# NEW GENERATION OF INDIVIDUAL SAFEGUARD SYSTEMS

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## Abstract

By taking advantage of the progress of new semiconductor γ-ray counters working at room temperature, we developped a compact and sensitive individual safeguard system using CdTe and $HgI_2$ sensors. Details of the electronics are presented. Two methods of overcoming the time dependent polarization effect are presented.

## Introduction

During the last ten years, nuclear radiation spectroscopy has progressively shifted from detectors based on a gaseous or vacuum tube structure (scintillator + photomultiplier, Geiger-Müller, ionization chamber...) to those of a solid absorption medium, especially silicon and germanium. However, the field of safeguard equipments has not followed this general trend and, today, is still completely served by the older sensors. This results from the low detection efficiency of silicon for γ-rays and from the necessity of cooling the Ge(Li) and H.P.Ge detectors. These were the only solid state detectors readily available up to now.

We wish to demonstrate here that with the availability of new high atomic number compound semiconductors (CdTe, $HgI_2$), progress in small volume safeguard and activity control equipments is possible. Furthermore, it should be mentioned that the amplitude of the signals from these devices is much more adapted to integrated circuitry. In this short paper, we first describe the properties of these new detectors and then describe the realization of an individual radiameter.

## The detectors

The fundamental properties of CdTe and $HgI_2$ spectrometers have been analysed elsewhere [1-3] and only the parameters of interest here will be considered. The general characteristics of these detectors, as compared to silicon (until recently the only solid state counter operating at room temperature), are summarized in Table I. Due to the high Z of the compound materials, an appreciable increase in efficiency is observed and consequently small volume sensors can be used. Only scintillators are more efficient (due to the larger volume), but need a larger space because they must be coupled to a photomultiplier and a high voltage is requested. Gas counter have a low density absorption medium and in general a rather high noise level.

### A. Cadmium Telluride

Different growing techniques, combined with the various compensation dopants lead to three different categories of crystals, each having specific properties :

a) N-type, resistivity $10^6$-$10^8$ Ω.cm, grown by the Bridgman technique, with indium compensation of the cadmium vacancies.

b) P-type, resistivity $10^6$-$10^8$ Ω.cm, grown by the travelling heater method (THM) with chlorine compensation.

c) P-type, resistivity $10^4$-$10^6$ Ω.cm, grown by the THM process, without special chemical compensation.

After cutting and standard surface lapping followed by cleaning, several surface treatments were used before metallic contacts were deposited on the opposite faces. Several contacts have been used : aluminium, electroless gold, electroless platinum, aquadag...). The simplest procedure consists in depositing by vacuum evaporation two aluminium contacts on the polished surfaces (no chemical treatment). Finally, the detectors made were encapsulated in a TO5 holder. (It is expected that the cost of such a solid state device will be low).

Detectors of the type described in b, which are those that have been mainly investigated up to now, show a typical time dependent polarization effect. This produces a gradual decrease in both counting rate and signal amplitude as a function of time the detector has been biased. Several methods will be proposed to suppress electronically this effect (below).

### B. Mercuric Iodide

Two main techniques are used to prepare single crystals of red $HgI_2$, both performed at low temperature (< 127°C), namely the vapour phase transport and the solvent methods. Crystals formed by the latter technique can be used directly for the detector manufacturing (thin platelets) ; crystals from the former have to be either cleaved (easy along a plane perpendicular to the [001]axis) or sliced and etched.

The contacts, which have to be chemically inactive with respect to the material components are either prepared by applying aquadag (emulsified graphite) or by vacuum deposition of palladium or germanium.

After mounting in a holder, the counter are completely sealed by a teflon spray ($HgI_2$ is corrosive and has a relatively high vapour pressure at room temperature.) The advantages and drawbacks of these two materials are given in Table II.

## The electronics

To demonstrate the possibility of using such detectors, we built a safeguard ratemeter.

The block diagram of the electronics is shown in figure 1-2.

