A CONTINUOUS RADON MONITORING SYSTEM BASED ON A SOLID-STATE SILICON DETECTOR

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ABSTRACT

This paper describes the design of a programmable stay-alone continuous radon monitoring system able to detect, count and store the amount of alpha particles with an energy of 5.49 MeV produced by the radioactive decay of environmental radon-222. It is included the electronic circuit design, the software development as well as the user interface and the hardware ensemble of all the system components.

KEYWORDS: radon monitoring, microcontroller, alpha detector.

1. INTRODUCTION

Radon is a natural radioactive gas, resulting from the alpha decay of radium-226, which occurs naturally in all rocks and soils and it is given off at ground level. Therefore, we all breathe it throughout our lives. As it immediately disperses in the air, its concentration is very low. Yet, radon seeps in enclosed spaces like mines, houses, schools, and working places where it accumulates due to inappropriate ventilation systems. Its 3.82 day middle life-time enables all its isotopes formed in building materials, or in the earth at approximately one meter from the surface, to reach indoors. In fact, the most important natural radioactive exposition for humans is the radon inhalation, which represents almost the 50% of the average radiation dose. Nowadays, it is well known that the risk of developing lung cancer rises with the level of radon and the exposition time. International survey efforts have been carried out in several countries in order to establish some indoors radon level charts. The average radon level indoors varies considerably among countries, because of the soil characteristics, building materials, climate, etc. Some reported average radon levels are: UK 20 Bq/m^3, USA is 46 Bq/m^3, Germany 50 Bq/m^3, Finland 123 Bq/m^3, Sweden 108 Bq/m^3, Ireland 60 Bq/m^3, and Czech Republic 140 Bq/m^3 [1].

Radon detection by means of a real-time, portable and remote sensing instrument is a genuine necessity in several research fields such as environmental radon air monitoring [2], volcanic activity monitoring [3], uranium ore deposits or geothermal fields' research [4], and earthquake-radon correlation [5]. Thus, the monitoring system presented in this work aims to fulfill the following requirements for adverse environmental conditions: a) remote system capability, b) low power consumption and c) low sensitivity to temperature variations.

2. SYSTEM DESIGN

The system is composed of two elements: the main hardware electronics and the software implementation necessary to coordinate the overall architecture and to allow the data mining. The characteristics of the system are detailed in the next paragraphs along with its hardware system construction.

2.1. Electronic Design

The electronic diagram shown in Figure 1 represents the radon detection system. The proposed system is built from a Discriminating Industrial Alpha Detector (DIAD). Its operation can be described as follows: when any alpha particle interacts with the surface of the DIAD, an output voltage pulse of 5 V and 300 ns is generated only if the energy of the particle is within a selectable energy window. As the minimum detectable pulse width for a CHMOS 8-bit Microcontroller (μC) 87C51 interruption request is 1500 ns, a pulse-conditioning circuit between the DIAD single channel analyzer (SCA) output pin and the μC INT0 input pin is needed. Thus, a monostable circuit has been configured applying a retriggerable multivibrator 74HC123 in order to generate a 2000 ns pulse. Immediately after the interruption request is recognized, the μC becomes active, increasing the counting. After that, the μC goes to the idle mode operation, so to save power. Moreover, the real-time clock (RTC) 146818A, used as the absolute time base, produces an interrupt request every minute. Until the integrating time is achieved, the counting is stored into two bytes of 8 KB static random access memory (SRAM) 6264LP-10. All counting data are preceded by the main two time parameters, namely, the date and the integrating time. Thus, a reserved memory space is saved daily in order to establish a temporal relationship with the measures to be realized. After the counting is stored, the internal μC counting register is cleared, and the system goes to the idle mode again. Besides, other interruption source is established by the RS-232 drivers/receivers MAX232, when the user establishes communication with a portable computer. In order to maintain a minimum energy consumption, three voltage saving regulators have been applied, considering as an input voltage source a rechargeable battery of 12 VDC/6.5 AH. A CMOS Programmable micropower positive voltage regulator ICL7663S has been implemented in order to supply all the IC's with +5 VDC. Meanwhile, a combination of an ICL7663S and a CMOS voltage converter ICL7662 provides –9 VDC to the DIAD. The overall average system consumption is 27.5 mA at room temperature and it increases to 33.5 mA only during a communication with a PC. The system can operate, at least, 194 hours continuously with the proposed arrangement. In order to increase the energy autonomy of the system, a photovoltaic module of 10 W, MSX-10, connected through a photovoltaic battery charge regulator has been added to the power supply system.

