

## COMPARATIVE SURVEY OF OUTDOOR, RESIDENTIAL AND WORKPLACE RADON CONCENTRATIONS

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Received 21 March 2014; revised 12 May 2014; accepted 13 May 2014

This study investigated radon concentrations in above-ground (i.e. first floor) workplace in Missouri and compared them with above-ground radon concentrations in nearby homes and outdoor locations. This study also examined the potential utility of using home and outdoor radon concentrations to predict the radon concentration at a nearby workplace (e.g. county agencies and schools). Even though workplace radon concentrations were not statistically different from home radon concentrations, the radon concentration at a particular home, or outdoor location, was a poor predictor of the radon concentration at a nearby workplace. Overall, 9.6 and 9.9 % of homes and workplace, respectively, exhibited radon concentrations of  $\geq 148 \text{ Bq m}^{-3}$ . Because of the percentage of workplace with elevated radon concentrations, the results suggest that additional surveys of workplace radon concentrations are needed, especially in areas of high radon potential, to assess the contribution of workplace radon exposure to an individual's overall radon exposure.

### INTRODUCTION

Radon ( $^{222}\text{Rn}$ ) is a radioactive gas formed from the decay of  $^{226}\text{Ra}$ , a member of the  $^{238}\text{U}$  decay chain. It is a major source of ionising radiation in the United States<sup>(1)</sup>, and protracted exposure to radon's decay products has been associated with an increased risk of lung cancer. Radon is the second leading cause of lung cancer after tobacco smoking and the primary cause of lung cancer among individuals who have never smoked<sup>(2)</sup>. Numerous studies have described the distribution of radon concentrations that occur in the home<sup>(3–6)</sup>.

Because overall estimates of radon exposures should incorporate both home and away-from-home exposures, the distribution of radon concentrations and duration of exposure in other settings deserves further assessment. Since individuals spend part of their day outside the home (e.g. workplace and outdoors), radon concentrations occurring in these other locations may contribute substantially to an individual's overall radon exposure. The National Human Activity Pattern Survey estimates that individuals (comprised of various age groups) spend on average 11 % of their day at another indoor location and 8 % outdoors<sup>(7)</sup>. The Iowa Radon Lung Cancer Study (IRLCS) found adult women spent varying time outside the home based on their age<sup>(8)</sup>. For example, women between the ages of 50 and 59 spent the most time ( $\sim 17\%$ ) in another building compared with any other age group. Women in the 20- to 29-age group

spent the most time outdoors ( $\sim 10\%$ ) compared with all other age groups with this percentage decreasing as age increases<sup>(8)</sup>.

Data regarding radon exposure in above-ground workplace, especially in the United States, are generally lacking<sup>(9, 10)</sup>. In addition, studies performing comparative analyses of radon concentrations in distinct environments (e.g. home, workplace and outdoors) within close proximity to each other are lacking. This study seeks to provide insights into the potential for radon exposure in a sample of workplace. The primary aim of this study was to characterise radon concentrations in above-ground workplace in Missouri and compare them with above-ground radon concentrations in nearby homes as well as to nearby outdoor locations. A secondary aim was to determine whether outdoor or residential radon concentrations have utility in predicting radon concentrations in nearby workplace.

This survey was carried out as an independent study of radon concentrations in Missouri following the Missouri Residential Radon Study<sup>(5)</sup> and the IRLCS<sup>(11)</sup>. These case-control epidemiologic studies evaluated the association between protracted residential exposure to radon and its decay products, and incidence of lung cancer among women. The greater part of Missouri is classified by the United States Environmental Protection Agency (US EPA) as having Zone 2 radon potential indicating that the state has overall moderate radon potential<sup>(12)</sup>. Zone 2 areas have

a predicted average indoor lowest liveable radon screening level between 74 and 148 Bq m<sup>-3</sup>. Within Missouri, northwest Missouri, however, has higher radon potential (Zone 1)<sup>(12)</sup>. This higher radon potential area includes elevated uranium content along the Missouri River Valley, areas of windblown glacial deposits east of the Missouri River Valley and black shales closer to Kansas City<sup>(13)</sup>. This study was conducted in a state where a previous US EPA survey estimated that 21 % of basement and 9 % of first-floor screening radon measurements exceed the US EPA's action level of 148 Bq m<sup>-3</sup><sup>(14)</sup>.

