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CONTINUOUS MONITORING (CRM & WLM) AS INDICATORS OF SHORT AND LONG TERM INDOOR RADON CONCENTRATIONS: PRECISION OR PERJURY?

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ABSTRACT

The relative usefulness of continuous monitors (CMs) is assessed for their precision and accuracy in predicting short and long term radon concentrations under EPA protocol conditions against the variables of time, weather, occupancy, an assumed equilibrium factor of 0.5, and whole house dynamics with Pylon AB5 portable CMs with concurrent CR and WL monitoring. Results obtained by a technician proficient in each technique were compared against charcoal canisters concurrently exposed for 2-7 days and alpha track monitors exposed concurently for 1 to 6 months. Both CM and Charcoal canisters were calibrated against National Bureau of Standards traceable radium-226 sources. Radon concentrations in the range of 2-50 pCi/L were monitored in 10 Northeast homes.

Radon concentrations change more dramatically with some variables than others. Working Level is more affected by occupancy than CR and both are influenced by weather patterns. Predicting radon concentrations based on an assumed equilibrium factor of 0.5 consistently fell outside the accepted norm of two standard deviations of accuracy and precision. I conclude that several factors significantly affect indoor radon concentrations. Further, the extrapolation of radon concentration based on an assumed equilibrium factor and working level monitoring is not a reliable predictor of indoor radon concentrations.

INTRODUCTION

For the past year several articles (Saum, Brodhead, Lamar. 1990) have been published on the subject of the ability of working level monitors (WLM) to accurately predict radon concentrations using an conversion factor based on an assumed equilibrium ratio (ER) of 50% attached and 50% unattached progeny of radon ^{222}. It was apparent that the accuracy of WLMs to predict radon concentrations based on an assumed equilibrium ratio merited further investigation.

In my routine investigation of buildings for indoor radon concentrations it became apparent that many home buyers were making purchasing decisions based, at least in part, on the results of working level (WL) converted to picocuries per liter (pCi/L) of air with no determination of the ER for the monitoring period being reported. Results of converted WL often varied significantly from pCi/L even though homes were subsequently monitored under very similar conditions and close time proximities (within thirty days). I sought to determine why test results between the two methods differed.

Were these differences attributable to changes in the indoor environment? Were outside environmental factors involved, or were ERs so different from the assumed one to one ratio of attached to unattached that the WL converted to pCi/L were predictably inaccurate?

From January to May, 1991, I monitored five occupied New England homes for concurrent concentrations of radon^{222} and radon progeny for periods of two to forty five days depending upon house and monitor availability. Additionally, in August, 1991 I simultaneously monitored the Environmental Protection Agency (EPA) National Air Research Laboratory (NAREL) as a control. From concurrent measurements running radon concentrations, radon progeny concentrations, and equilibrium ratios were determined. In all cases passive monitors accompanied the continuous monitor. In one case when one continuous radon monitor was not available, passive monitors were substituted.

Homes with indoor radon concentrations ranging from 2 to 50 pCi/L were chosen due to two considerations. The larger the sampling size the greater the accuracy of the tests. There is an inverse relationship between counts per minute (CPM) and standard deviation (SD) which I used to measure the numerical deviation from the arithmetical mean. Secondly, I

sought to duplicate radon concentrations that could be potentially reported as "elevated" according to current EPA guidelines when variable factors such as time of year and indoor verses outdoor conditions are taken into account. Last, I compared radon concentrations in pCi/L to WL converted to pCi/L based on a one to one ratio of attached to unattached radon^{222} progeny in indoor air.

METHODS AND MATERIALS

All homes were monitored according to current EPA protocols for indoor radon monitoring for all methods used. No requests were made to change test conditions or patterns of occupancy other than to maintain protocol conditions and record environmental factors such as temperature and wind speed. Outdoor temperature and relative humidity were recorded from the weather section of a daily newspaper[1].

Homes were monitored by making use of two Pylon AB5 portable radiation monitors owned by Ecodex Inc. Although both Pylon monitors are interchangeable for monitoring for either radon^{222} or radon progeny, each monitor was used consistently for sampling either radon or radon progeny. The Continuous Radon Monitor (CRM) was equipped with a Lucas cell with a 271 milliliter volume, a filtered intake tube and a flowmeter. To set up the Working Level Monitor (WLM) a AEP 47 Alpha Detection Assembly was fitted to the main body of the AB5 Portable Monitor. Both instruments were calibrated annually and accuracy checks were performed in accordance with manufacturers specifications prior to sampling against sealed calibrated radium^{226} standard sources.

