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REALISTIC UNCERTAINTIES FOR CHARCOAL AND ALPHA-TRACK RADON MONITORS

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ABSTRACT

The ability of activated charcoal and alpha-track radon monitors to estimate annual concentrations is a consequence of the measurement interval over which either type of monitor is used. In a case study of several hundred homes in Virginia and Maryland, a ± 90% uncertainty must be applied to single charcoal measurements to estimate the annual radon concentrations, and a ± 50% uncertainty must be applied to three-month alpha-track measurements (90% confidence levels).

INTRODUCTION

The realization that Radon-222 and its progeny constitute a health risk was brought to the attention of Virginia and Maryland homeowners in 1986 and 1987. Although the scientific community had recently reported on radon (1, 2, 3), homeowners were alerted by a series of news media reports that noted the recent discoveries of homes with radon problems in Pennsylvania and New Jersey. This quickly was followed by reports about radon activities of federal, state and county agencies concerned with public health. At the same time, news media and civic association attention was directed toward radon testing companies, and toward the Center of Applied Science at George Mason University. In the summer of 1986, only shortly before the regional news media started its coverage on radon, the Center had started to develop a pilot study in area homes. From late in 1986 to the present, the Center has received about 5000 letters and phone calls in which homeowners request information about the study. About 1800 homes are now being examined.

Almost all of the study homes are in Fairfax County in northern Virginia, and the contiguous Montgomery County in south central Maryland. A few homes are from surrounding counties. The geological rock units under Fairfax County extend through Montgomery County and to adjacent counties in central Virginia and northern Maryland. The radon "signature" of the rock units vary considerably from one rock unit to another. Aeroradioactivity maps (total gamma signal, measured from an airplane, due to radon, thorium, and potassium) show that each rock unit tends to vary in total radioactivity. Aeroradioactivity maps appear to be a good device with which to predict indoor radon, at least at the community level. No attempt has yet been made to examine the comparison between single radon measurements and the annual radon measurements in terms of the geological units under the home. This may be a fruitful line of study since season-to-season indoor radon variations are not the same in homes over different rock units. It may be that short term fluctuations of indoor radon are related to soil radon concentration as well as to soil permeability. This paper concentrates on comparisons using single charcoal and alpha-track measurements, without any consideration of the geology, home construction and home use factors. This is not an unreasonable approach, since the typical homeowner takes none of these factors into consideration. Also, studies in progress suggest that these variables are important but not significant enough to alter the conclusions discussed below.

PRECISION AND ACCURACY

At the present time, only two types of inexpensive radon moitors are widely used to measure indoor radon. The less expensive (about $10-$20 per monitor to the homeowner) type uses activated charcoal, packaged in a porous bag or in a small metal can. The somewhat more expensive (about $20-30 to the homeowner) type of monitor uses a radon sensitive film packaged in a plastic cup. Other methods, most of which involve the use of "grab samples" of indoor air, will not be discussed.

The most important problem faced by any measuring device for the homeowner is the natural variation in radon concentration. Radon concentrations are known to fluctuate rapidly, with low point to high point changes of more than 100%. These changes are due to changes in weather and home use. The question that this paper will address concerns the length of time required to obtain a meaningful estimate of the annual radon concentration. This requires deciding how precisely one wishes to estimate the annual radon concentration. In short, to obtain any given level of precision in estimating the annual radon level, how long must the radon concentration be measured?

The other important question that might be considered is accuracy. For discussions that follow, it will be assumed that the commercially available charcoal and alpha-track monitors are equally accurate. That is, over the interval of radon measurement, both are considered to be equally accurate. Although there is some debate on this point, it is generally recognized that both types of monitors carry a measurement uncertainty of about ± 25% at the 90% confidence level. For the following discussions, it will also be assumed that neither the charcoal monitor nor the alpha-track monitor yield results that are biased toward too-high or too-low measurements. The commonly used laboratories all routinely pass the EPA Proficiency Program, particularly over the early 1987 to present interval of this study. Consequently, the pattern of deviation of single measurements from annual measurements is considered to be related to natural variations in indoor radon concentrations. Finally, it will be assumed that the annual radon concentration can be adequately estimated by averaging radon concentrations from a series of four alpha-track measurements, each over three months. With these assumptions, single charcoal and single alpha-track measurements can be compared to annual radon concentrations.

