques

Fig. 1 shows the detector used in this work. The main concern was to make it mechanically strong, so no magnesium oxide reflector was used. For a detailed description of the detecting system, associated electronics and X--ray generation see references 2 and 3. The purities of the gases used, xenon and argon commercially available, are, respectively, 99.95% (impurities: Kr<400 v.p.m., N_2<10 v.p.m., O_2<5 v.p.m., H_2O<5 v.p.m., CO<5 v.p.m., CO_2<5 v.p.m CH_4<5 v.p.m.) and 99.9% (humidity<10mg/m^3), and they were continuously purified.

As in a previous work[10], to study efficiencies of wavelength shifters and in order to avoid reflections, no aluminium reflector was used, one of the quartz windows was replaced by a stainless steel cover and the inside face of the other was masked by a stainless steel plate with a central circular aperture (diameter 29mm) where a thin quartz disc with the wavelength shifter deposit could be placed. The thicknesses of the deposits were de-

termined by weighting.

To compare the light output of xenon and the promising mixture argon-5% xenon, and to avoid corrections due to the different risetimes of the pulses, dependent on the gas filling nature and the applied voltage (the pressure was kept constant), no differentiation was introduced on the amplifiers, an integrating time constant of 100 ns was used and, in order to match the characteristics of the pulse height analyser the pulses were fed through a linear gate. The charge pulses were analysed on the same way.

Work related to primary scintillations was carried on taking out the anode and teflon insulator. When alpha particles from a ThC+ThC' source were used the entrance window was made of mylar 6 μm thick, the beam was well collimated, and a vacuum path was created between the source and the mylar window to minimize straggling. In each photomultiplier three dynodes were short-circuited to the anode to avoid saturations.

To study the variation of the energy resolution with window area a rectangular aperture of 34x18mm was made in the stainless steel body of the counter; windows, framed in stainless steel, were then screwed into place with indium gaskets. The alpha source and the targets for X-ray generation were located as far away as possible from the entrance window, in order to get a relatively uniform flux of X-ray over the entire window area.

Experimental results and conclusions

Wavelength shifters

Following a previous work[10], 1,1,4,4 tetraphenylbutadiene and 4,4' diphenylstilbene, both NE scintillation grade, were studied in the xenon gas scintillation counter at a pressure of 940 Torr and an anode voltage of 5000 V (ionization chamber region).

X-rays from a ^{55}Fe source were used and the mean light pulse amplitude h was measured as a function of the thickness t of the wavelength shifter. In view of the conclusion of a previous work[10] together with some measurements for tetraphenylbutadiene and diphenylstilbene we consider that the data obtained at 5000 volts are representative of the behaviour of the wavelength shifter for any anode voltage down to about 2000 volts. To be able to compare this data with the data gathered before, p-terphenyl scintillation grade at its optimum thickness was used for normalization.

For each wavelength shifter the thickness t_M of maximum light output h_M and the minimum thickness t_m for which $0.9\ h_M = h(t_m)$ are tabulated, as well as the relative efficiencies at optimum thickness:

Wavelength shifter	t_M (mg/cm^2)	t_m (mg/cm^2)	relative efficiency
p-terphenyl	2.5	.55	1
tetraphenyl-butadiene	2.5	.20	1
diphenylstilbene	.25	.15	.9
Na salicylate	1.0	.45	.7
p-quaterphenyl	.28	.22	.6

In view of these results and taking into account information relative to possible deterioration of the tetraphenylbutadiene deposits[11], p-terphenyl was used as wavelength shifter.

Xenon and argon-5% xenon

Fig. 2 shows the secondary light outputs, L, from pure xenon and an argon-5% xenon mixture for aluminium X-rays, as a function of the anode voltage, using p-terphenyl as wavelength shifter. The anode was a 10mm diameter sphere and the pressure 970 torr. Charge measurements using alpha particles showed that for the range of voltages used there was no charge multiplication when xenon was the filling gas; the dashed line in the same fig. shows the charge gain, as a function of the voltage, for the argon-5% xenon mixture.