In addition to the Continuous Monitors, passive detectors were also run concurrently. Depending on the duration of the test period, from one to all of the following were deployed: Two day Ecodex Open Faced Activated Charcoal Canisters (ACC2), Ecodex Four Day Diffusion Barrier Activated Charcoal Canisters (ACC4), Ecodex Seven Day Diffusion Barrier Activated Charcoal Canisters (ACC7) and One to Twelve Month Alpha Track Detectors (ATD). Ecodex ACC's were analyzed in accordance with EPA and State of Florida accepted quality control (QC) procedures. Test results compared against known sealed calibrated radium^{226} standard sources and an independent radon chamber fell within acceptable QC limits

of two S.D. (Tables 1 & 2). Test results from a laboratory other than Ecodex, Inc. were compared to the mean value of all detectors inclusive of the period monitored (Table 2).

House #256 had an Electrostatic generator, or Positive Ion Generator (PIG) operating for the entire testing period. One unit each was integrated into three interconnected HVAC Systems. The size of the house was about ten thousand square feet or five to seven times the space for an average home.

From data collected, continuous values of radon, radon progeny, and equilibrium ratios were plotted. Additionally, results for passive integrated sampling devices were tabulated and compared against continuous monitors. Data from home #256 with the PIGs was compared to the other four homes and control. Environmental factors such as temperature and relative humidity were compared against changes in radon and progeny concentrations to analyze their relationships.

RESULTS

In home 204, six day monitoring at three hour intervals revealed a mean equilibrium ratio of 0.20 or 20% unattached progeny fraction. The Continuous Radon Monitor (CRM) averaged 2.6 with a standard deviation of 0.5. The equilibrium ratio averaged 0.20. When WL was converted to picocuries per liter in air using an assumed equilibrium factor of 0.50 the average radon concentration was underestimated by 61% (Figure 1). Interestingly, Table 1 illustrates equilibrium ratios that never exceed 25%. At all times during monitoring, at least 75% of the alpha particles had plated out on surfaces to become attached.

TABLE 1

CRM	WL RAW COUNT	WORKING LEVEL E	RATIO WL X 200	C.V.
2.7	487	0.0021	0.08	0.4	0.15
2.8	815	0.0040	0.14	0.8	0.29
3.3	965	0.0049	0.15	1.0	0.30
3.7	1,045	0.0053	0.14	1.1	0.29
3.3	1,131	0.0059	0.18	1.2	0.35
3.1	1,033	0.0053	0.17	1.1	0.34

2.5	979	0.0050	0.20	1.0	0.40
3.2	952	0.0048	0.15	1.0	0.30
3.5	1,137	0.0059	0.17	1.2	0.34
3.1	1,184	0.0062	0.20	1.2	0.40
3.0	1,152	0.0060	0.20	1.2	0.40
3.5	1,135	0.0059	0.17	1.2	0.34
3.4	1,151	0.0060	0.18	1.2	0.35
3.1	1,201	0.0063	0.20	1.3	0.40
2.6	1,127	0.0058	0.22	1.2	0.45
2.2	929	0.0047	0.21	0.9	0.42
2.0	911	0.0046	0.23	0.9	0.46
2.2	975	0.0049	0.22	1.0	0.45
2.5	934	0.0047	0.19	0.9	0.38
2.9	1,012	0.0052	0.18	1.0	0.36
3.0	1,065	0.0055	0.18	1.1	0.36
2.7	1,110	0.0057	0.21	1.1	0.42
2.5	949	0.0048	0.19	1.0	0.38
2.3	916	0.0046	0.20	0.9	0.40
2.3	875	0.0044	0.19	0.9	0.38
2.4	951	0.0048	0.20	1.0	0.40
2.3	1,014	0.0052	0.22	1.0	0.45
2.5	954	0.0048	0.19	1.0	0.39
2.4	1,028	0.0052	0.22	1.0	0.44
2.5	1,123	0.0058	0.23	1.2	0.46
2.8	1,136	0.0059	0.21	1.2	0.42
2.2	1,011	0.0051	0.23	1.0	0.47
2.2	919	0.0046	0.21	0.9	0.42
2.6	1,153	0.0060	0.23	1.2	0.46
2.9	1,188	0.0062	0.21	1.2	0.43
3.0	1,169	0.0061	0.20	1.2	0.41
2.4	1,167	0.0061	0.25	1.2	0.51
2.4	1,007	0.0051	0.21	1.0	0.43
2.0	759	0.0037	0.18	0.7	0.37
1.9	851	0.0042	0.22	0.8	0.44
2.1	898	0.0045	0.21	0.9	0.43
2.0	892	0.0045	0.22	0.9	0.45
2.0	898	0.0045	0.22	0.9	0.45
2.2	808	0.0040	0.18	0.8	0.36
1.8	820	0.0040	0.22	0.8	0.45
1.7	719	0.0034	0.20	0.7	0.40
2.0	725	0.0035	0.17	0.7	0.35
SD 0.5	149.0	0.00	0.03	0.18	0.06
Av 2.6	986	0.0050	0.20	1.0	0.39