Radon source strength underlying a building is an important predictor in determining whether a building may have elevated radon concentrations. Other factors that affect the local radon potential include the surface's radon transport properties, climate and the building's construction and operation. While radon source strength can vary significantly between buildings in the same locale, the authors hypothesised that the broad spatial geographic similarities of radon potential for a given locale in Missouri may be strong enough to produce geographic correlations between outdoor, residential and workplace radon concentrations.

## MATERIALS AND METHODS

### Sample selection

Participants were selected, between 2002 and 2004, in Missouri from a web-based directory (<http://extension.missouri.edu/directory/Places.aspx>) of county extension agencies. A staff member at each extension that works on environmental issues was contacted for possible participation in the survey. Contacts at several schools and other private workplace were also requested to perform radon testing to supplement geographic areas that lacked a County Extension Agency or an Agency contact.

### Radon measurements

Respondents who agreed by phone to take part in the study were mailed two Radtrak alpha-track radon gas detectors (Landauer, Inc., Glenwood, IL, USA), instructions for placing them in the home and workplace and a survey questionnaire between 2002 and 2004. The instructions instructed the participant to place one alpha-track detector (ATD) on the first floor, non-basement, of the home where they were residing and one ATD on the first floor, non-basement, of their workplace. Placement instructions that accompanied the detectors followed US EPA placement protocols<sup>(15)</sup>. The participant was asked to place the detector in a high-occupancy room at least 50 cm off the floor and at least 13 cm from other items. The Landauer ATD was selected, to provide a year-long radon concentration, based on its past performance

of good accuracy and precision compared with other commercially available ATDs<sup>(16)</sup> as well as its low cost, mailability and simplicity of use.

An outdoor radon detector (ORD) was mailed a few days after the ATDs were sent out, so that they could be placed during the same time as the ATDs. The outdoor detector was similar to the detector used in an outdoor radon survey of Iowa and Minnesota<sup>(17)</sup>. The unit was constructed using Lantrak alpha track plastic (Landauer, Inc.) enclosed in a plastic polyvinyl chloride pipe that was covered with Tyvek (DuPont, Wilmington, DE, USA) material at the bottom allowing radon to pass through. The ORD was attached to the top of a 1-m-long fibreglass pole. Participants were instructed to select a space to mount the detector module at least 1 m from an occupied building, while avoiding areas near significant air flowing out of the building (e.g. near vents or appliance exhausts). Once an acceptable placement location was selected, the participant was instructed to drive the post into the ground, ~23 cm deep, and to leave the post for a 1-y exposure period.

### Survey questionnaire

Once the devices were placed, the participants were instructed to record the placement date both on the side of the detector and on the survey questionnaire. The questionnaire was used to collect information on the following: detector placement date, addresses of placement, detector identification number, participant's confirmation of location of detector's placement (i.e. on the first floor), distance from the workplace or the outdoor placement to the home detector placement, main activity or function of the workplace and the total floors of the workplace.

### Sample handling

After the 1-y measurement period, participants were contacted and instructed to place the detector in a sealed envelope, record the ending date of the exposure period and return the ATDs to the project office. Upon return to the project office, the detectors were mailed to the laboratory using overnight delivery. Overnight delivery also minimised the chance that detectors could have picked up additional radon exposure while in transit. Alpha tracks were counted by Landauer using computer-assisted image analysis equipment to calculate the average annual radon concentration<sup>(18)</sup>. A similar process was followed for the return of the ORDs.

