Detector and Quantifier of Ionizing X-Radiation by Indirect Method

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ABSTRACT. The work presents the development of a device able to detect and quantify ionizing radiations. The transduction principle proposed for the design of the detector consists on using the properties of the fluorescent screens able to respond to the incident radiation with a proportional brightness. Though the method is well-known, it proved necessary to optimize the design of the detectors in order to get a greater efficiency in the relationship radiation / brightness; to that purpose, different models were tried out, varying its geometry and the optoelectronic device. The resultant signal was processed and presented in a visualization system. It is important to highlight that the project is in development and the results we obtained are preliminary. Key Words — X-Rays, Ionizing Radiations, Clinical Engineering.

1. Introduction
The Health Systems present, in general, such an ample range of radiological equipment with different characteristics, that it is necessary to make systematic measurements of the main parameters, the applied kilowatts that provides the penetration [Kw], the milliamps that circulate for the tube [MA] and the time of exposition [sec], in order to avoid the emission of inadequate dose.

The X radiation is an ionizing electromagnetic radiation of high energy. The X-rays are defined like faces of energy of smaller weight (photons) without an electric load that travel in waves of high frequency and at the speed of the light (300.000 Km. / sec.). Among the properties of the X-rays the following are quoted:

• Capacity to cause fluorescence in certain substances.
• They can cause biological changes in the living cells and go through the human body, much more easily when more penetrating they are (depending on the voltage [Kw] and electric current [MA] of the source).
• They are invisible and they cannot be detected by none of the senses
• They travel in straight lines and they can disperse.

In all cases, the interaction of radiation with matter has an ionizing effect, that is to say, the energy of the incident particles is transferred to the atoms (electrically neuter) liberating electrons with kinetic energy proportional to the interaction energy and resulting an atom with positive net load (ionized). The electromagnetic emission resultant from the exchange of energy with orbital electrons is called characteristic X-rays and its energy is peculiar of the atom in question. The photon can be absorbed in the process called Photoelectric Effect.
In light of the above stated it is deduced that all the phenomena of energy exchange between an incident radiation and matter give as a result the ionization of this matter, be it either solid, liquid or gaseous; so that, if we collect the loads liberated in the process we are under conditions not only of detecting this radiation but also of quantifying it. Several methods have been developed to detect ionizing radiations and they are based on the collection of the loads produced during the ionization process: Ionization Chambers, Tubes Geiger-Müller, Proportional Counter and Scintillation Counter (Scintillators) and all and each have specific properties for different radiation types and/or energy [1], [2], [3].

Nowadays intensifier screens (flexible sheets) are commonly used. They are made of a material able to interact with the X-rays better than the film and to transform them into visible light (luminescent material). The emitted light is called luminescence.

Materials can be made luminescent by very diverse stimuli such as Electric Currents, Chemical Reactions and X-rays, like in the intensifier screens.

The “luminescence” phenomenon is similar to that of the emission of the characteristic radiation of the X-rays (it affects the electrons of the external layer). When a luminescent material receives a stimulus, some of the electrons of the internal layers jump to the external layers (energetically superiors) and it will only return to its original layer when it loses energy as a photon. This process entails that, when returning to their situation of stability they liberate the energy absorbed, in photon form, and its wavelength corresponds to that of the spectrum of visible light. Therefore, each luminescent material emits a light of a particular colour. We can speak of two luminescence types according to the interval of time in which the electrons return to their stable situation:

- Fluorescence: While the stimulus on the fluorescent material lasts, the emission of visible light takes place, that is to say, the light lasts a very short time since the atom returns quickly to its stable situation. For example the intensifier screens.
- Phosphorescence: It is the phenomenon of emission of light during and after receiving the stimulus (although the light diminishes in intensity with the pass of time) due to a delay of the electron while returning to its place of stability. That is to say, the screen acts as an amplifier of the non-volatile radiation; and it makes possible to obtain a good radiographic quality using less radiation dose than when using the film without screens. [4], [10], [11]

Due to the high cost and to the impossibility of using the aforementioned detectors, it was thought of developing a device able to detect and to measure the X radiation with a range of acceptable dependability, low cost and technical viability.

2. Materials and methods

The measurements were made using Siemens X-Ray equipment and DINAN 500 equipment, a Light meter TES-1330, generic fluorescent screens sensible to the wavelengths corresponding to the visible spectrum (green or blue light) and a set of photo-diodes mounted on accessories with different designs that make it possible to transform the picked up luminescence into tension.

We used a microcontroller PIC 16F877 which is the main part of the processing and has an integrated analog-to- digital converter of successive approaches with a 10 bits resolution and eight multiplex conversion channels. The converter’s entries are available and can be single-ended, that is to say, tension levels referred to GND.

