Soil Radon, Permeability, and Indoor Radon Prediction

DOUGLAS G. MOSE
GEORGE W. MUSHRUSH
CHARLES E. CHROSNIAK
Center of Basic and Applied Science
George Mason University
Fairfax, Virginia 22030, U.S.A.

ABSTRACT / Attempts to predict which geographic areas should be associated with a high percentage of homes with unusually high indoor radon levels have been based on estimates of soil radon and soil permeability for geological units. In northern Virginia and southern Maryland, it appears that predictions of indoor radon based on estimates of homesite soil radon and soil permeability are very useful.

Introduction

National interest in the relationship between the development of lung cancer and the concentration of radon in typical homes has greatly increased the amount of available indoor radon data (Kerr 1988; Alter and Oswald 1987; Cohen and Gromicko 1988; Nero and others 1986). This interest has developed because an estimated 8–25 percent of all current lung cancer deaths are thought due in part to past exposure to inhalation of airborne radon (Puskin and Yang 1988). This concern has intensified since the discovery that inhaled radon passes through the lungs to be dissolved in body fluids and tissues (Pohl and Pohl-Ruling 1967; Lykken and Ong 1989; Henshaw and others 1990) and consequently may initiate soft tissue cancers.

Attempts to identify areas wtih an unusually high number of homes that contain elevated indoor radon concentrations is a very popular activity. Health officials would like to concentrate their rather limited funds on these areas. Radon testing and home repair companies would like to concentrate their efforts in a cost-effective fashion. We have found the compilation of radon measurements from testing companies to be useful only in areas where abundant indoor radon measurements are already available (Mose and others 1988). Radon potential maps for areas with relatively few indoor radon measurements must rely on other measurable quantities, such as the physical and chemical properties of the material underlying the homes (Mose and others 1990a). We and others have examined several methods, most of which involve bedrock composition, soil radon, and soil permeability. This article will show that a combination of soil radon and soil permeability is probably the best indicator for detecting potential radon problems on a particular homesite.

Indoor Radon and Soil Measurements

The Center of Basic and Applied Science has been collecting seasonal indoor radon from over 1500 homes in Virginia and Maryland, starting with the winter of 1986–1987. Most of the indoor radon measurements are from homes in Fairfax County in northern Virginia and the immediately adjacent Montgomery County in southern Maryland. Very different geological materials underlay the area (Fig. 1). The Coastal Plain Province consists of poorly cemented sand and clay strata that were deposited during the opening of the modern Atlantic Ocean, which began about 130 million years ago. The Culpeper Basin is an ancient rift valley that formed between about 190 and 170 million years ago and now contains basaltic rock and sandy sedimentary rocks. The Piedmont Province is composed of crystalline rocks that formed a great depth when the Appalachian Mountains were created about 600–300 million years ago and were exposed by slow uplift and erosion.

Homeowners in this study were provided with a series of alpha-track indoor radon monitors (type SF indoor radon monitor, Tech/Ops Landauer Corporation). Each alpha-track monitor was left in place for three months. At the 90 percent confidence level, these alpha-track monitors carry a ±25 percent uncertainty; were a single three-month measurement to be used to estimate the average year-long radon concentration, it would carry a ±50 percent uncertainty (Mose and others 1990b).

The three-month exposure intervals were selected so as to examine seasonal variations. The winter exposure interval was November, December, and January during the winters of 1986–1987 and 1987–1988. The spring exposure was February, March, and April of 1987 and 1988. The summer exposure interval was May, June, and July of 1987 and 1988, and the fall exposure was August, September, and October of 1987 and 1988. Although not all homeowners started their year of radon measurement in the same season, each home was provided with a sequence of four alpha-track indoor radon monitors to measure all four seasons. Homeown-

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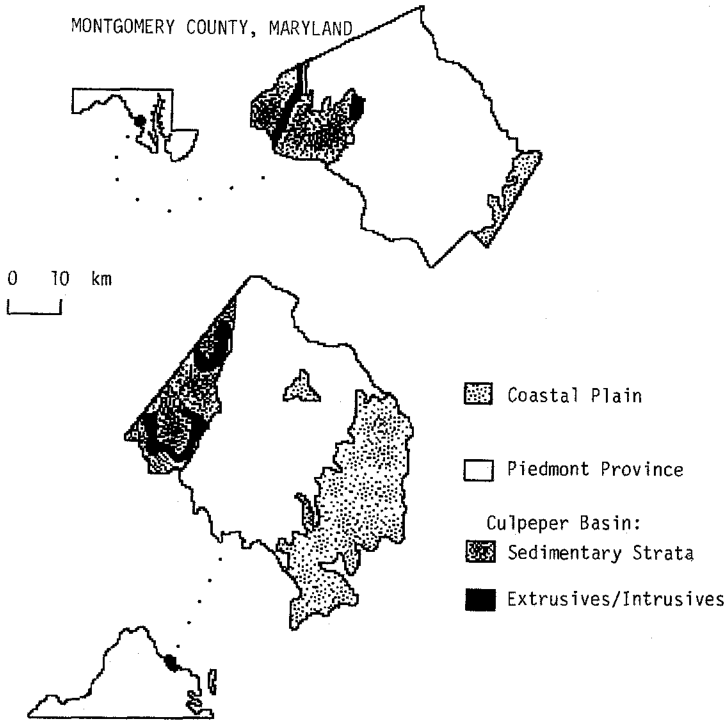

