Laboratori Nazionali di Frascati

LNF-87/70(R)
9 Luglio 1987

A. La Monaca:

SCINTILLATION GAS DETECTOR BASED ON A CHARGE COUPLED DEVICE: A FEASIBILITY STUDY OF A POSITION SENSITIVE DETECTOR FOR ESRF HIGH BRILLIANCE X-RAY SOURCE

Servizio Documentazione
dei Laboratori Nazionali di Frascati
P.O. Box, 13 - 00044 Frascati (Italy)

INFN- Laboratori Nazionali di Frascati
Servizio Documentazione

LNF-87/70(R)
9 Luglio 1987

SCINTILLATION GAS DETECTOR BASED ON A CHARGE COUPLED DEVICE: a feasibility study of a position sensitive detector for ESRF High Brilliance X-ray source.

A. La Monaca
I.N.F.N. - Laboratori Nazionali di Frascati - 00044 Frascati, Rome (Italy)

The present position sensitive detectors whether gas type, as a proportional chamber, or imaging solid state device, as a CCD, have serious troubles when used with high brilliance X-ray sources[1,2].

The gas detectors are limited strongly in count rates by spatial charge originated by avalanche discharge while the imaging solid state devices suffer for radiation damage even if in principle they can measure very high fluxes[3]. For overcoming the radiation damage the imaging solid state devices have been equipped with special X-ray converters, as a phosphorous coating on the coherent optic fibres. But phosphorous converter produces a not uniform response owing to not constant thickness of the coating. The presence of coating precludes its use for recording of fast changing patterns because of decay time of the low scintillation components associated to the principal (for example 0.3 μsec for the fastest and others of 1-1000 μsec according to the phosphorous type)[4]. Besides this the phosphorous

film peels under the high photon fluxes in a relatively short time. Also the position sensitive gas detector, found improvements in spatial charge effect by the use of multisteps chambers. In these chambers the avalanche discharge develops in more stages physically separate presenting a reduced local spatial charge. This increases the count-rates per pixel of about one order of magnitude[5] . But in any case using gas detector we cannot detect than a little more than 10^6 cps. for the whole area of detector because of the dead time of the electronics and the data acquisition system.

Therefore new detectors with new data acquisition systems, suitable for high photons fluxes, should be studied. We think to contribute at this development with a proposal of a prototype of a new position sensitive detector, which converts X-ray photons in UV photons, and an imaging solid state device, as a CCD commercial type, which detects UV photons [6]. Briefly we propose to use an imaging solid state device with an X-ray gas converter.

A possible scheme of proposed detector is shown in Fig. 1a and 1b. It is constitued by a gas detector which is divided in two parts, an X-ray absorption region and an UV emission region. Below the gas converter an optical fibre system and a CCD optical sensor are required. The coherent optic fibres collect the local flashes onto the sensitive area of CCD protecting it from direct radiation damage.

The operating mechanism is the following.

As soon as the X-ray photon is absorbed by the noble gas, the photoelectron produces a local small cloud of electron charge. This is guided by electric field E_0 in a gap between two grids, where it is accelerated by another electric field E_1 to gain enough energy to excite the atoms of the gas by collisions. The UV light flashes emitted by excited atoms can be seen by the CCD. The thickness of absorption and emission region and the values of the electric fields depend on the used gas.

The light emitted by electrons drifting in a noble gas in absence of charge multiplication at the pressure of 1 bar has a spectral distribution similar to the so-called "second continuous". The latter is attribued to the

