The on-ground calibration of the flight model of the HPGSPC onboard the SAX satellite: Calibration set-up and preliminary results (*)

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Summary. — The High Pressure Gas Scintillation Proportional Counter (HPGSPC) is one of the Narrow Field Instruments of the Italian-Dutch X-ray astronomy satellite SAX. Sensitive in the hard X-ray band (4–120 keV), with a very good energy resolution, the HPGSPC is well suited for studying in detail the cyclotron features present in the hard X-ray spectrum of some celestial sources. The scientific calibration of the flight model of the HPGSPC took place at the LABEN premises (Vimodrone-Milano) during October and November 1994. In this paper we briefly describe the on-ground instrument calibration system and we report some preliminary results that show the performances of both single/double event and position reconstruction/energy correction onboard processing. Preliminary results concerning the energy resolution and energy linearity are reported too.

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1. – Introduction

The High Pressure Gas Scintillation Proportional Counter (HPGSPC) is one of the Narrow Field Instruments (NFI) onboard the Italian Dutch satellite for X-ray astronomy SAX (Satellite Astronomia X), that will be launched in early 1996 [1]. The HPGSPC is a 5 atm (Xe + 10% of Helium) gas scintillation proportional counter, sensitive in the 4–120 keV energy band with a nominal energy resolution of about 4% at 60 keV. The HPGSPC will complement the iron line studies of the NFI Low Energy and Medium Energy Concentrators/Spectrometers and the source continuum observations of the Concentrators and the NFI Phoswich Detection System,

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performing high-resolution spectroscopy in the not yet well studied hard X-ray band. A second scientific goal of the HPGSPC is that of studying in detail the cyclotron absorption features that are present in the X-ray spectrum of many celestial sources above 10 keV [2, 3].

The flight model of the HPGSPC has been designed and is currently developed and tested by LABEN, an ALENIA Company, under the scientific responsibility of the Italian Space Agency (ASI) and of the Istituto di Fisica Cosmica ed Applicazioni dell'Informatica (IFCAI) del CNR. The construction of the Gas Cell was carried by AEG, Ulm, while the High Voltage Supplies, the front-end electronics, the main electronics and the data conditioning system were produced by LABEN. The integration and testing of the HPGSPC is currently being carried out at the LABEN premises, in Vimodrone (Milano).

In this paper, after briefly describing the Flight Model of the HPGSPC and the on-ground calibration set-up we report preliminary results that show the performances of the Electronics concerning the single/double event qualification and management and the position reconstruction and energy correction of the full area X-ray events. We report, too, preliminary results on the spectroscopic performances of the instrument.

2. – The flight model of the SAX HPGSPC

2·1. *The detector.* – A schematic of the detector is reported in fig. 1 [4]. The electron cloud produced in the 10 cm "Drift Region" is drifted by a 160 V/cm/atm reduced electric field toward a 1 cm depth high field (up to 2.4 kV/cm/atm) "Scintillation Region". The 170 nm VUV light produced in the scintillation region is detected by an array of seven EMI photomultipliers with 3.19 inches of diameter each, positioned

