SMALL SAMPLE RADON TESTING OF HOMES IN EAST TEXAS

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ABSTRACT

This paper covers the results of small sample radon testing of homes in East Texas. The program was voluntary and participation was offered to a group of technical personnel involved in the HVAC industry. Response was smaller than expected. The only people who showed an interest were ones who had a heightened awareness of health concerns, and cancer in particular. The technical findings show very wide temporal variability of the radon level. The implication is that short-term "grab samples" of air for determination of radon exposure may be much higher or lower than the average exposure. Based on this experience, a sample period of 120 to 168 hours is recommended to characterize exposure at a given time of year.

INTRODUCTION

While radon has received considerable attention in the press, coverage seems to be spasmodic, and to have little influence on the general public. This paper summarizes the experiences in one community in attempting to gage the extent of radon levels of concern in homes. The instrument selected for measurements was an early model of the Honeywell Professional Radon Monitor with the accessory Data Logger. The eventual program was very small, and no radon levels of concern were detected. However, the experience offers some useful insights on who is interested, the degree of variability to be expected during several days of sampling, and some conclusions about the use of an instrument of this type.

Motivation

As a resident of East Texas, and an engineering manager in the HVAC industry, I had considerable personal and professional interest in gaging the level of radon in several homes in this area. Being involved in trade association committees on indoor air quality, and receiving field inquiries on the subject, I was also interested in obtaining data on a recording radon monitor from a reputable, national manufacturer of instruments.

Preliminary Scenario

The original plan was that a number of homes would be monitored with a recording instrument to determine whether the radon levels were sufficient to warrant promotion of a more comprehensive program in the community. In fact, the original plan was that, if the levels from the initial survey warranted, a much wider survey with charcoal canisters and track-etech detectors would be proposed. The concept was that these would be provided at cost as a community service with the report to be sent in duplicate to the homeowner and to the sponsor. In this way, a large data base on radon levels could be compiled at a relatively low cost.

As it turned out, neither the level of interest nor the radon levels observed warranted a proposal for a wider range program.

Outline of the Actual Program

Since only one instrument was to be used for the preliminary survey, it was important to get homeowners who had an interest, who would report the results, and who could be relied upon to return the instrument. Use of the instrument was offered to about one dozen senior engineering personnel in the HVAC industry. These people, in turn, had the opportunity to expose several times their number to the opportunity to use the instrument, if their interest level was high enough to do so. HVAC Engineering personnel were selected because it was presumed that they were better informed about radon and its potential health effects than the general public, and should be more inquisitive in an area so closely allied to their area of employment.

The intended sample base was 10-20 homes. The instrument would be placed in each home for seven-to-ten days, and then moved to another site. The homeowner-engineer would provide a copy of the data logger printer output for analysis and comparison among sites.

In addition, longer-term measurements in one office setting were intended to standardize the program. With measurements in this office between residential monitoring exposures, we could watch for drift in the instrument or the radon level of the office, and use this information in analyzing the residential data.

Response

Response to the offer was disappointing. Initially, there had been some concern that we would be oversubscribed by people wanting to monitor the radon levels in their homes. In contrast, we had only three householders who expressed an interest.

The technical results of the program were such that we did not feel that it was worthwhile to seek a wider base of investigation. These technical results are discussed later.

Response Commentary

As noted, the small number of people who expressed interest in monitoring the radon levels in their homes was disappointing. The principal investigator sought to determine why there was so little interest, and what distinguished the three that were interested. While this field of investigation was informal, and is inferential at best, the observations seem to be valid and may be of value to other investigators.

First, the offer of the use of the instrument was not timed to follow one of the peaks of reporting in the press. Thus, there was no particular media-induced interest.

Second, there have been no widely publicized reports of a radon problem in this area. While there have been reports in the press in neighboring states, none have cited a problem in Texas, much less East Texas where the geology is much different than that of West Texas and the panhandle.

Third, I suspect there is some aspect of Pandora's box syndrome---don't look for problems. For example, if one were planning to sell his house, and it had a radon problem, would he really want to know about it?

One common element was found among the three engineers who decided to monitor their homes which set them apart from the others to whom the offer was extended. In all three cases, there is, or has recently been, cancer in the household. None of these were lung cancers.

A secondary, even more informal, survey was done of checkout clerks at stores where radon detectors (charcoal canisters) were on display at the check-out counter. In general, the check-out clerks who had these things sitting on their counters, didn't know what they were, didn't know what they were for, and didn't know why anyone would want one. More telling, none of those questioned had sold any! While this little survey is totally lacking in rigor, it certainly implies that there is not a broad-based, high level of

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concern about radon exposure in East Texas. (A subsequent personal communication with a representative of the Texas Department of Health indicates that a level of 14 pCi/L has been measured in a home in Longview, Texas.)