### Geocoding of home and workplace addresses

In each of these counties, the home, outdoor and workplace addresses were geocoded using ArcMap 8.3 (ESRI, Inc., Redlands, CA, USA) and a 2009

TIGER/line file of Missouri as the reference address locator. The output was verified to ensure that the geocoded point's location matched that of the home or workplace.

### Data analysis

Descriptive statistics (e.g. geometric mean and geometric standard deviation) were computed for the indoor (home and workplace) and outdoor radon concentrations. Geometric means were used to describe the central tendency of the radon measurements since their distribution was highly skewed (i.e. log-normal). A Student's paired *t*-test was performed to evaluate whether significant differences exist between radon concentrations from each of the three types of environments. Paired differences between the radon measurements from the sampling environments were examined to assess normality using Shapiro-Wilk test. Home and workplace and outdoor and workplace radon measurements were paired for the *t*-test based on the identification number of the participant who deployed the detectors. The data were transformed using a natural ln in cases when they did not follow a standard normal distribution. A Shapiro-Wilk test was performed on the ln-transformed data to verify whether they were normally distributed. Analyses were conducted on the data distributions following a normal distribution.

The utility for predicting the annual occurrence of radon in nearby workplace was evaluated using simple linear regression. The prediction of annual workplace radon concentrations given nearby annual residential radon concentrations was compared with the regression of predicting annual workplace radon concentrations based on nearby annual residential radon concentrations as well as the distance between the home and work detector locations. The addition of this distance variable was evaluated to determine whether a change in the distance between home and workplace locations had any impact on the value in predicting workplace radon concentrations given annual residential radon concentrations.

For these regression models, Pearson's correlation coefficients were computed to determine the strength of the linear relationship between the annual workplace radon concentrations and the predictor variables. To examine whether the errors (i.e. residuals) from these models were normally distributed, the Shapiro-Wilk test was performed. If the errors did not follow a standard normal distribution, the measurement data were ln-transformed. Normality of the ln-transformed data was further verified using the Shapiro-Wilk test. All regression analyses were conducted using the normalised data. To check for constant variance of the models' errors (i.e. homoscedasticity), the residuals (i.e. differences between sample values and fitted values) versus each model's predicted responses were plotted and their spread was evaluated.

### Quality assurance

The study followed the US EPA's guidelines for quality assurance to measure radon<sup>(15, 19–22)</sup>. Duplicate detectors (10 %) were treated identically to the primary device and positioned 10 cm from the primary detector. The ATDs were exposed to known radon concentrations (i.e. spikes) (5 %) in the US EPA's National Air and Radiation Environmental Laboratory and the ORDs in the laboratory of the Minnesota Radon Project to determine detector accuracy and precision.

In addition, field and laboratory control detectors (blanks) (5 %) were deployed to detect possible radon exposure encountered in the field and in transit to the laboratory. Two detectors (one detector designated as the blank and the other as the primary detector) were sent to participants. They were instructed to leave the blank detector closed and store it in a low-radon environment. After the exposure period ended, they were contacted to return both detectors. Duplicate, spiked and blank detectors were labelled in the same manner as primary devices to ensure identical processing by the laboratory.

### RESULTS

All the participants, who agreed participate in the study, reported that their residence or workplace had not been tested previously for radon. Two home and one workplace radon measurements were excluded because it was documented that these detectors were not placed on the first floor. This resulted in the inclusion of 82 outdoor, 83 home and 81 workplace radon measurements in the study.

### Sample characteristics

Radon measurements were collected from 80 out 114 Missouri counties with some counties having more than one set of radon tests performed. Figure 1 illustrates the spatial distribution of the study participants identifying their workplace, residence and outdoor locations. Graduated symbols for each type of environment tested distinguish areas with respect to the US EPA's radon action level of 148 Bq m<sup>-3</sup>.