The threshold for light multiplication is much lower for the mixture than for pure xenon, and for voltages below 1400 volts xenon is a "poorer scintillator". Again for voltages over 3000 volts xenon gives a lower light output. But, as the charge curve shows, this effect is associated with the charge multiplication process. This explains the data previously reported[8,9], working under conditions of large charge gains, and quoting light outputs from the mixture an order of magnitude larger than those from pure xenon. If the resolution is the important parameter of the detector, and this depends on the particular application, the relevant parameter is the light output below the charge multiplication threshold, or rather, dL/dV on the ionization chamber region. In this context xenon is a better scintillator than the mixture argon-5% xenon. These results were further confirmed using a 6mm diameter anode.

Xenon was then the filling gas choosen for the proportional scintillation counter.

Primary scintillation

In order to show the optical efficiency of the counter used in these experiments, primary scintillation spectra from silver X-rays and ThC+ThC' alpha particles are represented in fig. 3. The higher energy alpha peak corresponds to about 8.3 MeV dissipated in the detector. If this energy loss is taken into account the detector has the same optical efficiency as the gas scintillation counter of Sayres and Wu[12], which features the best resolution reported. The X-ray spectra in the same fig. illustrates the possibility of detecting the primary scintillations of relatively low energies well above the noise.

X-ray energy resolution and window area

Fig. 4 shows spectra for carbon, aluminium and manganese Kα X-rays resulting from the bombardment of graphite and aluminium targets with alpha particles and from a ^{55}Fe source with a chromium filter. The corresponding energies are 0.277 keV, 1.49 keV and 5.9 keV, respectively, and the conditions of pressure, applied voltage and the diameter of the spherical anode are quoted as well as the resolutions and widths at half maximum. The filling gas was xenon, continuously purified, and the wavelength shifter used was p-terphenyl with a thickness of about 2.5 mg/cm^2. From

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this type of data one arrives to the expression $\sigma_r = 0.081\ E^{-1/2}$ (E in keV), relating the relative standard deviation with the energy.

Aluminium X-rays were used to study the variation of the resolution with window area. Ten different sizes of window were used, circular and rectangular, covering a region between 16 and $480mm^2$. Within experimental uncertainties, of the order of 4%, no variation of resolution with window area was detected, as should be expected.

To compare the xenon gas proportional scintillation counter with silicon X-ray detectors, as far as resolution and window area are concerned, a compilation of data is represented in Fig. 5 for aluminium X-rays and in Fig. 6 for oxygen and carbon X-rays. The shaded areas are regions of typical resolutions of silicon detectors, based on available data from two well known manufacturers for the energy resolution at 5.898 keV, the manganese K_α X-rays, at low counting rates, for several detector dimensions. It was assumed that the electronic noise is independent of the energy dissipated in the detector and 0.1 was taken as the Fano factor for silicon. In Fig. 5 the band of window areas is limited by the data available; for a certain window area and a certain shaded region, the upper and lower resolution limits correspond to the use of resistor or pulsed optical feedback. Fig. 6 is similar, but of course, there is no sense in considering f.w.h.m. that would make the detector inoperative on account of noise counting rates, and the shaded regions were limited by full widths at half maximum of the order of a third of the X-ray energy. The regions so obtained for silicon detectors were confirmed to be reasonably correct by comparing with experimental data available for each of the X-rays considered. In particular, and due to its interest, experimental data are represented for carbon X-rays using silicon detectors (see Fig. 6), corresponding to the results of J.M. Jaklevic and F.S. Goulding[13] and R.G. Musket and W. Bauer[14].

The dashed lines in Figs. 5 and 6 correspond to the experimental energy resolutions of the xenon proportional scintillation counter as given by $\sigma_r = 0.081\ E^{-1/2}$ (E in keV).