To generalize these observations, it appears as though:

> Those who are interested in monitoring radon in their homes are people who have been sensitized to the threat of cancer in general, and the possible role of radon in cancer.

Technical Program

The Honeywell radon monitor was installed in one office and three homes. This monitor records a 4, 8, 12, or 24-hour integrated average level starting 12 hours after installation and continuing for 96 sample intervals. The unit employs a silicon detector and has a measurement range of 0.1 to 99.9 pCi/L (re. the EPA "action level" of 4 pCi/L.

The characteristics of each site are summarized in Table 1.

TABLE 1
TEST SITE CHARACTERISTICS

TYPE	STRUCTURE	FOUNDATION	INSTRUMENT PLACEMENT
Home 1	1 Story Brick Veneer, Frame	Slab or Grade	1st Story- Liv. Rm.
Home 2	2 Story Brick Veneer, Frame	Slab or Grade	1st Story- Liv. Rm.
Home 3	1 Story Brick Veneer, Frame	Slab or Grade	1st Story- Liv. Rm.
Office	2 Story Steel frame, concrete block & glass walls	Slab or Grade	2nd Story- Outside office

In each application, the unit was set for a 4 or 24-hour sample interval to provide either the greatest resolution in observing temporal trends, or the smoothest trend. The data is accumulated for up to 96 sample intervals, and then the data logger prints on a 2.25" paper tape on demand.

The output tape indicates the time interval setting, prints out the individual sample averages, the overall average, and the average for the last 12 hours (with a 4-hour interval). Then it prints a bar graph of the data. A sample is shown in Figure 1.

The data has been replotted to expand the vertical scale and compress the horizontal scale. On the original tape, several data points are marked with a "T" which is a "tamper" indication. This is intended to prevent a homeowner, whose property might be being checked prior to sale for example, from moving the monitor out of the area to be checked. In our tests, it indicates that we disturbed the unit to take a printout or some other equally innocent activity.

DATA ANALYSIS

Comparison of Sites

The volatility of the data shows why one should not infer the environment from a short duration "grab" sample. The statistics printed on Figure 1 show that the sample-to-sample variability was great. However, the mean of the 12-day sample is well characterized (the standard deviation of the mean is less than 8% of the mean).

TABLE II

Location	Sample Interval	Samples	Total Duration	Extreme Readings Hi Low	Average	Notes
Home 1 (SG)	4 Hr	66	264 Hr	3.0 0.1	1.0	1
Home 2 (WB)	24	10	240	0.7 0.1	0.3	2
Home 3 (JC)	24	7	168	0.6 0.0	0.3	3
Office (4/89)	4	36	144	1.4 0.1	0.3	4
Office (6/89)	4	42	168	1.2 0.0	0.2	5
Total	--	---	980 Hr	3.0 0.0	---	-

NOTES: Greatest sample-to-sample change was:
(1) 0.1 to 2.0 in successive 4 hr intervals
(2) 0.5 to 0.1 in successive 24 hr intervals
(3) 0.0 to 0.3 in successive 24 hr intervals
(4) 0.1 to 1.4 in successive 4 hr intervals
(5) 0.1 to 1.2 in successive 4 hr intervals

Table II gives a summary of the five cases studied. The office was examined before and after the residential tests. Homes 2 & 3 and the office were within a 2 mile radius. Home 1 was 40 miles away, and in the community cited in the earlier footnote. Thus, one may infer that the indicated higher average at Home 1 is not an artifact.

Temporal Trends

The data in Figure 1 is replotted in Figure 2 with major grid lines every 24 hours. Since the instrument does not time-tag the samples, we cannot assign a clock time to specific samples. However, we can examine the data in 24-hour slices to see whether any daily pattern is evident.

Some of the observations from this examination are that:

> Each day except one has at least one or more distinct peaks and significant valleys.

> On the ninth day, the measured radon level was quite constant.

> There is little consistency in the time of day at which peaks and troughs occur.

> Trends appear more cyclic when viewed on selected consecutive days than when viewed overall.

> The highest and lowest levels observed occurred in one twenty-four hour period.

The volatility shown in Figures 1 and 2 clearly indicates that short duration grab samples are not adequate for characterization of radon concentration. Normally, a grab-sample is taken in a matter of seconds and represents an almost instantaneous condition.