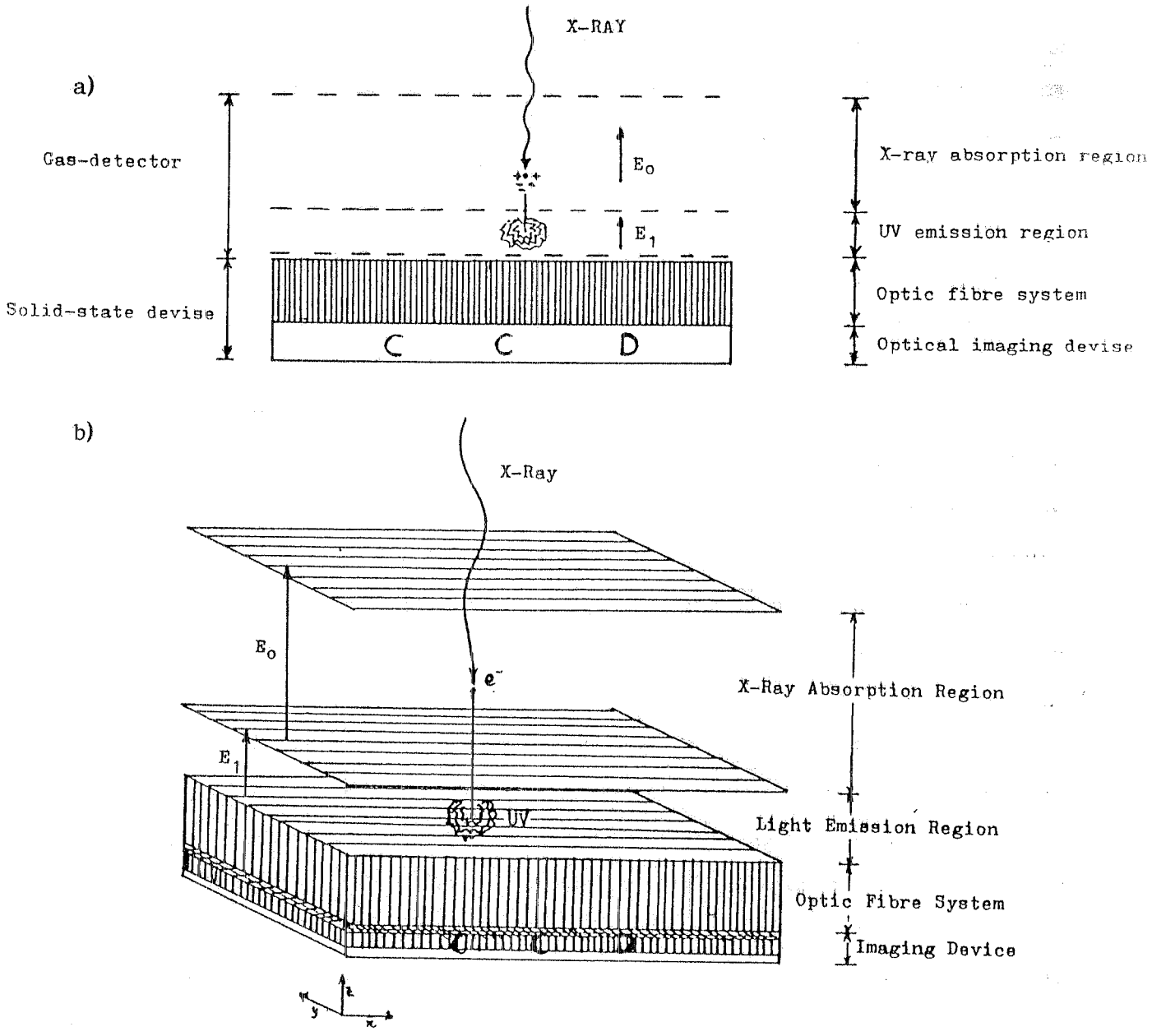

FIG. 1: a) Scheme of the Scintillation Gas Detector based on a Charge Couple Device; b) Three-dimensional view of SGD-CCD.

transition to ground state from molecular states exited by the collisions. The emission peaks are at 1280 Å for argon, 1420 Å for Kripton, 1730 Å for xenon, with a full width at half maximum of 100-140 Å (Fig. 2).

Photons of this energy cannot be used with CCD because of radiation damage effect. Recently, test made by our group at Frascati using UV photons of Synchrotron Radiation in the wavelenght range of 1000-1800 Å and a linear CCD, Thomson-CSF TH 7802A, showed an increase in the dark leakage current in cumulative and permanent way [8]. This effect is not dramatic and decreases at low temperature. Since this effect disappears over the thershold of 1800 Å, a wavelenght shifter of the light flashes of the noble gases can be used in operation with a CCD.

The shifting of the light emission to a more convenient wavelenght is based on energy transfer phenomena, so that the noble gas acts as donor to a convenient gas acceptor. Generally the light emission of acceptor gradually takes the place of donor emission as the acceptor density increases, while the amount of light emission of acceptor at constant density increases linearly with the increasing of the donor pressure. In Fig. 3 we report a diagram of light emission of Ar - N_2 mixture with low density of N_2 gas [9][10]. We can see that there is a continuous band from 1600 Å to 2700 Å, with a maximum peak at 2200 Å and two main emission lines at 2380 Å and 3580 Å. For higher density of N_2, about 5% more, the continuous band disappers and the intensity of such lines increases with nitrogen content [10]. In this photon energy range the spectral response of commercial CCD is relatively good with a quantum efficiency of about 20% (as measured also by us).