Radon detectors were placed in 2002 through 2004 during the months of September through February. About 70 % of the radon tests began in 2002 with a little more than half of the tests starting in the month of September (58 %) followed by ~25 % in December. Among the 81 workplace surveyed, 46 % (*n* = 37) only had a first floor, 32 % (*n* = 26) had a second floor, 17 % (*n* = 14) had a third floor and 5 % (*n* = 4) had a fourth floor. The placement of the workplace detectors averaged ~4 km and outdoor detectors averaged 3 m from the home measurement site.

Among the type of workplace surveyed, a little more than 75 % were county offices. Retail workplace

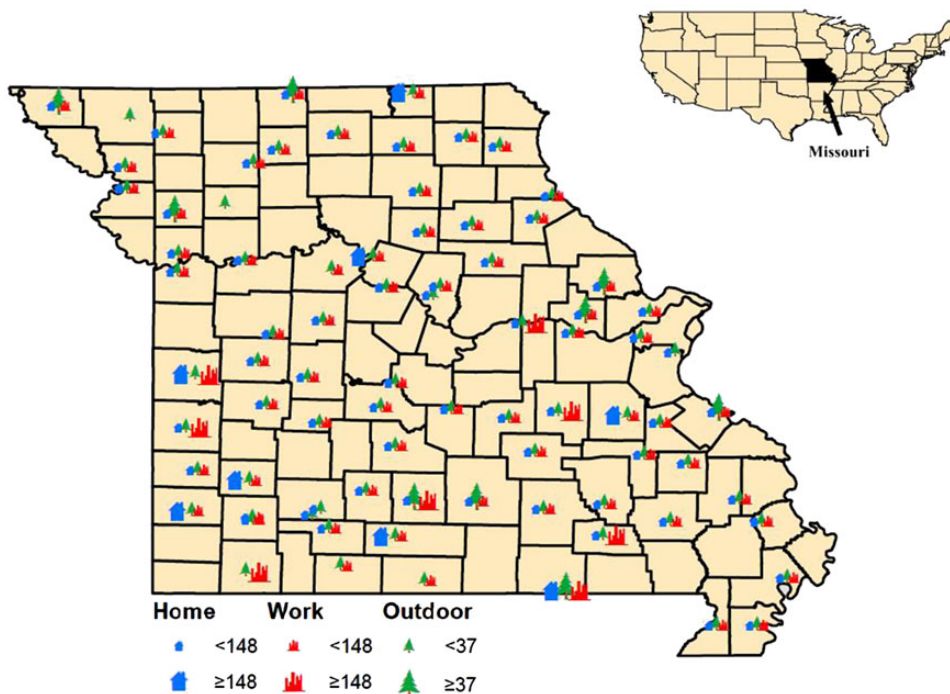


Figure 1. Annual radon concentrations ( $\text{Bq m}^{-3}$ ) by type of test environment across counties in Missouri.

**Table 1. Characteristics of radon concentrations ( $\text{Bq m}^{-3}$ ) by sampling environment.**

Environment	<i>N</i>	Geometric mean (GSD)	Range	Percentage $\geq 148 \text{ Bq m}^{-3}$
Indoor	164	53 (2.2)	7.4–400	9.8
Home	83	54 (2.2)	11–400	9.6
Workplace	81	51 (2.2)	7.4–333	9.9
County office	62	57 (2.0)	15–333	11
Retail	5	33 (2.3)	11–104	0
School	6	27 (2.1)	11–70	0
Service	8	43 (3.0)	7.4–233	13
Outdoor	82	25 (1.5)	11–111	0

(e.g. grocery, florist/gift shop and antique store) and schools each made up  $\sim 7\%$  of the sample. Service workplace (e.g. auto repair shop, heating/cooling contractor, church, insurance sales office and motel) comprised the remaining 10%. The median of the home and work radon concentrations were both  $52 \text{ Bq m}^{-3}$  (Table 1). About 10% of the home and 10% of the workplace radon measurements were equal to or exceeded the US EPA's radon action level.