CHARCOAL RADON MONITORS

The charcoal monitors used in this study include monitors from The Radon Project in Pittsburgh, Pennsylvania, Enrad Corporation in Gaithersburg, Maryland, and AirChek Corporation in Penrose, North Carolina. Charcoal monitors from The Radon Project have a vapor barrier to retard the adsorption of water which interferes with the adsorption of radon. These monitors are therefore, according to the manufacturer, to be left exposed to indoor air for about 7 days. The Enrad monitors do not have a vapor barrier, but are carefully weighed to determine the amount of water collection so as to appropriately adjust the measured radon concentration. The Enrad monitors are to be left exposed to indoor air for about 2-3 days. Monitors from The Radon Project and from Enrad are metal cans, while radon monitors from AirChek are porous paper bags. The AirChek monitors are to be exposed to indoor air for only 1-2 days, and water adsorption is not considered to be important.

The major benefit from the charcoal monitor is its low cost and rapidity in which it yields results for the homeowner. The major disadvantages are its sensitivity to water and to temperature (adsorption characteristics change measurably if indoor air changes to "uncomfortable" temperature conditions), and the fact that the radiation record is lost over a few days, providing no legal record other than the analyst's report. The limitation on the measurement interval to only a few days means that a useful estimate of the annual radon concentration requires a series of many charcoal monitors, or it requires that an estimate of uncertainty be applied to a single measurement. Some estimates on uncertainty obtained by using charcoal monitors over several weeks have been proposed (4), but no study of variations using a series of charcoal monitors over an entire year has yet been reported. In the following discussions, we report on homes in which we have one charcoal measurement and an estimate of annual radon concentration, plus we report on additional homes for which we have a single charcoal measurement and an alpha-track measurement over the season of charcoal measurement.

ALPHA-TRACK RADON MONITORS

The alpha-track monitors used in this study are from Tech/Ops Landauer Corporation in Illinois. With an adequate soil shield, they have been used for hydrocarbon exploration (5), earthquake prediction (6), and in the search for uranium and gold. In the past few years, they have been used without the soil shield to measure indoor radon. The indoor radon monitors also do not require the use of a permeable membrane required on soil monitors to keep out radon-219 and radon-220, the other radon isotopes that fortunately have very short half-lives. 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 monitor, producing 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. This relatively long measurement interval is a disadvantage when a homeowner or more often home buyer wants a measurement quickly. Estimates of analytical uncertainty for the alpha-track monitors are dependent on the measurement interval (7), so intervals of three months to a full year are often utilized.

ANNUAL RADON AND CHARCOAL MONITORS

The radon study of the Center of Applied Science has gathered charcoal and alpha-track measurements during 1987 and 1988. Because homeowners paid for their radon monitors, most returned their monitors and the questionnaires related to the monitors. There are now 152 homes which have a single charcoal measurement and an estimate of the annual radon concentration using the average of four seasonal alpha-track monitors. There are 329 homes which have a charcoal measurement and an alpha-track measurement over the season of charcoal measurement. In this paper, winter is November-January, spring is February-April, summer is May-July, and fall is August-October,

The charcoal measurements are from each month of the year, though a few months provided most of the comparisons (Figure 1). An overview shows that deviations of single charcoal measurements commonly occur that are more than 50% higher or lower than the seasonal alpha-track measurement. Only rarely, but sometimes, the deviation is on the order of 100%. Of course, these deviations are to some extent due to inaccuracies in the charcoal measurement and inaccuracies in the alpha-track measurement. However, since these analytical variations are thought to be random, the situation shown in Figure 1 is thought to represent a realistic picture of deviations caused by natural variations in radon.

Table 1 compares the single charcoal measurements to the annual radon concentrations. Charcoal-to-annual ratios of less than 1.0 represent cases where the charcoal measurement was less than the annual measurement; ratios of more than 1.0 represent cases where the charcoal was greater than the annual measurement. Most of the available charcoal measurements are from the summer interval (Figure 2), and even though the homeowners were instructed to use closed-home conditions, the majority of the summer measurements are less than the annual measurement. We suspect that closed-home conditions may somewhat simulate winter conditions, but not very completely. The lack of indoor-to-outdoor thermal convection in the summer, plus variable weather conditions probably prevent closed home conditions from reliably simulating a winter condition, or even a condition that might be considered average in terms of radon concentration.

The deviation of charcoal monitor radon measurements from annual radon concentrations does not appear to be a function of the indoor radon concentration (Figure 3), at least over the 1-20 pCi/l annual radon range of the study set. This observation supports the idea that the deviations are real, and not a consequence of measuring low radon concentrations.

Table 2 provides an estimate of the uncertainly that should be applied to a single charcoal measurement in order to estimate the possible annual radon concentration. For example, the data show that 67% of the homes yield a charcoal-to-annual deviation of up to ± 40%. This could be rephrased to say that at the 67% confidence level, the uncertainty that would be applied to a single charcoal measurement is ± 40% of the charcoal measurement. Similarly, one would apply a ± 90% uncertainty to the charcoal measurement if one wanted to be very sure (e.g., 90% confidence level) of the possible annual radon concentration. Obviously these uncertainties are considerably larger than the ± 25% uncertainty noted earlier that is applied to a single measurement, but only over the measurement interval. The much larger uncertainty is a consequence of the need to estimate the annual radon concentration, compared to the much less useful radon concentration during only the measurement interval.