At present we have no measurements concerning the use of mixture of Xe of Kr and N_2 so that we do not know which is the most convenient N_2 concentration nor if other gas can be used as acceptor. But to estimate the photon gain in each light flash we can take the case of a mixture of Xe with low concentration of N_2 at one bar of pressure. We fix an absorption region of 5 mm depth to have 64% of X-ray conversion at $\lambda = 1.54$ Å. The electron cloud generated in the gas has a diameter of $\sim$ 70 μm with $\sim$ 386 electrons drifting. The emission light starts at $E_1 = 700$ V/cm and the

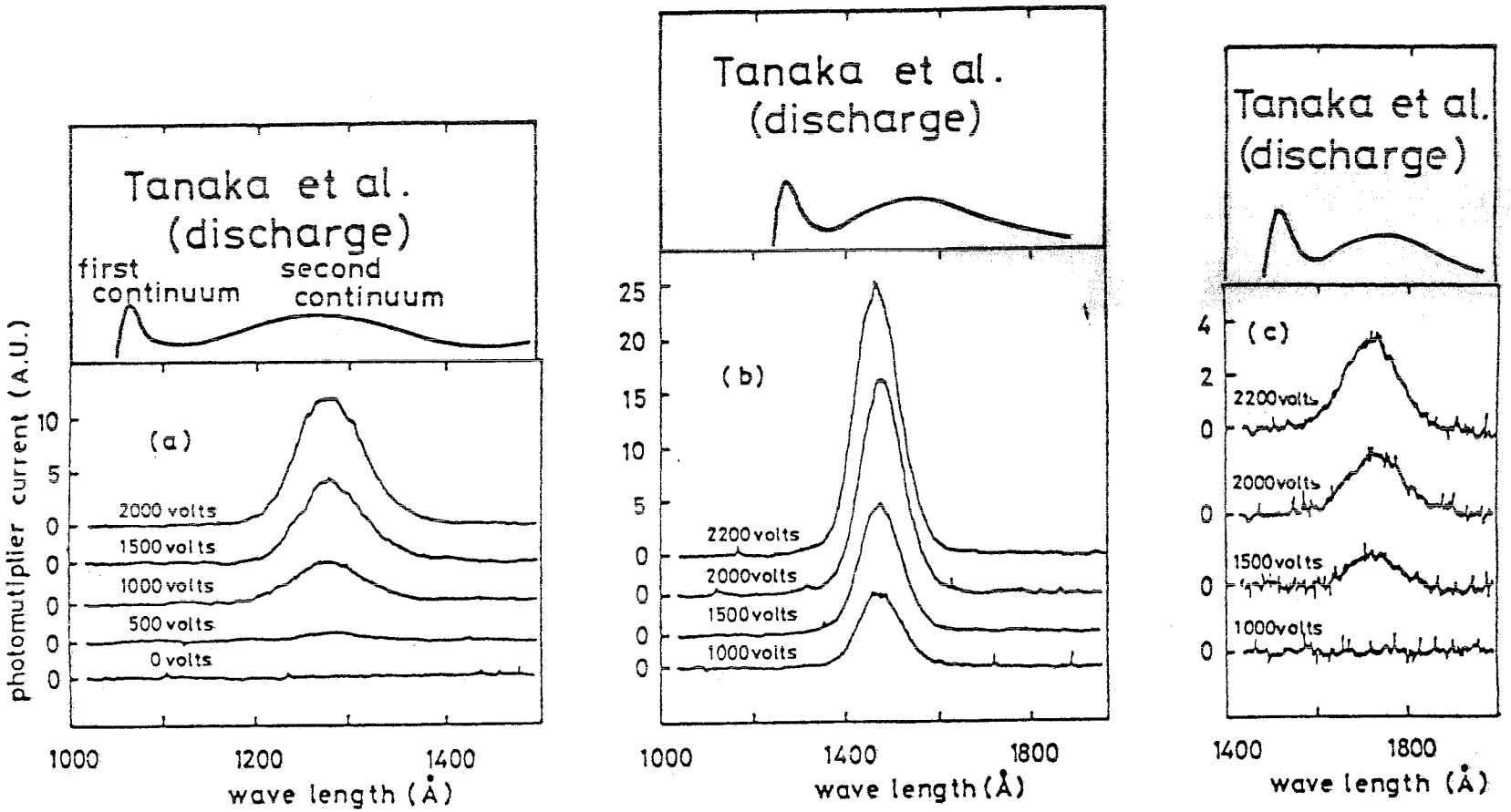

FIG 2 : Spectral distribution of the UV light emission of Argon at 760 torr (a), Kripton at 560 torr (b), Xenon at 360 torr (c) for various applied electric fields. No photons were observed in the wavelenght region of 2000-6000 Å for any of the gases. Continuous emission spectra from pure noble gas discharges are also shown taken from Y. Taneka et al. J. Opt. Soc. Am. 48 (1958) 304 (M. Suzuki and J. Kubota,1979) (7).

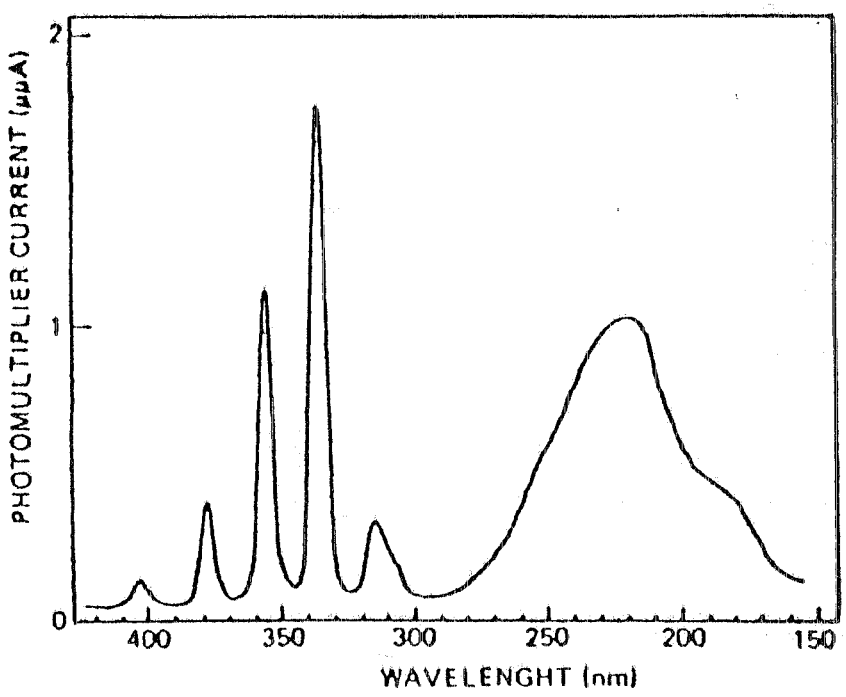

FIG 3 : UV emission of Ar (99,9%) doped with N (0.1%) (D.Stricker and E.T. Arakawa, 1964; also A. Anderson and G. Charpak, 1982) (9)(10).

electron multiplication starts at E'_1 = 6300 V/cm. Between E_1 and E'_1 light emission increases linearly and at E'_1 the value light efficiency is close to 100%[11]. The number of photons is equal to the energy taken by drifting electrons from the external field, divided by the average photon energy of the UV. An hundred of UV photons are generated by one electron drifting in one mm of the gas gap and about 3.8×10^4 photons are generated by the whole electronic cloud created by one X-ray event. This number is 50-200 time greater than that given by phosphorous coating. Moreover, the drift time of electron in one mm of gas-gap is about 25 nsec., the decay time of light emission is smaller than 90 nsec., while the formation time of excited molecules by collisions is less than 100 nsec.[7][12]. Adding also the drift time of electrons in the absorption region one has a maximum total scintillation dead time of $\sim$340 nsec. for each X-ray event.

For localizing the UV flashes isotropically emitted we have to use a coherent optic fibre system in front of the CCD and as close as possible to a small scintillation gas gap. Short silica fibres with a good transmission efficiency (0.4-0.6) in the above range of photon energy can be used.