According to the Shapiro–Wilk test, the paired differences between the ln-transformed workplace and ln-transformed home measurements followed a standard normal distribution ( $p = 0.20$ ) (an assumption of the

Student's paired  $t$ -test) as opposed to the non-transformed paired differences. This was also the case for the paired differences between the ln-transformed workplace and ln-transformed outdoor measurements ( $p = 0.57$ ). The residential and workplace radon concentrations were compared and found to be not significantly different ( $p = 0.33$ ), whereas the outdoor radon concentrations were found to be significantly different with the home ( $p < 0.0001$ ) and work ( $p < 0.0001$ ) radon concentrations. Overall, indoor and outdoor radon concentrations were found to be significantly different ( $p < 0.0001$ ). Unmatched data were not included in these analyses.

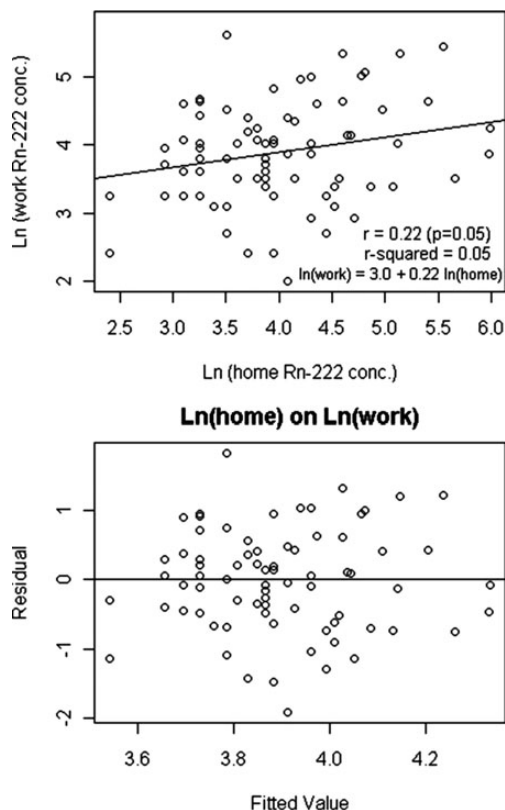


Figure 2. Scatter plot of annual  $\ln(\text{home } ^{222}\text{Rn concentration})$  versus annual  $\ln(\text{work } ^{222}\text{Rn concentration})$  and its residuals.

### Simple linear regression

After all the variables underwent an  $\ln$ -transformation, the best-fitted lines for both models were generated and plotted in Figures 2 and 3. A weak linear relationship was noted between home and workplace radon concentrations ( $r = 0.22$ ,  $p = 0.05$ ) and even a weaker relationship between outdoor and workplace radon concentrations ( $r = 0.11$ ,  $p = 0.34$ ). The Shapiro–Wilk test supported normality for the residuals of both models predicting workplace radon concentrations based on a nearby home ( $p = 0.98$ ) or outdoor ( $p = 0.98$ ) radon measurement (after all the variables were  $\ln$ -transformed). The  $r$ -squared coefficient indicated that only 5 % of the variability in the annual workplace radon measurements can be explained by the annual home radon measurements and even less (1 %) by the annual outdoor radon measurements. As indicated by the best-fitted line equation, a 1 % increase in the annual average home as well as the annual average outdoor radon concentration would each yield a 0.22- $\ln$  unit increase in the annual average workplace radon concentration. The

