FIELD COMPARISON OF COMMERCIALLY AVAILABLE SHORT-TERM RADON DETECTORS

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Abstract—**We performed a comparison of commercially available short-term radon detectors in order to determine the accuracy and precision of the detectors under actual field conditions. We exposed fifteen radon detectors, under field conditions, from each of six companies to a reference radon concentration. Five of the six companies tested did not pass the U.S. Environmental Protection Agency's previously established accuracy guideline (all individual relative errors ≤ 25%) and four of the six companies failed the EPA's precision guideline [coefficient of variation ≤ 10% at 150 Bq m^{-3} (4 pCi L^{-1})]. The findings suggest that the performances of commercially available radon detectors exposed under actual field conditions may not be as accurate or precise as those detectors available prior to the close of the EPA's National Radon Proficiency Program in 1998. It is unknown if this one-time "snap shot" represents the overall reliability of the accuracy and precision of commercially available radon detectors. Nonetheless, the findings suggest that additional double-blind testing of commercially available radon detectors under actual field conditions is warranted.**

Health Phys. 91(3):221–226; 2006

Key words: ^{222}Rn; radon; public information; charcoal canisters

INTRODUCTION

THE AVERAGE individual in the U.S. receives more radiation dose from exposure to indoor radon decay products (radon) than from any other source of natural or man-made radiation (NCRP 1988). The United States Environmental Protection Agency (U.S. EPA) estimates that approximately 21,000 radon-related lung cancer deaths occur each year in the U.S. (U.S. EPA 2003), making it one of the most significant public health risks in the U.S. (Johnson 2000). The U.S. Surgeon General, as well as the EPA, advocated that all homes be tested for radon (U.S. EPA 2004). A small percentage of homeowners follow the suggestion resulting in hundreds of thousands of homes tested for radon each year in the U.S. (Budd and Jalbert 2004).

The EPA's publication, "A Citizen's Guide to Radon: The Guide to Protecting Yourself and Your Family From Radon," (U.S. EPA 2004) recommends performing a short-term radon test in the lowest lived-in level of the home. The Citizen's Guide goes on to state that if the initial reported radon result is 150 Bq m^{-3} (4 pCi L^{-1}) or higher and quick results are needed, homeowners should take a second short-term test. The Citizen's Guide urges homeowners to consider taking steps to reduce the radon concentrations in their home if the average of the first and second tests is 150 Bq m^{-3} or higher.

Because of the widespread recognition in the mid-1980's of the potential health threat posed by residential radon exposure, the EPA established the Radon Measurement Proficiency Program (EPA-RMP) in 1986 to assist consumers in identifying organizations capable of providing reliable radon measurement analysis services. In fact, the EPA noted in their 1995 Radon Proficiency Handbook (U.S. EPA 1995), "because homeowners often decide whether action is required to reduce their home's radon concentrations based solely on these two measurements, it is crucial that the initial and follow-up screening radon measurements produce accurate and precise results." The EPA-RMP was a voluntary quality assurance program with the ambitious goals of promoting standardized measurement procedures and the further establishment of quality assurance programs throughout the radon detector industry. Once the EPA-RMP was established, several states required companies selling detectors to successfully pass the EPA's proficiency testing. A detector was considered proficient by the EPA if it produced a result within ± 25% of the chamber's radon concentration.

The EPA ended proficiency measurements in 1998 with the termination of the overall program that was then called the National Radon Proficiency Program (NRPP). Several years after the EPA's proficiency program ended, the EPA offered a one-time acknowledgment to two non-federal NRPPs, the National Radon Safety

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(*Manuscript accepted* 16 *January* 2006)

