RADON SOURCE RATE MEASUREMENTS USING MULTIPLE PERFLUOROCARBON TRACERS

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Abstract

An all passive monitoring system utilizing α-track detectors for radon and perfluorocarbon tracer (PFT) samplers for ventilation has been used to measure radon entry rates for 60 homes located within four separate areas of New York State (USA). Each home was divided into two or three zones so that multiple PFTs and multizone mass balance models could be used to compute zonal radon source rates. The whole house radon source rate for all 60 homes, averaged for a 2-7 week time period during the winter of 85-86, had a geometric mean of 4.94 Bq/s and an arithmetic mean of 10.0 Bq/s. Zonal mass balance equations applied to a tracer emitted in the soil outside 45 of the homes showed that, on average, 55% of the emitted tracer actually entered the houses. Diffusion alone cannot account for such a high value.

Introduction

Elevated radon concentrations in residential buildings can result from a variety of sources. The most ubiquitous source appears to be radon contained in the pores of radium-containing soil. However, high radon emissions in selected geographic areas have resulted from contaminated water supplies and from building materials with high radium contents. For the purpose of estimating average indoor radon concentrations, it is important to isolate the radon sources and measure their average radon emission rates.

One method that has been used for this purpose is to use a real-time radon "sniffer" to locate radon entry points and to compare their relative radon concentrations at these entry points. This method has proved useful for mitigation purposes but cannot adequately be related to radon emission rates because of differences in local ventilation rates. In addition, this method provides only short-term emission information rather than the more useful long-term, average values.

A second method, pursued in this study, utilizes mass balance modeling to estimate radon source rates. This method requires the simultaneous measurement of indoor radon concentrations and house ventilation so that the effects of source dilution by the infiltration of outdoor air can be isolated. A convenient ventilation technique for this purpose utilizes the constant emission, perfluorocarbon technology developed at Brookhaven National Laboratory. This technique can provide long-term, multizone ventilation information and, therefore, can be used to estimate long-term radon emissions occurring in different zones of a house.

As an extension to this work, we explored the concept of using a buried PFT permeation source to "visualize" the movement of radon from soil gas into the basement and throughout the house. That work will be reported here as well.

Theory and Experimental

Consider the two zone house pictured in Figure 1.

Let C_{Rj} = concentration of radon in zone j.
C_{RO} = concentration of radon in outdoor air.
C_{ij} = concentration of tracer i in zone j.
R_{Ij} = infiltration flow into zone j.
R_{Ej} = exfiltration flow from zone j.
R_{ij} = air flow from zone i to zone j.
S_j = emission rate of tracer j into zone j.
S_{Rj} = emission rate of radon into zone j.

Then a radon mass balance around each zone yields

$$S_{R1} = (R_{12} + R_{E1})C_{R1} - R_{21}C_{R2} - R_{I1}C_{RO} \quad (1)$$

$$S_{R2} = (R_{21} + R_{E2})C_{R2} - R_{12}C_{R1} - R_{I2}C_{RO} \quad (2)$$

Since all the flows and concentration are measured, the radon source rates can be calculated on each zone and summed to get the overall source rate for the house. Here, the radioactive decay of radon is assumed to be small compared with loss by ventilation. A similar derivation can be used to calculate the radon source rates in homes with more than two zones.

Now consider a tracer source with emission rate = S_3 buried outside the home as shown in Figure 1. Its penetration rate into house zone j = S_{3j} is given by

$$S_{31} = (R_{12} + R_{E1})C_{31} - R_{21}C_{32} \quad (3)$$

$$S_{32} = (R_{21} + R_{E2})C_{32} - R_{12}C_{31} \quad (4)$$

and the percentage of the emitted tracer that actually enter the house, hereby referred to as the fractional penetration, is given by

$$f_p = [(S_{31} + S_{32})/S_3]\times 100 \quad (5)$$

Using these techniques, sixty homes were studied - 15 in each of four areas in New York State, USA, in a program sponsored by the New York State Energy Research and Development Agency. All homes had either a basement or a crawl space. Figure 1 shows the experimental schematic for the determination of multizone radon source rates and a cutaway view of the probe used to emit the PFT into the soil. A two zone house is pictured there although some houses were separated into three zones by floor.

