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Accuracy Improvement of a PIN Photodiode Radon Counter

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Abstract
Radon is a natural, inert, invisible, odorless and chemically inactive radioactive gas emitted from the earth. Because inhaling radon and its radioactive-decay products causes irradiation of lung tissue, prolonged exposure to a high concentration of radon significantly increases the risk of developing cancer. For our experiments, we implemented a radon counter with a PIN photodiode radon-sensor module. This radon counter was calibrated using the radon measuring apparatus RAD7. Its performance was compared with the Safety Siren PRO 3 radon counter.

Keywords: *Radon, PIN Photodiode, radon counter, RAD7, Safety Siren PRO 3*

1. Introduction

Radon is a natural, inert, invisible, odorless, chemically inactive, and radioactive gas emitted by the earth. It is produced by the decay of uranium ore, such as radium, actinium, or thorium. Because it is inert and does not chemically bond to elements, it is released from soil into the atmosphere. Radon is emitted almost everywhere on earth, but some geographical regions have a higher concentration than others do. When radon decays, it releases alpha particles with energy of 5.5 Mega-electrovolts (MeV). Because inhaling radon and its radioactive-decay products causes irradiation of lung tissue, prolonged exposure to a high concentration of radon significantly increases the risk of developing cancer. It has been reported that the U.S. Environmental Protection Agency estimates that exposure to naturally occurring radon leads to 21,000 lung cancer deaths nationwide each year, making radon the nation's primary environmental health threat, second only to cigarette smoking, as a cause of fatal lung cancer.
There are many commercial instruments and techniques available for measuring radon indoors. Most detectors for evaluating indoor radon levels are passive in that they do not require external power. The principal drawback of passive detectors is that they only measure radon concentration at one specific location for a specific period. Because many variables influence radon concentration levels, a single estimate of radon concentration is likely to have a significant error. In [1], highly sensitive, electrostatic collection chambers using Columbia Resin 39 (CR-39) plastic track detectors were developed for measuring low-level radon. In [2], the unique characteristics and the shortcomings of track detectors for neutron and radon dosimetry is described and compared with those of alternative detector systems. In [3], low-cost alpha-particle sensor systems using special Positive Metal-Oxide Semiconductor (PMOS) transistors in a floating n-well were developed for radon and radon-daughter monitoring and dosimetry. In [4], a radon detector employed an electrically charged, pressed, porous metal filter that permitted radon-gas diffusion while blocking ambient light. It readily trapped both attached and unattached Polonium-214 (Po-214) and Polonium 218 (Po-2l8) ions present in gas passing through the filter. The filter was positively charged relative to the unbiased PN junction of a photo-diode detector within a detection chamber. In [5], an alpha particle detector was designed using a commercial silicon photodiode.
For our experiments, we implemented a radon counter with a PIN photodiode radon-sensor module [6]. This radon counter was calibrated using the radon measuring apparatus RAD7. Its performance was compared with the Safety Siren PRO 3 radon counter.

2. Safety Siren PRO3 radon counter

Fig. 1 Safety Siren PRO 3 radon counter

The Safety Siren PRO 3 radon counter shown in Fig.1 was used for experimental studies in this paper. The numeric LED display shows the level of radon gas in Pico Curies per liter (pCi/L). The display range is 0.0 to 999.9. The Safety Siren Pro Series 3 Radon counter's display is designed to notify the user of the level of radon gas on either a short-term or long-term basis, and is updated every hour if there is a change in the level of radon gas. The display for the short-term reading is an average of the levels of radon gas over the past seven days. The short-term reading allows the user to monitor short-term fluctuations in the home and provide a better feel for problems relating to seasonal and weather related variations in the radon levels. A green LED next to the letter "S" indicates this reading. When the short-term measurement reaches 4 pCi/L or greater, for 30 consecutive days or more, the audible alarm will sound.

3. PIN photodiode radon counter

A commercial PIN photodiode can be used to detect radiation, and particularly, alpha particles. It is low cost, has good quantum efficiency, and good energy resolution. It can also work with a low bias voltage. A PIN photodiode is more widely used than a conventional photomultiplier tube (PMT) because it requires less biasing to operate and it is very compact. The Mega 2560 is a microcontroller board based on the Atmega 2560. It has 54 digital input/output pins (of which 15 can be used as Pulse Width Modulation (PWM) outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB port, a power jack, an in-circuit serial programming (ICSP) header, and a reset button. It contains everything needed to support the microcontroller; it just needs to be connected to a computer with a USB cable or powered with an AC-to-DC adapter or battery. The Mega 2560 board is compatible with most shields designed for the Uno and the older Duemilanove and Diecimila boards. In our experiments, we used a radon counter assembled from very low-cost consumer electronics. The circuit designs for the power, high voltage generator, LCD, switch, LED, buzzer, microprocessor control unit (MCU), and sensor circuit were made. Using these circuit elements, we developed the PIN photodiode radon-counter printed circuit board (PCB) layout and then assembled the PIN photodiode radon counter shown in Fig. 2 [6].