0017-9078/06/0

Board (NRSB) and the National Environmental Health Association's National Radon Proficiency Program (NEHA-NRPP). This official acknowledgement extended from 30 March 2001 to 31 December 2002. The EPA continues to encourage states, the radon industry, and consumers to work together to identify elements that would improve non-federal radon proficiency programs and to adopt these elements as standards of practice (U.S. EPA 2000). However, neither the NRSB nor the NEHA-NRPP have performed routine reliability checks on commercially available radon detectors. The NEHA-NRPP has limited device testing to single-blind tests every two years. During single-blind testing, the vendors know they are being tested, but are blinded to the reference radon value. However, the NEHA-NRPP has not systematically performed blind testing of commercially available radon detectors. Nor have tests been performed under varying field conditions. The NRSB states, "to assure consumers and the public that radon measurement devices are accurate and reliable, they have created a panel for device evaluation and approval" (http://www.nrsb.org/index.html). Yet, the NRSB does not oversee a testing program for commercially available radon detectors. On 3 November 2005, the National Environmental Health Association (NEHA) and the American Association of Radon Scientist and Technologists, Inc. (AARST) issued a joint statement announcing both that AARST had purchased the stock of Price Consulting, Inc., the entity which has been administering the NEHA-NRPP and that the NEHA-NRPP will continue to operate as it has in the past. The announcement also stated that "NEHA and AARST are both committed to building a stronger proficiency program" and that "the two associations are currently exploring how they can take this already excellent program and improve it even further" (AARST 2005).

As a matter of record, the non-federal NRPPs have adhered to the previous EPA guidance that requires that the individual relative errors (IREs) of the measurements of all detectors exposed to known radon concentrations should be less than or equal to 25% (U.S. EPA 2000). Prior to 1992, the EPA calculated detector accuracy by exposing several detectors to known radon concentrations and requiring that the mean of the absolute relative error (MARE) be less than or equal to 25% (Field and Kross 1990). Although lack of precision was not a criterion used for rejection of proficiency testing, the U.S. EPA precision guidelines state that collocated detectors should produce a coefficient of variation less than or equal to 10% at 150 Bq m^{-3} (U.S. EPA 1992).

This study follows up on a similar comparison of commercially available detectors (Field and Kross 1990) that found that detectors from companies that had already passed EPA-RMP testing had better precision and accuracy than those detectors awaiting proficiency testing. Studies examining the accuracy and precision of commercially available short-term radon detectors under actual residential conditions are almost nonexistent. The primary objective of this study is to assess the accuracy and precision of several commercially available radon detectors in a residential setting.

METHODS

Study site

The basement of a 100-y-old farmhouse in rural southeast Iowa was chosen as the exposure site. The house was chosen as the exposure site for several reasons including close proximity to the University of Iowa campus, known elevated radon gas concentrations, a large basement with unobstructed air flow over the exposure area, and typical Iowa rural construction (poured concrete floor with block walls).

Radon detectors

The radon detectors from six companies were chosen to represent the major companies either commercially available or distributed by local health departments in the upper Midwest (Table 1). Detectors from company C were not obtained in time for use in this field study, but will be used in a planned follow-up study of detectors exposed in a controlled laboratory environment. The charcoal detectors from two companies (E and F) were purchased at local hardware stores. Charcoal detectors from two other companies (B and D) were donated by a local health department that had previously purchased them with the intent to distribute to local homeowners. The charcoal detectors from the final two companies (G and H) were purchased directly from the company which manufactures the detectors. The Electret Ion Chambers (EICs), which are generally used by professional radon testers, were supplied by Rad Elec, Inc. (represented by company A). An EIC consists of an electrically charged Teflon disc, called an electret, located inside an electrically conducting plastic chamber of a known air volume. EICs are passive devices that provide an integrated radon

Table 1. Radon detectors used in the intercomparison.

Company	Measurement method
A	Electret ion chamber[a]
B	Diffusion barrier charcoal adsorption canister
D	Diffusion barrier charcoal adsorption canister
E	Diffusion barrier charcoal adsorption canister
F	Diffusion barrier charcoal adsorption liquid scintillation
G	Diffusion barrier charcoal adsorption canister
H	Diffusion barrier charcoal adsorption canister

[a] Electret ion chambers obtained from Rad Elec, Inc.

gas measurement by sensing the radon-related ionization occurring within the detector chamber.