Measurements began in January of 1986 and lasted for 2-7 weeks depending on the house.

Zonal radon concentrations were determined with alpha-track detectors while multizone ventilation rates were measured using the constant emission, multiple PFT method. These techniques have been described elsewhere (1,2). Data was also collected on soil permeability and radium content for each of the sixty homes.

Results and Discussion

Table 1 lists the arithmetic mean, geometric mean and the median whole house radon source rate and average air exchange rate for each geographic region and for the entire group of homes. A plot showing the distribution of radon source rates for all 60 homes is shown in Figure 2.

Table 1: Whole house radon source rates and air exchange rates for each geographic region (Bq/s $\simeq$ 100 nCi/h).

Geographic Area	Radon Source Rates (Bq/s) Arithmetic Mean ± SD	Geometric Mean	Median	Air Exchange Rates ± SD(hr^{-1})
1	16.50 ± 13.20	11.60	12.00	.494 ± .152
2	2.16 ± 2.10	1.39	1.35	.771 ± .599
3	12.10 ± 17.70	6.51	7.36	.551 ± .364
4	9.48 ± 8.67	6.48	7.35	.659 ± .425
All	10.00 ± 12.20	4.94	5.69	.623 ± .426

Variability of as much as an order of magnitude can be seen when comparing the average radon source rates of each geographic region. This is in contrast to a variability of less than 50% in the air exchange rates indicating that the differences between radon concentrations in homes come primarily from differences in the amount of radon entering the homes. This result has been noted previously (3).

Table 2 lists the average percentage of radon and of the buried tracer that appeared in the basement or crawl space (rather than in the living area) for each geographic region and for the entire group. As opposed to the whole house radon source rate values, these numbers are more likely to have high error bounds because of the large number of measurements necessary for their determination. However, the numbers generally show that most if not all of both the radon and the buried tracer enter these homes through the basement or crawl space. This would tend to indicate that soil gas flow into a basement or crawl space represents the only important source of radon in these homes. We did find one home where significant amounts of radon and of the buried tracer entered the living area directly. However, on second look, that home was found to be a split level home with the first floor in contact with the soil.

Table 2: Percentage of radon and of the buried tracer appearing in the basement or crawl space. Also listed is the fractional penetration of the buried tracer.

Geographic Area	Percentage of source rate from basement or crawl space: Radon	Buried Tracer	Fractional penetration of buried tracer
1	95.3 ± 25.2%	80.6 ± 18.5%	45.3 ± 27.6%
2	(1)	90.9 ± 12.9	65.2 ± 18.1
3	87.7 ± 29.3	85.4 ± 24.9	39.5 ± 32.6
4	88.6 ± 28.1	95.0 ± 21.7	65.6 ± 30.5
All	90.5 ± 27.1	88.6 ± 19.5	55.4 ± 29.2

(1) Radon concentrations too low to make this calculation meaningful.

Table 2 also lists the average fractional penetration of the buried tracer in each geographic region and for all homes studied. The average fractional penetration for all homes was found to be 55.4 ± 29.2% with a median value of 62%. Making certain geometric assumptions, one can calculate the fraction of the buried tracer that would be expected to enter a home if diffusion was the only mechanism by which radon entered the home from the soil. This fraction turns out to be approximately 40% - significantly lower than the measured value. Note also that this calculation assumes that the building envelope and the soil have the same resistance to air flow, which in most cases would certainly not be true. In sum, we can only conclude that pressure-driven flow of soil gas into the home must be an important radon entry mechanism in most of the homes studied.

The concept of using buried tracer permeation sources to mimic radon movement from the soil into the house has proved to be quite useful and easy to implement. This technique is currently being used to investigate the effectiveness of various radon mitigation methods by measuring the fractional penetration of the tracer both before and after mitigation.