Fig. 2 Implemented PIN photodiode radon counter

4. Radon measuring apparatus RAD7

The RAD7 is a highly versatile instrument that can form the basis of a comprehensive radon measurement system. It may be used in many different modes for different purposes. The RAD7 radon monitor apparatus uses an air pump and a solid state alpha detector which consists of a semiconductor material that converts alpha radiation directly to an electrical signal. It has desiccant ($CaSO_4$) tubes and inlet filters (pore size 1 μm) that block fine dust particles and radon daughters from entering the radon test chamber. The RAD7's internal sample cell is a 0.7 litter hemisphere, coated on the inside with an electrical conductor. The center of the hemisphere is occupied by a silicon alpha detector. One important benefit of solid state devices is ruggedness. Another advantage is the ability to immediately differentiate radon from thoron by the energy of the alpha particle released. The RAD7 has also the ability to tell the difference between the new radon daughters and the old radon daughters left from previous tests. The equipment is portable and battery operated, and the measurement is fast. Fig. 3 shows the radon measurement system RAD7.

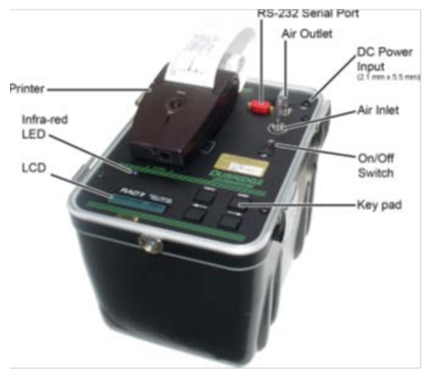

Fig. 3 Radon measuring apparatus RAD7

5. Experimental Results

The methyl methacrylate box was made for radon concentration calibration as shown in Fig. 4. The calibration experiment was done for 72 hours for varied concentration of radon gas. Using RAD7, the measured radon counts per hour of the Siren Pro 3 radon counters (siren1, siren2) and the implemented PIN photodiode radon counters (PIN2, PIN4) could be calibrated as shown in Fig. 5. Fig. 5 shows the linear regression analysis for 12 hours data average. Fig. 6, Fig.7, and Fig. 8 show those for 24, 36, 48 hours data average, respectively. The root mean square error (RMSE) and R^2 are summarized in Fig. 9.

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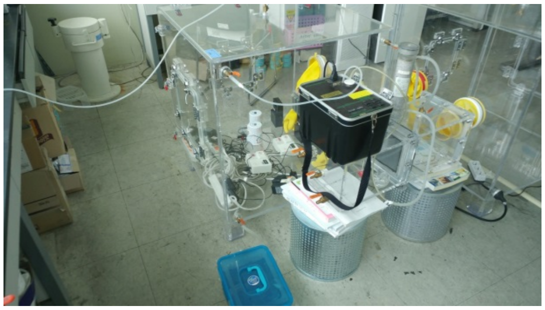
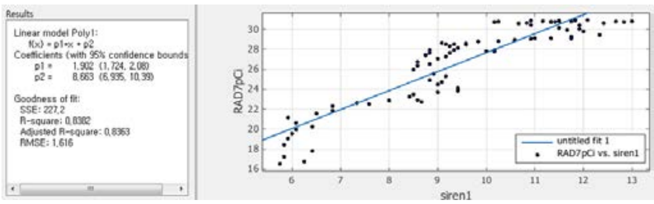


Fig. 4.Experimental set-up for radon calibration



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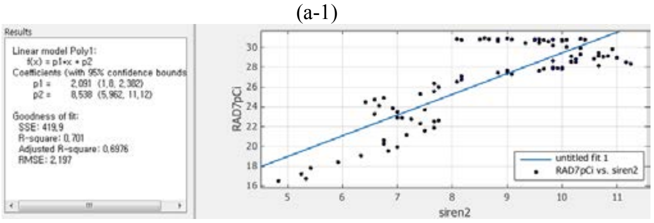

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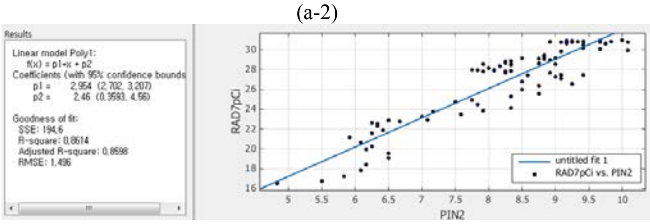