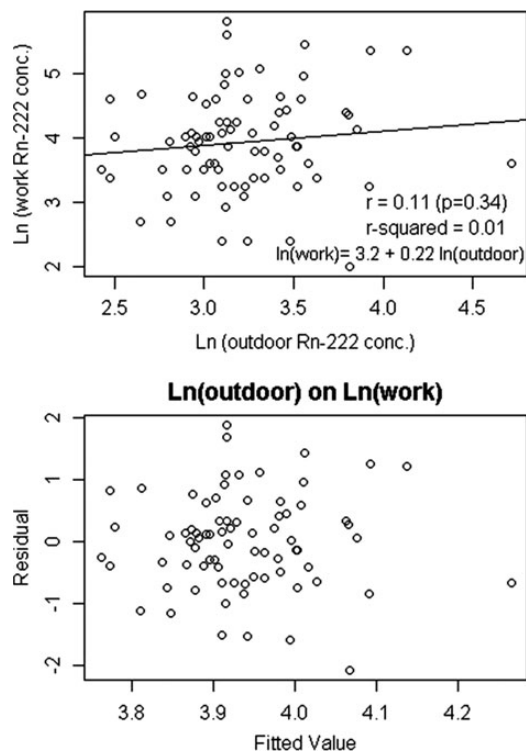


Figure 3. Scatter plot of annual  $\ln(\text{outdoor } ^{222}\text{Rn concentration})$  versus annual  $\ln(\text{work } ^{222}\text{Rn concentration})$  and its residuals.

prediction equations to relate the non-transformed measurements given the prediction equations based on  $\ln$ -transformed measurements with a constant of  $e$  (approximate value of 2.72) are as follows:

- (1) work radon concentration =  $e^{3.0} \times (\text{home radon concentration})^{0.22}$
- (2) work radon concentration =  $e^{3.2} \times (\text{outdoor radon concentration})^{0.22}$

To check for non-constant variance, an assumption of linear regression, the residuals (i.e. differences between sample values and fitted values) versus the predicted responses were plotted after the data were  $\ln$ -transformed. The constant variance assumption appears reasonable in the  $\ln$ -transformed data for the two models, as the spread in the residuals is similar throughout the distribution. When the distance between the home and workplace detectors was added as another predictor variable in the regression model predicting the annual workplace radon concentrations given the annual home concentrations, the  $R$ -squared value increased only slightly from 0.05 to 0.06.

### Quality assurance

Twelve per cent of the ATDs and 10 % of the ORDs had a collocated (i.e. side-by-side) detector placement. The mean coefficient of variation (COV) (SD/mean of duplicate measurements) for the duplicate ATDs and ORDs was  $\sim 7\%$ . Five per cent of the ATDs were exposed to known radon concentrations (spikes) in the US EPA's National Air and Radiation Environmental Laboratory. A mean COV of 8.3 % for an exposure at  $74 \text{ Bq m}^{-3}$ , a COV of 7.5 % at  $148 \text{ Bq m}^{-3}$  and 5.7 % at  $222 \text{ Bq m}^{-3}$  was found. About 10 % of the ORDs were exposed to known radon concentrations (spikes) in the radon chamber at the Minnesota Radon Project. There was no change in the calibration constant from 2002 to 2004. The mean COV for the spiked ORDs was 7%.

At least 5 % of the ATDs were designated as field controls (i.e. blanks). About 2 % of the ORDs were designated as field control detectors and 3 % as laboratory control detectors (blanks). The blank detectors exhibited no extraneous radon exposure above Landauer's lowest level of detection of  $4 \text{ Bq m}^{-3}$ . The spiked detector measurements were within the mean absolute relative error of 25 %, which meets the US EPA's guidelines of detector performance. The duplicate detector measurements also met the US EPA's suggested *a priori* 10 % precision criterion. Detailed information concerning quality assurance is presented elsewhere<sup>(22)</sup>.

### DISCUSSION

The findings from this study are most representative to areas of the United States with moderate radon potential (i.e. predicted average indoor lowest liveable radon screening level between  $74$  and  $148 \text{ Bq m}^{-3}$ ) and homes and offices similar to those surveyed as far as size, climate, geographic location, and heating, ventilation and air-conditioning practices. Compared with the geometric mean of the annual radon concentration in this study of 83 residences ( $54 \text{ Bq m}^{-3}$ ,  $\text{GSD} = 2.2$ ), the US EPA state radon survey for Missouri<sup>(14)</sup> found a smaller geometric mean ( $40 \text{ Bq m}^{-3}$ ,  $\text{GSD} = 2.7$ ) for screening radon concentrations in non-basement areas within residences. With respect to the US EPA's action level of  $148 \text{ Bq m}^{-3}$ , this survey found  $\sim 10\%$  of the annual home radon concentrations to be equal to or larger than this level. The US EPA state radon survey found similar rates (i.e. 9.2 %) of winter screening (i.e. short-term testing) radon concentrations in non-basement areas above this guidance level.

