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# Characterization of hemispherical area X-ray detector based on set of proportional counters with needle anodes

R.G. Figueroa [a,*], M. Santibañez [a], C.N. Valdes [b], M. Valente [a,c]

[a] Departamento de Ciencias Físicas, Universidad de La Frontera, Av. Francisco Salazar 01145, Temuco, Chile
[b] Centro Oncológico de Antofagasta, Los Pumas 10255, Antofagasta, Chile
[c] Institute of Physics E. Gaviola-CONICET LIIFAMIRx-University of Córdoba, Ciudad Universitaria, 5000 Cordoba, Argentina

## HIGHLIGHTS

- A hemispherical area X-ray detector is introduced.
- The detector employs gas proportional counters with needle anodes.
- The detector is robust, low cost and enables high rate counting (up to $10^6$ counts/s).

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## ABSTRACT

This work introduces a new, versatile and robust X-ray detector with hemispherical $2\pi$ geometry, based on a set of 15 small cylindrical proportional counters located in a hexagonal and pentagonal fullerene C60 pattern, at the same distance from the center (where a sample is placed). The counteranode consists of stainless steel sewing needles with spherical tips measuring approximately 80 μm in diameter. The space between the counters and the sample could contain air, the same gas as the counters or vacuum. This allows a significant increase in the count rates by a factor approximately equal to the number of counters connected. It is shown that an energy resolution of 20% for 5.9 keV photons can be obtained, and a global counting rate of around $10^6$ counts/s is achievable by the 15 Needle Anode Proportional Counters (NAPCs) operating in parallel mode, in our setup.

## 1. Introduction

The high intensity of modern X-Ray generators requires detectors with a faster and more efficient response to high counts rates, while maintaining energy resolution. Gas Proportional Counters (GPC) are good candidates to meet these requirements, as they can provide high count rates with an energy resolution of around 20% (or better) in the detection of soft X-rays (5.9 keV) (Knoll, 2000; Sauli, 2004; Veloso et al., 2010). GPC detectors are available in various configurations: Micro Strip Gas Chambers (MSGC) (Oed, 1988) and its later variants: Gas Electron Multiplier (GEM) (Sauli, 1997), Micro Hole and Strip Plate (MHSP) (Veloso, 2000), plane-parallel gas chambers, cylindrical detector with a central anode (Albul and Isaev, 1968; Bateman, 1985a,1985b; Comby and Mangeot, 1980), (wire or needle), among others. However, the Needle Anode Proportional Counters (NAPCs) provide a low cost alternative to these detectors, due to their geometric versatility and integration capability (Comby and Mangeot, 1980). These detectors could be used in X-Ray Fluorescence applications that do not require a good energy resolution.

Wire Anode Proportional Counters (WAPC) and Needle Anode Proportional Counters (NAPC), have similar electric characteristics, with a homogeneous electric field surrounding the anode. However, their electric field properties differ in shape; while the wire anode has a cylindrical electric field, the needle anode has a spherical electric field on the tip (Knoll, 2000). Moreover, both have position-sensitive detection capabilities (Baiocchi et al., 2004; Sauli, 1977). Nevertheless, WAPC detectors allow a directly localized detection with more robustness and geometric versatility (Sauli, 1977).

Several designs of NAPCs have been reported (Albul and Isaev, 1968; Bateman, 1985a, 1985b; Baiocchi et al., 2004; Comby and Mangeot, 1980; Ranzetta and Scott, 1967). However, so far a compact array of needle detectors had not been considered in a $2\pi$ detection geometry as proposed here. This configuration would provide an increase in the geometric detection efficiency and a

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[*] Corresponding author.

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high improvement in the overall count rate (proportional to the number of detectors) when the NAPC system operates in parallel mode (Smith, 1991), without loss of energy resolution. The aim of this work is to introduce the preliminary results of a new hemispherical ($2\pi$) GPC detector based on a series of small NAPCs with frontal windows, operating in parallel or independent modes. This is a design that allows the adoption of various geometries for applications such as X-Ray Fluorescence (XRF) and Total Reflection X-ray Fluorescence (TXRF), which need a good performance for both the counting rate and energy resolution.