ANNUAL RADON AND ALPHA-TRACK MONITORS

The number of alpha-track measurements in this study greatly exceed the number of charcoal measurements, mainly because the homeowners were alerted to the probably inherent uncertainty associated with the charcoal monitors. The charcoal monitors were probably selected by homeowners who wanted to experiment with the technology, or homeowners who wanted to make their own judgement as to the usefulness of the charcoal monitors.

There are presently a total of 828 homes for which the entire sequence of four three-month alpha-track monitors are available (Table 3). Winter alpha-track measurements tend to be greater than the annual concentration, and summer measurements tend to be less than the annual concentration; spring and fall measurements are less biased toward higher or lower measurements (Figure 4). This situation is obviously related to natural seasonal variations. One could apply a correction factor to adjust a measurement, and one could then apply an uncertainty to the measurement to estimate the annual radon concentration (Table 4). A comparison of Tables 2 and 4 shows the dramatic difference in the uncertainty estimate between the charcoal and the alpha-track detectors. For example, one could say that at the 67% confidence level, one would apply a ± 40% uncertainty to the charcoal measurement and a ± 25% uncertainty to the alpha-track measurement. To be very sure of the possible annual radon concentration, one would apply a ± 90% uncertainty to the charcoal measurement and a ± 50% uncertainty to the alpha-track measurement.

As was noted for the charcoal monitors (see Figure 3), the deviation of single alpha-track measurements from annual radon concentrations does not appear to be a function of indoor radon concentration (Figure 5). Deviations of about the same magnitude occur for both low and high radon concentrations, for all the seasonal intervals. The deviations are therefore concluded to be the result of natural variations in radon, and not measurement inaccuracies.

CONCLUSION

Almost all indoor radon measurements are currently obtained by homeowners using activated charcoal radon monitors or alpha-track monitors. Manufacturer estimates for the measurement interval (a few days for the charcoal and a few months for the alpha-track monitors) uncertainties are about ± 25% at the 90% confidence level. However much larger uncertainties must be applied to estimate the annual radon concentration. This uncertainty is about ± 90% for the charcoal monitors and about ± 50% for the alpha-track monitors.

One implication of these uncertainty estimates is that charcoal monitors should best be considered a "sampler" of indoor radon that is useful only for the measurement interval. Homeowners who wish to obtain a useful estimate of annual radon should be advised to use a series of charcoal monitors (perhaps 5 over 10 weeks), or a single alpha-track monitor exposed for perhaps three months. It may also be important to reconsider the validity of using 4 pCi/l as an "action level" to be applied to a single charcoal measurement. A single charcoal measurement of 3.9 pCi/l could in fact come from a home that has an annual radon concentration of more than 7 pCi/l. An "action level" of 2 pCi/l should perhaps be applied to charcoal measurements.

Another important observation concerns the concept of "closed-home" measurements. The available data show that the closed-home condition often yields measurements that are less than the annual radon concentrations, and very often less than the "worst-case" conditions thought to prevail in the winter. Variables such as geology-determined permeability behavior, weather and home construction may interact in ways that often prevent a closed-home condition from facilitating a short-term (charcoal monitor) worst-case measurement. The obvious implication is that homeowners, realtors and scientists should be cautious when using charcoal measurements to estimate annual radon concentrations. This caution, plus a realistic estimate of the measurement uncertainties, can generate radon estimates that have significance.

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Table 1

Ratio Between Characoal Measurements and Annual Radon Concentrations

Charcoal to Annual Ratio	Number of Homes	Charcoal to Annual Ratio	Number of Homes
0.0 to 0.09	2	1.01 to 1.1	14
0.1 to 0.19	4	1.11 to 1.2	17
0.2 to 0.29	9	1.21 to 1.3	10
0.3 to 0.39	3	1.31 to 1.4	4
0.4 to 0.49	8	1.41 to 1.5	1
0.5 to 0.59	10	1.51 to 1.6	1
0.6 to 0.69	11	1.61 to 1.7	3
0.7 to 0.79	14	1.71 to 1.8	1
0.8 to 0.89	15	1.81 to 1.9	1
0.9 to 0.99	9	1.91 to 2.0	3
Exactly 1.0	1	More than 2.0	11

Note: 56% of the charcoal measurements were less than the corresponding annual radon measurement, and 44% were greater than the annual measurement.