These diagrams show that even when the data is integrated and averaged over a four-hour period, the sample-to-sample variations are quite large. The variation between successive samples was as much as double the overall average reading. The following discussion on smoothing indicates the numbers of samples needed to reduce the measurement variations.

Smoothed data

Figure 3 shows the results of smoothing the data by averaging over successfully longer periods of time. The upper left recreates the 4-hour data of Figures 1 and 2. In the upper right, the first point plotted is the average of the first five, 4-hour samples. The subsequent points are a moving average of 20 hours of data.

FIGURE 1 RADON MEASUREMENTS IN AN EAST TEXAS HOUSE

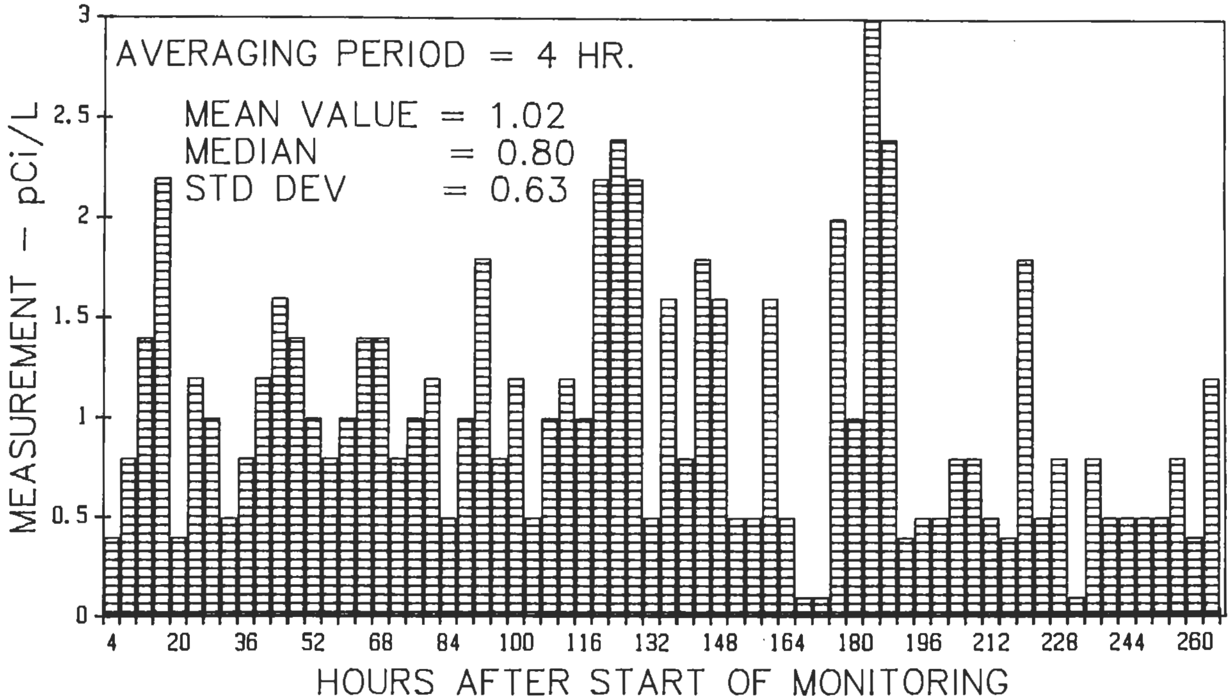


FIGURE 2 RADON MEASUREMENTS IN AN EAST TEXAS HOUSE

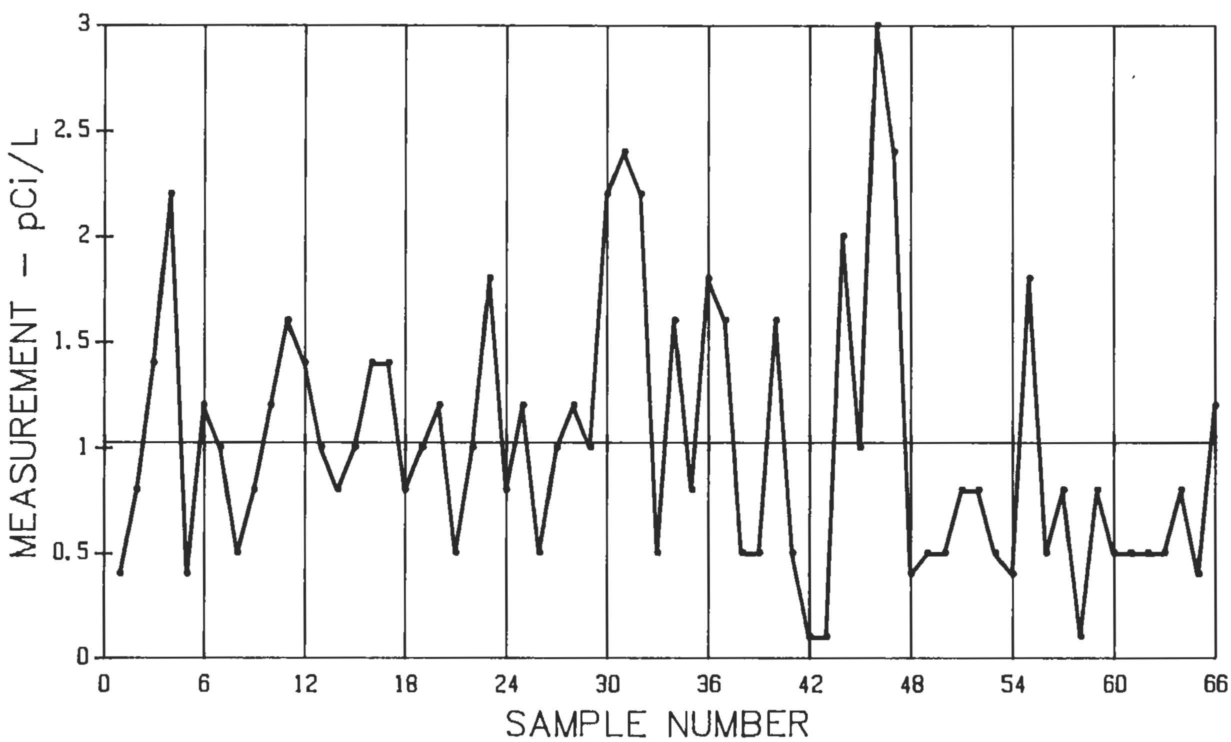


FIGURE 3 AVERAGED DATA

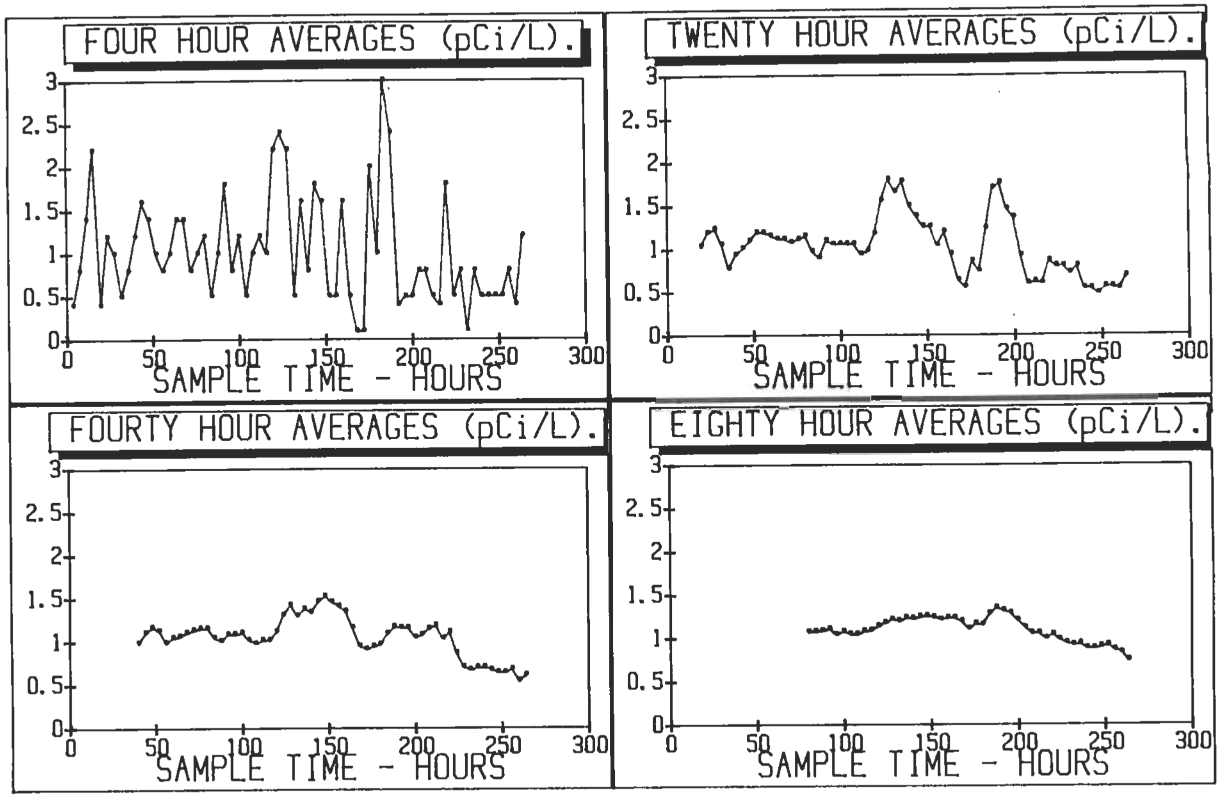
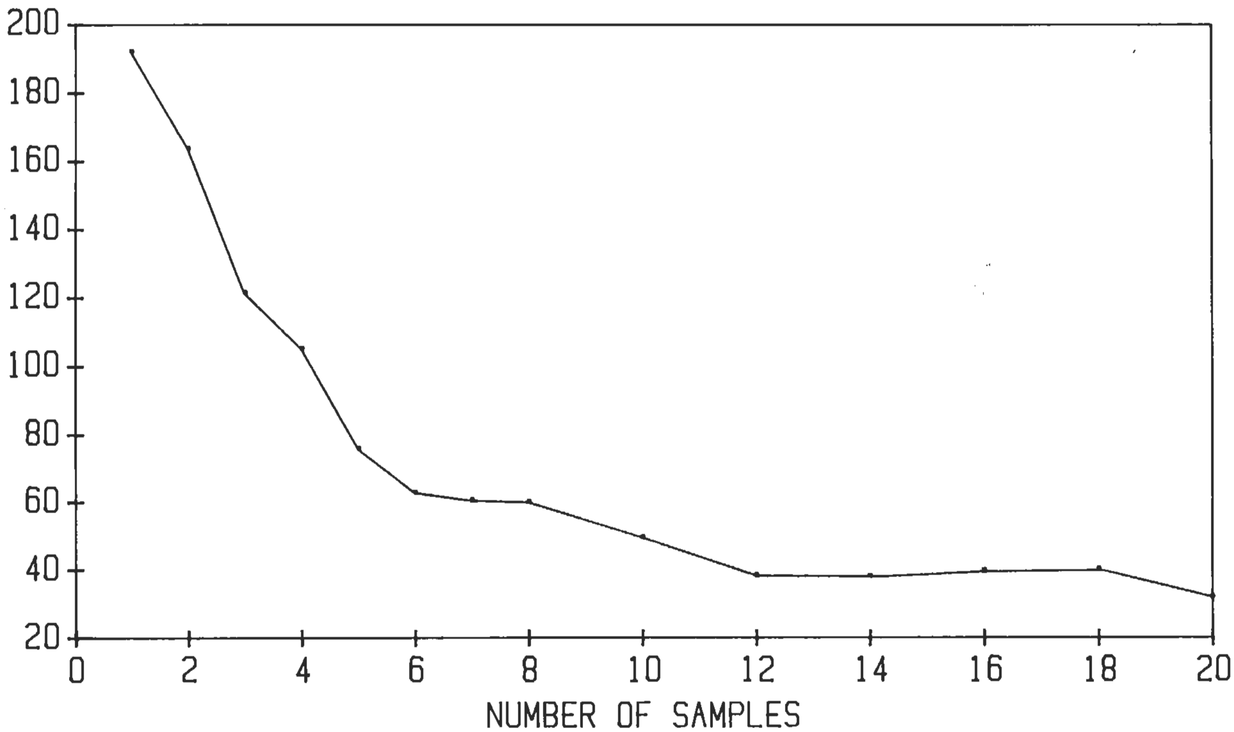


FIGURE 4 MAXIMUM DEVIATION FROM THE OVERALL MEAN AS A FUNCTION OF THE NUMBER OF SAMPLES



Remembering that the overall mean is 1.02, it is seen that a 20-hour average can deviate by about 75% from this mean. From the bottom two figures, one would infer that to get a "reasonably representative" sample, the minimum sampling period probably ought to be on the order of 40 to 80 hours.

This question is examined in a somewhat different manner in Figure 4. Data of the form of Figure 3 was analyzed for various numbers of 4-hour samples in the rolling average. The maximum percent deviation from the overall mean (plus or minus) was identified for each data set, and the result is Figure 4.

Interpretation of this figure is shown by example: if the sampling duration were decreased from 264 hours to 48 hours (12, four-hour samples), what would be the greatest percent deviation of the overall mean of the truncated data from the overall mean of the 264 hours of data. The answer is about 40% (actually 38.2%). The plateau in figure 4 suggests that if the sampling interval is to be extended beyond 48 hours, it ought to be extended far beyond. However, for most purposes, the 48-hour sample should suffice if it is well below, or far above, 4 pCi/L.