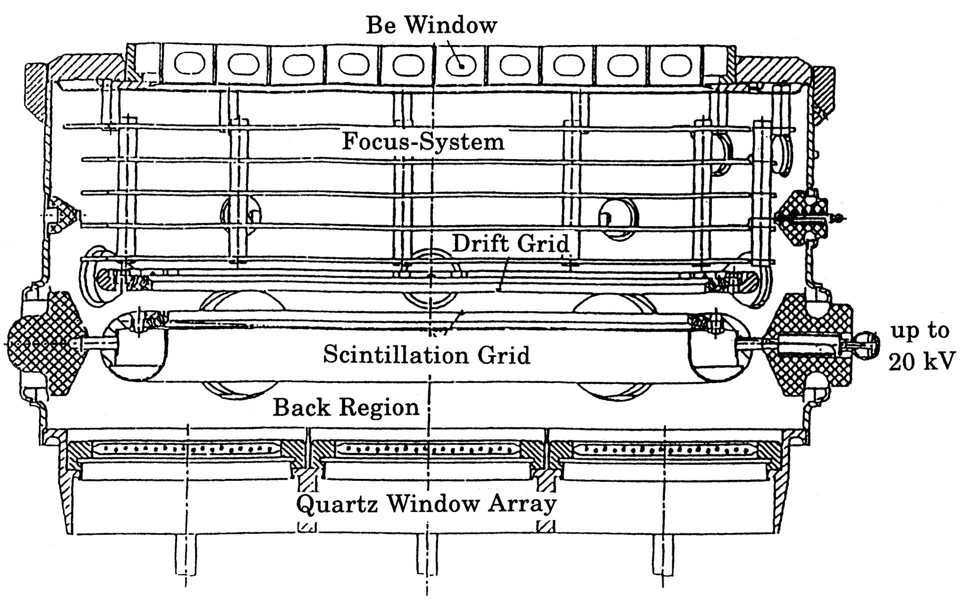

Fig. 1. – Schematic of the Flight Model of the SAX HPGSPC.

TABLE I.

Exposed geometrical area	450 cm^2
Entrance window	beryllium, 1.3 mm
Depth of “drift region”	10 cm
Depth of “scintillation region”	1 cm
Depth of “back region”	6.4 cm
VUV exit windows	7×3.3 inch diameter 6 mm thick, Suprasil
VUV readout	7×3.19 inch diameter PMTs, EMI D319 QB
Reduced electric field in the drift region	160 V/cm/atm
Reduced electric field in the scintillation region	up to 2.4 kV/cm/atm
Filling gas	xenon + 10% helium
Filling pressure	5 atm
Outer diameter	42.5 cm

about 7 cm below the scintillation region (the 7 cm region is defined as “Backregion”). The geometric useful area of the HPGSPC is 450 cm^2. To reduce the residual background the detector is shielded with 1 mm of lead +2 mm of tin. The main characteristics of the flight model are reported in table I. On the top of the detector a 10 cm collimator defines an almost circular field of view of $1.1° \times 1.1°$ FWHM. The collimator consists of hexagonal cells made of 50 μm of aluminium plated with 10+10 μm of lead. The transmission of the collimator is about 75%. During the on-ground calibration phase the HPGSPC was tested and calibrated without the collimator.

2·2. *The electronic unit.* – The Front End Electronics (FEE) is based on the technique of the gated integrator. The seven current signals coming out from the PMTs are slightly preamplified and shaped inside the Detector Unit (DU) and then transmitted to the Electronic Unit (EU) that constitutes the main electronic part of the instrument. In the EU the seven current PMTs signals are integrated by seven gated integrators each with a 8 μs integration time constant. A Sum signal is, then, obtained with an analogue sum of the seven integrated signals. The pulse duration is also measured by the Burst Length (BL) chain that measures the interval time between the 20% and 80% of the integrated sum signal. The integrated PMTs signals, the integrated sum signal and the burst length are finally multiplexed and converted by the ADC in 4096 channels for the PMTs signal and 256 channels for the BL signal. A detailed description of the data processing performed by the EU can be found in refs. [5, 6].

Among all the other functions two main tasks are performed by the EU: the single and double events management and the position reconstruction and energy correction of the events.

In the case of the HPGSPC the absorption of a X-ray photon occurs in the L (or lower order) shell if $E_X < 34.6$ keV (the xenon K-shell binding energy). In this case only a single electron cloud is produced, because the probability of atomic relaxation via Auger effect is much higher than fluorescence (Auger probability is about 89%) and, in any case, the mean penetration depth of the L fluorescence photon in 5 atm xenon is less than 1 mm. Only a single VUV light burst will then be produced and the HPGSPC electronics will detect what is defined as a “single” event.

For incident X-ray with $E_X > 34.6$ keV the probability to interact with the K-shell is 86%, while the probability that the atom relaxes via a K_α (29.7 keV) or K_β (33.8 keV) fluorescence photon is 87.5%. Because the main penetration depth of the K fluorescence photon is 4 cm (in 5 atm xenon), a pair of separate, but correlated, electron clouds (or VUV light bursts) can be produced. In this case the HPGSPC electronics can detect both "single" and "double correlated" events.