Table 2

Estimation of Uncertainty for Charcoal Radon Monitors

Amount of Deviation Between a Single Charcoal Measurement and the Annual Radon Concentration	Percentage of Homes with a Particular Level of Deviation Between the Charcoal and Annual Measurements
Less than ± 10% deviation	in 16% of the homes
20%	35%
30%	53%
40%	67%
50%	75%
60%	77%
70%	83%
80%	88%
90%	90%

Example: If one wanted to estimate the annual radon concentration correctly in 67% of a group of homes, one would apply a ± 40% uncertainty to the single charcoal measurement.

Table 3

Ratio Between Single Alpha-Track and Annual Radon Measurements

Single to Annual Measurement Ratio	Number of Homes in Each Seasonal Interval Winter	Spring	Summer	Fall
0.0 to 0.19	2 homes	3 homes	2 homes	5 homes
0.2 to 0.39	9	21	34	13
0.4 to 0.59	20	44	128	34
0.6 to 0.79	76	138	227	85
0.9 to 0.99	154	234	172	203
1.0 to 1.10	126	146	60	140
1.11 to 1.3	110	136	76	112
1.31 to 1.5	109	71	14	87
1.51 to 1.7	78	20	9	24
1.71 to 1.9	22	6	3	11
1.91 to more than 2.0	22	10	3	6
% Homes Below Annual	32%	53%	80%	41%
% Homes Above Annual	67%	45%	19%	57%
Median Radon Ratio	1.12	0.98	0.83	1.04
(1.0)/Median Ratio	0.89	1.02	1.20	0.96

Table 4

Estimation of Uncertainty for Alpha-Track Monitors

Step I Adjust the single alpha-track measurement to compensate for normal seasonal variations (see Table 3, bottom).

Measurement Season	Winter	spring	Summer	Fall
Typical Seasonal Bias	+12%	-2%	-17%	+4%
Correction Multiplier	0.89	1.02	1.20	0.96

Example: If a summer measurement is 10 pCi/L, the annual is probably closer to 10 x 1.20 = 12 pCi/L.

Step II Apply an estimate of uncertainty to the radon measurement.

Amount of Deviation Between a Single Alpha-Track Measurement & the Annual Radon Measurement	Percentage of Homes with a Particular Level of Deviation Between the Alpha-Track and the Annual Measurement
Less than ± 10% deviation	in 30% of the homes
20%	60%
30%	75%
40%	83%
50%	90%

Example: If one wanted to estimate the annual radon concentration correctly, in 75% of the homes, one would apply a ± 30% uncertainty to the single alpha-track measurement.