- Detector Biasing : The whole radiameter having to operate with standard 4.5 V batteries, the detector biasing was achieved by an asymmetric static converter. The transformer is spooled on a ferrite coil to reduce the radiant field background. A voltage doubler delivers the 100 V bias required at a total consumption of 3 mA at 4.5 V.

- Amplification : The detector is directly coupled to the FET ($T_2$ on fig. 2) input stage of the preamplifier. The bipolar transistor $T_1$ biases and protects the FET. At the preamplifier output, further amplification is made through the first two stages of an MC 98 18 P integrated circuit. Standard pulses are obtained after triggering the signals at an adjustable lower level. The last two stages of the I.C. are used as a monostable pulser, which signals are used either in the audiofrequency amplifier or in the scaler.

- Scaler : The counting of the pulser is performed by means of two MC 14518 I.C.

- Display : The counting rate is displayed by liquid crystals, the different segments being driven by three MC 14543 I.C., which analyze ~~and store BCP informations from the counters.~~ The liquid crystal device is a.c. biased at 30 Hz by a multivibrator IC MC 9818.

The mesuring cycle, which consists of reading and erasing the memorized informations is monitored by a time base (unijonction oscillator followed by a ring counter).

The total power required is delivered by a standard 4.5 V, whose voltage is continuously checked on the liquid crystals display. The total consumption is around 14 mA, allowing about 100 hours of uninterrupted use. This low power requirement results directly from the choice of a liquid crystal display and the use of C. MOS. I.C.

Other displays have been tested, especially GaAs LED. They are more readable, especially in dark, but the higher power needed (20 times more than for liquid crystal) drastically reduces the battery lifetime.

## Polarization effect in CdTe counters

When chlorine doped CdTe detectors are used, it becomes necessary to eliminate the polarization effect which modifies the counting rate. Two methods have been tested :

- Illumination of the detector by a small GaAs LED. This procedure does not increase the noise level of the counter. The mechanism responsible for the suppression of polarization is related to the saturation of the deep traps by light having exactly (by chance) the right wavelength. The drawback of this method is a reduction in efficiency of the sensor.

- A.c. biasing of the detector. Since the effect od polarization can be greatly attenuated by suppressing for a short period the applied voltage, we fabricated an a. c. detector biasing working at the frequency of the liquid crystal display. The information signal coming out of the time base (fig. 3) is split in two with one part biasing a transistor which suppresses the detector biasing and the other part [illegible] blocking the monostable so as not to count parasitic events due to the detector short circuits.

The overall dimensions of the instrument depend on the display mode used (fig. 4). They can start at the size of a large watch. In case of $HgI_2$ sensor, the low energy detection level is very small for $\gamma$ or X-rays ($\leq$ 5 keV). When CdTe counters are used, the device is sensitive not only to $\gamma$ or X-rays, but also to thermal neutrons through the nuclear reaction $^{113}Cd(n,\gamma)^{114}Cd$ which has a 20.000 b cross section (13,2 % of the cadmium isotopes are of mass 113).

As we pointed out in the beginning, the main objective of this report was to show the present capabilities of these new detectors. Many other applications are possible, especially around the nuclear reactors or in nuclear medecine.

## References

1. Proceed. Intern. Symposium on Cadmium Telluride, a Material for Gamma-ray Detectors, Strasbourg 1971, P. Siffert, A. Cornet Eds.

2. J.P. Ponpon, R. Stuck, P. Siffert, B. Meyer, C. Schwab, IEEE Trans. Nucl. Sci. NS 22 (1975) 182.

3. P. Siffert, A. Cornet, R. Stuck, R. Triboulet, Y. Marfaing, IEEE Trans. Nucl. Sci. NS 22 (1975) 211.

## Figure Captions

Fig. 1 Schematic of the electronic set-up.

Fig. 2 Block diagram of the electronic circuitry.

Fig. 3 A.C. biasing of the detector in case of polarization.

