1990_11

SUMMER TO SUMMER VARIATIONS IN INDOOR RADON

Paul DiBenenetto, Douglas G. Mose and George W. Mushrush

Center of Basic and Applied Science
George Mason University
Fairfax, VA 22030

Abstract

Indoor radon concentrations show a strong dependence on weather. Winter tends to be associated with higher than average indoor radon, and summer with lower than average. However, in northern Virginia, the summer of 1988 was wetter than the summer of 1987. Consequently, the regional indoor radon during the summer of 1988 was about 30% higher than during the summer of 1987, and indoor radon during the summer of 1988 actually exceeded the indoor radon level of the 1987-88 winter. Evidently care must be taken when attempting to estimate regional indoor radon concentrations, and homesite risk estimates should rely on long-term measurement intervals.

Key word index: summer precipitation, soil capping, alpha-track radon monitors, home heating system, radon and radon progeny, aeroradioactivity.

Introduction

The natural radioactive decay series beginning with Uranium-238 is the major source of natural radiation exposure in the environment. The most geologically significant uranium daughter is Radium-226, which precipitates in near-surface oxidizing conditions. Radium's daughter, radon, is a radioactive noble gas and is widely dispersed in the environment. Because of health implications, the early work on indoor radon has given rise to a broad range of research characterizing Radon-222 progeny and their occurence and control in inhabited structures (Nero, 1988). With the tendency for the gas to concentrate in buildings where air exchange is limited, radon is becoming identified as a major form of indoor air pollution.

National interest in the relationship between radon and lung cancer developed because an estimated 8 to 25 percent of all current lung cancer deaths are thought to be related to past inhalation of airborne radon (Puskin and Yang, 1988). The concern has intensified since the discovery that inhaled radon and its progeny pass from the lungs into the blood and body tissues (Pohl and Pohl-Ruling, 1967; Lykken and Ong, 1989; Henshaw and others, 1990), and may initiate many types of soft tissue cancers.

Soil and rock is the source of most radon to which people are exposed. The importance of soil as a source of indoor radon combined with the increasing evidence of unacceptably high radon concentrations in a significant fraction of houses has been discussed in several Virginia and Maryland studies (Mose and Mushrush, 1988; Mose et al., 1988, 1989; Mushrush and Mose, 1988a,b). These studies are designed to predict, on a geological basis, where high indoor radon levels might be found. Homes with high levels of indoor radon have also been discovered in many parts of the Appalachain Mountain system (Fleischer et al., 1982; Moschandreas and Rector, 1982; Hess et al., 1982, 1983, 1985; George and Eng, 1983; Fleischer and Turner, 1984; Froelich and Pearson, 1988; Muessig and Bell, 1988; Rose et al., 1988; Washington, 1988; Watson et al., 1988; Luetzelschwab et al., 1989; Smith and Hansen, 1989; Perritt et al., 1990). These and other studies in other areas have shown that geology, seasonal weather changes and home construction can each contribute to elevated indoor radon levels (Alter and Oswald, 1987; Sextro et al., 1987; Cohen and Gromicko, 1988; Buchli and Burkart, 1989; Crameri et al., 1989; Dudley et al., 1990; Steck, 1990).

The Center of Basic and Applied Science at George Mason University is conducting an in-depth regional survey in Fairfax County in Virginia. One aspect of this survey is an estimation of year-to-year variations of the indoor radon signature for the study area. This paper reports on the indoor radon characteristics of homes during the summers of 1987 and 1988, and comments on how the differences are caused by weather.

The Indoor Radon Study of the Center of Basic and Applied Science is available to all interested homeowners in Virginia and Maryland. About 70% of the current participants are in Fairfax County, Virginia located on the southwest and northwest margin of Washington, DC. About 30% are in the surrounding counties in Virginia and Maryland. The following discussion will discuss the indoor radon concentrations within Fairfax County (Fig. 1).

Fairfax County is composed of rock units of the Coastal Plain, the Culpeper Basin and the Piedmont Province. The Coastal Plain Province is present along the eastern edge of the study area. It consists of poorly cemented clastic sedimentary strata, mostly layers of clay and sand, that were deposited during the opening of the modern Atlantic Ocean. These deposits were formed between about 130 million years ago and the present. The western margin of the study area is part of the Culpeper Basin, a fault-bounded valley containing terrestrial clastic rocks (siltstone, sandstone, conglomerate) along with extrusive and intrusive igneous rocks (basalt and diabase) that were deposited during the Mesozoic Era, about 190-150 million years ago. The Piedmont Province extends from Maine to Georgia, and rock units of this province underlie most of the central part of the Virginia study area. These rock units are composed of metamorphic and igneous rocks that were formed when the Appalachian Mountains were created during the Paleozoic Era, about 600-300 million years ago.