## 2. Description of the counter

The hemispherical detector is based on 15 small NAPCs of cylindrical shape and is made of aluminum. The NAPCs are arranged in a hexagonal and pentagonal semi-fullerene C60 pattern, formed by 10 hexagonal and 6 pentagonal dispositions, 15 occupied by the NAPCs and 1 open for the incident radiation. This detector array is designed to detect fluorescent radiation from a sample at the center in a solid angle of $2\pi$ (see Fig. 1). The dimensions of each NAPC are 40 mm long and 10 mm in diameter. Each anode has a frontal Mylar aluminized window of 4 μm. The diameters of its inscribed circles in the hexagon and pentagon are 125 mm and 100 mm, respectively, and are located at the same distance from the sample.

The detection energy range of the NAPC detectors is between 3 and 20 keV approximately (Bateman, 1985a). Since the electric field surrounding the anode depends on its shape. To guarantee that the differences in the shape of the electric fields of all the units would not affect the energy resolution of the entire system, the shape of the tip and the diameter of the needles were selected using a digital microscope, making sure that each tip had the same semi-spherical shape of approximately 80 μm in diameter.

This design allows a better geometric efficiency without a great loss of energy resolution, because the detected X-rays pass through the same sample-detector distance. The geometric efficiency of this detection system is the net total area of cylindrical detection divided by the hemispherical area. In the design described above, the geometric efficiency is nearly 60%. The fullerene patterns also makes it possible to adapt to different experimental geometries by adding a collimator at the hemispheric top (only for incident beam) and exchanging its position with the NAPCs. Then, normal incidence, 45° incidence, grazing incidence or total reflection arrangements can be accommodated, as shown in Fig. 2.

## 3. Experimental setup and results

A single NAPC unit was made and its characteristics were studied, in terms of energy resolution, pulse height and count rates, vs. applied voltage. The entire set of detectors was subsequently constructed, and its characteristics were studied. In both steps, a P10 (90% of Argon + 10% of Methane) fill-gas was utilized at a pressure 100 kPa and under a continuous $1.7\times10^{-4}$ m$^3$/s flow.

In testing the single NAPC detector, two radiation sources, $^{55}$Fe with $6.7\times10^{7}$ Bq activity and $^{241}$Am with $3.7\times10^{9}$ Bq activity, were used, the first to directly irradiate the detector, and the second to excite a Pb sample to provide Lα and Lβ lines. A voltage in the range of 1.35–1.75 kV was applied to each detector, to ensure that it functioned as a proportionality counter. The pulses from the detector were pre-amplified by a customized charge-sensitive preamplifier constructed in-house, with features similar to those of the CREMAT CR 110 model, but with a higher gain. The pulses were then amplified and shaped by a Tennelec TC-244 amplifier, and recorded with a multichannel analyzer. The detector pulses were simultaneously monitored on an oscilloscope.

The entire system was tested with intense radiation produced by radiation from a synchrotron (LNLS Campinas Brazil) and an X-ray tube of 40 kV/100 μA, with silver (Ag) target and a beryllium end-window (FXR lab, Universidad de La Frontera). The synchrotron was used to ensure that every single NAPC functioned as designed under high intensity conditions. The X-ray tube was used