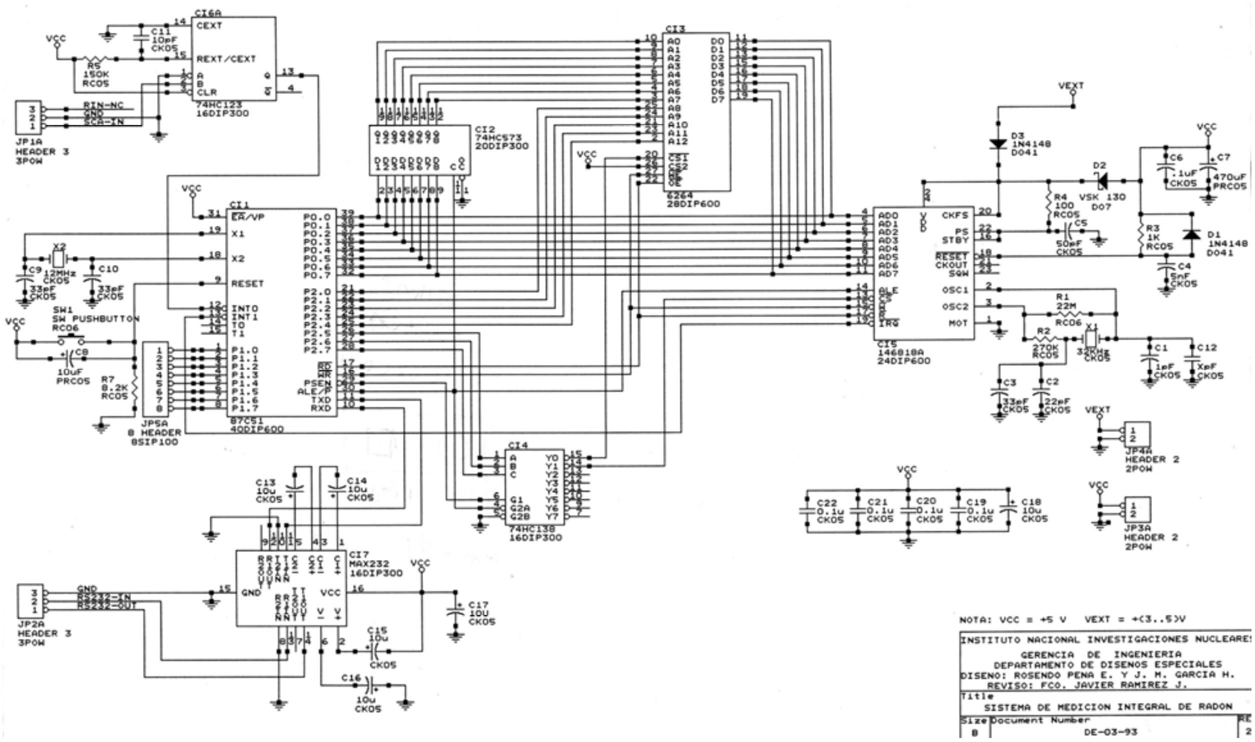

Figure 1. Electric diagram of the continuous monitoring radon system.

2.2. Software implementation

The software implementation includes two fundamental programs. The first one establishes the microprocessor tasks; it has been created in assembler language. The other was coded in C for a PC in order to exploit the information obtained from the system. In both cases several algorithms have been created, e. g. the interruption routine algorithm which allows dating the alpha counting and storing the count in a permanent memory. Once the space memory is surpassed, a circular data array is implemented. The integration time is a parameter that can be modified by the user between 15 and 1440 min. Thus, the memory capacity is able to keep information in a 41 day counting period, where each day is dated. The obtained information is written in a two column format containing the imposed integration time followed by the alpha counts.

Moreover, the system has an identity code able to distinguish it from any other similar system when a communication is requested from a computer or a microprocessor based-system.

2.3. Construction

The system has been conceived as a remote sensing unit, so, it must be able to work alone and in adverse environments. As a consequence, most of the system components are protected against outdoor conditions by a stainless steel sealed tube case, as shown in Figure 2.a. At one of its ends a protected detection radon chamber is located, where the environmental air can reach the semiconductor detector. At the top of the tube there is a sealed connector which allows to supply the voltage from the battery and to establish a serial communication with an external computer. The support battery has been installed in its own sealed case while the photovoltaic module is normally exposed to the environment (see Figure 2.b).