References and Acknowledgment

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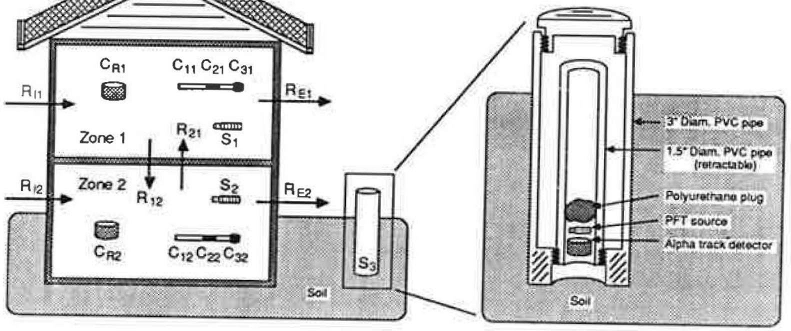

Figure 1. Schematic representation of the experimental system used to determine multizone radon source rates. Also shown is a cutaway view the apparatus used to release a tracer into the soil.

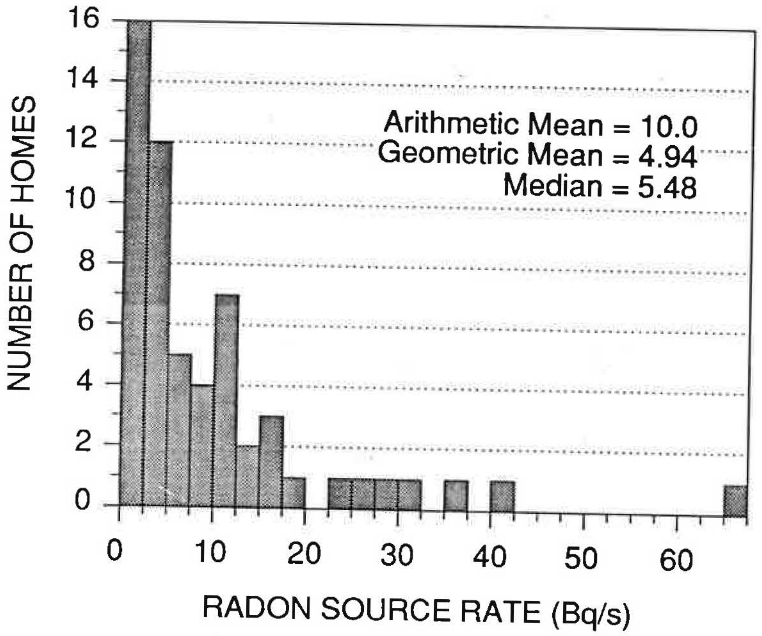

Figure 2. Frequency distribution of whole house radon source rates for 60 homes in New York State, U.S.A.

RADON LEVELS IN 300 HOUSES IN ROANE COUNTY, TENNESSEE*

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Abstract

In the winter of 1985 and summer of 1986, integrating radon monitors were placed in nearly 300 houses in a county in Eastern Tennessee (USA). Monitors were most frequently placed on top of the refrigerator in the kitchen but some were placed in basements. Average levels were higher in the winter than in the summer and levels were higher in basements than in other locations. Preliminary analysis of the spatial distribution of the radon results suggest that there is a significant clustering of houses with higher levels of radon.

Introduction

Since the discovery of American homes with levels of indoor radon progeny far in excess of the levels allowed in underground mines by governmental regulations, there has been greatly increased awareness of radon in residential environments. Homes with high levels of indoor radon have also been identified in Scandinavia. Underground miners exposed to radon progeny have experienced elevated incidence of fatal lung cancers and it is suspected that residential exposure may also lead to cases of lung cancer.

A study of indoor air quality has been completed in nearly 300 houses in a single county in Eastern Tennessee (USA). In addition to radon, combustion products, formaldehyde, polynuclear aromatic hydrocarbons, and energy conservation practices were surveyed during two seasons (Winter, 1985, and Summer, 1986).

Passive integrating monitors were used in this study to measure seasonal average levels of radon. Alpha track monitors (1) were obtained commercially (Terradex Corporation, Glenwood, IL 60425). During October and November, 1985, monitors were placed in 250 houses. In 32 houses, additional monitors were placed in the basement. During March and April, 1986, the above monitors were retrieved and monitors were placed in 285 houses. Monitors were placed in the basements of 40 houses at that time. During August, 1986, the monitors were retrieved. About 5% of the monitors returned to the vendor for analysis were unexposed blanks. The mean radon level detected in the blanks was 6.66 ± 3.33 Bq/m^3. About 5% of the monitors were utilized as replicates to estimate precision. The estimated standard deviation of measurements made with a single monitor is 55.5 Bq/m^3.

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