Fixing a gas gap depth d=1 mm, the diameter of the brightest part of UV flash, considerated as a lambertian source radiating in a hemisphere of radius 0.5 mm, can be estimated of about 1.5 mm. For obtaining better resolution demagnifying optic fibres have to be used. If optic fibre cones, in which each fibre is conical with a demagnification 5:1, are used, we can have a light flash spot on CCD area of 300 μm with about 2500 UV photons for one X-ray event. An integration over few X-ray events would produce a very good signal/noise ratio for a CCD system. But also for a commercial linear array of CCD with 1728 pixels of small size, operating at very high frequency (for example, pixel size 0.01x0.01 mm^2, cloking frequency 40 MHz and X-ray source 10^{11} phot./sec. at $\lambda = 1.54$ Å) for 50 μsec of integration time we could have $7x10^5$ UV photons per pixel in the case of normal optic fibres and $2x10^7$ UV photons per pixel in the case of demagnifying optic fibres suitable for generating a good signal/noise ratio for CCD[13]. The same good results will be obtained in the case of matricial CCD sensor with 512x512 pixels (0.023x0.016 pixel size, clocking frequency 10 MHz - Thomson firm-) illuminated by the same X-ray source, if the UV gain of the gas gap is opportunely chosen.

In conclusion the CCD based scintillation gas detector offers good possibility for detecting high photon fluxes. The best properties are its uniform response on the whole area thanks to the gas converting gas gap and the possibility of controlling the gain just acting on the electric field. Spatial resolution of detector depends on the light collecting system and can be also of about 0.3 mm.

We propose to build the mentioned detector in first instance in an unidimensional linear version and after in a two-dimensional version. A schematic representation of the experimental set-up is shown in Fig. 4. The tight pipe fluxing gas apparatus for suitable noble gas mixture working at pressure between 0.5 and 5 bars is designed. The requested precision in the noble gas mixture can be achieved by commercial fluxmeters. We acclude a design of the instrument that can calibrate 10^3 ppm of one gas in another (Fig. 5).