Fig. 4 View of the radiameter with liquid crystals display.

## TABLE I

## ROOM TEMPERATURE OPERATING SEMICONDUCTOR DETECTORS

| | SILICON | CADMIUM TELLURIDE | MERCURIC IODIDE |
|---|---|---|---|
| - Atomic Number | 14 | 48-52 | 53-80 |
| - Bandgap (eV) | 1.12 | 1.50 | 2.10 |
| - Photoelectric absorption coef. for 500 keV $\gamma$-rays (normalized) | 1 | 65 | 250 |
| - Energy per electron hole (eV) | 3.62 | 4.42 | 4.15 |
| - Charge carrier speed (cm/s) ($\mathcal{E} = 10^4$V/cm) | | | |
| electron | $10^7$ | $10^7$ | $10^6$ |
| holes | $10^7$ | $10^6$ | $4.20^4$ |
| **PRESENT CHARACTERISTICS** | | | |
| Maximum thickness (mm) | 5 | 2 | 1 |
| Typical current (nA) | 10-100 | 10 | 0,1 |
| Typical voltage (V) | 100-300 | 100-500 | 20-500 |
| Lower detection energy level (keV) | ≥ 20 | ≥ 15 | ≤ 5 |

## TABLE II

| | ADVANTAGES | DRAWBACKS |
|---|---|---|
| CdTe | Large energy domain (15 keV - 1.5 MeV)<br>Stable material<br>Larger volume | Higher noise level ($\simeq$ 20 keV) |
| $HgI_2$ | - Low noise<br>- Sensitivity to low energy photons ( < 5 keV)<br>- Small energy per electron-hole pair with respect to bandgap | Small energy domain ( < 200 keV)<br>Stability problems if not protected<br>Corrosive material<br>Small volume |

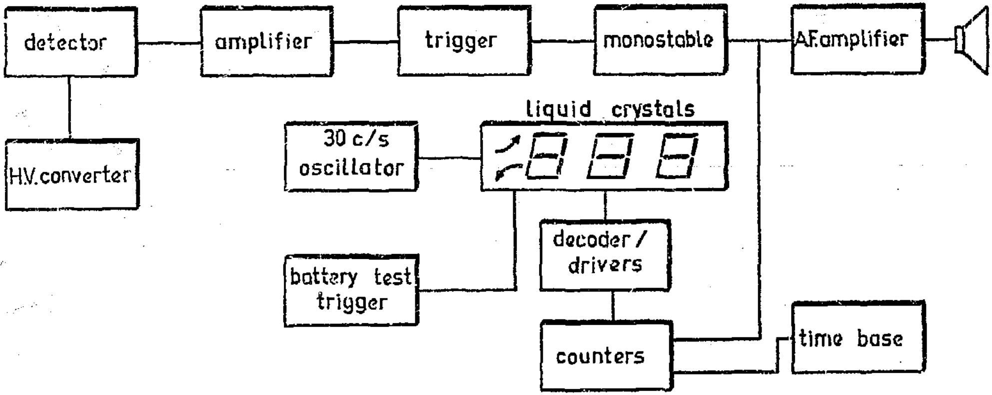
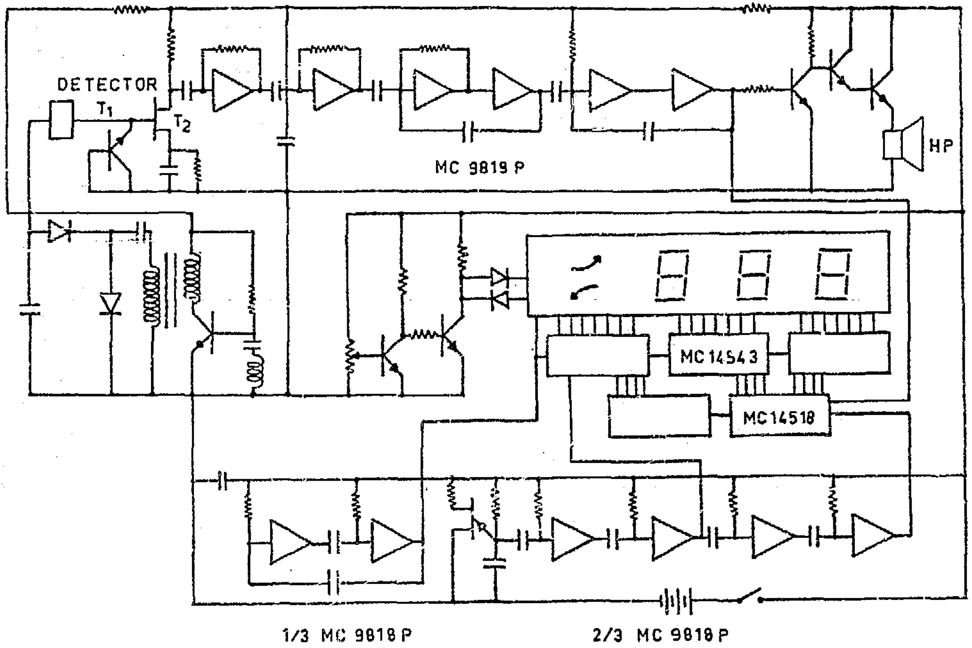