The bottom two views in figure 4 also illustrate the fact that there is some long-term variation as well as the short-term volatility of the data. The smoothed data is fairly constant out to about 125-150 hours. Then there is an upward blip, followed by a gradual downward trend. The inference to be drawn from this is that if the average measured value is near the EPA action level, and if that level is to be the decision criteria for remedial action, the sample probably ought to be extended over several weeks at least.

Figure 5 shows the results of a different form of smoothing. Here, the data is smoothed with a first order filter with the algorithm

$$Y_{n+1}=Alpha*X_{n+1}+(1-Alpha)*Y_n$$

where $0.0<Alpha<1.0$
and Y_n is initialized at X_n

The slow rise in the upper left-hand view is an artifact which results from having to "charge up" the slow acting filter. The droop towards the end of the sample period is quite real.

We see that as our filter constant [alpha] increases, the filter responds more rapidly to the input. While this means that the output approaches the overall mean of 1.024 more rapidly, it also means that more of the 4-hour input data variability to the filter passes through to the output.

Subjectively, the alpha value of 0.05 looks about right. With this value, we would want to wait about 125-150 hours after the start of the test before we took our reading to represent the full period.

Comparing Figures 4 and 5, it appears as though the rolling average gives a more stable measure in less total sample time than the first order filter. While more sophisticated filters could be developed, there does not appear to be any motivation to do so.

Statistical Considerations

The volatility of the data in Figures 1 and 2 suggests a random process worthy of some statistical analysis. As a first step, the data was analyzed to determine sample-to-sample variations. The results are plotted in Figure 6. Examination of this figure emphasizes even more strongly the random nature of the process.

Within this randomness, there seems to be some sense of order. One way to examine this is to determine the time between successive peaks in the original data. The results are shown in Figure 7, which shows peak-to-peak durations of 8, 12, 14*, 16, 20, and 22* hours. (The values indivisible by 4 result from two consecutive peak readings of the same amplitude (e.g., 20 and 24 hours after the preceding peak.) The grid on Figure 2 made it clear that, if there was a periodicity, it was not 24 hours. The data in Figure 7 indicate that there is no regular periodicity to the occurrence of successive peaks in the radon measurements of Figure 1. By simple inference, the same is true of the valleys.

The statistics of the amplitude were considered by sorting all the observations in rank order and then analyzing them to develop the cumulative distribution shown in Figure 8. This figure also shows a third order polynomial fit to the curve.

This diagram helps to emphasize the fact that the extreme value is almost four times the magnitude of the 50th percentile case. The practical implication is that a small sample may substantially overestimate the true magnitude of the radon exposure, and may also severely underestimate the extreme exposure.

CONCLUSIONS

Need for further sampling

The small data sample in this experiment, complemented by one reading from another source, suggests that there would be a benefit to more radon measurements being taken in East Texas homes to better quantify the risks in the area. Although the soil tends towards heavy clay which would minimize radon leakage to the surface and into homes, the clay layers are liberally perforated with oil and gas wells and exploratory holes.

Sampling Protocol

The sampling protocol should be adaptive making use of recording instruments such as that used in this program along with charcoal canisters and alpha track monitors. The recommended sample period for instrumented measurements and charcoal canisters is 120 to 168 hours.

The shorter period could be used for the instrument so that it could be moved to a new site once per week with time for set up, stabilization, etc.

Additional Research

An instrumented test program of the sort used in this investigation should be conducted using more sample sites and longer sampling intervals. Ideally, the test would span 12 months at a dozen or more sites selected to represent a range of buildings, soil types and geology.

The results of the additional work would give a better understanding of the dynamics of radon concentration in a home and how the dynamics change with season and site. This understanding is vital to assure that any sampling protocol for wide-spread sampling will provide sufficient sensitivity to correctly identify properties where remedial action is appropriate, while minimizing the risk of "false alarms" leading to unnecessary remedial action. For the extended test, the sites should be prescreened to get a good sampling of radon levels ranging from an average of below 1pCi/L to well above 4.