From Fig. 5 one may infer the practical conclusion that for window areas below about $25mm^2$ the silicon X-rays detector has better resolution than the xenon gas proportional scintillation counter; between 25 and $190\ mm^2$ there is competition between both types of detectors; and the xenon counter dominates above $190mm^2$. The energy resolution of silicon detectors varies with counting rate as the electronic noise depends on the time constants used. The insert of Fig. 5 shows for several time constants, a typical variation of the f.w.h.m. with detector area for aluminium X-rays in Si(Li) detectors (full lines) and in the Xe PS counter (dashed line). Again those curves were calculated from data available for

5.89 and 6.40 keV X-rays[6]. Then, in Figs. 5 and 6 the effect of higher counting rate would be a shift upwards of the shaded areas that correspond to silicon detectors; and recalling the previous example of the aluminium X-rays (see Fig. 5) one may take the band between $25mm^2$ and $150mm^2$ as the region of competition between silicon detectors and the Xe PS counter.

From this type of data emerges Fig. 7: the shaded area is a region of competition between semiconductor and xenon detectors as far as energy resolution and window area are concerned; the left side region corresponds to a better performance for silicon detectors; the right side region to a better performance of the xenon proportional scintillation counter.

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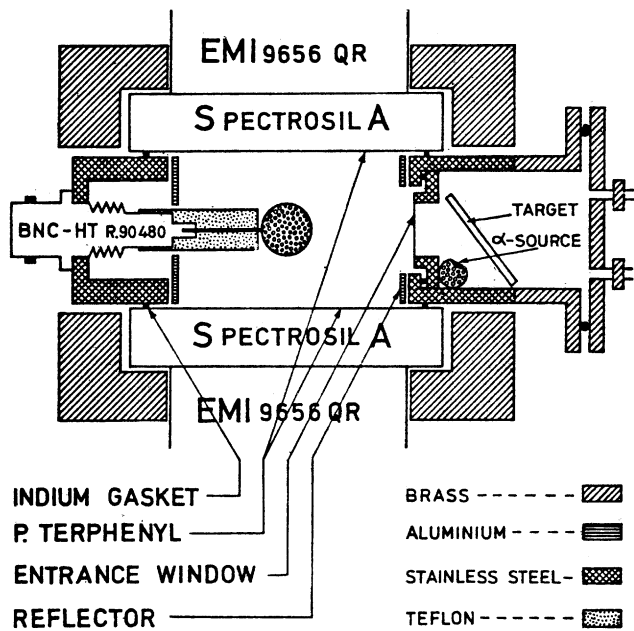14- R.G. Musket and W. Bauer, in "X-ray energy spectrometry" R. Woldseth, Kevex Corp. (1973) 1.20.

Fig. 1 - The xenon proportional scintillation counter (Fig. taken from ref. 3; permission granted for its reproduction is gratefully aknowledged).
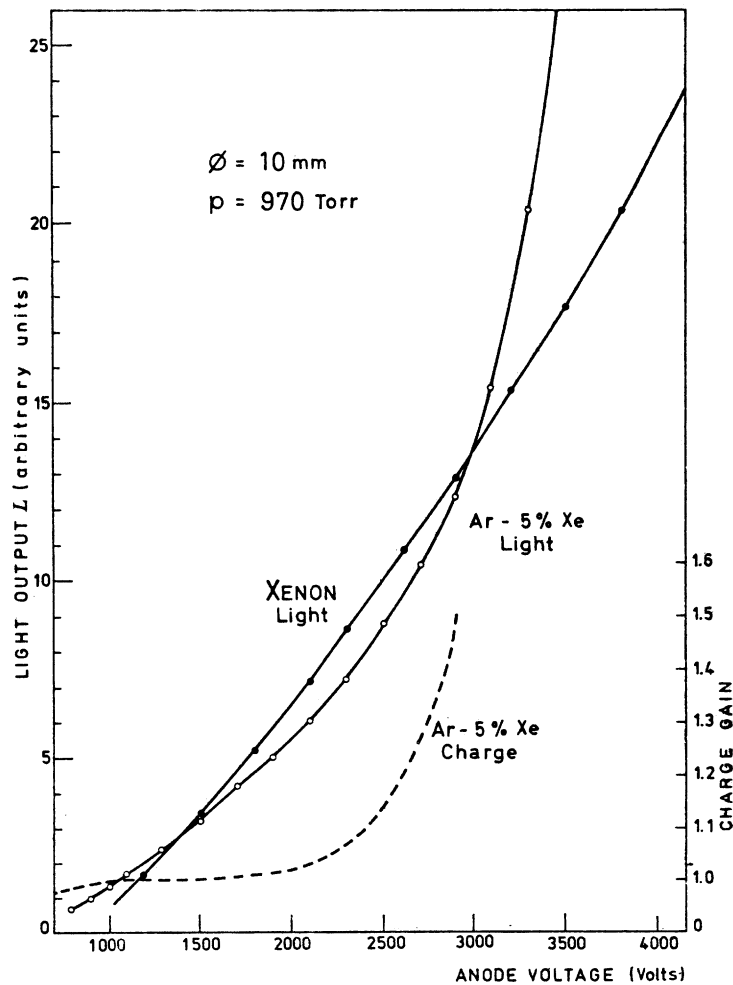