The actual measurements were performed by the authors using standard procedures recommended by the EIC manufacturer. The EICs were used to provide a secondary comparison to the reference radon value and to aid in assessing the degree of homogeneity in the exposure area. All EIC measurements were adjusted for background gamma radiation using a Ludlum Measurements, Inc., Model 19 MicroR Meter (Ludlum Measurements, Inc., 501 Oak Street, P.O. Box 810, Sweetwater, TX 79556). The two sets of detectors from Company A are the same type of detectors, but were exposed for different exposure periods. Companies B and D-H represent different companies marketing radon detectors to the general public.

Placement of the radon detectors was performed in accordance with EPA protocols for screening measurements (U.S. EPA 1992, 1993). All the detectors were placed a minimum of 10 cm away from other objects, including other radon detectors. A femto-TECH continuous radon monitor (CRM) was positioned in the center of an 8-m^2 platform 1 m above floor level. Radon detectors from all companies were evenly distributed around the CRM. Except for normal entering and exiting, all windows and exterior doors in the home were closed 24 h prior to and during the testing period.

The femto-TECH radon monitor was calibrated before the study period commenced against a femto-TECH "master" unit. The "master" unit was calibrated in the Bowser-Morner Radon Reference Laboratory, which maintains a cross comparison with the EPA radon facility at Las Vegas. The accuracy of the femto-TECH CRM is estimated to be within 10% at 300 Bq m^{-3}. The CRM provided hourly printouts of the radon concentrations and was placed in the sampling location a week prior to initiation of the intercomparison. The 4-d exposure was initiated at 1630 hours on 24 October 2004 and terminated at 1700 hours on 28 October 2004. The basement's temperature and relative humidity were monitored hourly during the entire 4-d exposure period.

The radon measurement periods and numbers of detectors exposed from each company are listed in Table 2. With the exception of the EICs obtained from Rad Elec, Inc. (E-PERMs), the measurement periods were based on the recommended exposure duration, as indicated in the instructions that accompanied each type of detector. Four E-PERMs were exposed for the 3-d exposure period and fifteen for the 4-d exposure period in order to evaluate the homogeneity of the basement radon concentration. Although there were two different radon measurement termination dates, all measurements were initiated at 1630 hours on 24 October 2004. One detector from each company including Rad Elec, Inc., was used as a field control detector, which remained sealed and stored in a low radon environment during the course of study. The controls were labeled in identical fashion to the exposed detectors to ensure identical processing and mailed from a local post office back to the companies with the other detectors the morning of 30 October 2004. The measurement results for each type of detector were compared to the reference values established for the various exposure periods by the CRM. The individual relative error was used as the measure of accuracy and the coefficient of variation was used to measure the precision of the measurements (Table 2).

Table 2. Precision and accuracy of radon detectors.

Company	Number of detectors	Exposure (d)	Radon conc. mean ± S.D. (Bq m^{-3})	COV (%)	Number of detectors with IRE > 25%[a]	MARE[b] (%)	Reference radon conc. mean (Bq m^{-3})
A	4	3	292 ± 22	7.3	0	4.9	281
B	15	3	274 ± 30	10.7	0	9.1	281
A	15	4	311 ± 15	4.3	0	4.1	300
D	15	4	218 ± 30	13.4	8	27.8	300
E	15	4	355 ± 52	14.6	3	19.1	300
F	15	4	237 ± 41	16.8	5	21.0	300
G	15	4	344 ± 22	6.5	1	14.8	300
H	15	4	211 ± 15	6.6	13[c]	29.8	300

[a] The results of all the individual relative errors (IREs) must be ≤25% to pass proficiency tests. Its calculation is shown below: $IRE = |M_i - T_i| / T_i \times 100\%$,
where: IRE = individual relative error for device i, in percent, for each measurement; M_i = measured value for device i; and T_i = target value for device i.
[b] The mean of the absolute values of the relative errors.
[c] All 15 of the exposed detectors would exceed an IRE of 25% if the reported blank value of 19 Bq m^{-3} (0.5 pCi L^{-1}) was subtracted from each reported measurement.