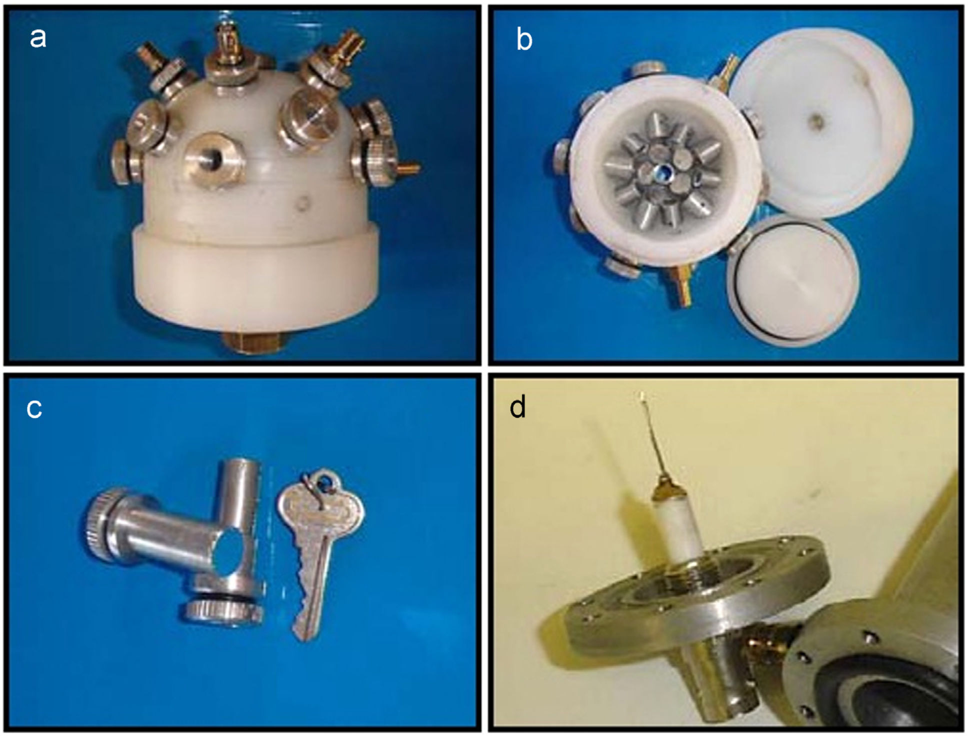

**Fig. 1.** (a) General view of detector, (b) open detector with sample holder, (c) NAPCs and (d) needles anode.

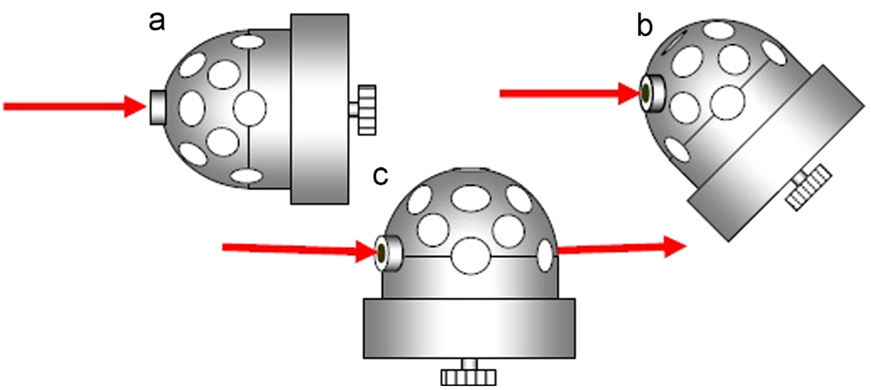

**Fig. 2.** : Possible experimental setups for hemispherical detector: (a) normal incidence (90°), (b) oblique incidence (45°) and (c) grazing incidence or total reflection.

to excite samples of Ti, Zn and Zr through a well-collimated X-ray beam at normal incidence, obtaining Kα lines of 4.51 keV, 8.63 keV and 15.77 keV, respectively. The entire system was electronically integrated to function with upto 15 NAPCs in with pulses from each detector joining into a common point that connects to a preamplifier (type CREMAT CR 110), then to amplifier unit (Tennelec TC-244) and a multichannel analyzer (MCA).

Fig. 3 shows a typical proportional countertrain pulses can be seen, corresponding to Pb Lα and Lβ lines excited by an $^{241}$Am radioactive source. This figure shows the ability of the system to perform as an X-ray spectrometer using the pulse height spectrum to give energy information of the incident X-rays. Additionally the trains pulses do not show lose its pulse height resolution when the gain was configured to a good spatial resolution. The energy resolution was measured by irradiating the detector with 5.9 keV X-rays from the $^{55}$Fe source, obtaining around 20% FWHM (for the half of the plateau range) (see Fig. 4), which is similar than the resolution obtained by other authors for this type of detectors (Knoll, 2000; Bateman, 1985a,1985b).