Figure 1. Geological provinces in Montgomery County, Maryland, and Fairfax County, Virginia.

Table 1. For each season, percentage of homes that recorded their highest seasonal indoor radon concentration[a]

County	Number of homes	Time of highest indoor radon concentration (% of homes)			
		Winter	Spring	Summer	Fall
Fairfax County, VA	689	41	18	12	29
Montgomery County, MD	202	32	21	12	30
Fairfax and Montgomery	891	39	19	12	30

[a]Compilation taken from homes that successfully completed four seasons of basement radon measurements.

ers were advised that due to natural variations, individual homes require a full year of testing (Fleischer 1988; Scott 1988; Hess and others 1985). Unfortunately, some scientists conducting regional surveys involving the homes of relatively uninformed citizens have not adequately stressed this problem to the homeowner participants in their studies.

A compilation of basement radon data shows that the winter season tends to be the season of highest indoor radon (Table 1). Winter measurements tend to be taken during the time when the home is most often closed and therefore least affected by the low-radon outside air. A detailed compilation of the measurements (Table 2) shows that basement measurements in the winter tend to be about 50 percent higher than first-floor measurements, in terms of the average radon, median indoor radon, and the percentage of homes over 4 pCi/l. We believe that the radon characteristics of our study group are similar to that of the entire Fairfax County and Montgomery County population, in that about 35 percent of the community have basement annual (i.e., year-long average) indoor radon above 4 pCi/l, and about 20 percent have first floor annual radon above 4 pCi/l. In the study area a relatively large portion of the approximately 1 million people who live in the study area reside in their home for less than five years, and the prevalence on indoor radon has affected the home-sales and home-loan markets.

As shown in Tables 1 and 2, about 75 percent of the study participants occupy homes in Fairfax County, Virginia. Since most of our indoor and soil radon measurements are from Fairfax County, the following dis-

Table 2. Compilation of seasonal indoor radon measurements[a]

Season and county	Number of homes	Radon (pCi/l)		% over		
		Average	Median	4 pCi/l	10 pCi/l	20 pCi/l
Basement indoor radon measurements						
Winter						
Fairfax Co., VA	844	4.4	3.2	38%	6%	1%
Montgomery Co., MD	293	4.9	3.1	40	11	2
Spring						
Fairfax Co., VA	829	4.1	3.0	33	5	1
Montgomery Co., MD	242	4.7	3.1	36	9	2
Summer						
Fairfax Co., VA	927	3.3	2.5	24	2	0
Montgomery Co., MD	323	3.6	2.7	27	4	2
Fall						
Fairfax Co., VA	898	4.2	3.2	35	4	1
Montgomery Co., MD	307	4.4	3.2	36	9	1
First-floor indoor radon measurements						
Winter						
Fairfax Co., VA	180	3.1	2.2	21%	3%	0%
Montgomery Co., MD	35	4.4	3.6	35	10	3
Spring						
Fairfax Co., VA	132	2.8	1.9	18	3	0
Montgomery Co., MD	33	5.1	2.2	23	11	4
Summer						
Fairfax Co., VA	133	2.8	1.8	15	1	0
Montgomery Co., MD	44	2.3	1.7	17	0	0
Fall						
Fairfax Co., VA	131	3.1	2.3	20	0	0
Montgomery Co., MD	41	3.3	2.5	30	0	0

[a]In this table, the basement has one or more soil-facing walls, and first-floor has no soil-facing walls.

cussions will emphasize Fairfax County. Although fewer data are available for the Montgomery County, Maryland, portion of our study, the observations that will be made for Fairfax County generally apply to the homes in Montgomery County.