RESULTS

The mean temperature was 15.6 ± 0.4 °C with a mean relative humidity of 78.2 ± 2.2%. The gamma radiation background level averaged 7.88×10^{-13} C kg^{-1} s^{-1} (11 μR h^{-1}). A plot of the hourly radon measurement results, obtained from the CRM, is shown in Fig. 1. The radon concentration in the basement showed considerable variation, especially during the first two days of the study. The average integrated radon concentration for the measurement period can be seen in Table 2. Table 2 also provides the mean reported radon concentrations, standard deviation, coefficient of variation (COV) and the number of detectors with an individual relative error in excess of the EPA's guideline ($\leq$ 25%). The relatively small COVs within the two groups of electret ion chambers, exposed for each time period, suggest a fairly homogeneous radon concentration in the measurement area.

Other than the E-PERMs, which were used to assess homogeneity of the exposure, only the 3-d exposure detectors from Company B reported radon concentrations all within the individual relative errors (IREs) of $\leq$ 25%. Only the commercially available detectors from two companies (G and H) met the EPA's guideline for precision (COV $<$ 10%).

Fig. 2a and b displays the distribution of individual test results from each company for the 3-d and 4-d exposure periods, respectively, as compared to the radon reference value. The reported radon concentrations for the blanks were all $<$ 19 Bq m^{-3} (0.5 pCi L^{-1}) with the exceptions of the blanks from Companies B and H. Company B reported that they did not receive the blank in sufficient time after exposure to provide an accurate result. Company H reported a value of 19 Bq m^{-3}.

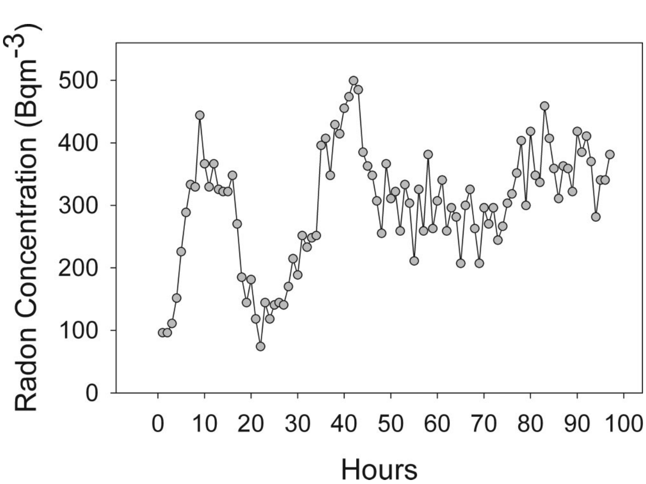

Fig. 1. Hourly plot of the radon measurements obtained from the continuous radon monitor for the 4-d sampling period.

DISCUSSION

As part of the EPA-RMP, single-blind testing was required routinely to pass proficiency. In the case of single-blind testing, the detectors that would undergo testing were provided to the EPA by the detector manufacturer. However, as part of the EPA-RMP in 1989, the EPA purchased commercially available detectors, exposed them to known radon concentrations in their radon chamber, and submitted the detectors to the vendors for analyses. The EPA considered this double-blind testing since both the commercial vendors did not realize they were being tested and they were unaware of the radon concentrations in the chamber. The General Accounting Office (GAO) noted that the EPA's first efforts to test radon measurement companies in this manner indicated that some firms were having difficulty providing consistent and accurate measurements (U.S. GAO 1990). The GAO found that 7 of 36, or about 20 percent, of the firms that had passed single-blind proficiency testing in 1988 failed testing in 1989 during double-blind testing (U.S. GAO 1990).

