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Author(s): R. D. Bolton
G. J. Arnone
J. P. Johnson

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HOME RADON MONITOR MODELED AFTER THE COMMON SMOKE DETECTOR

R.D. Bolton, J.P. Johnson, G.J. Arnone, Los Alamos National Laboratory

ABSTRACT

The EPA has declared that five million or so of the nation's 80 million homes may have indoor radon levels that pose an unacceptably high risk of lung cancer to occupants. They estimate that four times as many people die from radon-induced lung cancers as from fires in the home. Therefore the EPA has recommended that all homes be tested and that action be taken to reduce the radon concentration in homes that test above the 4 pCi/L level. The push to have homeowners voluntarily test for elevated radon levels has been only marginally successful. A reliable, inexpensive, and accurate in-home radon monitor designed along the same general lines as a home smoke detector might overcome much of the public reluctance to test homes for radon. Such a Home Radon Monitor (HRM) is under development at Los Alamos National Laboratory. To be acceptable to the public, HRMs should have the following characteristics in common with smoke detectors: low cost, small size, ease of installation and use, low maintenance, and high performance. Recent advances in Long-Range Alpha Detection technology are being used in the design of a HRM that should meet or exceed all these characteristics. A proof-of-principle HRM detector prototype has been constructed and results from tests of this prototype will be presented.

INTRODUCTION

The Surgeon General has warned that radon is the second leading cause of lung cancer (1). Radon is estimated to cause between 7,000 and 30,000 lung cancer deaths in the United States each year. Between 1,000 to 4,500 of these deaths could be avoided if the five million homes with elevated radon levels could be identified and mitigated to levels below the 4 pCi/L action level recommended by the EPA (2). For example, in New Mexico, it is estimated that about 8 - 10% of the state's 632,000 homes have been tested with about 25% showing radon levels above the 4 pCi/L level. The average cost for short-term testing (2 to 90 days) is about \$150 and for long-term testing (longer than 90 days) the average is about \$35 per home (3). Long-term tests generally provide a better measurement of the year-round radon exposure from living in a particular house and represent the best measurement method on which to base remediation decisions, especially for homes with radon concentrations near the action level. The average cost per home to mitigate high radon levels is estimated to be about \$1,200 so the total remediation cost to US homeowners and landlords could reach as high as \$6 billion. With such large expenditures on the part of the home owning public being recommended by the EPA, it is important that the decision to mitigate be based on the most reliable and accurate measurements available.

A reliable, inexpensive, and accurate in-home radon monitor designed along the same general lines as a home smoke detector might overcome much of the public reluctance to testing for high radon levels. This detector, the Home Radon Monitor (HRM), would provide radon concentration level measurements at intervals of one hour or less. These measurements would be stored in onboard nonvolatile memory so that the integrated long term radon exposure could be extracted, compared to a threshold exposure level, and an alarm activated if the threshold was exceeded. The radon concentration history would be maintained for at least one year and could be read through a communications port for detailed analysis of exposure patterns. To be acceptable to the public, such a detector would need to have the following characteristics in common with smoke detectors:

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|-------------------------|---|
| a. Low cost | HRMs should retail for less than \$50 each. |
| b. Small size | HRMs should be no bigger than a wall clock. |
| c. Ease of installation | HRMs should hang on the wall like smoke detectors. |
| d. Low maintenance | HRMs should require at most a yearly battery replacement. |
| e. Ease of use | HRMs should have a high radon alert light or audible alarm. |
| f. High performance | HRMs need high accuracy and stability to preclude false alarms. |

Recent advances in Long-Range Alpha Detection technology (4), under development at Los Alamos National Laboratory, are being used in the design of a HRM prototype that should meet or exceed all the characteristics listed above. A proof-of-principle HRM prototype has been built in order to address the size, maintenance, and performance objectives. In order to provide a significant improvement over existing radon measurement devices, this proof-of-principle prototype should have an operating range of at least 0.1 to 100 pCi/L and a one hour measurement accuracy of ± 0.1 pCi/L at the remediation action level of 4 pCi/L recommended by the EPA.

