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SEASONAL VARIATION IN 2-DAY SCREENING MEASUREMENTS OF ^{222}RN

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ABSTRACT

This study examines ^{222}Rn data from a group of 234 houses in which each level of every house was tested with a 1-year alpha track detector and the lowest livable level was tested four times, once during each of four seasons, with a 2-day charcoal canister. This study focuses on 1) how the seasonal variation in 2-day screening measurements affects the decision to take further action, when based on a single 2-day canister test, 2) how season affects estimates of the annual living area average, and 3) how the average of four seasonal canister readings compares with the 1-year alpha track measurement taken on the same floor.

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

INTRODUCTION

Short-term screening tests for radon are used to determine if action should be taken to reduce radon levels or if additional testing (usually of one year duration) is needed to more accurately characterize health risks to radon exposures. Radon concentrations vary seasonally (1) and so the result of the short-term screening test will be, in part, a function of the season in which the test is made.

The U.S. Environmental Protection Agency provides assistance to states in conducting surveys of indoor radon. A subsample of houses in states beginning their indoor radon surveys during the early part of 1989 were the first to use charcoal canisters in each of four seasons along with 1-year alpha track detectors (ATDs). These data were used to determine 1) how season affects a decision to take further action, 2) how season affects estimates of the annual living area average (ALAA), and 3) how the average of four seasonal canister measurements compares with the 1-year ATD measurement on the same floor.

METHODS

Homeowners were given alpha track detectors for a 1-year deployment and four open-faced charcoal canisters over the course of 12 months. One ATD was placed on each livable level up to a maximum of 4 levels, except for single story homes which received two ATDs. One charcoal canister was exposed on the lowest livable level during each of the four seasons. The homeowners were instructed to use the same location for all four canisters.

For this analysis, seasons are defined as:

Winter: December 1 - March 31
Spring: April 1 - June 30
Summer: July 1 - September 30
Fall: October 1 - November 30.

Houses were required to have: 1) one canister measurement within each season, 2) all canister measurements separated from each other by at least 30 days, 3) floor codes available for at least three of the four canister measurements (i.e., one missing floor code was permitted), 4) all available canister floor codes must agree, and 5) canister floor codes must match the lowest ATD floor code.

All houses were on a permanent foundation and had at least one floor at or below ground level. Analyses were performed separately for basement and nonbasement houses. A basement house is defined as any house where the lowest livable level has at least one wall built against earth. All other houses in the study were defined to be nonbasement houses.

RESULTS AND DISCUSSION

DISTRIBUTION OF SCREENING MEASUREMENTS BY SEASON

A total of 234 houses met the above criteria, 162 basement houses and 72 nonbasement houses. These houses were located in Iowa, Maine, Ohio, Vermont, and West Virginia. Table 1 displays the arithmetic mean, standard deviation, geometric mean, and geometric standard deviation in each of the four seasons, by floor and overall. As reflected by the parameter estimates in Table 1, the distribution of measurements are essentially the same in all seasons except summer. Summer measurements tend to be lower than the other season measurements; the geometric mean was about 15% lower for basement measurements and about 50% lower for first floor measurements in nonbasement houses. Closed-house conditions may not have been maintained during the summer.

VARIATION IN SEASONAL SCREENING MEASUREMENTS

A coefficient of variation (CV) was calculated for each of the 234 houses (CV = standard deviation of the four seasonal measurements divided by the mean of the four measurements, expressed as a percentage). The results are summarized in Table 2. As noted in Table 2, 12 houses were excluded because the mean of the four measurements was less than 0.5 pCi/L and CVs become unstable whenever the denominator of the CV statistic approaches zero.

The CVs appear to be about the same regardless of the concentration level, e.g., houses with means of the four seasonal measurements near 2 pCi/L exhibit about the same percentage variation as houses with means of the four measurements near 15 pCi/L. The average CV for all 222 houses was 40%.

SEASONAL AFFECT ON DECISIONS FOR FURTHER ACTION

Using 4 pCi/L as the point at which some further action is taken, classifying each seasonal measurement as ≤4 pCi/L or >4 pCi/L results in 16 possible patterns of outcome. Two of these patterns give clear decisions: when all four measurements are ≤4 pCi/L or all four measurements are >4 pCi/L. The other 14 patterns give conflicting decisions and are tabulated in Table 3. Of 234 houses, 66 (28%) had conflicting decisions. Thirty-two (48%) of the 66 houses fell into pattern #5 where the winter measurement indicated taking action but the other 3 measurements indicated no action was necessary. Thirteen (20%) of the 66 houses fell into pattern #3 where the fall, winter, and spring measurements indicated taking further action but the summer measurement did not. In 57 (86%) of the 66 houses, the winter and summer measurements disagreed; however, in 5 of these, summer indicated taking action while winter indicated no action was necessary. These 5 houses were all basement houses, 3 in Iowa and 2 in Maine; all were 2-story (plus basement) except one Iowa house which was 1-story (plus basement).