In this study, five out of the six companies tested did not pass the U.S. EPA's previously established accuracy guideline (all individual relative errors $\leq$ 25%) and four of the six companies failed the EPA's precision guideline [coefficient of variation $\leq$ 10% at 150 Bq m^{-3} (4 pCi L^{-1})]. In fact, the mean of the IREs for 2 out of 6 companies exceeded 25%. In addition, since the value was not reported as $<$ 19 Bq m^{-3} for the blank from Company H, the Indoor Radon and Radon Decay Product Measurement Device Protocols (U.S. EPA 1992) would dictate subtracting 19 Bq m^{-3} from each of the fifteen reported radon concentrations. If the IREs are recalculated for Company H after the subtraction of 19 Bq m^{-3}, all fifteen detectors would exceed an IRE of 25%. However, homeowners in the vast majority of cases would not submit blank detectors, but rather use the test result as reported as a basis for future actions.

The study was performed in accordance with the EPA radon testing protocols, but under actual field conditions (U.S. EPA 1992, 1993). As pointed out in the EPA's 1995 National Radon Proficiency Handbook (U.S. EPA 1995), because charcoal-based detectors allow continued adsorption and desorption of radon, the method does not provide a true integrated measurement over the measurement period. However, the use of a diffusion barrier over the charcoal can reduce the effects of drafts and humidity. It is well known that the results from charcoal adsorption detectors are often weighted more by the radon concentrations toward the end of the exposure (Field and Kross 1990). In this study, the radon concentrations were slightly higher toward the end of the

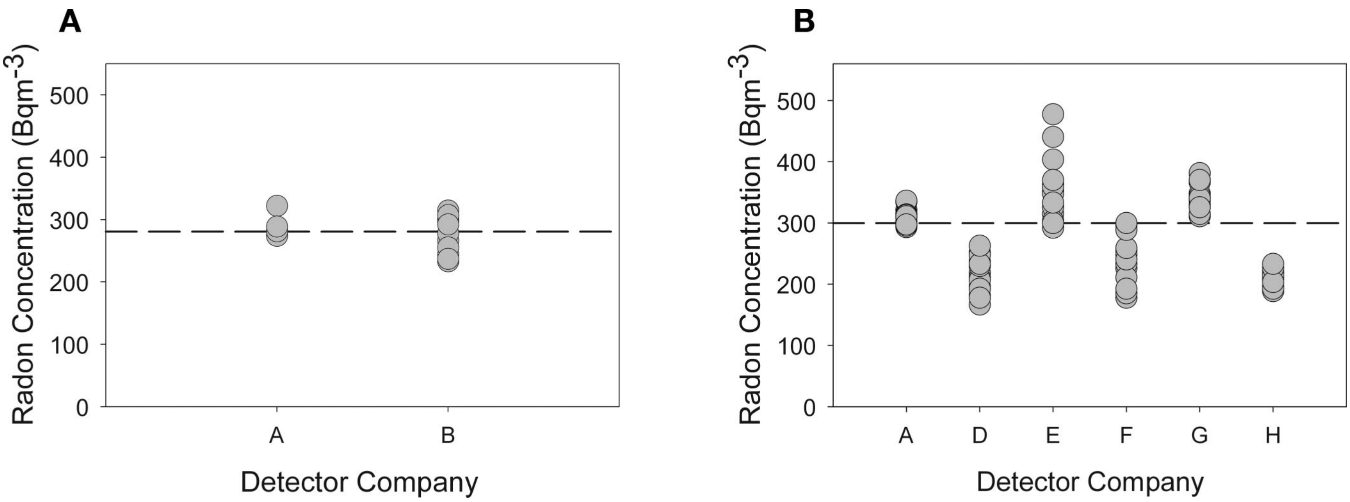

Fig. 2. (a) Comparison of the fifteen detectors from Company B and four electret ion chambers (Company A) as compared to the radon reference concentration (dotted line) obtained from the continuous radon monitor for the 3-d measurement period; (b) Comparison of the fifteen detectors from Companies D, E, F, G, H and fifteen electret ion chambers (Company A) as compared to the radon reference concentration (dotted line) obtained from the continuous radon monitor for the 4-d measurement period.

study, which may explain the higher reported radon values from Companies E and G. However, it does not explain the poor precision exhibited by the detectors from Company E.