Methodologies

The measurement of airborne radioactivity in homes is normally reported in terms of radon concentration. This is somewhat confusing to homeowners, who learn that most inhaled radon is almost immediately exhaled, and that it is the polonium daughters of radon that mainly contribute to the lung cancer risk. The observed indoor concentration of Rn-222 and its progeny depends on three factors: the entry or production rate from radium in the source material, the ventilation rate, and the rate of Rn-222 decay. Because of radium's long half life and lack of chemical reactivity, Rn-222 itself acts much like a stable pollutant whose concentration can be determined by a comparison of the entry and ventilation rates. The decay product concentration is somewhat more complex, but, as a practical matter, the decay product concentration is indicated approximately by the overall radon concentration. By convention radon concentrations are reported, because in a home the radon-to-radon progeny ratio is relatively constant. This is unlike a mine, where rock releases radon and not radon progeny, and the radon-to-radon progeny ratio is very dependent on the rates of ventilation and rock removal.

The indoor radon monitors used in this study are from the Tech/Ops Landauer Corporation in Illinois. They are called "alpha-track monitors" and are of a type long used for geological investigations (Hess et al., 1985; Alter and Oswald, 1987). With an adequate soil shield, they have been used for hydrocarbon exploration and earthquake prediction, and in the search for uranium and gold. The indoor radon monitors do not require the "soil shield," which is a permeable membrane required on soil monitors to keep out Rn-219 and Rn-220. These radon isotopes fortunately have very short half-lives and are not found in indoor air. The indoor radon monitor does have a dust filter, through which the radon can pass. A fraction of the radon produces alpha particles that penetrate the small square of plastic film inside the monitors, and produce alpha-tracks that are enhanced by chemical etching.

The nuclear tracks recorded on the small square of plastic film inside these monitors are not affected by normal variation in home humidity and temperature, and the dislocation sites (more commonly called alpha-tracks) are permanently recorded on the film. The humidity and temperature insensitivity and the permanent record keeping are probably the major advantages of the alpha-track monitors. The inexpensive alpha-track monitors with their small fragment of film require at least one month for enough tracks to accumulate in a typical home to generate a useful measurement. Estimates of analytical uncertainty for the alpha-track monitors are related to the measurement interval, so intervals of three months to a full year are often utilized. In the following study, three month exposure intervals were used. At the 90% confidence level, these alpha-track monitors carry a +/- 25% uncertainty for the three month measurement interval, and a +/- 50% uncertainty if used to estimate the average year-long indoor radon concentration.

At the end of each seasonal interval, the homeowner is sent a quarterly report concerning the radon "picture" in Virginia and Maryland during the previous quarter, and a request to send in their exposed monitor. Homeowners who have not finished their series of four monitors are also sent their next monitor.

Results

In northern Virginia and southern Maryland, the local weather is monitored by about 300 volunteer weather stations. The weather reports are compiled by the National Oceanic and Atmospheric Administration, and distributed as monthly summaries. According to the weather summaries for the summer intervals, the summers of 1987 and 1988 had essentially the same maximum temperatures and average atmospheric pressures, but the summer of 1988 had about 20% more precipitation (Table 1). Although there is some disagreement on the effect of rainfall, we think that when the land surface is capped with intergranular water, soil radon cannot move vertically and escape directly from the soil to the atmosphere. When radon accumulates in the soil around a home, below this near-surface layer that is saturated with water, one would expect that indoor radon would increase.

An overview of the seasonal indoor radon variations can be seen by compiling basement radon measurements in Fairfax County (Table 2). Although it is commonly thought that indoor radon is always at its greatest concentration during the winter (Mose and Mushrush, 1988), this is clearly not always the case. The data show that the summer of 1988 had a higher regional indoor radon level than the winter of 1987-88. The increase in regional indoor radon from the summer of 1987 to the summer of 1988 was so extreme that the median indoor radon increased by almost 50% and the percent of homes over 4 pCi/l almost doubled.

The extent to which each geological unit contributed to this summer-to-summer increase in indoor radon provides a better estimate of the regional increase in radon. From a geologist's point of view, the study area is very useful (Fig. 2). There is a large diversity of rock units which includes poorly consolidated sediments, sedimentary rocks, igneous rocks and metamorphic rocks. Considering this great diversity, the summer-to-summer increase is surprisingly uniform (Table 3).

Other comparisons can be made using home construction factors. Most of the area homes have basements with walls composed of concrete blocks or poured concrete. Earlier studies have shown that basements with concrete block walls tend to have higher indoor radon concentrations (Mose et al., 1988; Mushrush and Mose, 1988b). This is presumably because the blocks are joined by mortar which tends to crack, allowing soil gas enriched in radon to enter. A review of the summers of 1987 and 1988 shows this difference (Table 4). Apparently the effect of basement wall construction persists during the summer, even though the summer is the interval when windows are most frequently left open to admit cooling (and low-radon) outside air.

Another comparison involves the type of home heating system. Most homes have either a gas or oil furnace or use electrical heat, normally in the form of a heat pump. Earlier studies had shown that the electrical heating system homes tend to have higher indoor radon concentrations (Mose et al., 1988; Mushrush and Mose, 1988b). This is presumably because homes with a furnace develop a partial vacuum within the home when the furnace operates, and this partial vacuum draws into the home more radon-poor outside air than radon-enriched soil air. However, although the homes are not heated during the summer, a review of the summers of 1987 and 1988 again shows that homes with electrical heating systems have higher indoor radon, particularly during the second summer (Table 5).