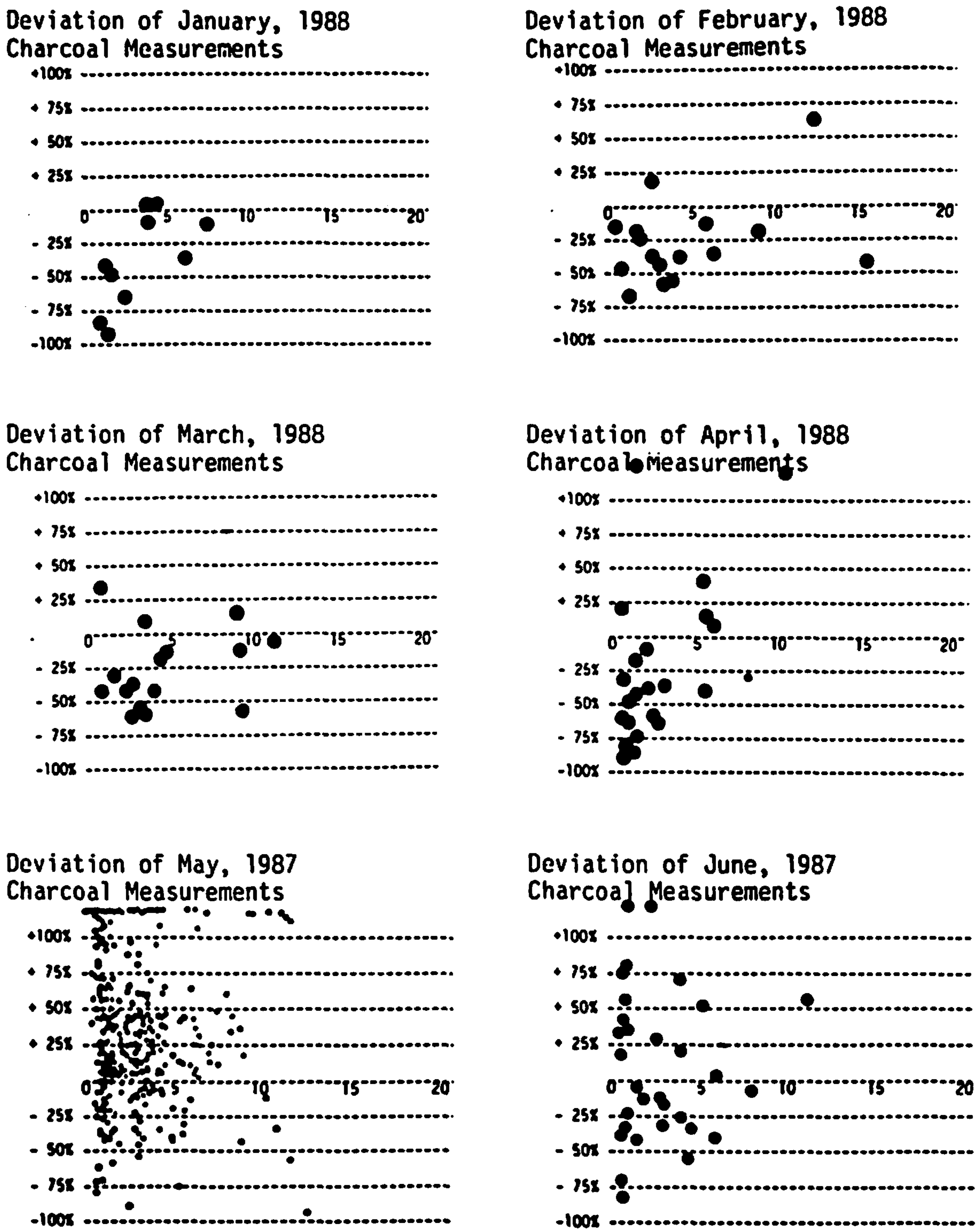

Figure 1 (Part 1)

PERCENTAGE DEVIATION (VERTICAL AXIS) OF CHARCOAL MONITOR RADON MEASUREMENTS FROM SEASONAL MEASUREMENTS vs SEASONAL MEASUREMENTS (HORIZONTAL AXIS) FROM THREE-MONTH ALPHA-TRACK RADON MONITORS (shown in pCi/l)