The HPGSPC electronics is able to recognise and process both single and double events: events that differ in time less than 40 μs (that is the maximum transit time in the Drift Region) are recognised as correlated events and flagged as double events. The capability to manage the "double correlated" events permits not only to reconstruct the energy of the incident X-ray above the xenon K edge, but also to improve the background rejection using the fluorescence-gated technique [7].

As the total solid angle subtended by the PMTs (*i.e.* the UV light collected by the PMTs) depends on the (x, y) position of the scintillation point, a second main task of the EU is that of reconstructing the (x, y) scintillation position of the event and of correcting the measured energy (sum signal) using dedicated look-up tables that contain the appropriate energy correction factor for each position. A detailed description of the onboard algorithm can be found in [8].

Finally, the EU is also in charge of formatting and transmitting data in different operative modes: during the on-ground calibration session we extensively use the diagnostic direct operative mode that includes for each event the maximum set of measured parameters: arrival time, uncorrected energy (sum signal), seven PMTs signals, corrected energy, burst length, position, correlation flag, onboard source calibration flag.

3. – The on-ground calibration experimental set-up.

In SAX all data acquired by the Instruments are processed, stored and transmitted to ground station by the On Board Data Handling system (OBDH). This is connected via the Response Bus (RB), the Block Transfer Bus (BTB) and the Interrogation Bus (IB) to the Intelligent Terminal (IT) of each Instrument. The HPGSPC IT is composed basically of two 80C86 digital microprocessors inside the Electronic Unit. Scientific data comes from the HPGSPC IT in packets of fixed length and are transmitted via BTB while the information about the health of the HPGSPC is carried by the RB (both on 16-bit data). The interrogation messages toward the HPGSPC IT are transferred by the IB on 32-bit instructions.

During the on-ground calibration measurements we used the Instrument Test Equipment (ITE), *i.e.* the data acquisition system developed by LABEN. The ITE is a computer-controlled system with a probe, the On Board Data Handling Bus Emulator and Probe (OBDH BEP), which interfaces the HPGSPC Electronic Unit. The OBDH BEP allows the direct access to the OBDH Bus. It retrieves data from HPGSPC coming on the BTB and RB and sends them to a VAX station using the TCPIP protocol. Details of hardware and software of the ITE are reported in ref. [9].

The on-line data handling, the off-line processing and archival of data from ITE were performed by the IFCAI calibration support system that mainly consists of a PC IBM DX4 100 Mhz, a Magneto-Optic Support with a capacity of 1.2 GB and 2 Laptop PC 386 Toshiba.