LONG-RANGE ALPHA DETECTION TECHNOLOGY

Monitors based on Long-Range Alpha Detection technology (LRADs) measure alpha contamination by detecting the ionization that alpha particles create in air (5). The energy lost by an alpha particle in ionizing an air molecule is approximately 35 eV, so a typical 5.5-MeV alpha decay from ^{222}Rn will produce approximately 157,000 ions. Each ionized electron will quickly attach to another air molecule creating an ion pair consisting of two charged molecules. These ion pairs can be transported to an electrode where the current produced can be measured. Airflow LRADs use air currents to transport ions to the collection electrode. Detectors of this type are useful for monitoring irregularly shaped or metal objects (6). Electrostatic LRADs use an electric field to attract ions onto the electrode. Detectors of this type have been successfully used for monitoring flat surfaces such as concrete walls and floors or for soil surface contamination measurements (7). Measurement of alpha decay rates can be made in two distinct modes. If the alpha decay rate is low enough to preclude pileup, current pulses produced by individual alpha decays can be counted. This is called the 'single event' measurement mode. If the alpha decay rate is too high to resolve individual current pulses, the integrated current at the ion collection electrode is measured. This is called the 'integrated current' mode. LRADs are unique in that the ionization produced from alpha decays in air are measured directly, without the gas gain, special gases, thin windows or other characteristics typical of ionization detectors.

In order to measure radon gas, air samples are drawn into a detection volume through electrostatic and particulate filters via fans or through diffusion. The electrostatic filter prevents the 10^7 ions/cm³ that are generally present in air from entering the detection volume. The particulate filter insures that radon progeny attached to airborne particles do not enter into and decay in the detection volume, creating ions that would bias the measurement. Ions produced and collected within a detection volume can be attributed to one of the following sources:

Material Contamination: The material from which an LRAD is constructed will contain some alpha contamination. When contamination located on the inside surface of the detection volume decays, ions will be produced and the measured current will increase. The background signal that can be attributed to material contamination is typically less than 0.02 femtoamperes (fA) of integrated current (8) or 0.05 counts/minute per liter of detector volume.

Penetrating Radiation: External sources of penetrating radiation, such as cosmic rays, will produce ionization that will add to the overall current measured. However, a minimum ionizing cosmic ray will only produce approximately 1000 ion pairs per liter of detection volume. Therefore, the integrated current due to cosmic rays is less than 0.1 fA per liter of detector volume. Penetrating radiation will not produce large enough current pulses to contribute to the single-event count rate.

Radon Gas: Because radon is a noble gas it is unaffected by particulate or electrostatic filtering and will enter into the detection volume. Some radon will decay and produce ionization in this volume. The ionization produced by these decays is proportional to the concentration of radon. A radon concentration of 1 pCi/L will produce from 1 to 2 fA of integrated current, depending on detector design and geometry, and 2.2 counts/minute per liter of detector volume.

Radon Progeny: Radon progeny from radon decays inside the detector can plate out on inside surfaces or be swept out of the detector by the airflow. In airflow LRADs most of the progeny are swept out of the detector while in electrostatic LRADs most of the progeny become attached to the inside walls. In-growth from ^{222}Rn daughters reaches equilibrium in about three hours. Because radon daughters ^{218}Po and ^{214}Po are also alpha emitters, electrostatic LRADs at equilibrium will see three alphas for each ^{222}Rn atom that decays within the detection volume.