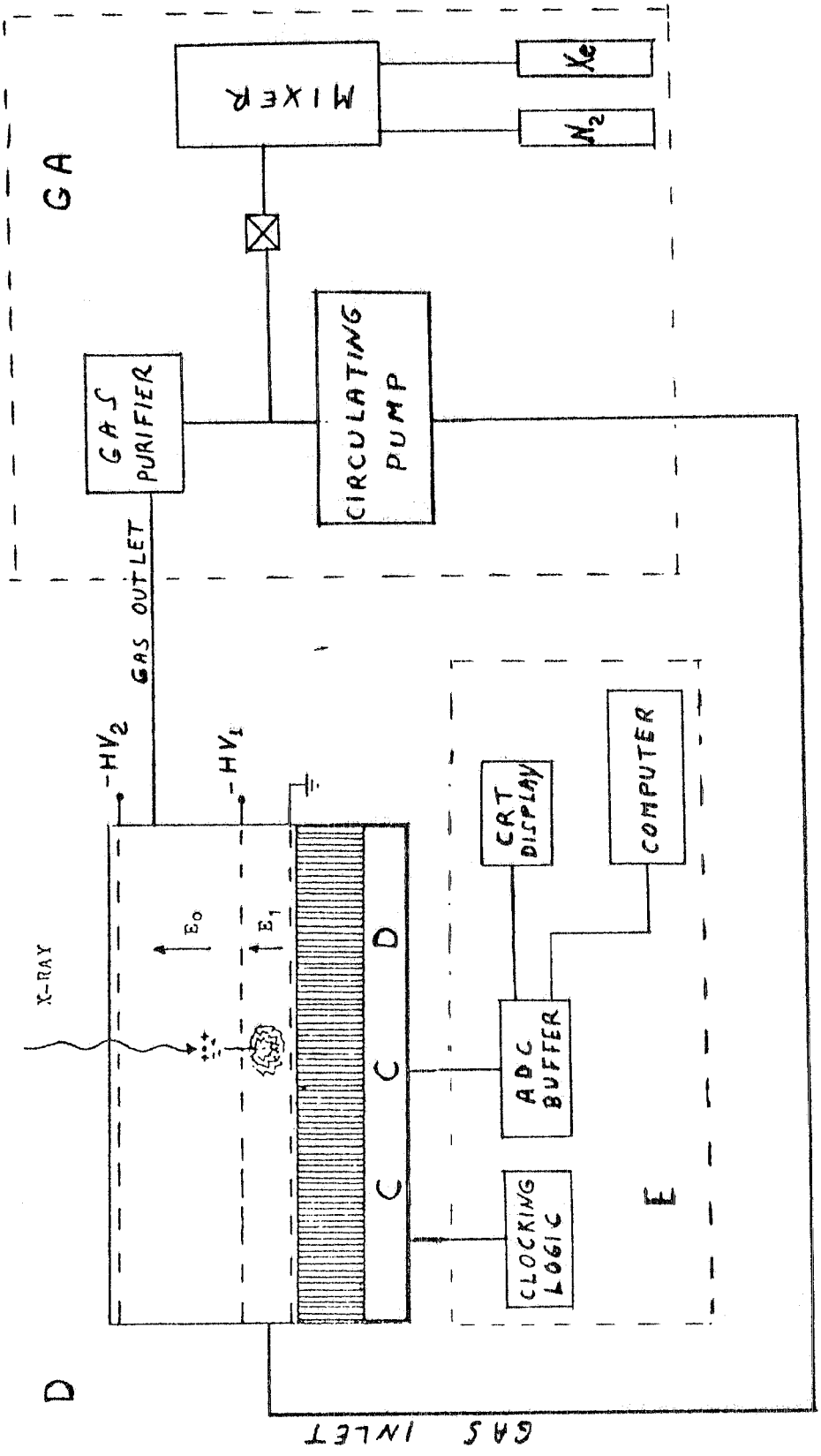

FIG. 4 : Schematic representation of the experimental set-up: D-Detector; GA-Gas Apparatus; E-Electronics.