Fig. 2 - Light output from xenon (full circles) and from argon-5% xenon mixture (open circles) as a function of the anode voltage. The dashed line (right hand scale) represents the charge gain vs. anode voltage for the Ar-5% Xe mixture.
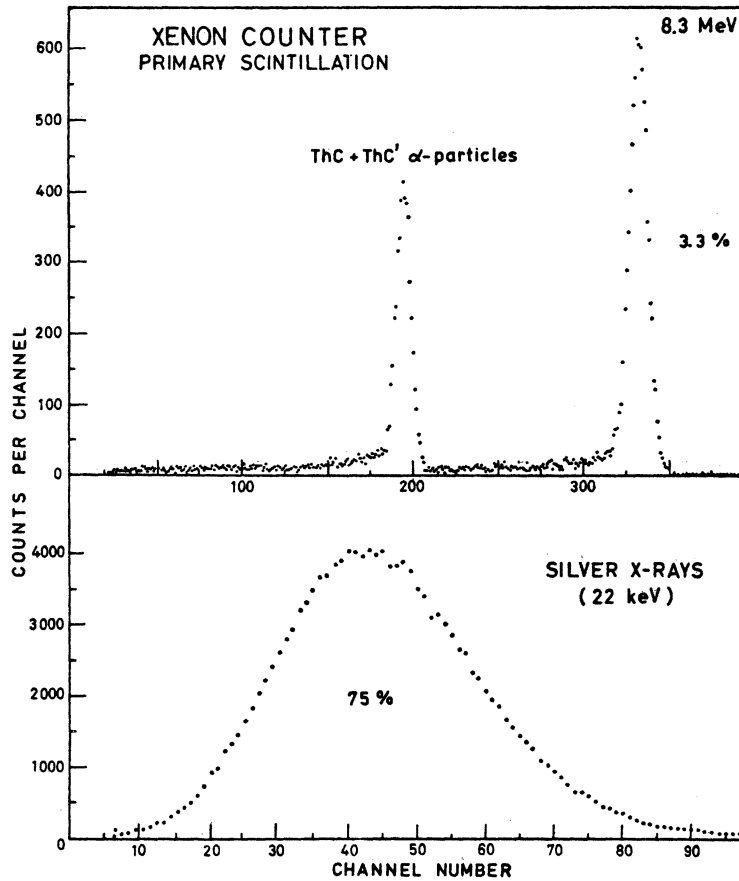
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Fig. 3 - Primary scintillation spectra of
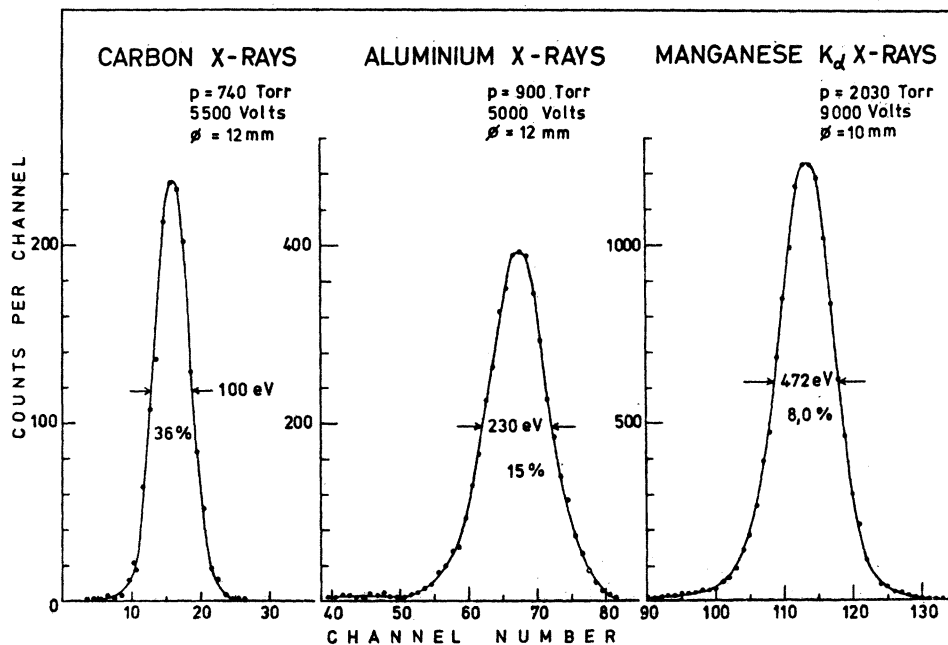ThC+ThC' alpha particles and of silver X-rays