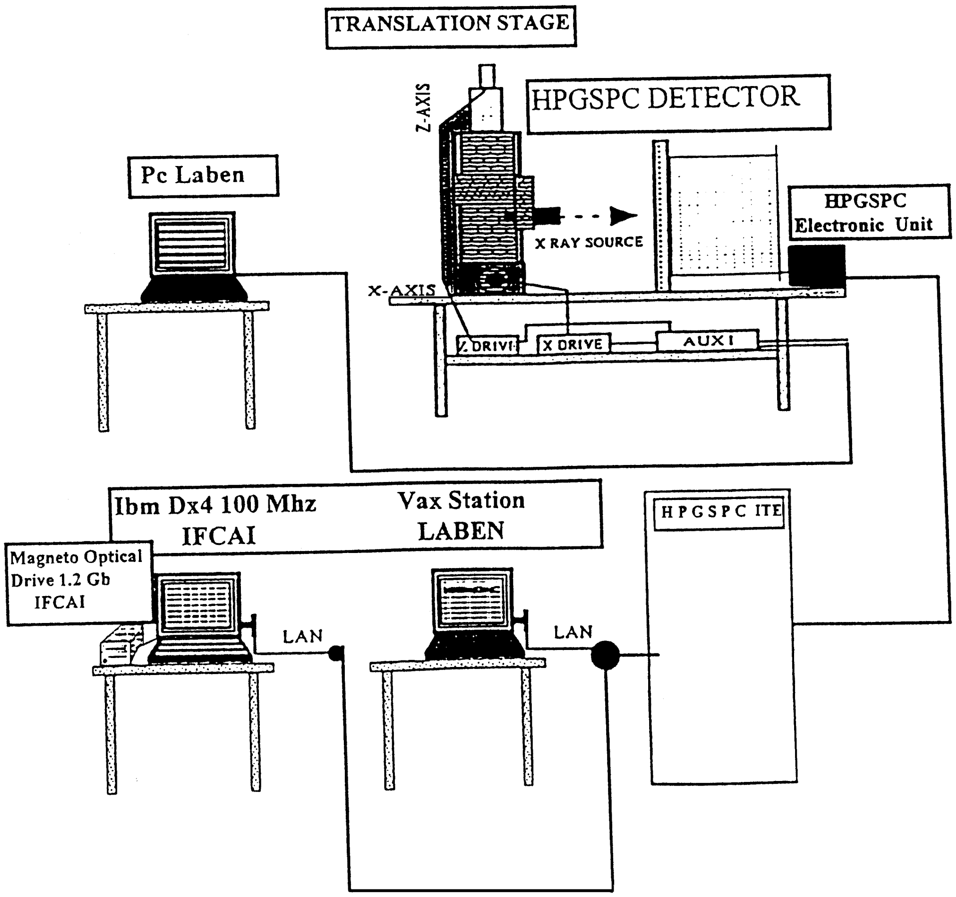

Fig. 2. – Calibration set-up schematic.

Finally a two-axis Translation Stages System, that is a part of the Mechanical Ground Support Equipment developed by LABEN, was used to positioning collimated X-ray sources in the relevant points of the entrance window of the detector. The TS was controlled by a PC, and the sources were moved upon the window with a positioning accuracy (for both axes) of about 0.1 mm. A schematic of the calibration set-up is shown in fig. 2.

4. – Preliminary calibration results

4·1. *Single- and double-event qualification and management EU performances.* – The capability of the EU to manage and qualify single and double events in order to use the fluorescence gated technique has been verified trough the analysis of the spectral response to well collimated "on axis" calibration sources.

In fig. 3a) we report a position reconstructed/energy corrected (see subsect. 4·2) spectrum of X-rays from an ^{241}Am source well collimated on the axis of the instrument (no background has been subtracted). Both the single and the pair of correlated events