Since homes are usually not heated during the summer, the higher summer indoor radon in the group with electrical heating systems probably occurs because heat pumps are commonly used for whole-home cooling during the summer. When a house is closed to preserve cooled air, indoor radon derived from the underlying soil increases.

Discussion

The summer-to-summer variation is particularly important for scientists who are currently trying to identify radon problem areas and to develop what have been called radon potential maps. It now appears that if indoor radon measurements are used to develop maps for adjacent areas, the work should be conducted by using measurements from a single season and not by using measurements from different seasons. For example, the U.S. Geological Survey (Otton et al., 1988) has recently published a radon potential map for Fairfax County (Fig. 3). As shown in Table 6, the correlation between the U.S.G.S. Radon Potential Number (first column on Table 6) and the indoor radon for each set of homes is rather good. However, this may not have been the case if the radon measurements had been conducted in different seasons, or during the same season in different years in different parts of the county. As shown in Table 6, the radon relationship to each U.S.G.S. Radon Potential Number is much higher for the summer of 1988 compared to the summer of 1987.

The problem of seasonal changes in indoor radon has some implications for the federal and state radon surveys that are currently being conducted, particularly if the season to season change noted in the present study is typical. One implication is that if two areas (e.g., state or county size areas) which in fact have the same radon potential are tested for indoor radon during different seasons, they will probably be seen to have different indoor radon potential. This now appears to be true, even if the same season was used but in different years. Furthermore, if soil radon varies with weather in the same way that indoor radon does, it appears likely that radon potential maps based on soil radon characteristics (e.g. Otton et al., 1988) would apply most directly to intervals when the weather simulates the conditions that prevailed when the soil characteristics were compiled. Alternatively, it would be necessary to develop several radon potential maps, corresponding to times of cool and wet weather, warm and dry weather, and so on. To create national or regional radon potential maps based on soil characteristics that relate particular radon potential numbers to particular median radon levels or to a particular percentages of homes over 4 pCi/l, it would be necessary for the entire map area be examined under similar weather conditions. To whatever extent the weather conditions varied throughout the area of a radon potential map during the time of soil characterization, the map will contain inherent inaccuracies that over- or underestimate the relative radon potentials.

Another type of radon potential map uses surface radioactivity, measured from an airplane (Mose et al, 1988).
An aeroradioactivity map is available for Fairfax County (Fig. 4). As shown in Table 7, an increase in aeroradioactivity compares well with an increase in indoor radon. However, the comparison for the summer of 1987 is quite different from the summer of 1988. It is obvious that had the areas underlain by

the more radioactive rocks (mostly in the western parts of the county) been examined for indoor radon during the summer of 1988, and the less radioactive area during the summer of 1987, the correlation between aeroradioactivity and indoor radon would potentially have been seen as being quite different.

Relatively few characterizations of soil over a large area can actually be made during a single season. The only characterization of which the authors are aware is aeroradioactivity, in that several hundred square kilometers can be measured in a week, and several thousand square kilometers can be measured in a single season. We therefore recommend that should regional radon potential maps be constructed by state and federal agencies, strong consideration should be given to first obtaining regional spectral aeroradioactivity data using 5 to 10 kilometer wide flight-line spacings (or less). A map of this type provides a mechanism to compare widely separated areas. This would be followed by data aquisition using 1/2 to 1 kilometer flight-line spacing, as was done for Fig. 4, to accurately determine relative radon potential on a local scale. In this fashion, regional radon potential maps can be constructed that do not contain seasonal bias caused by varying weather conditions.

Conclusion

The indoor radon concentrations in several hundred homes in northern Virginia show a strong dependence on weather conditions. A comparison between the indoor radon signature of the study area during the summers of 1987 and 1988 shows generally higher levels of radon during the second summer, based on comparisons using geological units, basement wall construction and home heating system. The higher levels of indoor radon apparently occurred because the summer of 1988 had more rainfall, which prevented a significant amount of soil radon from escaping directly to the atmosphere.

Prior to the present study, only two reports examined season-to-season variations. Hess et al. (1985) found a measurable difference by comparing indoor radon in about 60 homes during the 1980-81 winter with about 60 homes during the 1981-82 winter. Our study of indoor radon in northern Virginia reaches a similar conclusion, but is based on several hundred homes, under well documented weather changes. The other paper is by Mose et al. (1989), and it compared well documented weather conditions with indoor radon, during the winters of 1986-87 and 1987-88. In this study, as in the present report, indoor radon is seen to be related to the amount of rainwater (or snow), which "caps" the ground, and increases the soil radon available to move horizontally into homes.

One implication of seasonal variations involves the estimation of annual radiation dose related to radon. It now appears that during some intervals, when rainfall is unusually low, indoor radon is reduced. Intervals with more precipitation would be characterized by a higher indoor radon signature. However, as shown in our study, one might find that dry winter conditions and wet summer conditions could result in similar radiation dose. To realistically estimate variations in the annual radiation dose for a large area like a county or state, it would be necessary to create a series of maps which present the radon situation for several combinations of temperature and precipitation.

The discovery of significant summer-to-summer variations, and the observation that sometimes the winter can closely simulate a summer in terms of indoor radon, indicates that single season measurements may not be very useful. This is apparent, even if the season of measurement is the winter. This reinforces the idea that "closed-home" conditions which are thought to simulate winter conditions can sometimes incorrectly estimate the annual dose, and that single short-term measurements under this condition should be interpreted with caution.