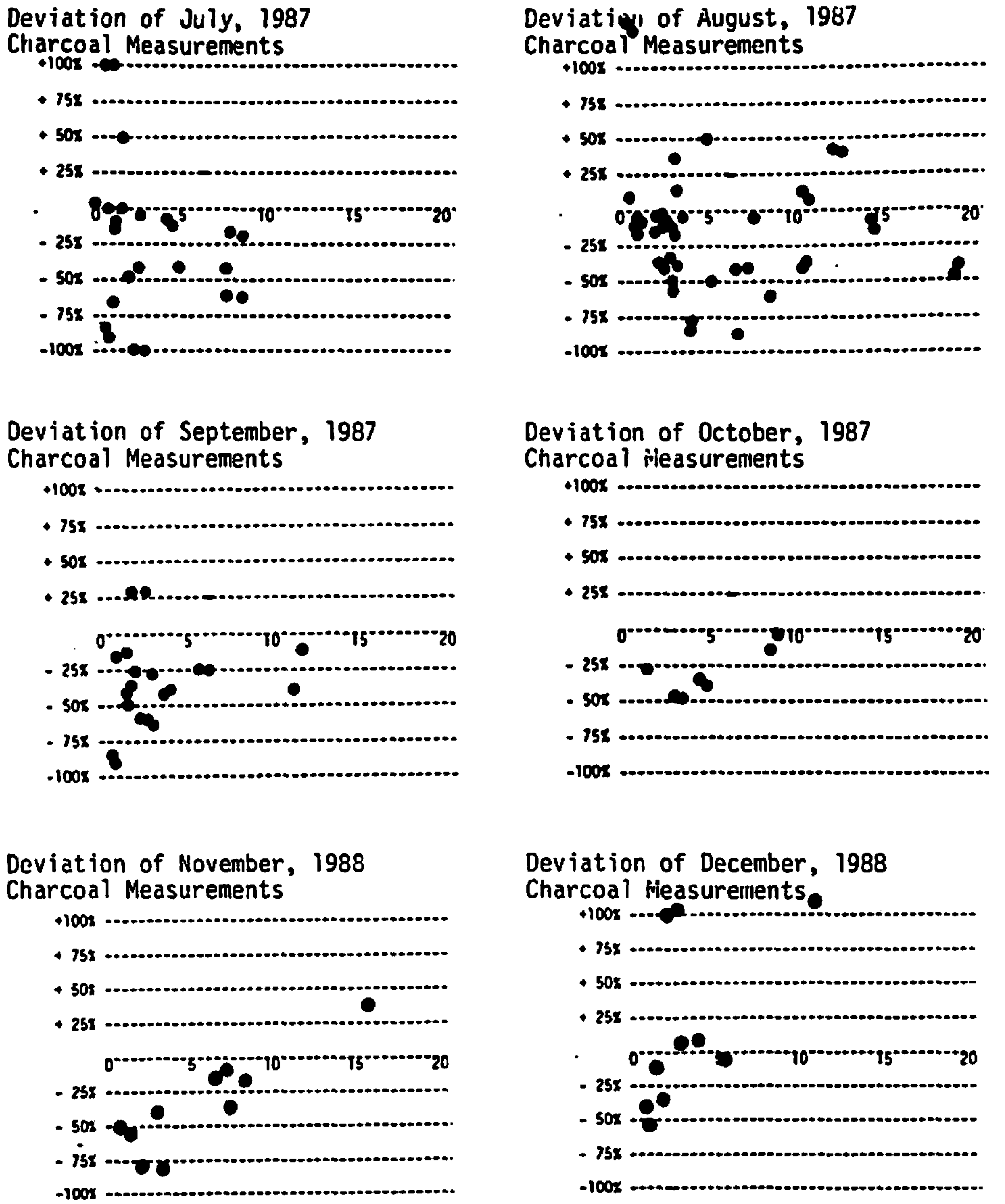

Figure 1 (Part 2)

PERCENTAGE DEVIATION (VERTICAL AXIS) OF CHARCOAL MONITOR RADON MEASUREMENTS FROM SEASONAL MEASUREMENTS vs SEASONAL MEASUREMENTS (HORIZONTAL AXIS) FROM THREE-MONTH ALPHA-TRACK RADON MONITORS (shown in pCi/l)