HOME RADON MONITOR PROTOTYPE

A HRM prototype detector has been constructed from a set of nesting stainless steel camping pans. The simplicity of design and construction inherent in LRAD-technology-based detectors is readily seen in the HRM schematic diagram and photograph shown in Fig. 1. Sample air enters the 1.5-L detection volume via diffusion through an electrostatic/particulate filter (9) attached to the lid. Filtering is required to prevent radon progeny attached to particulates, such as dust motes, cigarette smoke, or automobile exhaust, from entering into and possibly decaying in the detection volume. The HV pin is held at high voltage (typically 300 VDC) relative to the outer pan. The Teflon standoffs are designed to minimize leakage currents between the inner and outer pans and between the inner pan and the high voltage pin. A current path exists from the inner pan to the outer pan through the signal BNC connector and an electrometer. An electrostatic field of about 40 V/cm exists within the detection volume. Radon gas decaying within this volume will produce ions which are attracted to the HV pin, the lid, and the inner pan. The charge that collects on the inner pan is grounded to the outer pan through the electrometer. The current pulses produced by collecting the ions from individual alpha decays can be counted or the total integrated current measured.

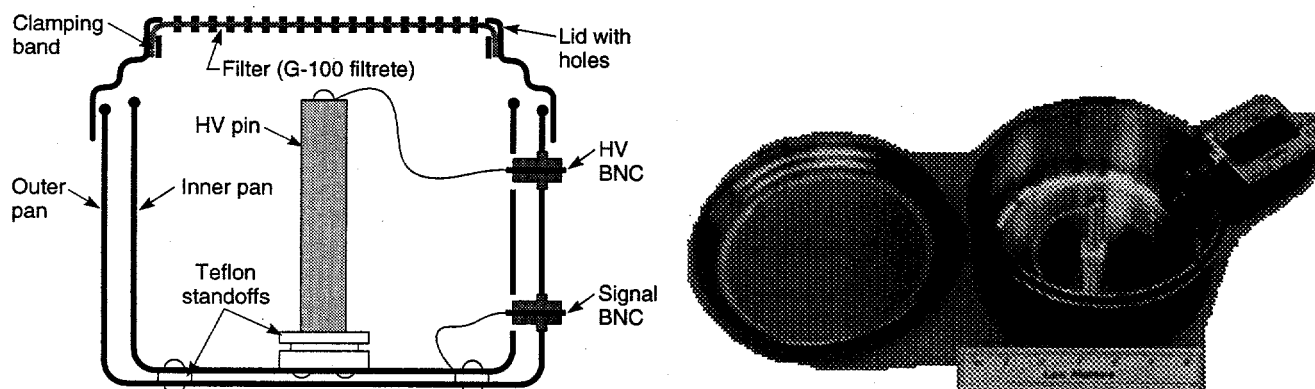


Fig. 1: HRM prototype detector schematic diagram and photograph.

The current generated in an LRAD-technology-based detector from the ionization produced by 1 pCi of radon gas is less than 1 fA. Measurement of such small currents requires a very sensitive electrometer coupled to a detector designed and constructed to eliminate leakage currents. Fig. 2 shows a block diagram of an electrometer specifically designed for LRADs. The current to voltage input stage, A1, of this electrometer uses an ultra-low input current operational amplifier in the standard current to voltage configuration. This amplifier maintains the "-" input at the same potential as the "+" input by means of the closed loop feedback action. Because the "+" input is tied to ground or zero voltage, the "-" input is forced to this same potential and functions as a virtual ground. The current flowing into this stage, I_{in} , flows through the feedback resistor, R_f , which produces an output voltage, E_{out} , equal to $-(I_{in} \cdot R_f)$, therefore for an input current of 1 fA, and an R_f of 100 G Ω , E_{out} would be -100 μV . The input conversion gain is selectable providing -100 μV out for either 1 fA or 10 fA input current. The current to voltage input stage, A1, is followed by a gain stage, A2. This stage provides a buffered output and has a selectable gain of 1 or 10. A1 also drives A3, which provides an integrated version of the signal. The time constant of this integrator is selectable for either 5 or 10 seconds. The electrometer includes a gain

potentiometer for calibration and an offset potentiometer for nulling the circuit. The circuit is very low power and can operate for several years on a set of batteries.