Perhaps the most important conclusion is that it is very difficult to predict lifetime health risks due to exposure to radon based on a measurement of a single week, a single season, or even an entire year. It is becoming increasingly obvious that seasonal and year-to-year variations in weather play an important role in determining the exposure to indoor radon. The best approach is probably the regular placement of alpha-track indoor radon monitors, used with one year exposure intervals. In this fashion, the home occupant accumulates a permanent record of radon exposure, and can detect and rectify unanticipated increases in indoor radon.

References

Alter H.W. and Oswald R.A. Nationwide distribution of indoor radon measurements, a preliminary data base. Journal of the Air Pollution Control Association 37:227-331;1987.

Buchli R. and Burkart W. Influence of subsoil geology and construction technique in indoor air Rn-222 levels in 80 houses of the central Swiss Alps. Health Physics 56:423-429;1989.

Cohen B.L. and Gromicko N. Variation of radon levels in U.S. homess with various factors. Journal of the Air Pollution Control Association 38:129-134;1988.

Crameri, R. Brunner, H. Buchli, R. Wernli, C. and Burkart, W. Indoor Rn levels in different geological areas in Switzerland. Health Physics 57:29-38;1989.

Daniels D.L. Geophysical-geological analysis of Fairfax County, Virginia: U. S. Geological Survey, Report 80-1165: 1-64;1980.

Dudney C. and Hawthorne A. Radon-222, Rn-222 progeny, and Rn-220 progeny levels in 70 houses. Health Physics 58:297-311;1990.

Fleischer R.L., Mogro-Campero A. and Turner L.G. Fleischer, R.L., Mogro-Campero, A. and Turner, L.G. Indoor radon levels - Effects of energy-efficiency in North Carolina Homes. Environmental. International 8:105-109;1982.

Fleischer R. L. and Turner L. G. Indoor radon measurements in the New York capitol district. Health Physics 46:999-1011;1984.

Froelich A.J. Folio of geologic and hydrologic maps for land use planning in the Coastal Plain of Fairfax County and Vicinity, Virginia. U.S. Geological Survey Miscellaneous Investigations Series Map I-1423;1985a.

Froelich, A.J. Map and geotechnical properties of surface materials of the Culpeper basin and vicinity, Virginia and Maryland: U.S. Geol. Survey Miscellaneous Investigation Series, Map I-1313-E;1985b.

Froelich R.K. and Pearson C.A. Potential radon hazard in Rhode Island estimated from geophysical and geological surveys. Northeastern Environmental Science 7:30-34;1988.

Froelich A.J. and Zenone C. The relation of water quality to geology and land use changes in Fairfax County and vicinity, Virginia. U.S. Geological Survey Miscellaneous Investigation Series Map I-1561;1985.

George A.C. and Eng J. Indoor radon measurements in New Jersey, New York and Pennsylvania. Health Physics 45:374-400;1983.

Henshaw D.L., Eatough J.P. and Richardson R.B. Radon as a causative factor in induction of myeloid leukaemia and other cancers. The Lancet 335:1008-1012;1990.

Hess C.T., Weiffenbach C.V. and Norton S.A. Variations of airborne and waternborne Rn-222 in houses in Maine. Environmental International 8:59-66;1982.

Hess C.T., Weiffenbach C.V. and Norton S.A. Environmental radon and cancer correlations in Maine. Health Physics 45:339-348;1983.

Hess C.T., Fleischer R.L. and Turner, L.G. Field and laboratory tests of etched track detectors for Rn-222: Summer vs. winter variations and tightness effects in Maine houses. Health Physics 49:65-79;1985.

Leavy B.D., Froelich A.J. and Abram E.C. Bedrock map Leavy B.D., Froelich, A.J. and Abram, E.C., 1983, Bedrock map and geotechnical properties of rocks of the Culpeper Basin and vicinity, Virginia and Maryland: U.S. Geological Survey Miscellaneous Investigation Series, Map I-1313-I;1983.

Luetzelschwab J.W., Helweick K.L. and Hurst K.A. Radon concentrations in five Pennsylvania soils. Health Physics 56:181-188;1989.

Lykken G.I. and Ong W.S. Evidence of exhalation of stored environmental Rn determined by whole-body counting. Health Physics 57:161-162;1989.

Moschandreas D.J. and Rector H.E. Indoor radon concentrations. Environment International 8:77-82;1982.

Mose D.G. and Mushrush G.W. Regional levels of indoor radon in Virginia and Maryland. Environmental Geology and Water Sciences 12:197-201;1988.

Mose, D.G., Mushrush G.W. and Kline S.W. The interaction of geology, weather and home construction on radon in northern Virginia and southern Maryland. Northeastern Environmental Science 7:15-29;1988.

Mose D.G., Mushrush, G.W. and Kline, S.W. Winter-to-winter variations in indoor radon.: Journal of Toxicology and Human Health 28:129-150;1989.

Mose D.G., Mushrush G.W. and Chrosniak, C.E. Reliability of inexpensive charcoal and alpha-track radon monitors: Natural Hazards, in press.