Fig. 4 - Spectra of carbon (277 eV), alumini-
um (1.49 keV) and manganese K_α (5.898 keV)
X-rays obtained with the xenon proportional
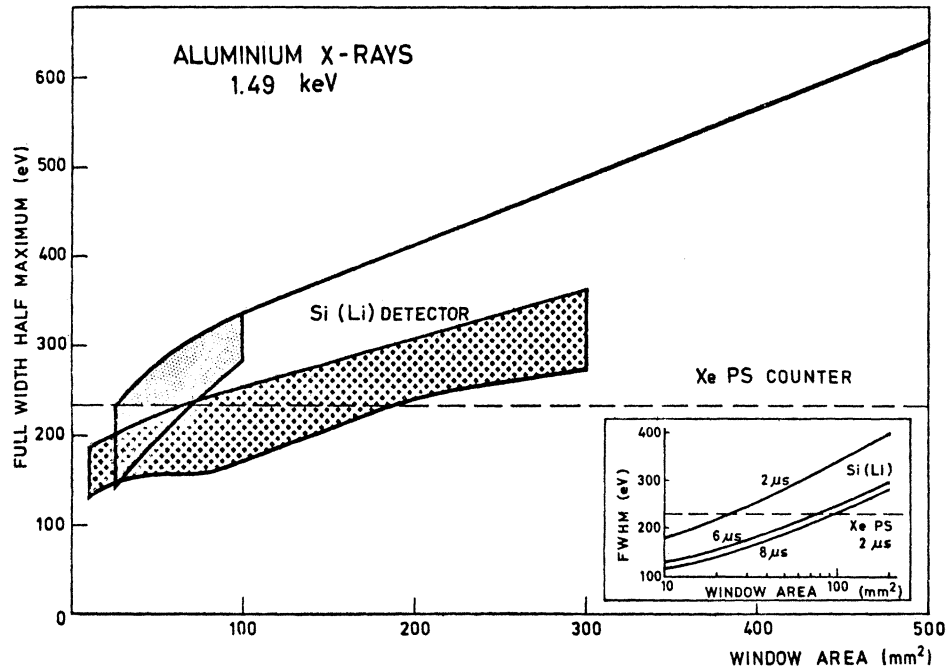scintillation counter.

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Fig. 5 - Full lines and shaded areas corres-
pond to typical values of f.w.h.m. for 1.49
keV in Si(Li) detectors (see text); dashed
line represents experimental f.w.h.m. of the
xenon proportional scintillation counter for
the same energy.

