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RELATIONSHIP OF SOIL RADON FLUX TO INDOOR RADON ENTRY RATES

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ABSTRACT

Easily deployable methods to measure soil radon flux are of interest to home builders in order to estimate the radon potential at a site prior to construction. Passive E-perm radon flux monitors (H-type) were deployed outdoors at a home at 12-hr intervals for one year to examine the variability and reliability of this method of estimating radon flux. Continuous basement-level indoor radon measurements were collected at 5-min intervals during the same time period, at the same home. This allowed a direct comparison of the relationship of soil radon flux, as measured by the H-type chambers, with actual indoor radon concentrations measured in the home. Meteorological measurements (barometric pressure, wind speed, temperature, and rainfall) collected at the site provided additional parameters that may correlate with radon flux and indoor concentrations.

INTRODUCTION

Extensive epidemiological studies have linked inhalation of the radioactive decay products of radon (collectively referred to as radon), a naturally occurring gaseous decay product of radium present in all soils, to an increased risk of lung cancer (*1*). Approximately 18,000 lung-cancer deaths are attributed to radon annually in the United States. Radon typically enters homes through cracks at the soil-foundation interface, often driven by a pressure differential across the house/subsoil boundary. As radon contributes over half of the radiation dose received by the public from all sources, the Environmental Protection Agency (EPA) recommends remediation of concentrations above 4 pCi/L (148 Bq/m^3).

As radon measurements are commonly conducted in occupied homes, most mitigations involve retrofitted installations. This often results in greater expense and a compromised design, as compared to placement during home construction. A simple method to determine radon flux from the ground would, in combination with other observations, provide a useful approximation of the radon-emanating potential at a site prior to building. The ideal device would be easily deployed, passive, and capable of a short-term measurement. In addition to a soil flux measurement, other parameters that are generally considered, as they are known to effect indoor radon concentrations, include soil characteristics (e.g., moisture, permeability, and temperature), geological circumstances (e.g., rock type and faulting/shearing), and atmospheric conditions (e.g., wind speed, barometric pressure). As the influence of some parameters on indoor radon concentrations can vary daily and seasonally, other approaches (*2*) have estimated radon potential for single-family homes using year-round measurement results.

In the present study, soil radon flux was measured for over one year in coincidence with meteorological and indoor radon measurements. The objective was to examine the applicability of short-term soil flux measurements in the estimation of indoor radon concentrations under various climatic conditions. Although some meteorological parameters investigated in this study may not influence observed radon activity similarly at sites with different soil properties and house construction, but other parameters, such as atmospheric temperature, are important when possible reasons for variability in radon measurements are investigated.

EXPERIMENTAL

All measurements were conducted on property containing a ranch-style single-family house located west of Albany, NY. The poured-cement basement foundation, completed in 1977, overlies several cm of subslab gravel and contains an open sump area of 1 m^2. The basement, with a 90 m^2 (1000 ft^2) footprint, is finished and contains three rooms. A 92,000 BTU forced hot-air furnace is located in a 9 m^2 room with the open sump. The furnace fan is also used sporadically during the summer to circulate the central air conditioning. The surrounding soil is a combination of rock and clay, with a high water table typically in the spring (due to snow melts and prolonged rains).

Continuous indoor-air radon measurements were collected at 5-min intervals using an AB-5 passive radon detector (PRD; Pylon Electronic Development Co. Ltd., Ottawa, Canada) interfaced with a personal computer. The PRD is an alpha-scintillation counter with an efficiency of 72%, a background of 0.2 cpm, and a lower limit of detection (at 95% confidence level) below 1 pCi/L. The PRD was calibrated in a radon chamber (Bowser-Morner Inc., Dayton, OH) prior to use and was placed 2 m above the basement's open sump area during the study. The system was initially susceptible to power failures, resulting in five episodes of lost measurements.