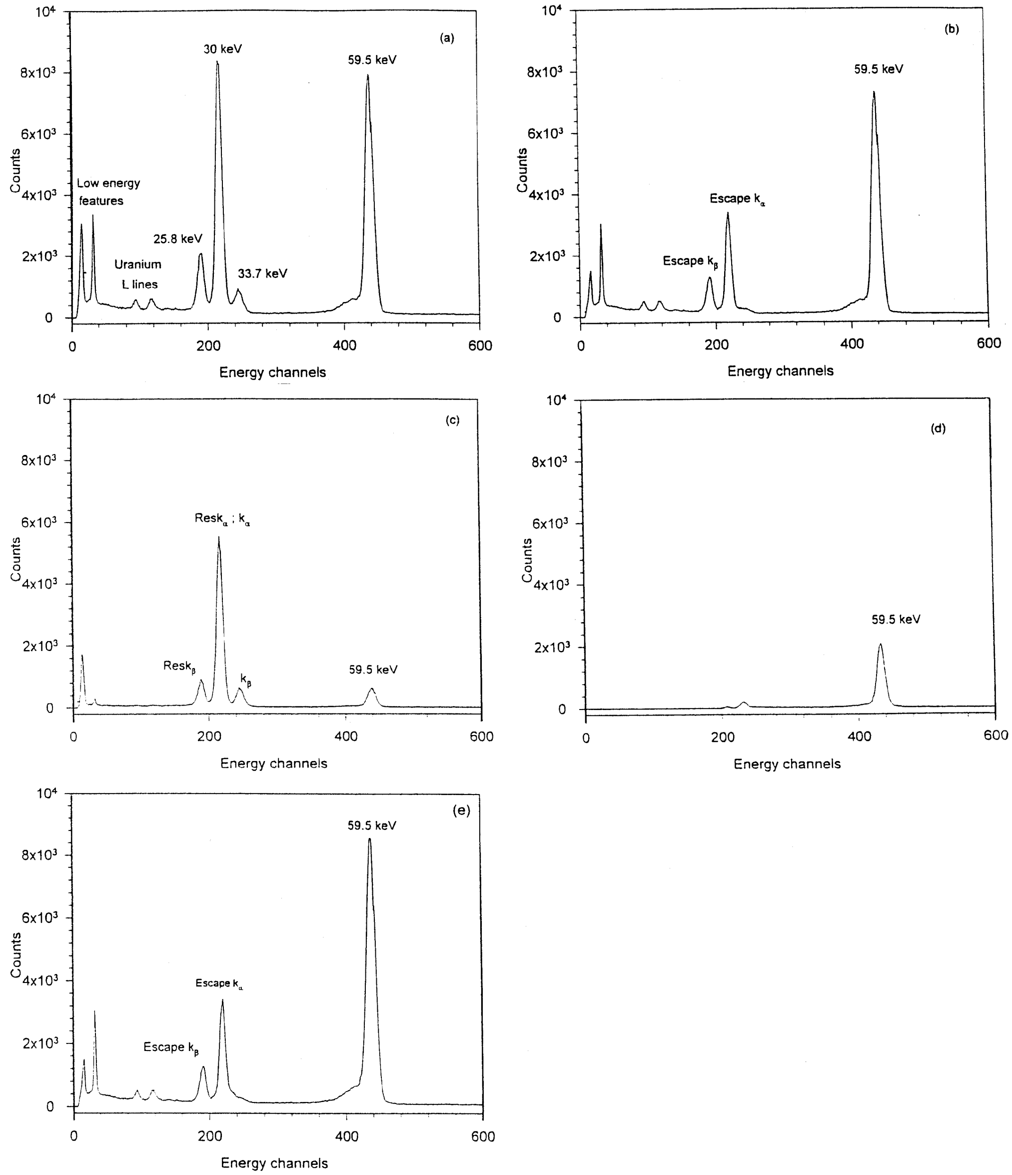

Fig. 3. – In a) the single + double events spectrum of the ^{241}Am source is shown. Double events are accumulated separately. In b) only single events are accumulated. c) Only double events are accumulated separately. Note that, as we expected, the L lines of uranium disappeared. d) Spectrum of double events recognized as residual and fluorescence and summed: there are no features except the 59.5 keV americium line. e) Full spectrum of ^{241}Am 59.5 keV line as seen by the HPGSPC. The two peaks around 30 keV are now the K_α and K_β escape peaks.

(double events) are accumulated in the spectrum: the events of the pair are accumulated separately. In the spectrum the ^{241}Am line ($E_{\mathrm{X}} = 59.5$ keV) is clearly visible. The line at 33.7 keV corresponds to the K_β fluorescence of the xenon while the line at 25.8 keV corresponds to the Res K_β residual peak ($E_X - K_\beta$). The line at about 30 keV corresponds to the K_α xenon fluorescence and to the Res K_α residual peak ($E_X - K_\alpha$). The two peaks at 13.6 keV and 16.9 keV are due to L fluorescence from Uranium that is an impurity in the beryllium entrance window [8].

The features in the low-energy part of the spectrum (below 10 keV) are due to photons absorbed in the back region of the detector. These photons give rise to an electron cloud that drifts back toward the wires of the HV grid; these electrons, scintillating along an anomalous path near the wires, produce a low number of UV photons. The two clearly visible lines are related to the two main peaks in the spectrum, that is to the ^{241}Am 59.5 keV and to the 30 keV xenon fluorescence photons. The low-energy features can be almost at all rejected via burst length selection, due to a shorter time duration of the scintillation process.

The ^{241}Am spectrum of the events qualified and flagged by the EU as "single" is reported in fig. 3b). The 59.5 keV line is only slightly reduced showing, as expected, that most of the photons detected at 59.5 keV are single events. While the K_β fluorescence line essentially disappeared, the Res K_β and Res K_α lines correspond, now, to the escape K_α and K_β peaks, *i.e.* to events for which the fluorescence photon gets lost.