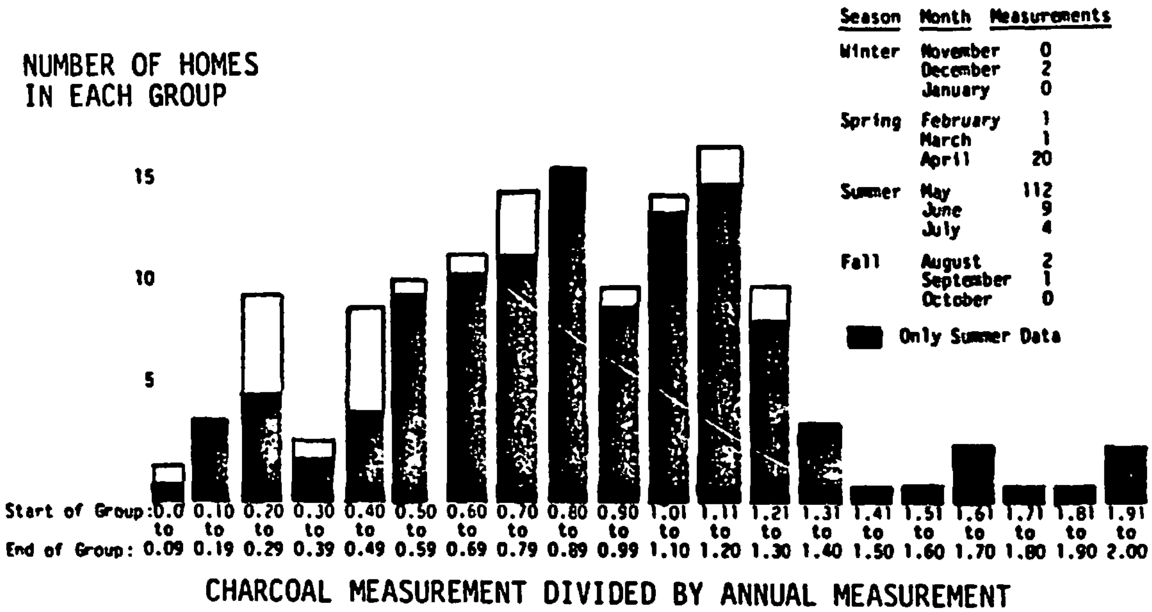

Figure 2

HISTOGRAM SHOWING NUMBERS OF HOMES WITH PARTICULAR CHARCOAL-TO-ANNUAL RATIOS

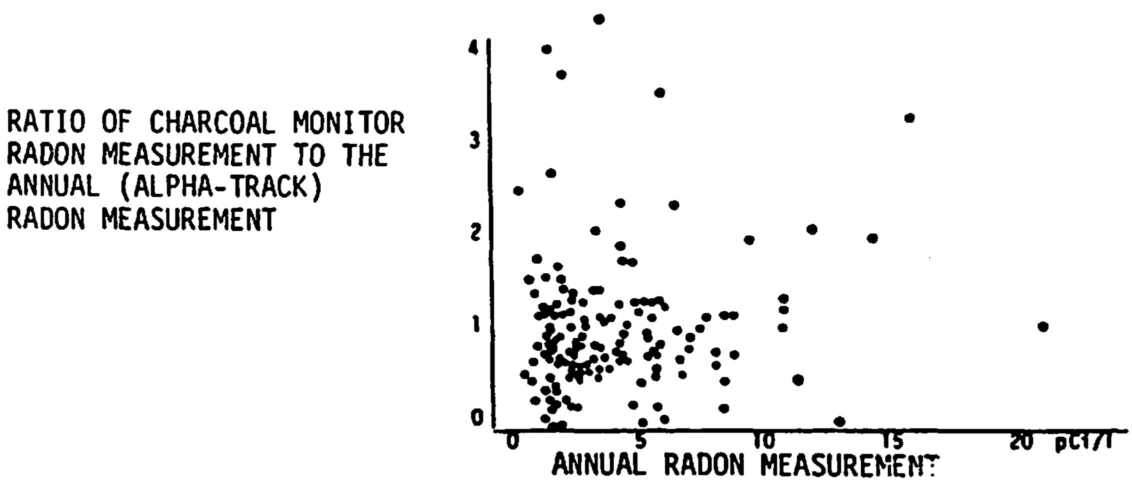

Figure 3

COMPARISON BETWEEN CHARCOAL/ANNUAL RATIOS vs ANNUAL RADON MEASUREMENTS

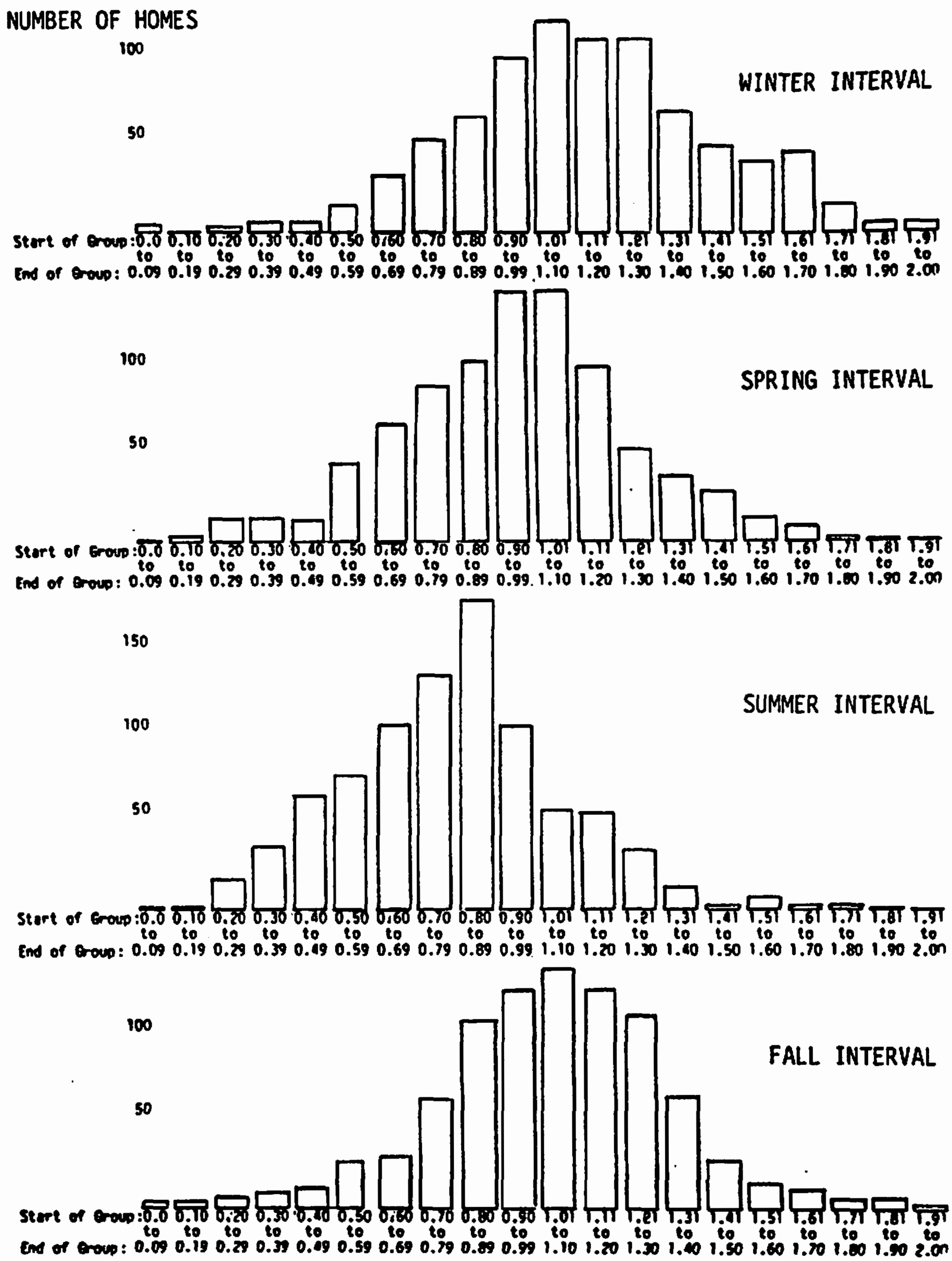

Figure 4

GRAPH SHOWING NUMBERS OF HOMES (VERTICAL AXIS) WITH PARTICULAR RATIOS BETWEEN SINGLE ALPHA-TRACK AND ANNUAL MEASUREMENTS (HORIZONTAL AXIS)