Soil radon flux measurements were conducted using H-type chambers containing a charged Teflon disc (electret). These passive radon measurement devices are commercially available (Rad Elec Inc., Frederick, MD) and have been described elsewhere *(3,4)*. During deployment, radon enters the 960-mL chamber through the Tyvek sheet in contact with the soil and exits filtered vents. Another H-type chamber, separated from the soil by aluminum foil, provides the background discharge rate due to leakage and the environmental gamma flux. Chambers, placed in the same location during the entire study, were loaded with electrets and deployed at approximately 12-hr intervals. The voltage reader was calibrated using electrets exposed at the calibration chamber and were periodically checked with reference electrets.

Air temperature was recorded at 5-min intervals using NIST-traceable temperature loggers (Onset Computer Corp., Pocasset, MA) placed in the attic, living area, basement (near and far from PRD), and outdoors (near flux chambers). A NIST-certified weather station (Vantage Pro; Davis Instruments Corp., Hayward, CA) recorded meteorological parameters (pressure, humidity, rainfall, and wind direction and speed) at the site during the latter part of the study. As it is wireless, the weather station is susceptible to transmission failures, resulting in periods of missing data.

RESULTS AND DISCUSSION

Indoor measurements

Radon concentrations measured in the basement of the house are shown in Figure 1 for the entire project. For display purposes, the measurements have been binned into ½-hr intervals. It is obvious that a seasonal pattern exists, with low, relatively steady indoor radon concentrations occurring during the late winter, and higher, widely variable concentrations prevailing during the summer and fall. While homeowners are generally encouraged to conduct radon measurements during the heating season when indoor concentrations are presumably greatest, results from this study show that indoor radon levels were lowest during the heating months and highest during the warmer months. For example, during the month of February, the average indoor radon concentration was 5.6 pCi/L, with a range of 1 to 13 pCi/L. Ratios of 24-hr maximum/minimum concentrations show only two days with values above five. However, during July the radon concentrations varied from 1 to 27 pCi/L and averaged 10.5 pCi/L. The 24-hr maximum/minimum concentration ratios in July exceed five on 11 days, demonstrating the great variability in radon concentration levels during the warmer months. If this seasonal differential is the norm, rather than the exception, then wintertime measurements would likely underpredict actual annual exposure. Not coincidentally, the lowest radon concentrations occurred during a period of snow melts and water accumulation in the sump pit, thereby effectively blocking radon migration into the house, while the highest levels coincided with periods of high temperature differentials.

To illustrate the effect of the diurnally changing temperature gradient that occurs during the summer and fall months, a sequence of 10 days is shown in Figure 2. Based on the bullets in the figure that designate midnight, it can be seen that radon concentrations generally increase during the night, peaking around 3 am, before decreasing during the daytime, and eventually rising again in the early evening. As commonly noted in the literature, temperature differences are likely the driving force behind the diurnal fluctuation. During the night, the house is warmer than the surrounding outdoor air, so the upward convective transport of air leads to decreased basement pressure and an enhanced indoor radon concentration. Conversely, as the outdoor temperature increases during the daylight hours and the sun heats the roof (and attic) of the house, a "temperature inversion" develops that suppresses radon infiltration from the soil, until the radiational cooling resumes at night. Under these cyclic conditions it is important that, if an accurate short-term radon measurement is to be obtained, testing should be conducted at 24-hr intervals.

Other meteorological parameters demonstrated less influence on observed radon levels. The barometric pressure generally exhibited long-term changes rather than diurnal cycles, and radon concentrations were not noticeably influenced by pressure changes. For example, during the study, the maximum pressure drop observed in a 24-hr period was 15 mbar. As shown in Figure 3, this large decrease in barometric pressure did not alter the diurnal radon concentration pattern. Therefore, the effects of pressure variations are not considered further here. Wind speed showed an apparent diurnal cycle, with the highest speeds occurring in the early afternoon and the lowest speeds after midnight. While it was expected that higher wind speeds would provide sufficient negative pressure gradients in the house to induce advective radon transport, radon concentrations showed no correlation with the diurnal wind-speed pattern, except when the wind cycle coincided with the temperature cycle. A meteorological parameter that did appear to effect the indoor radon concentrations was precipitation. As shown in the figure, periods following significant rainfall were often accompanied by decreased indoor radon levels. While water acts as a barrier to gas transport as it fills the voids that exists between soil particles, and thereby strongly diminishes surface emanation, the magnitude of the effect of rain on subsurface (1-2 m) radon entry into the house is unclear from this study.