To explore the possible correlation between indoor radon and soil radon, alpha-track monitors were deployed to measure indoor as well as soil radon. Comparisons between soil radon and indoor radon using data from alpha-track monitors and exposure intervals of several months are very rare (Brookins 1986, 1988). Virtually all the available studies were conducted with soil probes that measure soil gas radon (and estimate permeability) over only a few minutes (Tanner 1988). Unfortunately, the radon emanation depends on several factors other than the radon concentration of the soil and its permeability. Most of these other factors are related to variations in weather, which change the amount of soil moisture, soil temperature, and atmospheric confining pressure (Rose and others 1988; Luetzelschwab and others 1989). Since measurements using soil probes are only momentary estimates of the radon emanation of a soil, the study reported in this article utilized only alpha-track monitors to estimate the radon content of the soil, and the exposure intervals were one to three months. Soil radon measurements (type SM soil radon monitor, Tech/Ops Landauer Corporation) and soil permeability measurements were made at 150 of the study homes for which we have indoor radon measurements.

It is intuitively obvious that soil permeability also should be examined. Several studies have shown that radon and other soil gases flow more rapidly as the sorting and grain size increase (Tanner 1964). To approximate the soil permeability at each home site, the homeowners who obtained a soil radon monitor were provided with directions for making a simple percolation (i.e., infiltration) test. The homeowners were asked to bury the soil radon monitors in a 2-ft hole, between 5 and 20 ft from the home; when the monitors were later exhumed for analysis, the homeowner made the percolation test. This test consisted of filling the hole with water, letting this water soak into the soil, and then pouring 1 gal of water into this presoaked hole. The homeowner was asked to note the time required for the water to soak into the soil, and the diameter of the hole

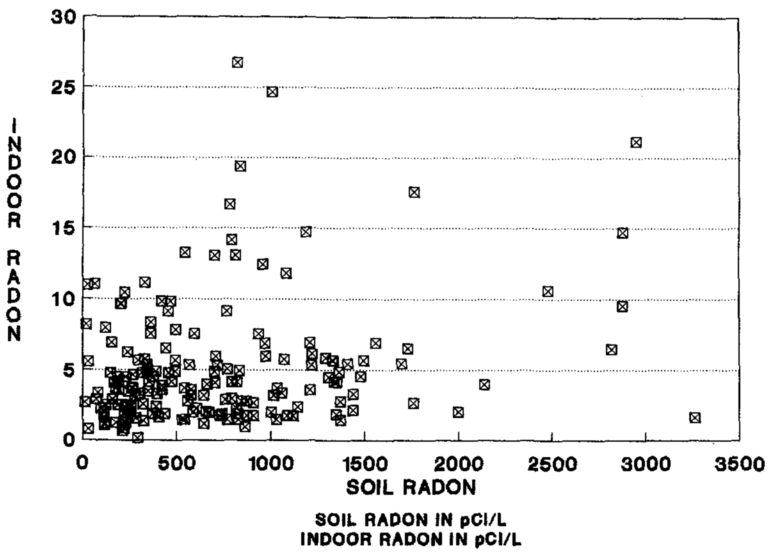

Figure 2. Comparison between basement indoor radon measurements and soil radon measurements, using the subset of 150 homes for which both measurements were obtained.

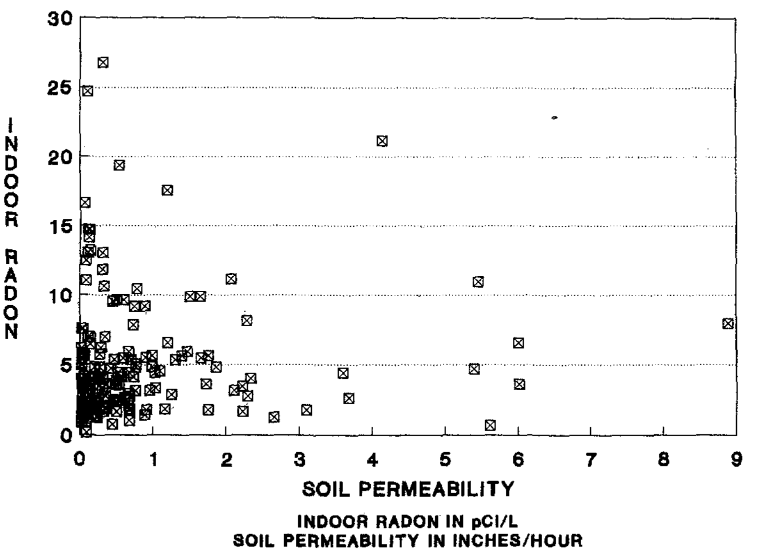

Figure 3. Comparison between basement indoor radon measurements and soil permeability measurements.

(most were about 6 in.). The soil permeability measurement was therefore a measure of the rate of water flowing through the surface of a hole against which the 1 gal of water was poured and was recorded as inches per hour.