In comparison with this study's geometric mean of annual radon concentrations of  $51 \text{ Bq m}^{-3}$  ( $\text{GSD} = 1.4$ ) for 81 workplace (7 % were schools), a national survey of radon levels in US public schools, performed by the US EPA from 1990 through 1991 school year<sup>(23)</sup>, found the arithmetic mean of the 5-month radon measurements to be smaller ( $30 \text{ Bq m}^{-3}$ ). The

mean for schools from the national survey was, however, slightly larger than the geometric mean of  $27 \text{ Bq m}^{-3}$  ( $\text{GSD} = 2.1$ ) for only schools in this study. Ignoring local radon source potential, a larger average radon concentration would have been expected for the school survey compared with this study because the school survey measured radon in frequently occupied rooms with ground contact that were closer to the soil source than the deployment of radon detectors for this study (above ground first floor). This study, however, had larger radon concentrations. Compared with the percentage (10 %) of workplace equal to or above the US EPA's action level for this study, there was a smaller percentage (1.5 %) of the rooms in the US EPA school survey that were equal to or above this action level. The difference between the two studies may also be affected by air exchange rates or other factors (e.g. radon source potential) between buildings sampled in both studies.

The geometric mean of the annual outdoor radon concentrations of  $25 \text{ Bq m}^{-3}$  ( $\text{GSD} = 1.5$ ) was slightly larger than the mean ( $22 \text{ Bq m}^{-3}$ ) of the annual average outdoor radon concentrations in a nationwide ambient study by the US EPA for Missouri<sup>(24)</sup>. The US EPA's national outdoor survey only performed radon measurements at one location within a state using electret ion chamber radon detectors that were deployed successively for 3-month time periods to estimate an average yearly radon concentrations. This study conducted multiple outdoor radon measurements in various regions throughout the state as compared with the US EPA survey that relied on one outdoor radon measurement in one location in each state.

Annual average workplace radon concentrations were not statistically different from nearby annual average home radon concentrations ( $p = 0.33$ ). Both types of annual measurements had geometric means close to  $50 \text{ Bq m}^{-3}$  ( $\text{GSD} = 2.2$ ). Based on radon test measurements in 100 homes in Minnesota, the Minnesota Radon Project<sup>(25, 17)</sup> estimated the radon concentrations in other buildings (e.g. workplace and schools), however, to be half of first-floor bedroom radon concentrations for the IRLCS. It should be noted that the median radon concentrations (workplace and first-floor homes were  $70$  and  $130 \text{ Bq m}^{-3}$ , respectively) in the Minnesota study were much higher than this study (workplace and home were both  $52 \text{ Bq m}^{-3}$ ). In contrast, studies by Gaidolfi *et al.* in Italy<sup>(26)</sup> and Iyogi *et al.* in Japan<sup>(27)</sup> found that schools and workplace exhibit larger annual average radon concentrations than the annual radon concentrations measured in dwellings. Gaidolfi *et al.* found the differences between the annual radon concentrations in schools and homes to be smaller when the floor level where the measurements took place was taken into account. Iyogi and colleagues also noted that the workplace radon concentrations were smaller based on active detector measurements during

working hours when air conditioning was activated compared with non-working hours.