SEASONAL AFFECT ON ESTIMATING ALAA

The following model (2) was used to estimate the relationship between 2-day screening tests and ALAA (annual living area average):

Table 1. Summary Statistics for Houses Tested in Each of Four Seasons

Type of House	No. Houses Tested	Location of Measurement	Parameter*	Winter (Dec.-Mar.)	Spring (Apr.-June)	Summer (July-Sept.)	Fall (Oct.-Nov.)
Basement	162	Basement	AM	5.9	6.0	5.0	5.6
			SD	5.1	5.7	4.7	4.8
			GM	3.9	4.0	3.3	4.0
			GSD	2.7	2.6	2.7	2.5
Nonbasement	72	1st Floor	AM	2.1	2.1	1.1	2.3
			SD	3.2	2.9	1.5	3.1
			GM	1.1	1.2	0.6	1.3
			GSD	3.1	2.9	3.4	3.0
All Houses Combined	234	Lowest Level	AM	4.8	4.8	3.8	4.6
			SD	4.8	5.3	4.3	4.6
			GM	2.7	2.8	1.9	2.8
			GSD	3.3	3.1	3.7	3.0

* AM = arithmetic mean
SD = standard deviation
GM = geometric mean
GSD = geometric standard deviation

Table 2. Coefficient of Variation (CV) Versus Radon Concentration Level for Individual Houses Tested in Each of Four Seasons

Mean Concentration pCi/L	No. Houses	Mean CV 1/	Standard Deviation of CVs	Minimum CV	Maximum CV
< 0.5 2/					
0.5 - 2.0	75	45.0	22.4	6.8	135.2
2.1 - 4.0	48	42.1	17.7	13.9	74.2
4.1 - 6.0	34	35.1	16.8	2.9	78.0
6.1 - 10.0	40	31.6	16.1	9.5	75.5
10.1 - 15.0	17	39.7	17.8	20.7	71.5
> 15.0	8	40.7	20.5	13.5	77.7
Overall	222	39.9	19.6	2.9	135.2

1/ The standard deviation of the four measurements on a given house when multiplied by 100 and divided by the mean concentration provides an estimate of the relative seasonal variability or coefficient of variation (CV) for that house.

2/ All 12 houses with mean concentration ≤ 0.5 pCi/L were excluded from this analysis because of instability of CVs at low concentrations.

Table 3. Number of Houses With and Patterns of Occurences of Conflicting Decisions Based on Four Seasonal Measurements of Indoor Radon in Each of 234 Houses

Pattern	Season				No. Houses
	Winter	Spring	Summer	Fall	
1	-	+	+	+	1
2	+	-	+	+	5
3	+	+	-	+	13
4	+	+	+	-	1
5	+	-	-	-	32
6	-	+	-	-	1
7	-	-	+	-	4
8	-	-	-	+	1
9	-	-	+	+	0
10	-	+	-	+	1
11	-	+	+	-	0
12	+	+	-	-	3
13	+	-	+	-	0
14	+	-	-	+	4
					66

+ = measurement is greater than 4 pCi/L
- = measurement is equal to or less than 4 pCi/L

123

Table 4. Relationship Between Annual Living Area Average and 2-Day Canister Measurements by House Type and Season

Type of House / Parameter	Season: Winter	Spring	Summer	Fall
Basement				
No. Houses	147	147	147	147
Prediction Equation	$\hat{Y} = 1.23 + .53X$ (.17)* (.03)	$\hat{Y} = 1.32 + .53X$ (.18) (.03)	$\hat{Y} = 1.67 + .54X$ (.22) (.05)	$\hat{Y} = .92 + .63X$ (.16) (.03)
Residual Error, $\hat{\sigma}$	0.42	0.42	0.50	0.37
Correlation	0.78	0.80	0.70	0.83
Nonbasement				
No. Houses	66	66	66	66
Prediction Equation	$\hat{Y} = .93 + .79X$ (.12) (.06)	$\hat{Y} = .75 + .87X$ (.12) (.07)	$\hat{Y} = 1.37 + 1.01X$ (.21) (.18)	$\hat{Y} = .75 + .82X$ (.10) (.05)
Residual Error, $\hat{\sigma}$	0.28	0.29	0.50	0.24
Correlation	0.90	0.86	0.55	0.94

* Standard error of estimate given in parentheses.

$$Y_i^{1/2} = (a + bX_i)^{1/2} + e_i$$

where

Y_i = ALAA in the i^{th} house, calculated as the mean of ATD measurements, one from each floor, except for single story houses which had two measurements taken on the same floor.