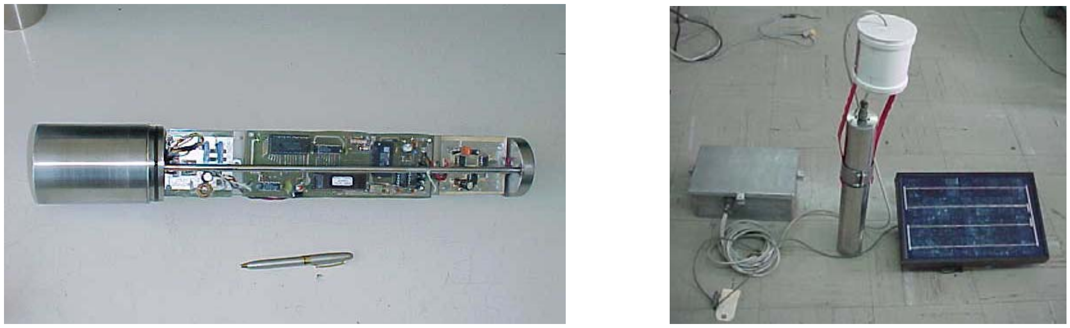

Figure 2. a) The continuous monitoring radon electronic cards and 2.b) the system hardware.

3. RESULTS AND DISCUSSION

The electronic part of the system has been tested by applying sequential pulses to the µC INT0 input pin, to find that the maximum frequency response is 32 kHz. In order to calibrate the behaviour of the whole system, an americium 241 alpha radioactive source was used, provided that the energy level of its emitted alpha particles is close to that of radon. Moreover, the detection system was exposed during several days to a controlled radon chamber; the results are shown in the figure 3 [6].

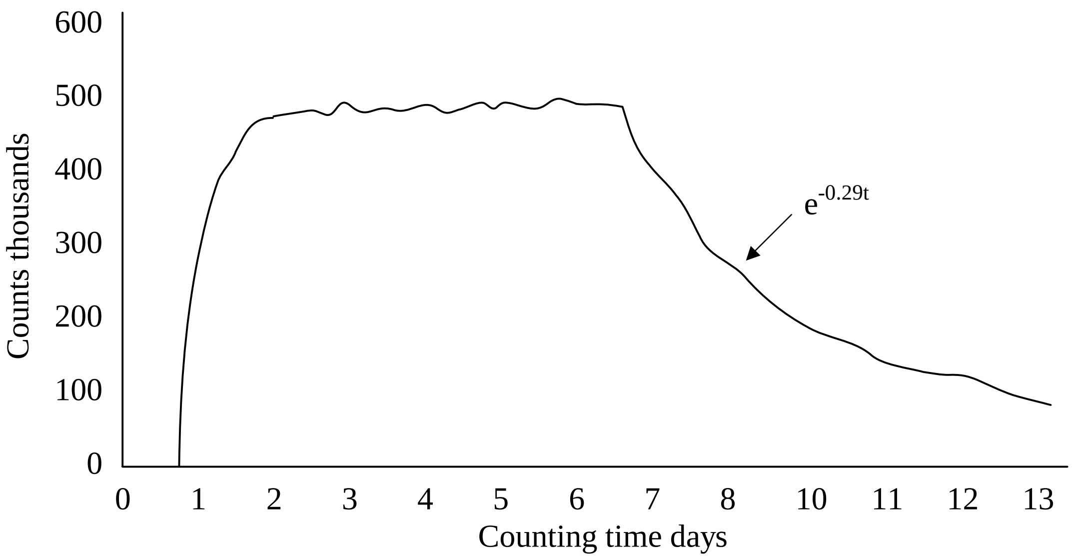

Figure 3. Experimental detection characteristic obtained from controlled radon chamber exposure.

The experimental outcome can be summarized as follows: after the radon concentration reaches equilibrium, the system presents a saturation counting region. After that, an exponential decay in the counting is observed once the system has been isolated from the chamber. The experimental time constant obtained from the data equals 3.44 days. This value is clearly smaller than the expected 3.82 days of the radon half life. The difference can be produced by the not fully hermetic interconnection between the radon chamber and the detector. In order to probe this hypothesis a commercial detector was connected in parallel with the constructed one. Under the same experimental conditions, the time constant obtained from the commercial system reaches 3.225 days. So, the response of the proposed system is higher than the commercial one.

The continuous radon monitoring system has been designed and tested successfully in a uranium chamber under controlled conditions in the laboratory, as well as in working conditions in a normal environment. These tests took place also during several days. Thanks to the proposed design, the system initialisation, operation and exploitation became a simple task.

The applications of the monitoring system could be extended or oriented to the measurement of another sources of alpha nuclear particle emission.

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Electronic engineer, studied at the Superior School of Mechanical and Electric Engineering (ESIME) of the National Polytechnic Institute (IPN) of Mexico in 1976. He got the PH.D. in electronic engineering in 2005 at the Technological Institute of Toluca (ITT).
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He patented the invention of a ¨System to Detect Capacitively the displacement and the Speed in Axial Movements¨. He has teaching experience for more than 15 years imparting different subjects on electronics and more than 20 specialized courses in the nuclear field, including international courses organized by the OIEA.