FIGURE 7 SAMPLE-TO-SAMPLE VARIATIONS OF RADON MEASUREMENTS IN AN EAST TEXAS HOUSE

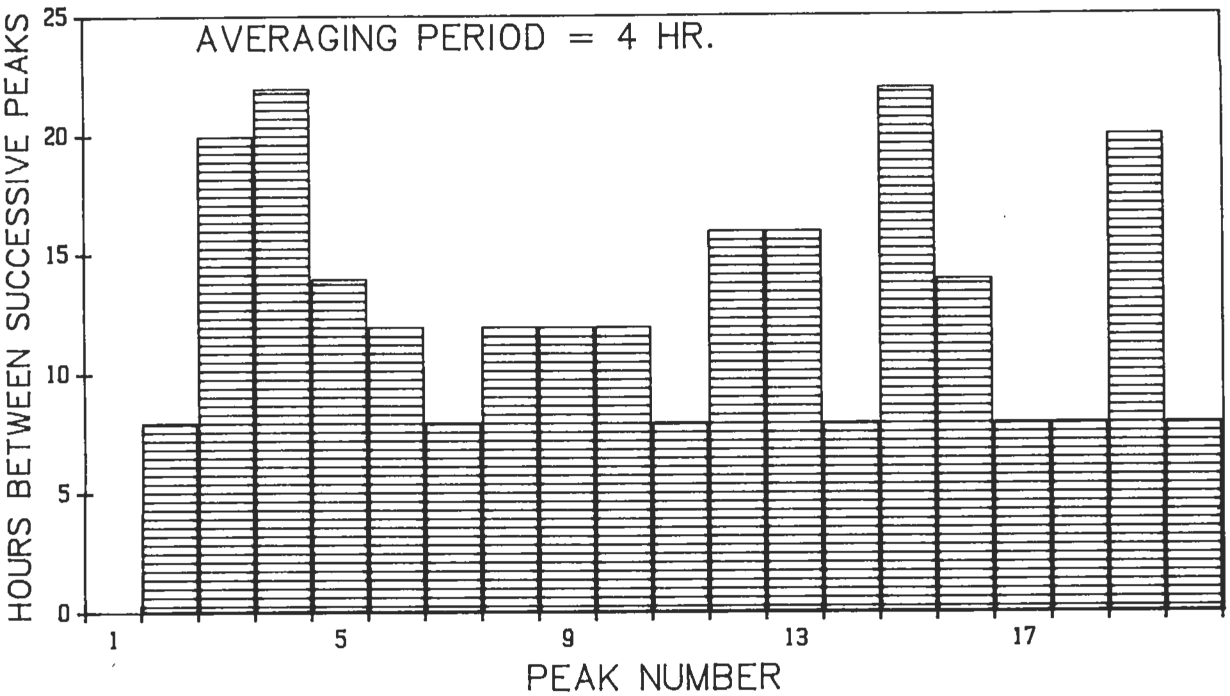


FIGURE 8 CUMULATIVE STATISTICS OF RADON MEASUREMENTS IN AN EAST TEXAS HOUSE (4 HR. AVG.)