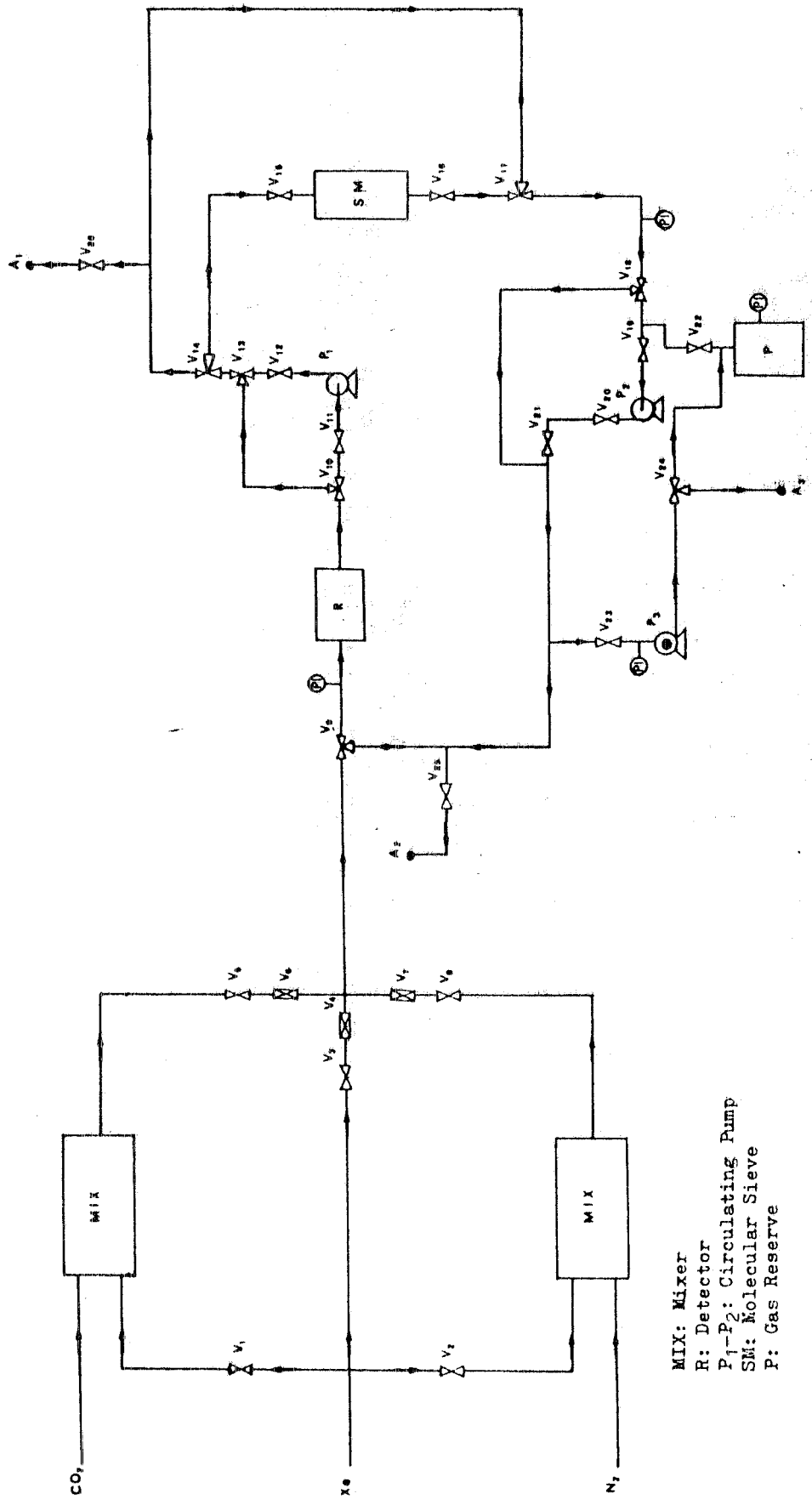

FIG. 5 : Scheme of the Gas Apparatus for doped noble gas fluxing in a tight pipe working at 5 bars. The apparatus has been designed and will be manufactured by the SOL firm.

The detector should be built and tested at Frascati Synchrotron Radiation Facility by our group increased with some persons working under ESRF contract. Services and workshops of INFN-LNF will be used.

At present the total cost of detector can be only approximative. Our estimate is about 150 kECU apart from computer as specified in the following:

Gas apparatus	70	kECU
Gas detector	20	
Demagnifying optical system + CCD	40	
Electronics	20	
TOTAL	150	kECU

REFERENCES

(1) A. La Monaca, A. Bigi, A. Ripamonti, N. Roveri, M. Iannuzzi; R. Messi: "Small angle X-ray Diffration of Collagen Fibrils Using a Three--dimensional Imaging Gas Detector". International Conference on Biophysics and Synchrotron Radiation, Frascati (1986). In press by Springer and Verlag, Berlin.

(2) J. Hendrix: "Contribution to the ESRP Detector Study Group". ESRP-IRI--21/84.

(3) R.H. Dyck, Fairchild CCD Catalog (1984) 1988.

(4) U.W. Arndt: "X-ray Television Area Detectors". Nucl. Instr. and Meth. 201 (1982) 13.

(5) A. Breskin, G. Charpak, S. Majewski, G. Melchart, A. Peisert, F. Sauli: "High Flux Operation of the Gated Multistep Avalanche Chamber". Nucl. Instr. and Meth. 178 (1980) 11.

(6) A. La Monaca: "Proposal for a New Type of Drift-Chamber Area Detector for X-ray Radiation from the European Machine". ESRP-IRI-24/84.

(7) M. Suzuki and S. Kubota: "Mechanism of Proportional Scintillation in Argon, Krypton and Xenon". Nucl. Instr. and Meth 164 (1979) 197.

(8) INFN-LNF: Rapporto di Attività, "Sviluppo di nuovi rivelatori" pag.46.

(9) D. Strickler and E.T. Arekewa, J. Chem. Phys. 41 (1964) 1783.

(10) D. Anderson and G. Charpak: "Some Advances in the Use of the Light produced by Electron Avalanches in Gaseous Detectors". Nucl. Instr. and Meth. 201 (1982) 527.

(11) A.J.P.L. Policarpo, M.A.F. Alves, C.A.N. Conde: "The Argon-Nitrogen Proportional Scintillation Counter". Nucl. Instr. and Meth. 55 (1967) 105.

(12) A. Breskin, A. Cattai, G. Charpak, A. Peisert, A. Policarpo, F. Sauli: "Advances in Vacuum Ultraviolet Detection with Multistep Gaseous

Detectors and Application to Cerenkov Ring Imaging".
IEEE Trans. Nucl. Sci. NS 28, N.1 (1981) 429.

(13) A.J.P.L. Policarpo: "the Gas Proportional Scintillation Counter".
Sp. Sci. Instr. 3 (1977) 77.

(14) J.D.E. Beynon and D.R. Lamb: "Charge-Coupled Devices and their Applications". Mc Graw-Hill Co. London (1980).