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PART IV: Radionuclides

Chapter 12

SUMMER INDOOR RADON EXCEEDS WINTER INDOOR RADON

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Abstract: It has been considered true for many years, probably because of commentary in US-EPA publications for the general public, that winter concentrations of indoor radon are greater than summer concentrations. The higher amount in the winter is attributed to the observation that people normally keep their windows closed during the winter, allowing indoor radon concentrations to rise. The lower radon concentrations in the summer might occur because often open their windows, allowing low-radon outside air to enter the home. It now appears that seasonal rainfall can cause unexpected indoor radon concentrations. In our study of over 1000 homes, where indoor radon was measured seasonally over an entire year, a summer season that had above normal rainfall had higher indoor radon than the prior winter, which had below normal precipitation.

Key words: precipitation, radon monitors, radon, aeroradioactivity

1. INTRODUCTION

Soil and rock are the sources of most radon to which people are exposed. Homes with high concentrations of indoor radon have been discovered in

many parts of the Appalachian Mountain system. In the following study regional levels of indoor radon are compared to precipitation, geological unit, home construction factors and soil radioactivity, as measured from an airplane (aeroradioactivity survey). Our investigation has concentrated on a set of over 1000 homes, about 70% of which are in Fairfax County in northern Virginia, and about 30% or which are in the surrounding counties in Virginia and Maryland. The following discussion will discuss primarily the indoor radon measurements within Fairfax County.

2. METHODOLOGY

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. The indoor radon monitor has 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.

Participation in the test program required that the homeowner participate in a four-season testing period. The homeowner provided an exact location on a county map which, when compared to a geological map, made it possible to identify the geologic rock unit underlying the home. A questionnaire completed by the homeowner at the start of the test series served to quantify home construction factors (type of basement, age of home, etc.). Another questionnaire was completed at the end of each seasonal measurement interval to describe home use (number of heating days, number of days with opened windows, location of monitor, etc.). The first alpha-track radon monitor in each home was opened near the start of a season so as to facilitate a study of seasonal variations (winter was November, December and January, spring was February, March and April, summer was May, June and July, and fall was August, September and October). At the end of each seasonal interval, the homeowner was sent a quarterly report concerning the radon "picture" in Virginia and Maryland during the previous quarter.

3. EFFECT OF PRECIPITATION

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 dis-

tributed as monthly summaries. According to the weather summaries for the summer intervals, the two subsequent study summers had essentially the same maximum temperatures, but the second summer had about 20% more precipitation than the first summer and about 10% more precipitation than the previous winter, Table 1.

Table 1. Summer weather conditions

SEASON YEAR	TOTAL PRECIPITATION	AVERAGE TEMPERATURE
Summer 1	9.9 inches	84.4 °F
Winter	10.1	48.4
Summer 2	12.0	83.9

Note: This chart was generated from monthly weather summaries titled "Metropolitan Washington Climate Review" that cover Fairfax County, Montgomery County and adjacent areas. The compilations in this table are averages, obtained using measurements from the Washington-National Airport, Baltimore-Washington Airport, and Washington-Dulles Airports.

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 below this near-surface layer saturated with water in the soil around a home, 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 (see Table 2). Although it is commonly thought that indoor radon is always at its greatest concentration during the winter, this is clearly not always the case. The data show that the second summer had more precipitation than the previous winter and the previous summer, and the second summer had a higher regional radon average than the previous winter and the previous summer.

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

SEASON AND YEAR	AVERAGE RADON	MEDIAN RADON	% OVER 4 pCi/l	% OVER 10 pCi/l	NUMBER OF HOMES
Basement Indoor Radon Measurements					
Winter 1	5.1pCi/l	3.9pCi/l	49%	9%	286
Spring 1	4.1	2.9	33	5	487
Summer 1	3.0	2.4	23	2	735
Fall 1	3.8	3.0	34	3	772
Winter 2	4.0	2.8	33	5	525
Spring 2	3.9	3.0	33	5	334
Summer 2	4.2	3.5	41	5	126
Fall 2	6.2	4.2	53	9	108

SEASON AND YEAR	AVERAGE RADON	MEDIAN RADON	% OVER 4 pCi/l	% OVER 10 pCi/l	NUMBER OF HOMES
First Floor Indoor Radon Measurements					
Winter 1	3.4pCi/l	2.4pCi/l	23%	5%	39
Spring 1	2.6	1.6	16	4	76
Summer 1	2.1	1.6	11	0	125
Fall 1	2.7	2.2	21	0	115
Winter 2	2.9	2.1	23	2	100
Spring 2	3.1	2.0	24	2	59
Summer 2	3.0	1.8	32	0	22
Fall 2	4.5	3.9	50	5	20

Note: summer 2 higher precipitation than summer 1.

4. OTHER COMPARISONS

From a geologist's point of view, the study area is very useful, comprising of a large diversity of rock units which includes poorly consolidated sediments, sedimentary rocks, igneous rocks and metamorphic rocks. Although the average indoor radon varies considerably from unit-to-unit, the summer-to-summer radon increase caused by precipitation is quite uniform as shown below in Table 3.