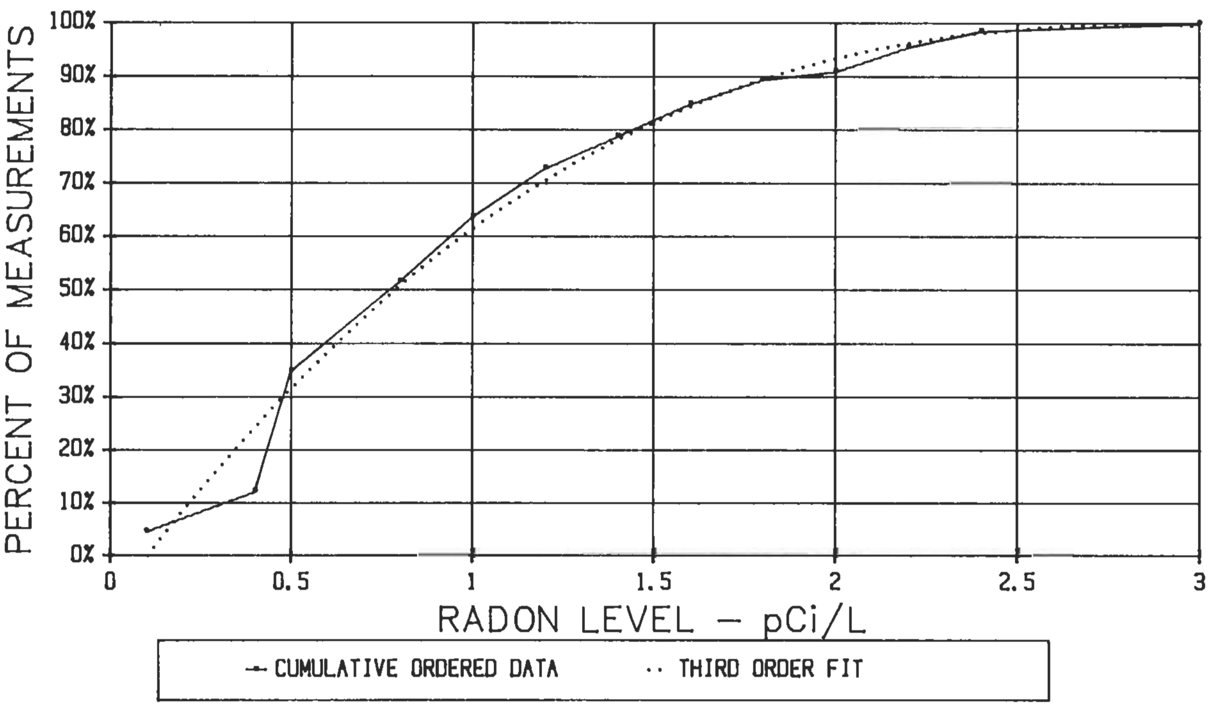


FIGURE 5 DATA SMOOTHED WITH A FIRST ORDER FILTER

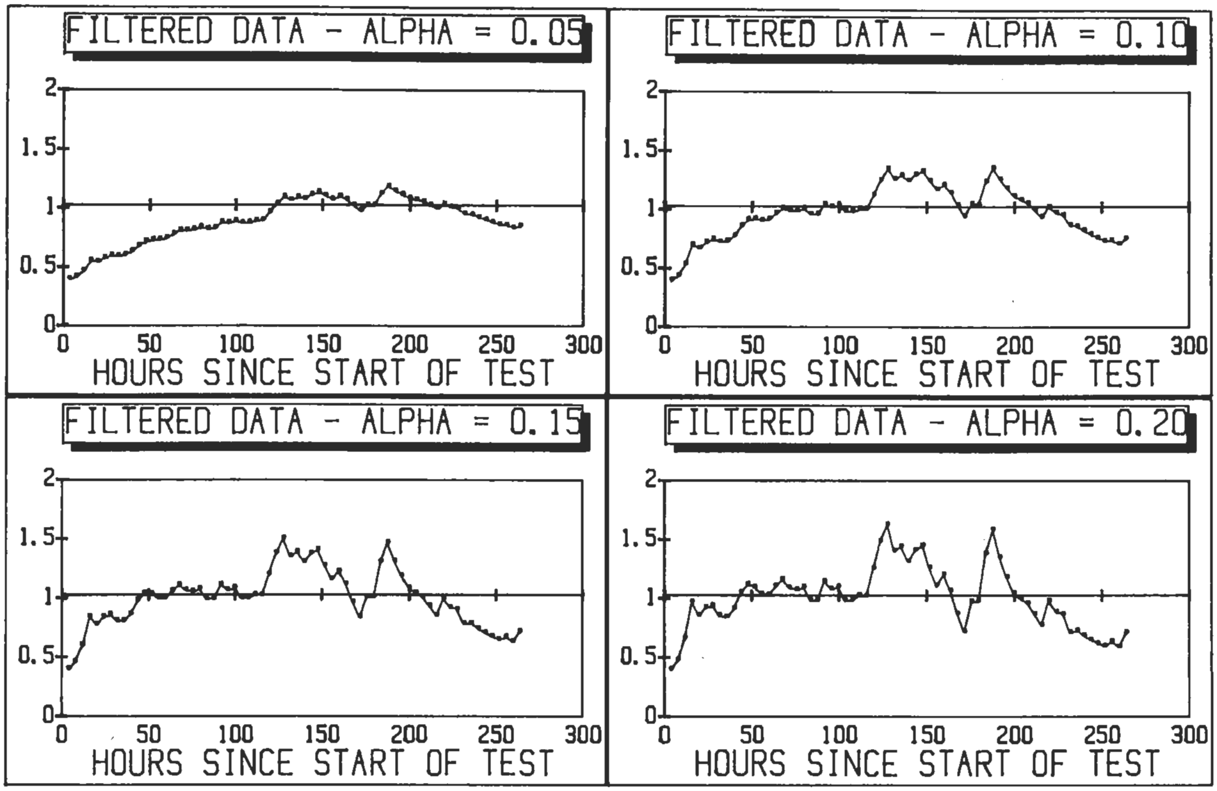


FIGURE 6 SAMPLE-TO-SAMPLE VARIATIONS OF RADON MEASUREMENTS IN AN EAST TEXAS HOUSE