In fig. 3c) we show the ^{241}Am spectrum of the events qualified and flagged as "double" (*i.e.* only correlated events). Beside the expected peaks that correspond to the usual K_α and K_β fluorescence and residuals, a peak at 59.5 keV is still present (although largely reduced): it is due to events coming from the ^{241}Am source that are coincident in the 40 μs correlation window. The contribution of coincident events is not negligible because of the high count rate of the source (about 1000 counts/s).

In fig. 3d) the double correlated event spectrum is reported after the double events have been recognised and summed: the pairs of events flagged as double are accepted if at least one has an energy corresponding to the K_α or K_β line and, if this is the case, the energy of the Residual and of the fluorescence are summed.

Finally fig. 3e) shows the full (single + double events) spectrum. The results reported, although quite preliminary, show that the single- and double-events qualification and management processing as implemented on the SAX HPGSPC is rather well working on the flight model.

4·2. *Position reconstruction and energy correction EU performances.* – In order to recover the intrinsically good energy resolution of the HPGSPC, it is necessary to multiply the Sum signal by the ratio *Kc* of the total effective solid angle "on axis" to the total effective solid angle subtended by the PMTs array at the (x, y) scintillation position. The energy correction procedure requires, then, to use an appropriate (x, y) position reconstruction algorithm to evaluate the *Kc* ratio from an experimental look-up table implemented onboard [8].

During the calibration session the look-up table of the *Kc* correction factor has been experimentally determined measuring the 22 keV peak of a well collimated ^{109}Cd source line in about 200 different points sampled on the entrance window. To verify the capability of the EU to correct the energy for events uniformly distributed on the entrance window full area spectra of the calibration sources have been acquired.

To simulate a full area illumination the radioactive calibration source was positioned 2 m off the entrance beryllium window. In fig. 4 we report both the unreconstructed and energy reconstructed spectrum of the 22 keV and 25 keV lines of the ^{109}Cd source.

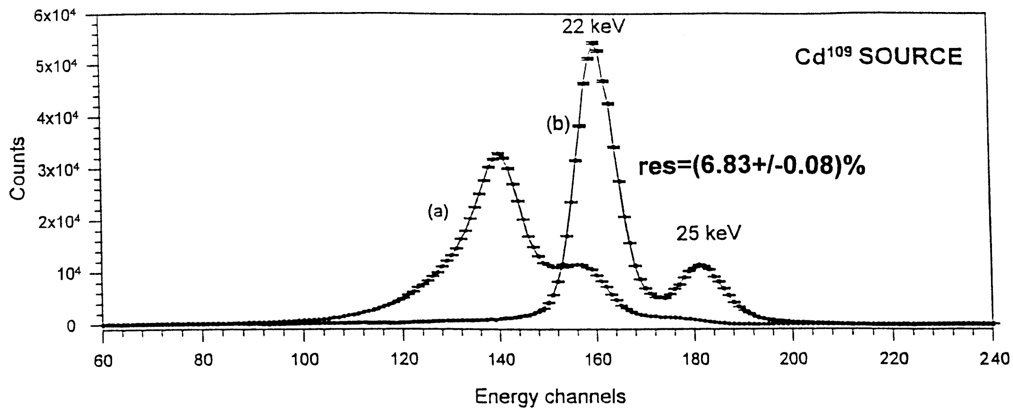

Fig. 4. – a) Unreconstructed and b) reconstructed spectrum of the 22 and 25 keV lines of a ^{109}Cd source.