In contrast, Poffijn *et al.*<sup>(28)</sup> found a greater percentage of dwellings (24 %) that exceeded 200 Bq m<sup>-3</sup> compared with schools (12 %) or public buildings (10 %) in a Belgian study covering 79 houses<sup>(29)</sup>, 421 schools and 36 other buildings, although the distribution of the radon measurements in homes and schools was similar (both had medians of 90 Bq m<sup>-3</sup>). Similar findings were found in a survey in Finland consisting of 2-month home and workplace alpha-track measurements during the spring<sup>(30)</sup>. A poor correlation was observed ( $r = 0.18$ ,  $p = 0.04$ ) between 333 workplace (detectors deployed in actual area of work) and 939 home (447 living room and 492 bedroom) measurements. The geometric mean radon concentration in the dwelling (68 Bq m<sup>-3</sup>) was more than three times larger than the concentration in the workplace (20 Bq m<sup>-3</sup>). A survey in New Mexico (United States) also found the median radon concentration in 47 dwellings (56 Bq m<sup>-3</sup>) to be three times larger than the median concentration on the first floor of 65 offices (19 Bq m<sup>-3</sup>)<sup>(9)</sup>. The lower office radon concentrations may be attributed to high air exchange rates often encountered in office buildings. The radon concentrations across floors in office areas were not statistically different (i.e. basement radon concentrations were not found to be larger than upper-floor radon concentrations).

In this study, the geometric mean of the annual radon concentration at a workplace or at a nearby residence was double the annual radon concentration at a nearby outdoor location. As part of the IRLCS, annual average indoor and outdoor radon concentrations were measured in Iowa<sup>(11, 17)</sup> and differed to a greater degree. The geometric mean annual concentrations in the bedrooms were slightly larger than three times higher than outdoor levels in Iowa.

### Limitations

The representativeness of the findings is generalisable to a limited sample composed predominately of county extension offices in a mid-continent, moderate climate region. Other types of workplace may have different ventilation practices, building structures and additional floors that have the potential to affect the variability in annual average radon concentrations. Another limitation is the inability to take into account the effect of air circulation patterns on the annual average radon concentration in workplace where ventilation use varies by work hours (e.g. evenings, nights and weekends).

### Strengths

This survey presented a unique opportunity to compare and characterise annual average above-ground (i.e. non-basement) measurements of radon in

three distinct environments within close proximity to each other. The study represents one of the largest surveys of long-term occupational above-ground radon concentrations in the USA and the largest study of occupational radon concentrations ever performed in Missouri. An advantage of enrolling extension agency workers who were experienced with issues of environmental health, and therefore, were equipped with technical expertise, increased the likelihood of proper placement and return of radon detectors. For this reason, they were more likely to participate and may be a useful resource in future self-monitoring studies as well as the potential to be a cost-effective approach to test multiple environments within close proximity to each other.

Findings from this study demonstrate that some above-ground office areas exhibit similar radon concentrations to upper floors in homes. In fact, the percentage of the home radon measurements greater than their matching workplace measurements and vice versa were comparable as well as the percentage of the workplace and home radon concentrations equal to or larger than the US EPA's radon action level of 148 Bq m<sup>-3</sup>. Based on these findings, radon concentrations in the non-basement first floor of homes and workplace present a similar level of concern indicating that attention needs to also be placed on the measuring of radon in workplace since individuals spend part of their day inside these other buildings as well. A weak correlation was noted between home and workplace radon concentrations and even a weaker relationship between outdoor and workplace radon concentrations. These results suggest that annual non-basement home and outdoor radon concentrations are poor surrogate measures of the annual level of radon in nearby above-ground workplace.

### CONCLUSION

This study provides insights into the potential for radon concentrations in above-ground workplace and the potential agreement between workplace and residential radon concentrations in a sample composed predominately of county extension offices. Systematic nationwide surveys are needed to assess above-ground workplace radon to generate more accurate estimates of overall radon exposures.

### ACKNOWLEDGEMENTS

The authors thank Drs Cowles, Anthony, Laurian and David Osterberg for their review of earlier drafts of this manuscript.

### FUNDING

This work was supported by the National Institute of Environmental Sciences, National Institutes of

Health (grant numbers RO1 ES05653, P30 ES05605); the National Cancer Institute, National Institutes of Health (grant number RO1 CA85942) and the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention (grant number T42OH008491).

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