The insert shows typical f.w.h.m. for Al
X-rays as a function of window area and time
constants both for Si(Li) detectors (full li-
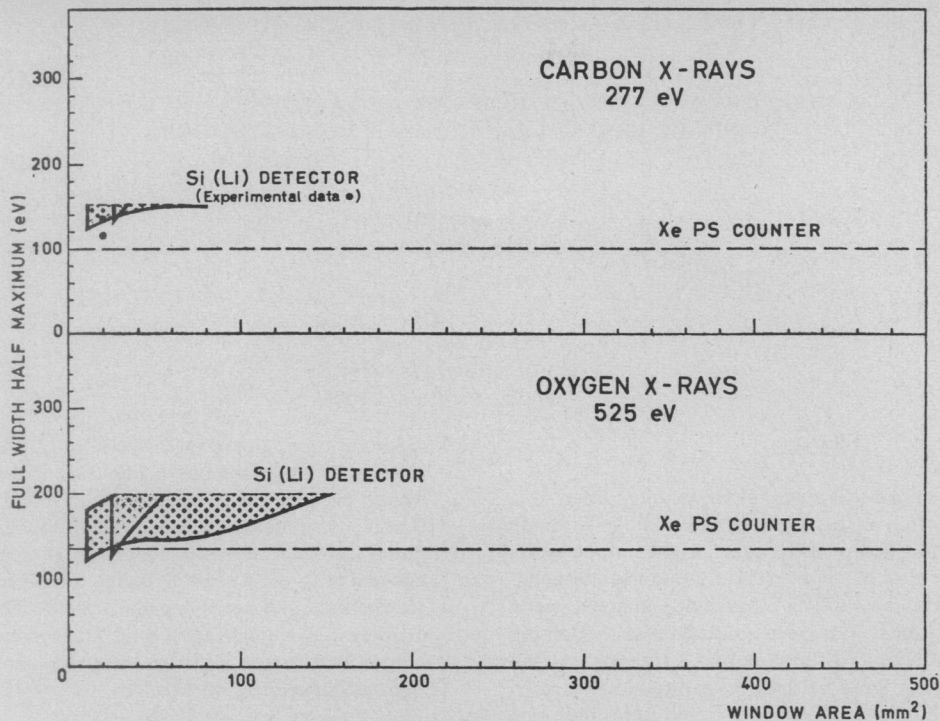nes) and for Xe PS counter (dashed line).

Fig. 6 – Full lines and dashed areas corres-
pond to typical values of f.w.h.m. for 277 eV
and for 525 eV in Si(Li) detectors (see text).
The dashed lines represent the experimental
f.w.h.m. of the xenon proportional scintilla-
tion counter for carbon and oxygen X-rays.
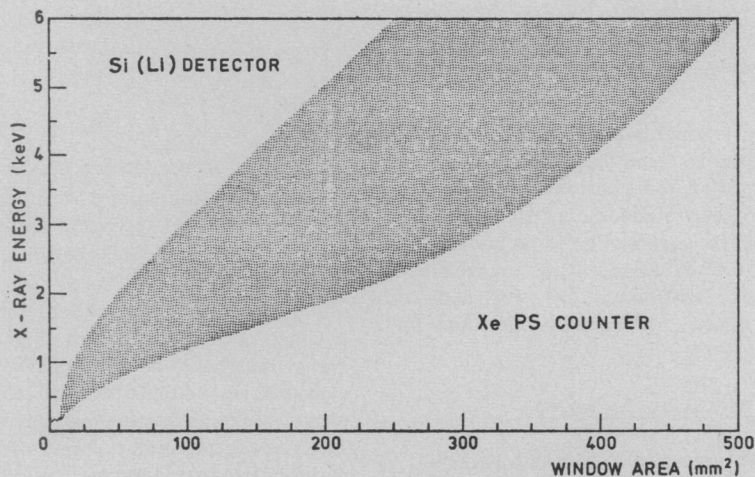Full circles are experimental values taken
from refs. 13 and 14.

Fig. 7 – Comparative performance of semicon-
ductor and xenon proportional scintillation
detectors when the energy and window area va-
ry within the ranges shown. The shaded area
represents the region where both detectors
are competitive; the left side region corres
ponds to a better performance of Si(Li) detec
tors and the right side to a better performan
ce of Xe PS counters.

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