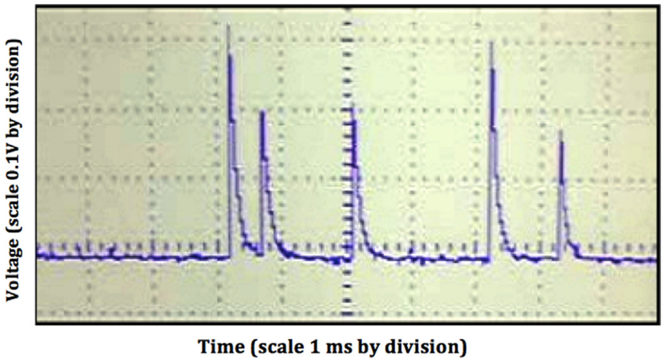

**Fig. 3.** : Pulses train signal output corresponding to the Pb Lα and Pb Lβ pulses.

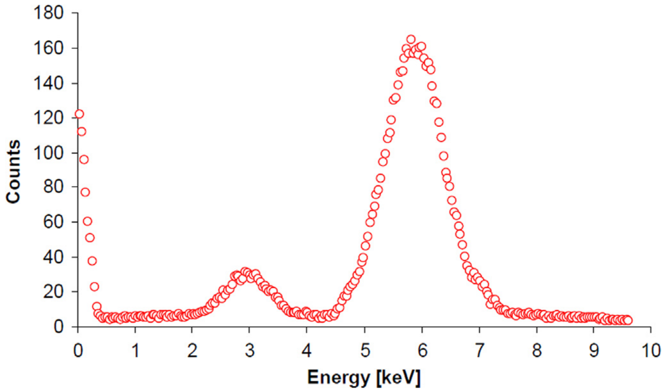

**Fig. 4.** : Typical pulse height distribution for 5.9 keV gamma rays from a $^{55}$Fe source.

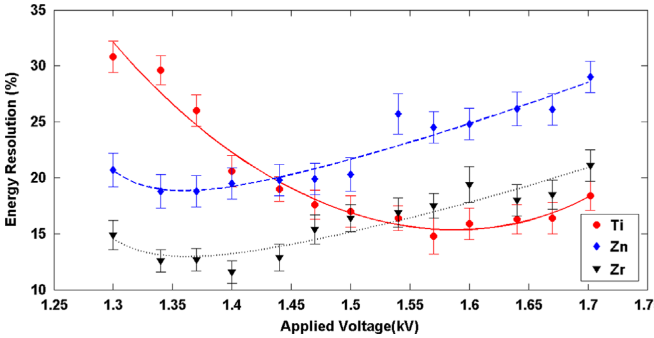

**Fig. 5.** : Average energy resolution vs. applied voltage for Kα lines of Ti (4.51 keV), Zn (8.63 keV) and Zr (15.77 keV). Samples where excited with an X-ray tube current of 100 μA.

Fig. 5 shows the average energy resolution in the proportional counter for Kα lines of Ti (4.51 keV), Zn (8.63 keV) and Zr (15.77 keV). These lines were obtained by irradiating samples with an X-ray tube configured with a current tube of 100 μA. Fig. 6 shows the pulse-height spectra of TiK (4.51 keV), ZnK (8.63 keV) and ZrK (15.77 keV) recorded with a NAPC for a sample composed of three elements Ti, Zn and Zr, irradiated with the same X-ray tube; demonstrating that this detector can resolve multi-elementary samples. Nevertheless, Fig. 5 shows that, when the applied voltage to detector exceeds 1.43 kV, the energy resolution for Ti begins to get better than that for Zn, and when it exceeds 1.53 kV it is better than that for Zr. This can be attributed to the fact that for Zn and Zr, the energy resolution gets worse as the detector approaches the Geiger–Mueller mode. The energy resolution in this type of detectors is different from that of the traditional detector with a wire anode, due to the non-uniformity of the multiplication gas zone at the tip of the needle. This would affect low energy photons (Ti K), because increasing the field (voltage) tends to concentrate the charging track on the top of the corona of amplification, producing minimum energy resolution, just before passing to the Geiger–Mueller countermode.