X_i = 2-day charcoal canister measurement in the i^{th} house taken in the basement for basement homes and on the first floor in nonbasement homes,

a, b = parameters to be estimated, and

e_i = random error for the i^{th} house, assumed to be normally distributed with mean 0 and variance σ^2.

Eight different models were determined, one for basement houses and one for nonbasement houses in each of the four seasons. Of the original 234 houses, 21 were deleted from this analysis for the following reasons: 15 due to missing ATD measurements and 6 due to ATD exposure being less than 325 days. All remaining houses had ATDs exposed for >325 days and <395 days and all ATD start dates, within the same house, were within 30 days of each other. The results are summarized in Table 4. Major conclusions are:

a) The prediction equation, residual error and correlation for basement houses are basically the same for all seasons. For example, given a 2-day measurement of 4 pCi/L in each season, the predicted annual living area average for the four seasons varies from 3.4 to 3.8 pCi/L.

b) The prediction equation for nonbasement houses is basically the same for all seasons. For example, given a 2-day measurement of 4 pCi/L in each season, the predicted annual living area average for the four seasons varies from 4.0 to 5.4 pCi/L--the summertime equation gave the highest predicted value.

c) In each of the four seasons, the prediction equation for basement houses differs significantly from the prediction equation for nonbasement houses. For example, the coefficient of X for basement houses varies from 0.53 to 0.63 for the four seasons, whereas the coefficient of X for nonbasement houses varies from 0.82 to 1.01 for the four season.

d) The intercepts in all equations shown in Table 4 are significantly greater than zero, that is, the fitted equation does not pass through the origin. This would suggest that the ratio model Y/X=b (or Y=bX) is not an appropriate model for analyzing long-term versus short-term relationships since it assumes an equation that passes through the origin.

THE MEAN OF FOUR SEASONAL MEASUREMENTS VS 1-YEAR ATD MEASUREMENTS

Of the original 234 houses with four seasonal screening measurements 217 had 1-year ATD measurements taken on the same floor, with an exposure period >325 days and <395 days. These houses were used to compare the mean of 4 seasonal measurements with a corresponding 1-year ATD measurement on the same floor. The results are shown in Table 5.

The 1-year ATD measurements tend to be higher than the mean of the four canister measurements, an average of .82 pCi/L higher in basement houses and .77 pCi/L in nonbasement houses. The geometric mean of 1-year ATDs is 14% higher than for short-term seasonal measurements in basement houses and about 67% higher than for short term measurements taken on the first floor in nonbasement houses. Both are statistically significant at $p=0.01$.

CONCLUSIONS

In this sample of 234 houses, 66(28%) had conflicting results in one or more seasons indicating the need to take further action. Thirty-two (48%) of these 66 had their winter measurement >4 pCi/L while the spring, summer, and fall measurements were ≤4 pCi/L; thirteen (20%) of the 66 had fall, winter, and spring measurements >4 pCi/L while the summer measurement was ≤4 pCi/L. Currently, EPA recommends additional testing if a screening measurement exceeds 4 pCi/L. Also, EPA recommends mitigation if an annual measurement exceeds 4 pCi/L. Houses with a true concentration of around 4 pCi/L will have the largest chance for error. With a CV of 40%, the standard deviation of canister measurements for concentrations of 3, 4, and 5 pCi/L will be 1.2, 1.6, and 2.0 respectively.

The prediction equation for estimating ALAA from 2-day screening measurements does not differ by season. However the equations do differ by house type, basement versus nonbasement, with the nonbasement houses having the larger coefficient. The intercepts for all equations are significantly greater than zero.

The 1-year ATD measurement tended to be higher than the mean of the four canister measurements. Quality control conducted on blank ATDs indicated a positive bias due to leaky bags used for storage and mailing.

REFERENCES

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2. White, S.B., Clayton, C.A., and Alexander, B.V. A statistical analysis: predicting annual ^{222}Rn concentrations from 2-day screening tests. Paper presented at The 1990 International Symposium on Radon and Radon Reduction Technology, Atlanta, Georgia. February 19-23, 1990.

Table 5. Comparison of Annual Concentrations Based on 1-Year Alpha Track Measurements and Four Seasonal Charcoal Canister Measurements

Type of House	No. of Houses	Parameter*	Instrument: ATD	Instrument: Four Canister Measurements
Basement	151	AM	6.52	5.70
		SD	5.43	4.48
		GM	4.70	4.11
		GSD	2.44	2.38
Nonbasement	66	AM	2.74	1.97
		SD	2.75	2.40
		GM	2.02	1.21
		GSD	2.05	2.61

* AM = arithmetic mean
SD = standard deviation
GM = geometric mean
GSD = geometric standard deviation.