Indoor Radon and Site-Specific Measurements

The median ratio between the soil radon and the indoor radon for this subset of homes with both indoor and soil radon measurements was about 150:1, but the individual soil-to-indoor ratios ranged from less than 10 to more than 2000 (Fig. 2). Similar trends were noted when comparing indoor radon and soil radon for particular seasons. Presumably this variation in soil-to-indoor ratios is due in large part to soil permeability, but other factors are probably important. The variation in soil-to-indoor radon ratios is, in fact, so severe that soil radon measurements alone can not reasonably be used to identify homesites that might have a potential indoor radon problem. Similarly, soil permeability alone can not serve to identify which homesites might have a radon problem (Fig. 3).

Figures 2 and 3 show that soil radon alone or soil permeability alone can not identify problem homesites. The assumption that there ought to be a tendency for indoor radon to increase if the soil radon and the soil permeability both increase caused us to hypothesize that both parameters could be combined into a simple-to-understand chart that could be used by home build-

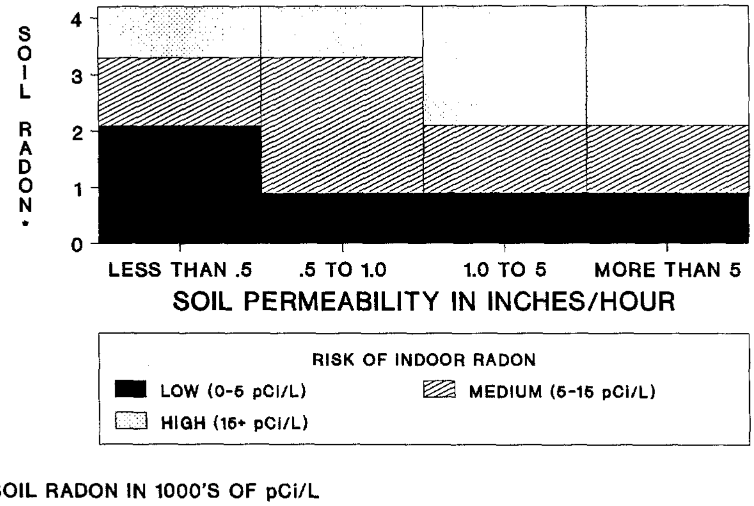

Figure 4. Indoor radon prediction chart, developed using soil radon and soil permeability measurements from homes measured for indoor radon.

Table 3. Summary of measurements used to develop the radon prediction chart (Figure 4)

		Predictions (%)			
Field of indoor radon prediction	Number of homes	Correct	Almost correct within 1 pCi/l	Too low	Too high
Less than 5 pCi/l	139	70	9	20	1
5–15 pCi/l	11	73	18	9	0
More than 15 pCi/l	1	100	0	0	0

ers and homeowners. Following a lengthy comparison between soil radon, soil permeability, and indoor radon, the chart shown in Figure 4 was constructed. The predictability using this chart is about 75 percent (Table 3).

The usefulness of a radon potential chart for a particular homesite, such as the chart shown in Figure 4, needs to be qualified. Our comparison of soil data and indoor radon data was developed from homes only in our northern Virginia and southern Maryland study area. In other areas, one might expect different soil-to-indoor relationships. In a colder climate, where homes are more insulated and windows less often opened, one would expect generally higher indoor radon values for particular soil radon values. The opposite would be true for a warmer climate. One might also predict that in a wetter climate, where more frequent rainfall more often "caps" the soil and prevents vertical escape of soil radon to the atmosphere, the indoor radon values would be greater.

Conclusion

Indoor radon measurements are now available for many populated areas in the United States, particularly in the states within the Appalachian Mountain system. Homeowner interest allowed the Center of Basic and Applied Science at George Mason University to gather several thousand indoor radon measurements for homes in northern Virginia and southern Maryland. These data, together with measurements of soil radon and soil permeability, have been examined to determine ways in which to predict indoor radon concentrations.

Studies of indoor radon, soil radon, and soil permeability at individual homesites show that neither soil radon alone nor soil permeability alone can adequately predict indoor radon. A combination of soil radon and soil permeability is quite effective using commercially available and homeowner-placed soil radon monitors and a simple water infiltration test. Since this conclusion was based on homeowner workmanship, which is of variable quality, and is based on only one soil radon and permeability test, we suspect that multiple measurements by a trained technologist would yield still higher indoor radon predictability.

Simple measurements are important to develop if a national reduction of indoor radon is to ever be a reality. The predictive methods that involve estimations of soil radon and soil permeability are most useful to homebuilders who wish to construct the home so as to anticipate problems and to homeowners who wish to estimate the cost of remediating a home with a radon problem. These predictive methods are also useful to determine if a home with presently low indoor radon might change as the home settles. If a homeowner can obtain a simultaneous measurement of soil radon and soil permeability, correct predictions about indoor radon can be made in the majority of homes.

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