Fig. 7 shows the dependence of the counting rate with the X-ray tube current, for different applied voltages, generated by a Zn sample in a XRF measurement. A linear response for a current of X-ray tube of up to 500 μA and a maximum counting rate of 1.0–2.3 × $10^5$ c/s (readout per NAPC) and a total counting rate around $10^6$ c/s with the 15 NAPC operating like one unit, was obtained for 1300 V (red continuous line), 1400 V (blue dashed line), 1500 V (black dot line), 1600 V (black continuous line) and 1700 V (green dot line). At high currents, around, 1000 μA, signs of saturation manifested by a deviation from the linear behavior into

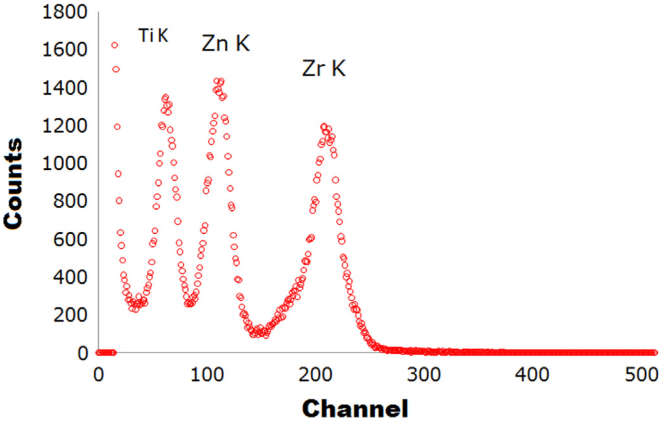

**Fig. 6.** : Counting rate vs. channel number for a multi-element sample of Ti, Zn and Zr.

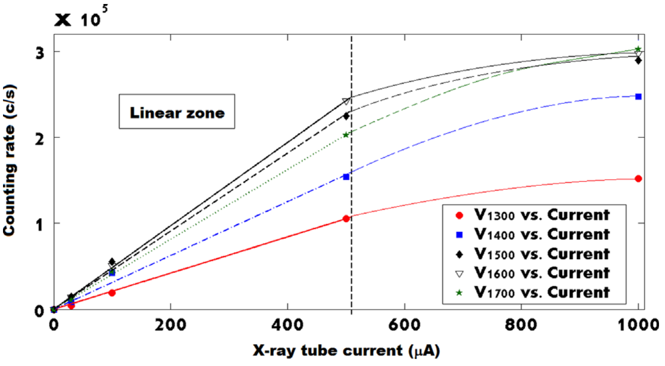

**Fig. 7.** : Counting rate vs. X-ray tube current for several applied voltages. (For interpretation of the reference to color in this figure, the reader is reffered to the web version of this article.)

a limited counting rate not affected by changes in voltage. The 1700 V curve presents a lower slope than 1500 V and 1600 V curves, as the detector's operation begins the transition to the Geiger–Mueller countermode. Finally, with increasing radiation, reduction in pulse height and deterioration of energy resolution are observed.

## 4. Conclusions

A robust, cheap and compact design of an X-ray area detector that allows a $2\pi$ geometry detection, and consists of 15 NAPCs in a hemispheric geometry arrangement, is shown to enable an overall counting rate on the order of $10^6$ counts/s, when operated in the parallel mode at an applied voltage of 1.4 kV (half of the plateau range). The average energy resolution was around 20% for 5.9 keV photons (to the same applied voltage) and an energy resolution in XRF application of 18% and 11.6% was obtained for photon energies of 8.63 keV and 15.77 keV, respectively. These energy resolutions are consistent with other detection systems based on GPC detectors, and were shown to be able to resolve fluorescence energy lines in multi-elemental samples. However, the principal advantages of the proposed system are the improved geometric efficiency and the high count rate, compared to the traditional detection systems used in XRF.

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