Muessig K. and Bell, C. Use of airborne data to direct testing for elevated indoor radon: Northeastern Environmental Science 7:45-51;1988.

Mushrush G.W. and Mose D.G. Regional variation of indoor radon over three seasons. Environmental Toxicology and Chemistry 7:879-887;1988a.

Mushrush G.W. and Mose D.G. The effect of home construction on indoor radon in Virginia and Maryland. Environment International 14:395-402;1988b.

Nero A.V. Jr. Radon and its decay products in indoor air: An overview. In Nazaroff W.W. and Nero A.V. Jr (eds): "Radon and Its Decay Products in Indoor Air." New York: Wiley-Interscience, 1988:1-56.

Obermeier S.F. and Langer W.H. Relationships between geology and engineering characteristics of soils and weathered rocks of Fairfax County and vicinity, Virginia. U.S. Geological Survey Professional Paper 1344 1986:1-30.

Otton J.K., Schumann R.R., Owen D.E., Thurman N., and Rice C.A. Map showing radon potential of rocks and soils in Fairfax County, Virginia. U.S. Geological Survey Miscellaneous Investigation Series, Map MF-2047;1988.

Perritt R., Hartwell T., Sheldon L., Cox B., Clayton C., Jones S. and Smith, M. Radon-222 levels in New York State homes. Health Physics 58:147-155;1990.

Pohl E. and Pohl-Ruling, J. The radiation dose received by inhalation of air containing Rn222, Rn220, Pb212 (ThB) and their decay products. Annals da. Academia de Ciencias 39, 393-404;1967.

Puskin J.S. and Yang Y. A retrospective look at Rn-induced lung cancer mortality from the viewpoint of a relative risk model. Health Physics 54:635-643;1988.

Rose A.W., Washington J.W. and Greeman, D.J. Variability of radon with depth and season in a central Pennsylvania soil developed on limestone. Northeastern Environmental Science 7:35-39;1988.

Sextro R.G., Moed, B.A., Nazaroff W.W., Revzan K.L. and Nero, A.V. Investigations of Soil as a Source of Indoor Radon. In Hopke P.K. (ed): "Radon and its Origins." ACS Symposium Series 331 1987:10-29.

Smith D.L. and Hansen J.K. Distribution of potentially elevated radon levels in Florida based on surficial geology. Southeastern Geology 30:49-58;1989.

Steck D. A comparison of EPA screening measurements and annual Rn-222 concentrations in statewide surveys. Health Physics 58:523-530;1990.

Washington P.A. Proper scaling of radon surveys, a perspective based on natural radon sources in southern Vermont. Northeastern Environmental Science 7:40-44;1988.

Watson J.E. Jr., Adams W.C., Xie Y. Fong S.W. and Newman H.J. Survey of Rn-222 in North Carolina Homes. Health Physics 55:71-75;1988.

Figure Captions

Figure 1. Map showing the geological provinces in Fairfax County.

Figure 2. Map showing the geological units in Fairfax County, compiled from the reports of Leavy et al. (1983), Froelich (1985a, 1985b), Froelich and Zenone (1985), and Obermeier and Langer (1986). Index to symbols: 1= Coastal Plain sedimentary strata, 2= Piney Branch Complex (mafic and ultramafic intrusions), 3= Unnamed mafic and ultramafic inclusions, 4= Occoquan Granite, 5= Falls Church Tonalite, 6= Sykesville Formation (metasedimentary melange), 7= Indian Run Formation (metasedimentary melange), 8= Annandale Group (mica schist and metagraywacke), 9= Popes Head Formation (phyllite and metasiltstone), 10= Peters Creek Schist (mica schist, metagraywacke and phyllite), 11= Culpeper Basin diabase intrusions and basaltic extrusions, 12= Culpeper Basin sedimentary rocks.

Figure 3. Map showing areas of low, intermediate and high potential for indoor radon problems (modified from Otton et al., 1988; on the original map, "lowest" is areas 1 and 2, "intermediate" is areas 3 and 4, and "highest" is area 5).

Figure 4. Map showing areas of lowest, intermediate and highest aeroradioactivity (modified from Daniels, 1980; on the original map, "lowest" is where the total-gamma count was less than 200 counts per second, "intermediate" is where the count was between 200 and 400 c.p.s., and "highest" is where the count was over 400 c.p.s.).