detector
amplifier
trigger
monostable
AF.amplifier
H.V. converter
liquid crystals
30 c/s oscillator
battery test trigger
decoder / drivers
counters
time base

Fig. 1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T1
T2
MC 9819 P
HP
MC 14543
MC 14518
1/3 MC 9818 P
2/3 MC 9818 P

Fig. 2

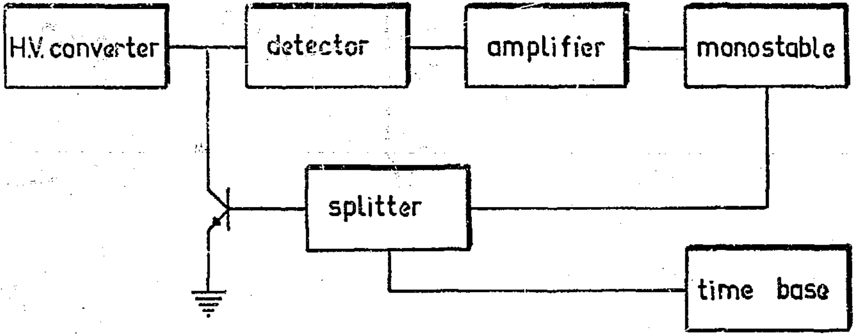
H.V. converter
detector
amplifier
monostable
splitter
time base

Fig. 3

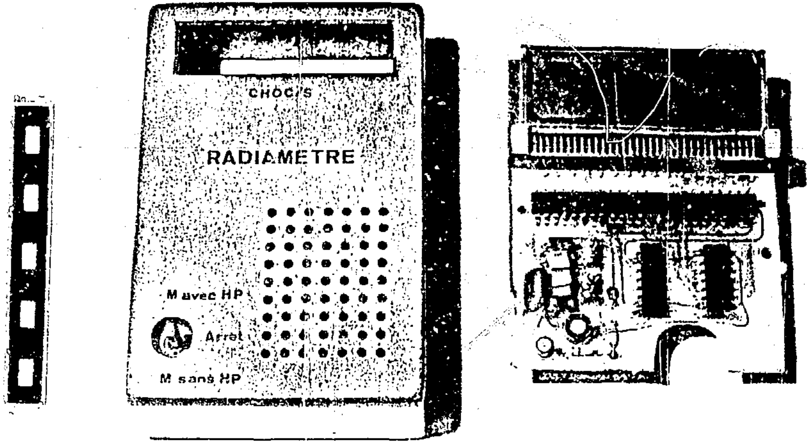

Fig. 4