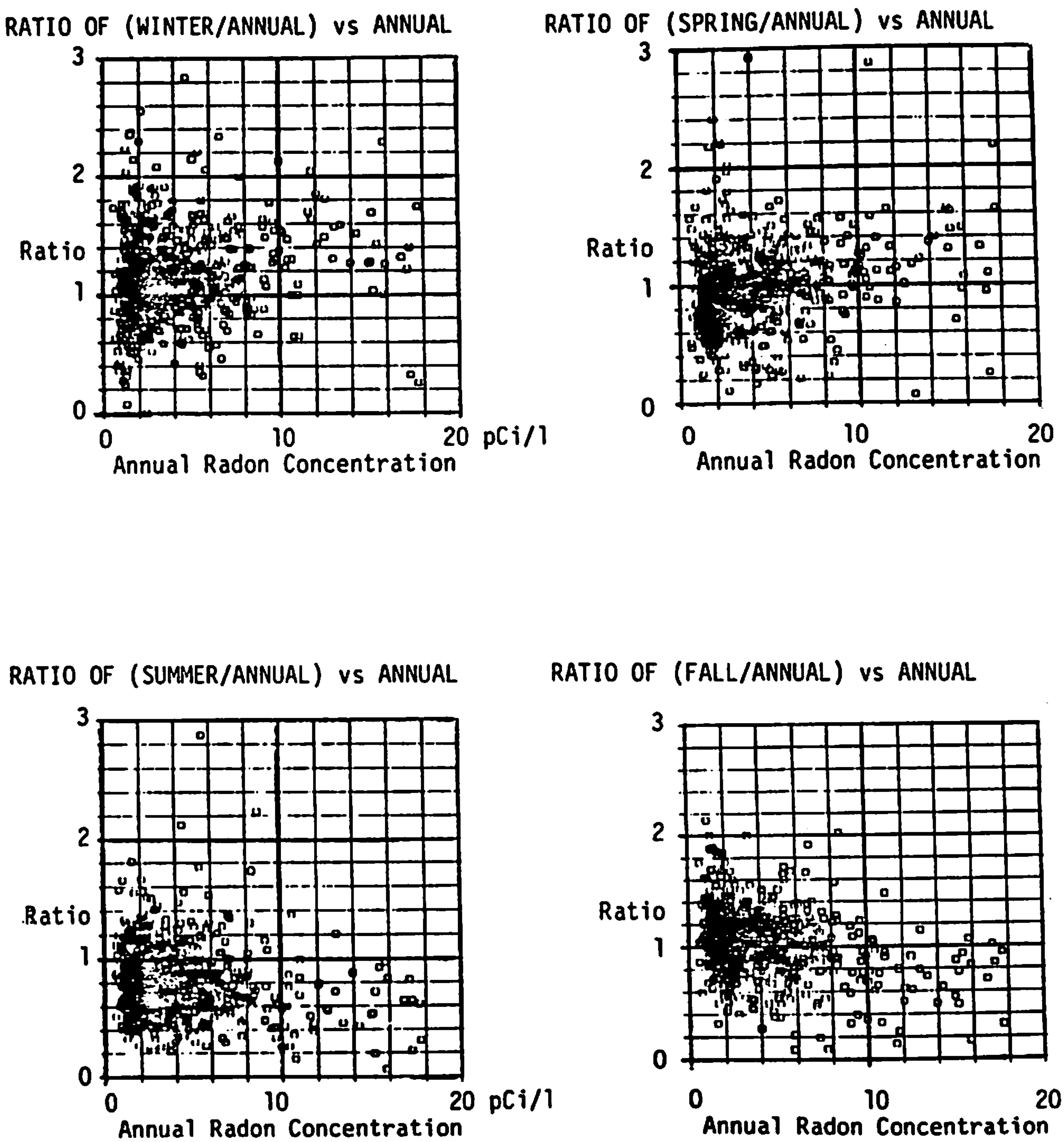

Figure 5

COMPARISON BETWEEN ALPHA-TRACK/ANNUAL RATIOS vs ANNUAL RADON CONCENTRATION