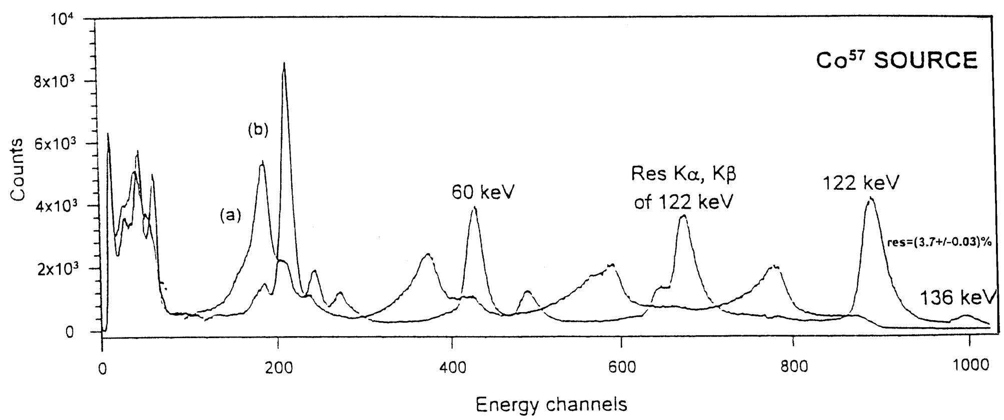

Fig. 5. – a) Unreconstructed and b) reconstructed spectrum of ^{57}Co source. Besides the 122 keV (the resolution of the reconstructed spectrum is 3.7 + 0.03% FWHM) and the 136 keV lines with relative residual and fluorescence lines, there are lines at about 60 keV (Am ?) and 68 keV. At energies less than 10 keV lines due to events absorbed in the back region are quite evident. However, they can be rejected via Burst Length selection.

In the reconstructed spectrum the two lines of the ^{109}Cd source are rather well resolved and the energy resolution is 6.8% (FWHM).

As second example a spectrum of ^{57}Co radioactive source is shown in fig. 5. All the lines and the residual peaks are very well reconstructed showing that the algorithm is properly working in the entire HPGSPC energy range. The low-energy features present below 10 keV are due to events that are absorbed in the backregion.

Finally, in fig. 6 we report the spectrum of the environmental background seen by the HPGSPC in the Laben Clean Room (integration time = 30 minutes). Apart from the xenon K_α and K_β fluorescence peaks, the L fluorescence lines of the uranium

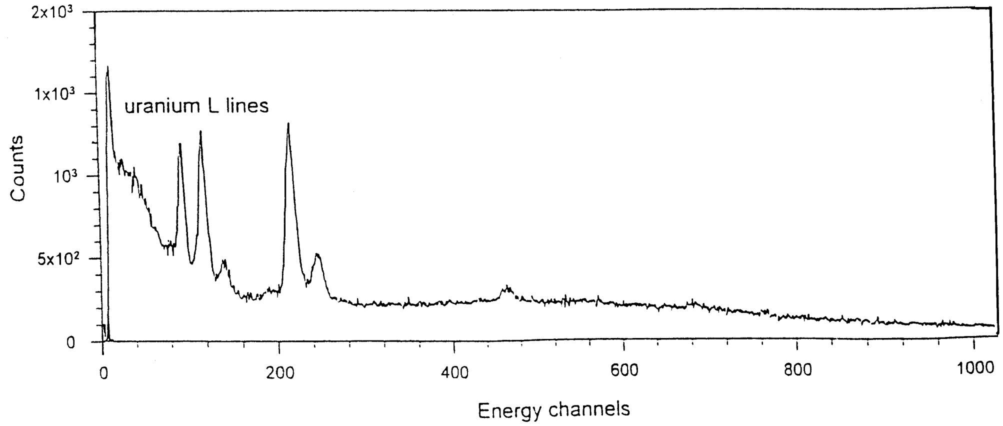

Fig. 6. – Reconstructed background spectrum as seen by the HPGSPC in the LABEN Clean Room.

(impurity of the beryllium window) and the low-energy feature produced by the photons absorbed in the backregion are also clearly visible. The total background count rate in the whole energy range is about 200 counts/s.