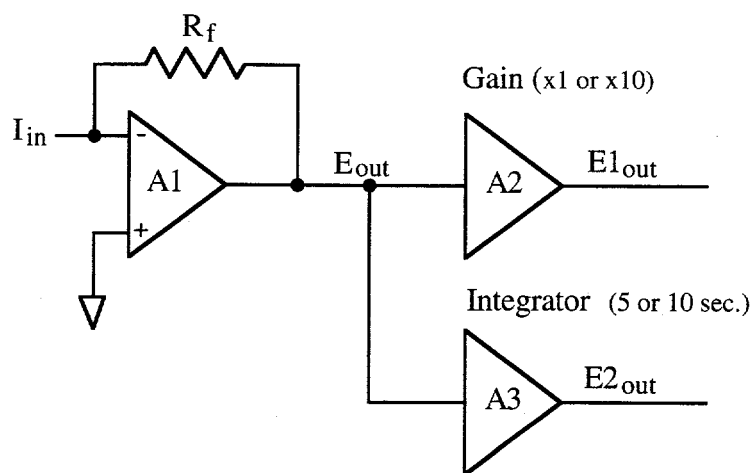


Fig. 2: LRAD-specific electrometer block diagram.

The conversion of femtoampere currents seems relatively straight forward, but there are several effects that can cause errors in the measurement. First, leakage currents at the critical node, the "-" amplifier input, must be kept extremely low if one is trying to resolve femtoampere currents. Also the amplifier's bias current, i.e. the current that flows into the amplifier's inputs, must be very low. Although bias current errors can be canceled out by providing an offset adjustment, bias currents vary with temperature. There are other errors, such as the temperature coefficient of resistance and the voltage coefficient of resistance, which cause the conversion gain to change as a function of temperature or voltage. Cancellation techniques have been incorporated in the design of this electrometer to minimize these effects.

The HRM prototype detector was tested using sources of ^{222}Rn and ^{220}Rn gas constructed by enclosing naturally occurring uranium and thorium ores in bottles. Gas from these bottles was injected into the HRM prototype detector to study speed of response, radon daughter in-growth, and 'single event' pileup. Data acquisition and analysis were done using a personal computer (10). Electrometer outputs were acquired at 3 to 5 readings/second, and the results were displayed on the computer screen as a strip chart and recorded to disk. The raw data were averaged into 1-minute bins and, along with the 'single event' count, the results were displayed and recorded to disk for later analysis.

RESULTS

The current output of the HRM prototype detector operating in a 1 pCi/L radon environment over a typical 1 minute time interval is shown in Fig. 3. The current pulses at time 20 and 40 seconds are due to ions from individual alpha decays. The average integrated charge per 'single event' from the 5.5-MeV decays of ^{222}Rn in the HRM prototype detector is about 2.4×10^{-14} Coulombs. This value corresponds to an ion collection efficiency of 95%. In a 40-V/cm electrostatic field, all the ions from a single alpha decay are collected within a 3-second time interval. These 'single event' current pulses can be easily distinguished from the background current so long as the frequency of decays is low enough to preclude significant pile-up. For the HRM prototype detector 'single event' pile-up starts to significantly affect radon level measurement precision at about the 15 pCi/L level.

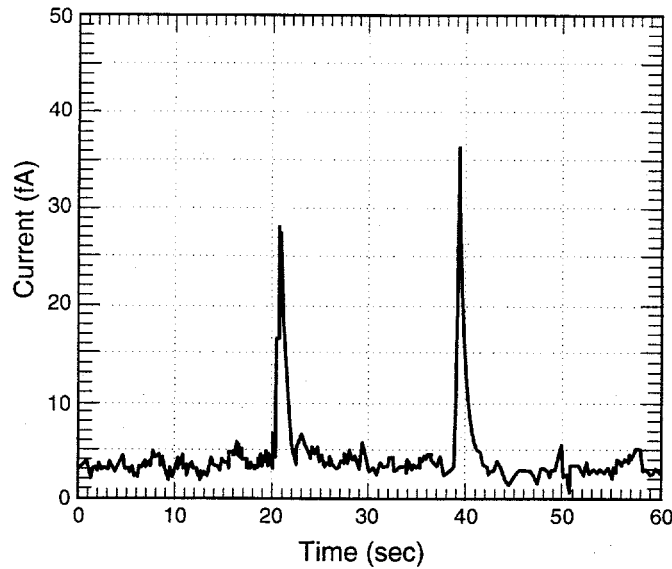


Fig. 3: HRM prototype output showing 'single event' current pulses from individual alpha decays.