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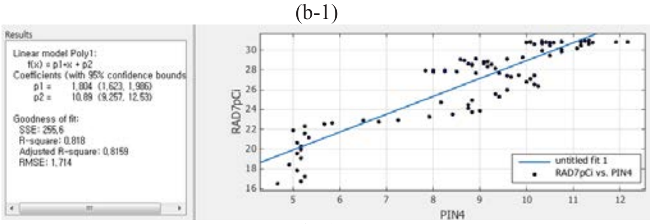
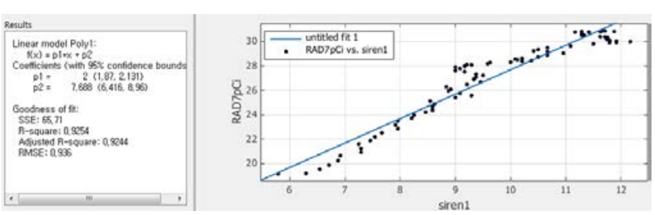


(b-2)

(x-axis : counts/hour, y-axis : pCi/L)

Fig. 5. Linear regression analysis for 12 hours data average



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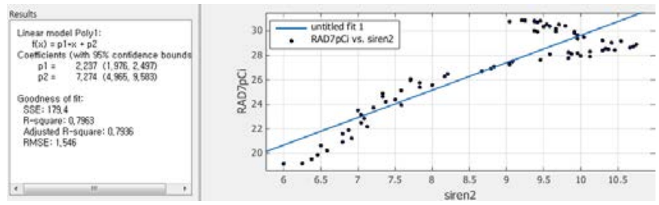

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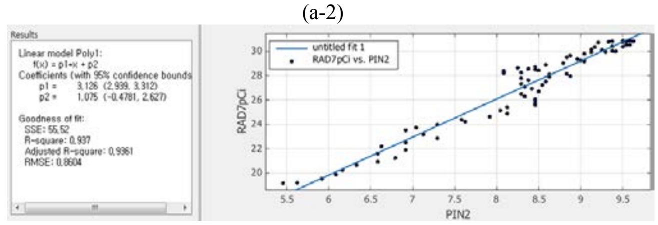

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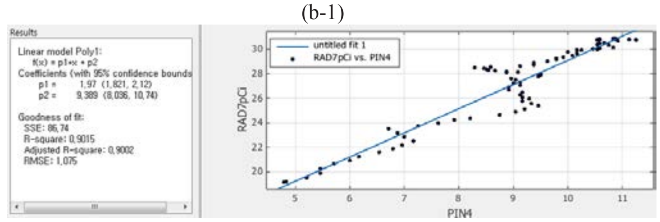
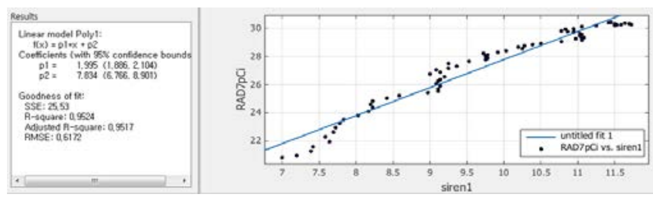


(b-2)

(x-axis : counts/hour, y-axis : pCi/L)

Fig. 6. Linear regression analysis for 24 hours data average



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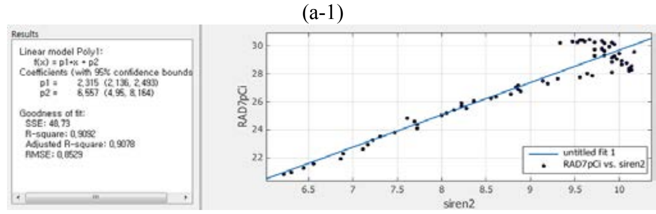

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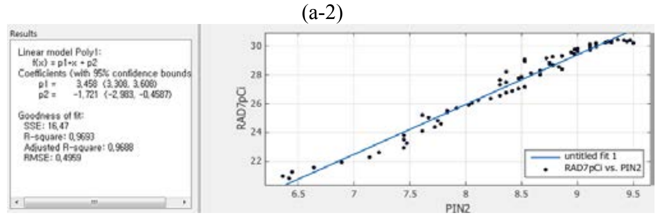