Outdoor flux measurements

The H-type chamber is a simple, passive method to measure soil radon flux, but there are caveats to its use. While Al foil was placed between the soil and H-type chamber to act as a barrier to radon emanation into the latter, it was observed early in the study that discharge rates for the background chamber generally increased with continued use due to the development (generally within a week) of pinholes in the Al foil. Replacement of the Al foil always resulted in a substantial decrease in the background discharge rate. Therefore, an average background discharge rate, representative of values observed following a change of Al foil, was used in the flux determinations. While background discharge rates varied during the study due to the pinholes, values were much lower than the flux rates through the Tyvek sheet. Other leakage was due to the inherently incomplete seal between the Tyvek and the Al foil, which led to an increased discharge of the background electret. Secondly, following several months of exposure it was noted that one H-type chamber produced low results, and duplicate sampling was therefore conducted to the examine variability. While flux measurements with the duplicate samples were an average of six times greater than those conducted with the "plugged" H-type chamber, measurements conducted after replacement with a new H-type chamber produced an average duplicate ratio near unity. The reason for failure of the H-type chamber is under investigation, but it may have been due to soiling of the Tyvek. During periods of heavy precipitation the paper towel and Al foil underlying the H-type chambers typically become soaked. These conditions must surely diminish radon transfer into the chambers during the measurement periods.

The measured radon soil flux rates indicate a slight seasonal pattern, with the greatest exhalation occurring during the late summer months. Flow of radon-containing soil gas is aided by the lower moisture content and cracks in the clay soil that occur during periods of little precipitation at the site. Low flux rates during winter may be due to a combination of frozen ground and periodic snow melt, while those in the spring are likely caused by increased precipitation. The average flux observed during the year (1.00 +/- 0.59 pCi/m^2-sec) is typical of reported values. The measured fluxes ranged from 0, when the ground, paper towel, and Tyvek sheet were soaked, to 3.75 pCi/m^2-sec, on a dry summer day. The flux showed no apparent diurnal pattern, although the ratio of day/night flux values did average 1.7. As expected, radon flux from the soil is strongly affected by precipitation. Except for the seasonal similarity, there is no obvious correlation of outdoor radon flux with indoor radon concentrations, probably due to influence on each by different meteorological parameters.

CONCLUSIONS

In this study measurements of indoor radon concentrations have been correlated with meteorological parameters and soil flux measurements. Diurnal indoor radon patterns are heavily influenced by indoor and outdoor temperature differentials. Though previous studies have linked barometric pressure and wind speed to indoor radon levels, results from this study show little correlation among these parameters. Soil-gas flux measurements were primarily influenced by precipitation. While the H-type chambers are capable of determining radon flux prior to home construction, the influence of environmental factors (e.g., temperature differentials) may limit their applicability for estimating indoor radon concentrations.

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REFERENCES

1. National Academy of Sciences, *Health Risks of Radon and Other Internally Deposited Alpha-Emitters* BEIR IV, National Academy Press, Washington DC (1988).

2. M.E. Kitto, C.O. Kunz, and J.G. Green, "Development and Distribution of Radon Risk Maps in New York State", *J. Radioanal. Nucl. Chem., Articles*, **249(1)**, 153 (2001).

3. P. Kotrappa, J.C. Dempsey, and L.R. Stieff, "Recent Advances in Electret Ion Chamber Technology for Radiation Measurements", *Rad. Prot. Dosimetry*, **47(1)**, 461 (1993).

4. L. Stieff and P. Kotrappa, "Passive E-perm Radon Flux Monitors for Measuring Undisturbed Radon Flux from the Ground", Proc. International Radon Symposium, American Assoc. of Radon Scientists and Technologists (1996).