A memory EPROM was used to increase the capacity of registration of realized measurements. The memory space necessary to store the data will be given by the following factors:

- Maximum quantity of emissions X-Rays tube.
- Maximum sampling frequency.
- Quantity of equipments to be tested.
- The A/D converter resolution.

To provide an interface with the user we added a keyboard and a LCD display of 16 characters. Protocol RS232 will be used for the communication with a PC.
3. Results
Figure 1 shows the proposed measurement system.

Here is a description of the system stages:

A) **X-Rays Source:** It is an X-Ray equipment that will generate the radiation and control the main parameters at the same time. When varying the values of Kw, MA, and time, different radiation levels are obtained. On the other hand it is necessary to regulate the collimator appropriately to assure a radiant field limited and directed towards the device put to the test. In order to improve the radioprotection conditions, an accessory has been designed to minimize the emission of radiation between the ray tube and the device. It consists on a truncated pyramid whose superior base coincides with the collimator and the inferior one with the sensor, it is important to add that it has a peephole with a glass which is used to observe the process and both (walls and glass) are lined with plumb. The source should be placed and adjusted to emit appropriate doses according to security protocols [5].

B) **X-Ray transduction:** For the design of the detector we used an intensifier screen following the aforementioned principles.

C) **Optoelectronic Unit:** For this unit we used a photo-diode with a semi-spherical and flat surface. To optimize the detection of the components we designed accessories with different geometric shapes and different characteristics (mirror, metalized, opaque) so that the luminescence of the screen concentrates on the photo-diode.

D) **Conditioner:** In this stage we used filtrate circuits, amplification circuits and sampling-retention circuits with the purpose of obtaining an appropriate signal for the processing stage. [6]

E) **Signal Processing and Digital Presentation Unit:** The electric signals obtained in the previous block as an answer to the detected light are sent to an analog-to-digital converter included in a microcontroller which is the main processing part. (See Fig.2)
Figure 2. Outline of the processing and display system.

The EPROM memory is used to increase the device capacity. The main advantage of using this type of memories is the simplicity of its implementation on the printed circuit board as with only two pins the bidirectional data transmission is established and with another two pins the clock signal timer is connected. The memory address is configured with three pins and the data writing can be protected with one pin without affecting its reading. The transmission and timer pins are of the open collector type and it is relevant to connect them to pull-up to Vcc resistances.

The keyboard allows us to navigate through the options menu available on the display that also shows the messages from the microcontroller, lets us read stored data and visualize the registered parameter, among other functions.

The microcontroller has a USART module that solves easily the communication with a PC. This function will be useful to transfer the radiation values stored in the device and to analyse them with a calculation sheet. An integrated circuit makes it possible to reach the required tension levels according to norm RS-232. [7], [8].

Initially we practised some tests to analyse the characteristics of the fluorescent screens to be used. Then, we tested their variations according to the received radiation levels.

| Screens | Kv  | mA  | t [sec.] | Intensity [lux] |
|---------|-----|-----|----------|-----------------|
| Green   | 50  | 100 | 0,1      | 10              |
| Blue    | 50  | 100 | 0,1      | 7,2             |
| Green   | 60  | 200 | 0,1      | 13              |
| Blue    | 60  | 200 | 0,1      | 9,6             |

Chart 1: Test of the fluorescent screens
These tasks were carried out using also a light meter in order to determine the magnitude of the intensity of the issued light. The resulting values are shown in Chart 1:

Later on the detectors were tested using a DINAN 500 rays-equipment and the signal conditioning stage was included to obtain the values. The registered data are detailed in Chart 2:

| H [cm.] | Kv    | mA    | t [sec.] | V [volts] | Sensor |
|---------|-------|-------|----------|-----------|--------|
| 100     | -     | -     | -        | 0,08      | Base   |
| 100     | 50    | 100   | 0,1      | 1,71      | To     |
| 100     | 50    | 100   | 0,1      | 1,42      | B      |
| 100     | 50    | 100   | 0,1      | 1,94      | C      |
| 100     | 70    | 200   | 0,1      | 2,57      | To     |
| 100     | 70    | 200   | 0,1      | 2,33      | B      |
| 100     | 70    | 200   | 0,1      | 2,73      | C      |

These values prove the behaviour of each sensor that registers the variations of the preset radiation levels and the correct operation of the sampling-retention systems.

The next stage is the validation of this data by means of tests with equipments that use commercial radiological parameters.

4. Conclusions

The developed methodology and the preliminary results indicate that the device makes possible to determine the issued radiation level by an X-Rays tube.

The field tasks have enabled us to establish measuring protocols and the development of specific accessories.

We work on the correlation of the parameters preset in the consoles with the data obtained by the designed device.

The obtained values will be compared with the ones got by commercial radiological test equipment with the purpose of validating the results.

With this design we hope to produce a compact test tool that allows the measuring of the main radiological parameters at an accessible cost and with an acceptable efficiency.

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