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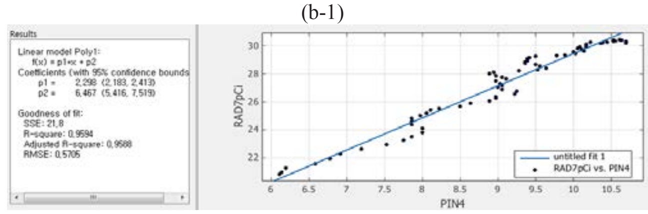
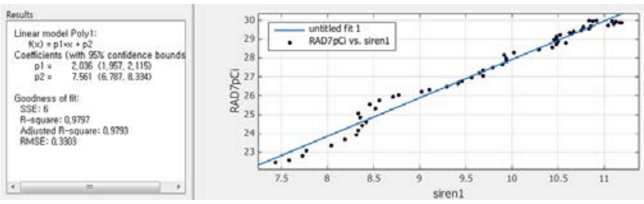


(b-2)

(x-axis : counts/hour, y-axis : pCi/L)

Fig. 7. Linear regression analysis for 36 hours data average



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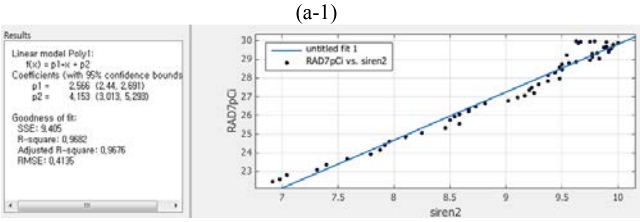

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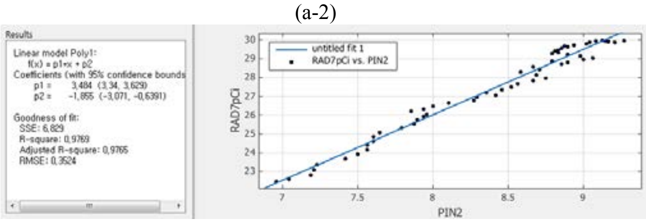

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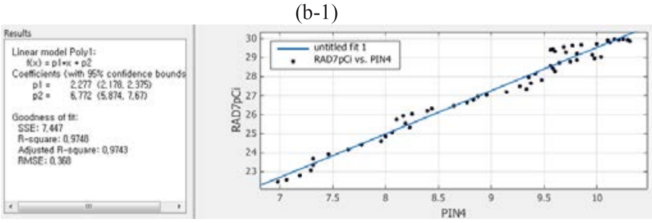
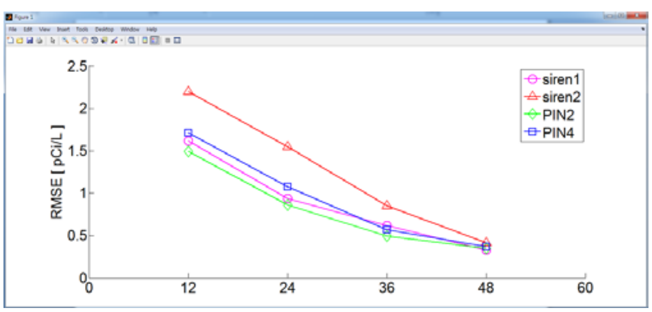


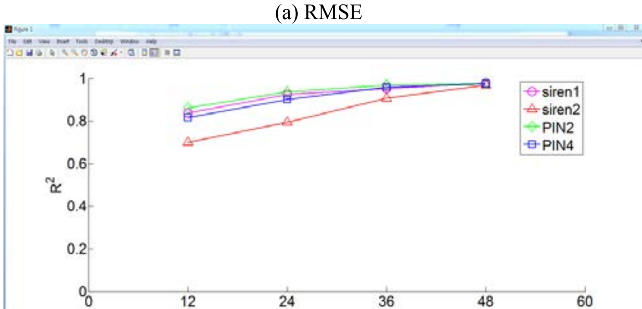
(b-2)

(x-axis : counts/hour, y-axis : pCi/L)

Fig. 8. Linear regression analysis for 48 hours data average



(a) RMSE



(b) R^2

Fig. 9. RMSE and R^2 for 12, 24, 36, 48 hours data average

We can see from Fig. 9 that the longer the measured data are averaged, the smaller the RMSEs become and the larger the R^2 become. This means that the measurement accuracy will be improved if the measured data are averaged for a long time. But, it is effective for a constant radon concentration level.

6. Conclusions

In this paper, we implemented a radon counter with a PIN photodiode radon-sensor module. This radon counter was calibrated using the radon measuring apparatus RAD7. The calibration experiment was done for 72 hours for varied concentration of radon gas. Using RAD7, the measured radon counts per hour of the Siren Pro 3 radon counters (siren1, siren2) and the implemented PIN photodiode radon counters (PIN2, PIN4) could be calibrated. Some linear regression analysis techniques were done for 12, 24, 36, 48 hours data average, respectively. We found that the longer the measured data were averaged, the smaller the RMSEs became and the larger the R^2 became. This means that the measurement accuracy will be improved if the measured data are averaged for a long time.

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