Figure 1

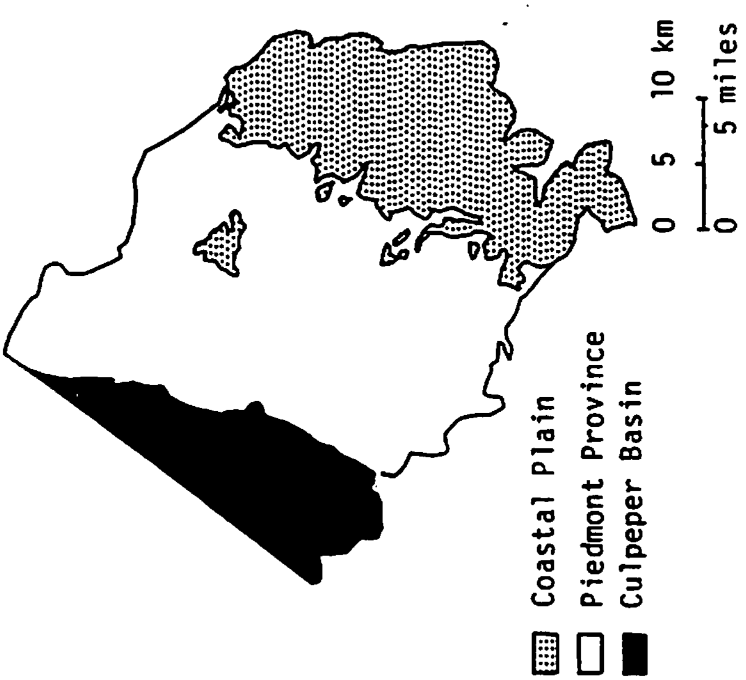
▨ Coastal Plain
☐ Piedmont Province
■ Culpeper Basin
0 5 10 km
0 5 miles