The underestimated values for the detectors from Companies D, F, and H may be related to the environmental parameters (humidity, temperature, etc.) of the home. To establish calibration curves for varying relative humidities (RH), some private reference laboratories such as Bowser-Morner expose groups of charcoal canister detectors for various exposure periods at a minimum of three humidities: midrange (around 50% RH), low (around 25% RH), and high (around 75% RH).[†] It is unknown how many companies that manufacture radon detectors for the public perform a similar calibration of their charcoal detectors. The higher humidity encountered at the study home may have reduced the efficiency of the charcoal to adsorb the radon. However, in most cases, varying humidity can be adjusted for in the analyses by weighing the detector to determine the addition of water except in the case where the charcoal in the detector adsorbs water prior to placement, as this procedure will not account for this moisture.

Because over a million short-term radon measurements each year are performed under varying field conditions, commercial detectors should provide reliable performance under a variety of environmental conditions. If the detector is not robust enough to perform reliably under varying conditions, the conditions under which it can perform reliably should be noted on the instruction sheet. The exposure site in this study exhibited radon concentrations well in excess of average radon concentrations in typical U.S. homes. Measurements of lower radon concentrations have even more uncertainty, so the detector measurements would likely have been even less accurate and precise at these lower radon concentrations. The findings of this study support the need for further double-blind testing of commercially available radon detectors under varying conditions commonly found in the field. Since the close of EPA's proficiency program, to the authors' knowledge, only personnel at the Pennsylvania Department of Environmental Protection have performed occasional double-blind device performance tests for devices that are marketed in Pennsylvania.

The high percentage of commercially available detectors from the various companies tested yielding unsatisfactory accuracy and precision is too remarkable to be seen as caused only by chance. However, these results merely provide a snap shot into the accuracy and precision of commercially available short-term radon measurement devices, exposed under high humidity, several years after the close of the EPA's proficiency program. We plan to follow-up this field comparison by exposing commercially available short-term radon detectors under controlled, but varying, laboratory conditions to further assess the accuracy and precision of commercially available radon detectors.

It should be noted that this paper is not a comparison between short-term charcoal radon detectors and electret

[†] Personal communication, P. Jenkins, P. Bowser-Morner Reference Radon Laboratory, Dayton, OH; 25 February 2005.

ion chambers. While electret ion chambers are true integrating detectors generally used by radon professionals, they can also produce results that lack accuracy and precision if the technician fails to perform adequate quality assurance/quality control or fails to follow the manufacturer's recommendations such as keeping them clean and free of dirt or dust that might inadvertently discharge the electrets. Furthermore, there are other radon detectors (such as long-term radon detectors, electronic radon detectors, etc.) that are marketed directly to the general public. The authors suggest that these devices also should undergo routine double-blind testing to determine their accuracy and precision.

To its credit, the EPA continues to encourage states, industry, and consumers to work together to identify those elements that would improve non-federal radon proficiency programs and go beyond EPA's former voluntary proficiency program. Unfortunately for consumers buying radon detectors, insufficient action has occurred since the termination of the EPA's proficiency program in 1998 among the stakeholders to assure that the general public has access to reliable radon detectors that perform well under the various conditions that may be encountered in the field. The public can only make informed decisions as to whether or not to perform radon mitigation if the devices they are using for testing produce accurate results. One possible plan of action to improve the accuracy and precision of commercially available radon detectors would require any state that receives EPA's State Indoor Radon Grant (SIRG) funding to perform routine double-blind tests of radon detectors sold within that state. The NRSB, AARST, and the NEHA need to continue to work constructively together to adopt a unified approach to testing commercially available radon detectors under actual field conditions. The authors suggest the development of a working group, which includes representatives from the EPA, to further explore the accuracy and precision of commercially available radon detectors over an extended period and promote the regulatory role of states, consortium of states, or federal entities (or their designees) to oversee the reliability of radon measurement devices sold to the public in the United States.

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