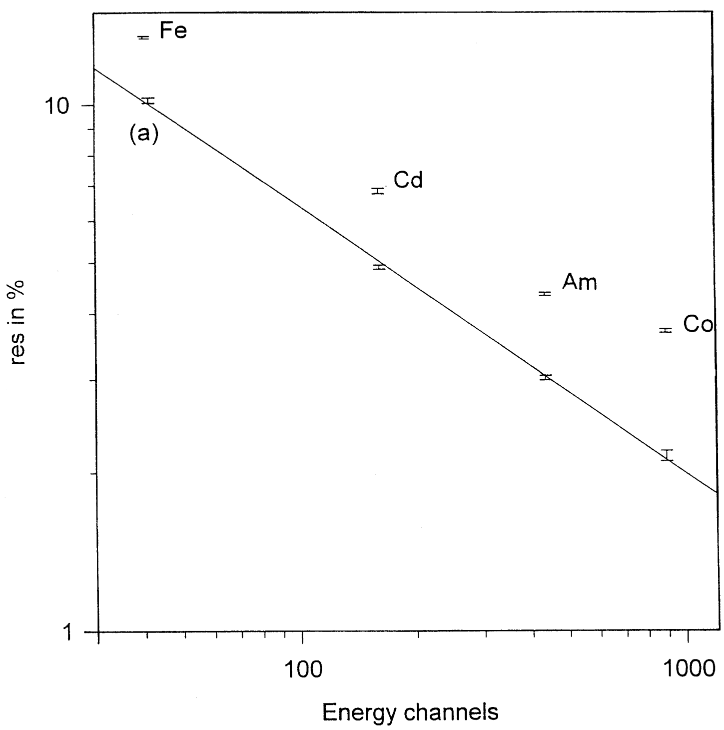

Fig. 7. – Energy resolution as a function of the energy: the curve (a) is for collimated illumination and is approximated by the $C{\cdot}E^{-\alpha}$ law (best fit is for $C = 66 \pm 7$ and $\alpha = 0.505 \pm 0.02$). The points above the curve (a) are the full-area measured energy resolutions.

4·3. *Spectroscopic performances.* – The spectroscopic performances of the HPGSPC are summarised in fig. 7 that shows the energy resolution as a function of the energy in the case of both full-area and well-collimated "on axis" X-ray illumination. The HPGSPC energy resolution is shown to be well approximated by the $C \cdot E^{-0.5}$ law for the collimated illumination. In the full-area case a deviation from the square-root law is observed at higher energy.

The linearity of the HPGSPC response has been also verified. Because of the limited number of energy lines, we do not see any evidence of the jump around the K edge where a jump of about 177 eV has been recently measured [10].

5. – Conclusions

In this paper we reported some preliminary results on the Flight Model of the SAX HPGSPC obtained during the first session of the on-ground calibration of the instrument, performed at the Laben premises during October 1994.

We have shown how both the single/double event management and the position reconstruction/energy correction techniques processed by the Flight Model of the Electronics Unit are very well working. The spectroscopic performances of the detector are shown both for well-collimated "on axis" X-ray source and for full-area X-ray illumination. Although preliminary, the results are quite promising and indicate that the HPGSPC may meet the scientific goals it has been designed for.

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REFERENCES

[1] Scarsi L., *Astron. Astrophys. Suppl. Ser.,* **97** (1993) 371.
[2] Makishima K. *et al.*, *Astrophys. J.,* **365** (1990) L59.
[3] Nagase F. *et al.*, *Astrophys. J.,* **375** (1991) L49.
[4] Agnetta G., Biondo B., Celi F., Di Raffaele R., Giarrusso S., La Rosa S., Manzo G., Re S. and Sole L., *Nuovo Cimento C*, **13** (1990) 421.
[5] HPGSPC Electronic Unit Spec., Laben, doc. SX-SP-LA-329 issue 2 (1993).
[6] Manzo G. *et al.*, *The flight model of the high pressure proportional counter onboard the SAX satellite*, manuscript in preparation.
[7] Manzo G., Davelaar J., Peacock A., Andresen R. D. and Taylor B. G., *Nucl. Instrum. Methods A*, **177** (1980) 595.
[8] Giarrusso S., Manzo G., Santangelo A., Biserni M. and Dalla Ricca P., *Nucl. Instrum. Methods A*, **354** (1995) 567.
[9] Dal Fiume D., Frontera F., Nicastro L., Orlandini M., Trifoglio M., Forlanelli G., Iavarone S., Poulsen J. M. and Butler R. C., this issue, p. 811.
[10] dos Santos G. M. F., Morgado R. E., Tavora L. M. N. and Condè C. A. N., *Nucl. Instrum. Methods A*, **350** (1994) 316.