Figure 2

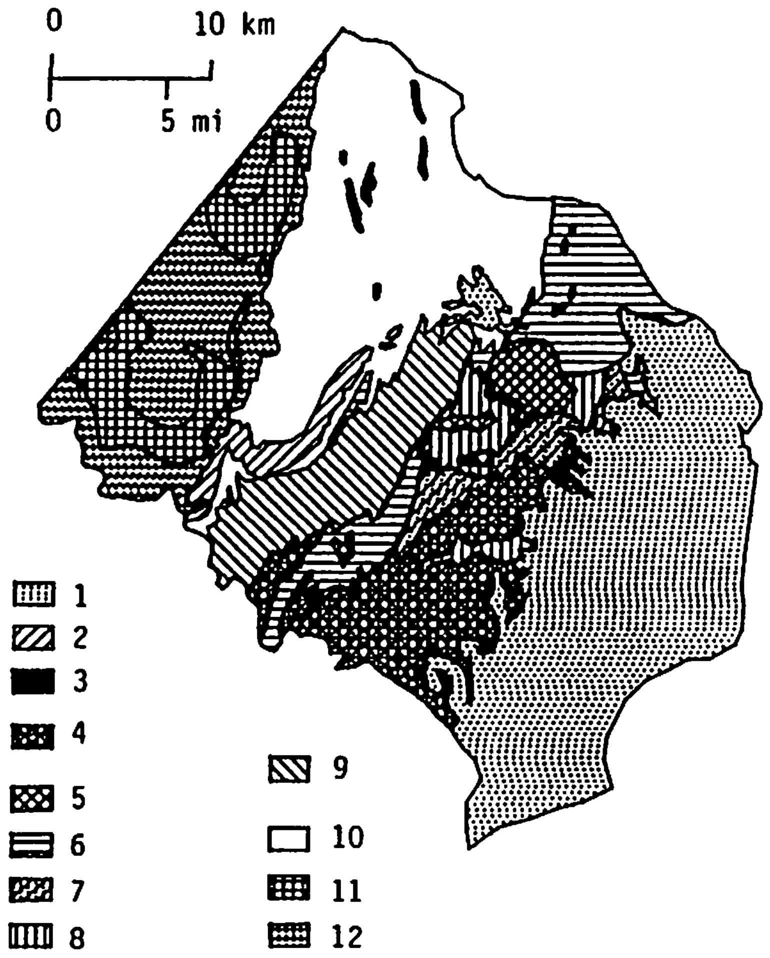

Figure 3

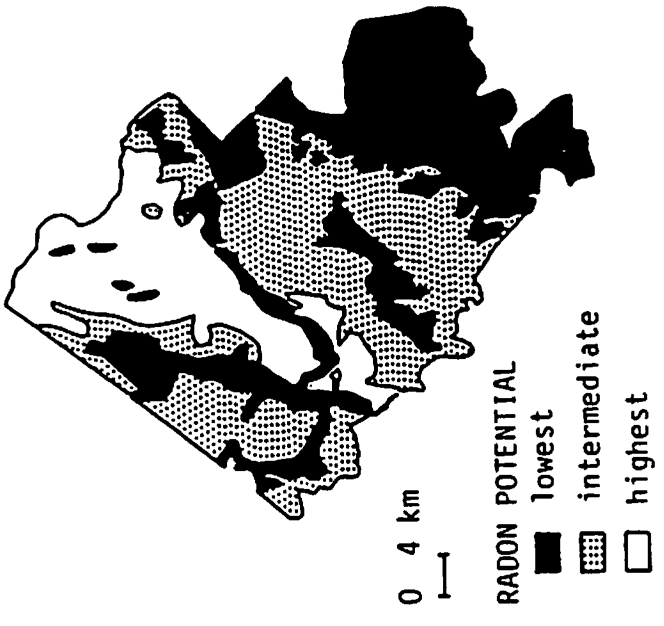

Figure 4

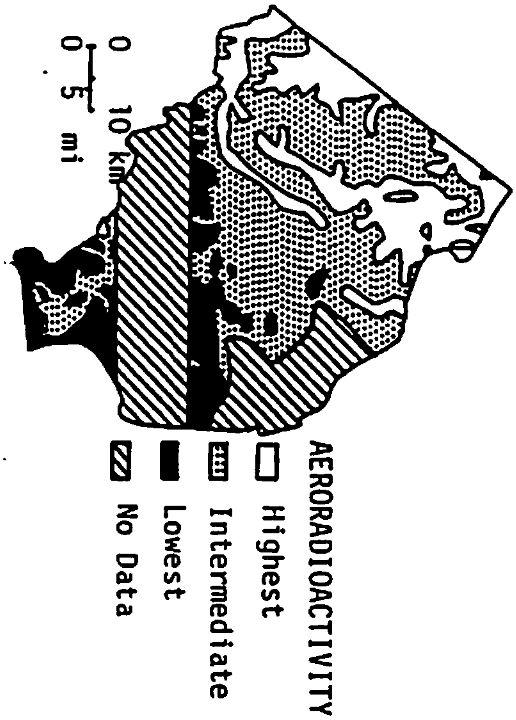
0 10 km
0 5 mi
AERORADIOACTIVITY
Highest
Intermediate
Lowest
No Data

Table 1. Compilation of weather conditions during 1987 and 1988.

Note: This chart was generated from monthly weather summaries titled METROPOLITAN WASHINGTON CLIMATE REVIEW that cover Fairfax County, Montgomery County and adjacent areas. These summaries are available at no charge from: Cooperative Program Branch W/OSO141X4, U.S.Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Silver Spring, MD 20910. The compilations in this table are averages, obtained using measurements from the Washington-National Airport, Baltimore-Washington Airport, and Washington-Dulles Airports.

Table 2. Seasonal indoor radon measurements in Fairfax County, Virginia.

Table 3. Summer indoor radon compilations for geological units in Fairfax County, Virginia.

Table 4. Comparison of basement wall construction with summer indoor radon.

Table 5: Comparison of home heating system with summer indoor radon. Note: In the study area, the electrical heating system is usually a heat pump. Homes with a heat pump normally use the device for whole home cooling in the summer. A small percentage of the homes with both a heat pump (used mainly for temperatures above 40 degrees Fahrenheit) also had an oil or gas combustion system. These homes were listed under "Oil and Gas Heating System" since the oil or gas heater is more frequently used during the heating season.

Table 6. Comparison between summer basement indoor radon measurements and the U.S. Geological Survey radon potential numbers (Otten et al.,1988).

Table 7. Comparison between total gamma aeroradioactivity and summer basement indoor radon in Fairfax County, Virginia.

Table 1

SEASON OF EACH YEAR	TOTAL AMOUNT OF PRECIPITATION	AVERAGE MAXIMUM TEMPERATURE	AVERAGE MAXIMUM PRESSURE
1987 Summer	9.9"	84.4 F	30.3 mm
1988 Summer	12.0"	83.9 F	30.3 mm

Table 2

Basement Level Indoor Radon Measurements:

SEASON AND YEAR	AVERAGE RADON	MEDIAN RADON	% OVER 4 pCi/l	% OVER 10 pCi/l	NUMBER OF HOMES
Winter 86/87	5.1 pCi/l	3.9 pCi/l	49%	9%	286
Spring 87	4.1 pCi/l	2.9 pCi/l	33%	5%	487
Summer 87	3.0 pCi/l	2.4 pCi/l	23%	2%	735
Fall 87	3.8 pCi/l	3.0 pCi/l	34%	3%	772
Winter 87/88	4.0 pCi/l	2.8 pCi/l	33%	5%	525
Spring 88	3.9 pCi/l	3.0 pCi/l	33%	5%	334
Summer 88	4.2 pCi/l	3.5 pCi/l	41%	5%	126
Fall 88	6.2 pCi/l	4.2 pCi/l	53%	9%	108

First Floor Indoor Radon Measurements:

SEASON AND YEAR	AVERAGE RADON	MEDIAN RADON	% OVER 4 pCi/l	% OVER 10 pCi/l	NUMBER OF HOMES
Winter 86/87	3.4 pCi/l	2.4 pCi/l	23%	5%	39
Spring 87	2.6 pCi/l	1.6 pCi/l	16%	4%	76
Summer 87	2.1 pCi/l	1.6 pCi/l	11%	0%	125
Fall 87	2.7 pCi/l	2.2 pCi/l	21%	0%	115
Winter 87/88	2.9 pCi/l	2.1 pCi/l	23%	2%	100
Spring 88	3.1 pCi/l	2.0 pCi/l	24%	2%	59
Summer 88	3.0 pCi/l	1.8 pCi/l	32%	0%	22
Fall 88	4.5 pCi/l	3.9 pCi/l	50%	5%	20

Table 3

Indoor Radon During the Summer of 1987:

GEOLOGICAL ROCK UNIT	NUMBER OF HOMES	AVERAGE RADON	MEDIAN RADON	% OVER 4 pCi/l
Coastal Plain Province				
Sedimentary strata	92	1.9 pCi/l	1.7 pCi/l	7%
Culpeper Basin				
Diabase	22	1.9 pCi/l	1.7 pCi/l	0%
Sandstone/Conglomerate	40	2.6 pCi/l	1.9 pCi/l	13%
Siltstone/Shale	8	5.4 pCi/l	2.7 pCi/l	38%
Piedmont Province				
Meta-Mafic Rock	12	2.2 pCi/l	1.4 pCi/l	25%
Occoquan Granite	54	2.6 pCi/l	2.0 pCi/l	13%
Falls Church Tonolite	21	2.2 pCi/l	2.3 pCi/l	10%
Sykesville Formation	107	2.9 pCi/l	2.4 pCi/l	20%
Indian Run Formation	36	2.6 pCi/l	1.8 pCi/l	14%
Annandale Group	52	3.2 pCi/l	2.6 pCi/l	31%
Popes Head Formation	86	3.5 pCi/l	2.8 pCi/l	24%
Peters Creek Schist	193	3.8 pCi/l	3.3 pCi/l	36%

Indoor Radon During the Summer of 1988:

GEOLOGICAL ROCK UNIT	NUMBER OF HOMES	AVERAGE RADON	MEDIAN RADON	% OVER 4 pCi/l
Coastal Plain Province				
Sedimentary Strata	7	2.4 pCi/l	2.0 pCi/l	14%
Culpeper Basin				
Diabase	4	4.8 pCi/l	2.2 pCi/l	25%
Sandstone/Conglomerate	3	5.5 pCi/l	6.5 pCi/l	67%
Siltstone/Shale	4	3.5 pCi/l	2.6 pCi/l	25%
Piedmont Province				
Meta-Mafic Rock	1	2.9 pCi/l	2.9 pCi/l	0%
Occoquan Granite	6	4.0 pCi/l	1.7 pCi/l	33%
Falls Church Tonolite	3	2.1 pCi/l	2.5 pCi/l	0%
Sykesville Formation	9	3.0 pCi/l	2.1 pCi/l	22%
Indian Run Formation	6	4.5 pCi/l	4.0 pCi/l	67%
Annandale Group	11	4.7 pCi/l	4.4 pCi/l	64%
Popes Head Formation	17	3.7 pCi/l	3.5 pCi/l	41%
Peters Creek Schist	42	5.0 pCi/l	3.9 pCi/l	45%

Table 4

SEASON	TYPE OF BASEMENT WALL	AVERAGE RADON	MEDIAN RADON	% OVER 4 pCi/l	NUMBER OF HOMES
Summer of 1987	Concrete Block	3.0 pCi/l	2.5 pCi/l	24%	469
	Poured Concrete	3.0 pCi/l	2.3 pCi/l	19%	237
Summer of 1988	Concrete Block	3.8 pCi/l	3.4 pCi/l	41%	81
	Poured Concrete	4.6 pCi/l	3.5 pCi/l	40%	40

Table 5

SEASON	HEATING SYSTEM	AVERAGE RADON	MEDIAN RADON	% OVER 4 pCi/l	NUMBER OF HOMES
Summer of 1987	Oil or Gas	2.7 pCi/l	2.3 pCi/l	18%	381
	Electrical	3.7 pCi/l	2.8 pCi/l	31%	215
Summer of 1988	Oil or Gas	3.1 pCi/l	2.5 pCi/l	32%	59
	Electrical	5.0 pCi/l	3.9 pCi/l	48%	61

Table 6

Indoor radon measurements from the summer of 1987:

USGS RADON POTENTIAL	NUMBER OF HOMES	AVERAGE RADON	MEDIAN RADON	% OVER 4 pCi/l
1	123	2.0 pCi/l	1.7 pCi/l	9%
2	98	2.8 pCi/l	2.5 pCi/l	17%
3	188	3.3 pCi/l	2.6 pCi/l	26%
4	129	3.2 pCi/l	2.8 pCi/l	23%
5	131	4.2 pCi/l	3.4 pCi/l	39%

Indoor radon measurements from the summer of 1988:

USGS RADON POTENTIAL	NUMBER OF HOMES	AVERAGE RADON	MEDIAN RADON	% OVER 4 pCi/l
1	9	2.4 pCi/l	2.3 pCi/l	0%
2	8	3.0 pCi/l	2.0 pCi/l	25%
3	26	3.8 pCi/l	3.4 pCi/l	42%
4	21	5.2 pCi/l	3.6 pCi/l	43%
5	25	4.7 pCi/l	4.0 pCi/l	50%

Table 7

AERORADIO-RADIOACTIVITY	NUMBER OF HOMES	AVERAGE RADON	MEDIAN RADON	% OVER 4 pCi/l
Indoor radon measurements from the summer of 1987:				
100-200 cps	51	2.7 pCi/l	2.1 pCi/l	18%
200-300 cps	142	3.0 pCi/l	2.1 pCi/l	23%
300-400 cps	262	3.1 pCi/l	2.6 pCi/l	24%
400-500 cps	94	4.0 pCi/l	3.1 pCi/l	35%
500-600 cps	8	4.8 pCi/l	4.5 pCi/l	63%
Indoor radon measurements from the summer of 1988:				
100-200 cps	5	2.2 pCi/l	2.2 pCi/l	0%
200-300 cps	16	3.0 pCi/l	2.3 pCi/l	13%
300-400 cps	45	4.3 pCi/l	3.7 pCi/l	47%
400-500 cps	14	5.5 pCi/l	4.7 pCi/l	57%
500-600 cps	1	-	-	-