Several LRAD prototype detectors have been calibrated in the Radon/Radon Daughter Environmental Chamber operated by RUST Geotech at the DOE's Grand Junction Projects Office in Colorado (11). These detectors were operated in the 'integrated current' mode in a variety of configurations. Fig. 4 shows detector response to radon concentrations ranging from 0.06 to 825 pCi/L. For each detector at each point, a 1-hr data set was taken after radioactive equilibrium was reached. The arithmetic means of these 1-hr data sets, minus a constant background due to leakage currents and cosmic rays, are plotted against the mean radon concentration as determined by RUST Geotech personnel. As can be seen from this plot, LRADs operating in 'integrated current' mode respond linearly, with R^2 s of 0.999 or better, over the entire 4-decade radon concentration test range.

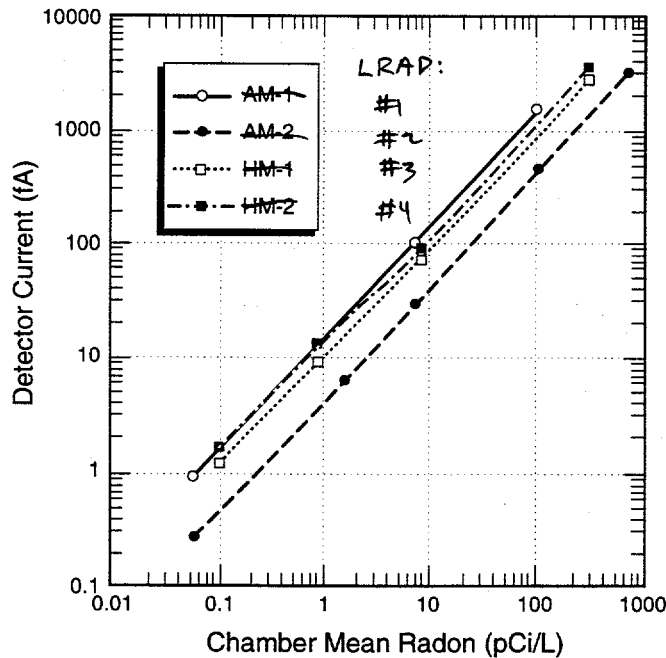


Fig. 4: ^{222}Rn response of LRADs when operated in integrated current mode.

By combining the 'single event' counting mode with the 'integrated current' mode the HRM prototype detector spans an operating range from zero to 800 pCi/L or higher. At the low end precision is limited by 'single event' counting statistics. For the 1.5-L HRM prototype detector this leads to a 1 hour measurement precision of 0.1 pCi/L at a radon concentration of 4 pCi/L, assuming material contamination of 0.05 counts/minute and that half of the ^{218}Po and ^{214}Po radon daughters will decay into the detection volume instead of into the detector walls. A larger detection volume would improve measurement precision at the expense of lowering the changeover point from the 'single event' counting mode to the 'integrated current' mode.

Long term stability of an LRAD-technology based HRM operating in 'single event' mode is assured due to the digital nature of the measurement. Calibration in the 'single event' mode is similarly simplified. There is a large detection region, from about 1 to 15 pCi/L, where the 'single event' and 'integrated current' measurement modes overlap. Calibration of the detector in the 'integrated current' mode can be tied to readings obtained from 'single event' mode while operating in this overlap region. Because LRADs collect the air ionization from alpha decays directly without relying on gas amplification of the total charge, a major source of long term drifts in the calibration of the detector in 'integrated current' mode is removed.

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