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

GEOLOGICAL ROCK UNIT	NUMBER OF HOMES	AVERAGE RADON	MEDIAN RADON	% OVER 4 pCi/l
Indoor Radon Summer 1				
Coastal Plain Province				
Sedimentary Strata	92	1.9pCi/l	1.7pCi/l	7%
Culpeper Basin				
Diabase	22	1.9	1.7	0
Sandstone/ Conglomerate	40	2.6	1.9	13
Siltstone/Shale	8	5.4	2.7	38
Piedmont Province				
Meta-Mafic Rock	12	2.2	1.4	25
Occoquan Granite	54	2.6	2.0	13
Falls Church Tonolite	21	2.2	2.3	10
Sykesville Formation	107	2.9	2.4	20
Indian Run Formation	36	2.6	1.8	14
Annandale Group	52	3.2	2.6	31
Popes Head Formation	86	3.5	2.8	24
Peters Creek Schist	193	3.8	3.3	36
Indoor Radon Summer 2				
Coastal Plain Province				
Sedimentary Strata	7	2.4pCi/l	2.0pCi/l	14%

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

Note: summer 2 higher precipitation than summer 1

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 during the winter. This is presumably because the blocks are joined by mortar which tends to crack, allowing soil gas enriched in radon to enter. During the study summers, this difference was noted, 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.

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

SEASON	TYPE OF BASEMENT WALL	AVERAGE RADON	MEDIAN RADON	% OVER 4 pCi/l	NUMBER OF HOMES
Summer 1	Concrete Block	3.0pCi/l	2.5pCi/l	24%	469
	Poured Concrete	3.0	2.3	19	237
Summer 2	Concrete Block	3.8	3.4	41	81
	Poured Concrete	4.6	3.5	40	40

Note: summer 2 higher precipitation than summer 1

Most homes have either a gas or oil furnace or use electrical heat, normally in the form of a heat pump. During the winter, homes with electrical heat tend to have higher than average radon concentrations, 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. It is also interesting to note that while homes are not heated during the summer,

homes with electrical heating systems had higher indoor radon, Table 5. 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.

Table 5. Comparison of home heating system with summer indoor radon

SEASON	HEATING SYSTEM	AVERAGE RADON	MEDIAN RADON	% OVER 4 pCi/l	NUMBER OF HOMES
Summer 1	Oil or Gas	2.7pCi/l	2.3pCi/l	18	381
	Electrical	3.7	2.8	31	215
Summer 2	Oil or Gas	3.1	2.5	32	59
	Electrical	5.0	3.9	48	61

Note: summer 2 higher precipitation than summer 1. 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.

We have found that a good and inexpensive radon potential map can be derived by a survey of surface radioactivity, measured from the air. An aeroradioactivity map is available for Fairfax County. As shown in Table 6, an increase in aeroradioactivity compares well with an increase in indoor radon. 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.

Table 6. Comparison between total gamma aeroradioactivity and summer basement indoor radon in Fairfax County, Virginia

AERORADIO-ACTIVITY	NUMBER OF HOMES	AVERAGE RADON	MEDIAN RADON	% OVER 4 pCi/l
Indoor radon measurements summer 1				
100-200 cps	51	2.7pCi/l	2.1pCi/l	18%
200-300 cps	142	3.0	2.1	23
300-400 cps	262	3.1	2.6	24
400-500 cps	94	4.0	3.1	35
500-600 cps	8	4.8	4.5	63
Indoor radon measurements summer 2				
100-200 cps	5	2.2pCi/l	2.2pCi/l	0%
200-300 cps	16	3.0	2.3	13
300-400 cps	45	4.3	3.7	47
400-500 cps	14	5.5	4.7	57

AERORADIO-ACTIVITY	NUMBER OF HOMES	AVERAGE RADON	MEDIAN RADON	% OVER 4 pCi/l
500-600 cps	1	-	-	-

Note: summer 2 higher precipitation than summer 1

5. DISCUSSION

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 adjacent summers 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 second summer had more rainfall, which prevented a significant amount of soil radon from escaping directly to the atmosphere. It now appears that the concentration of indoor radon is related to the amount of rainwater (or snow), which "caps" the ground and prevents soil radon from escaping out of the soil surrounding the home.

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.

6. CONCLUSIONS

Indoor radon concentrations show a strong dependence on precipitation, geological unit, home construction and soil radioactivity. Intervals of greater precipitation tend to have higher indoor radon. In a geologically complex terrain where geological units are numerous and genetically different, some units can be associated with significantly higher indoor radon. Homes with concrete block basement walls and electrical heating systems tend to have higher indoor radon. Soils with greater aeroradioactivity tend to have homes with higher indoor radon. With some care, prediction of indoor radon appears possible if the more important parameters are carefully measured.

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.