The average ER of House 202 (above) of 20% unattached did not vary significantly from House 210. House 210 had the highest ER of the five homes tested, 26%. Table 2 illustrates the

ACTUAL AND CALCULATED WL
ASSUMES 0.50 EQUILIBRIUM

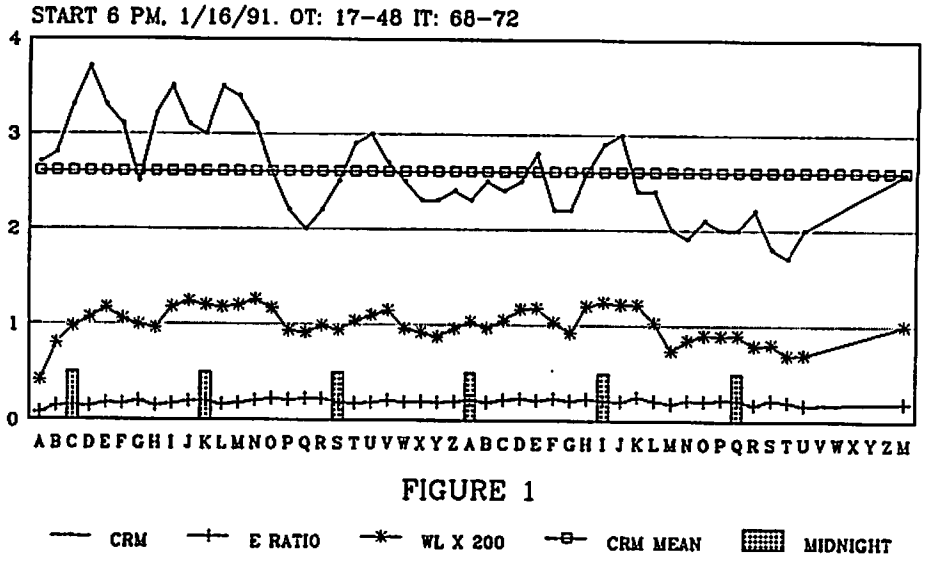

FIGURE 1

HOME #204 6 DAYS, 3 HR INTERVALS

mean values of continuous radon monitors, passive monitors working levels, and equilibrium. It is noteworthy that this study shows equilibrium ratios in homes averaging 15.8% for homes excluding the Positive Ion Generator. Results are three to four times lower than the assumed ER of 50%.

TABLE 2

LOCATIONS	NAREL	210	204	212	255	263	ER
CR MEAN	9.70		2.60	7.2	27.9		
2 D. ECC		46.0	2.90	7.10	31.3	4.40	
4 D. ECC					31.4	4.30	
7 D. ECC		38.10	2.30	7.00			
16 D. IAT		33.00					
16 D. IAT		31.80					
EPA	10.00						
MEAN	9.85	37.23	2.60	6.90	30.2	4.35	
S.D.	0.15	5.59	0.24	0.35		0.63	.05
ER MEAN	0.10	0.260	0.20	0.101	.069	ND	.13
WL MEAN	0.01	0.090	0.005	0.0069	.038	.0001	
WL*200 MEAN	2.00	18.00	1.38	7.6	0.02	N/A	

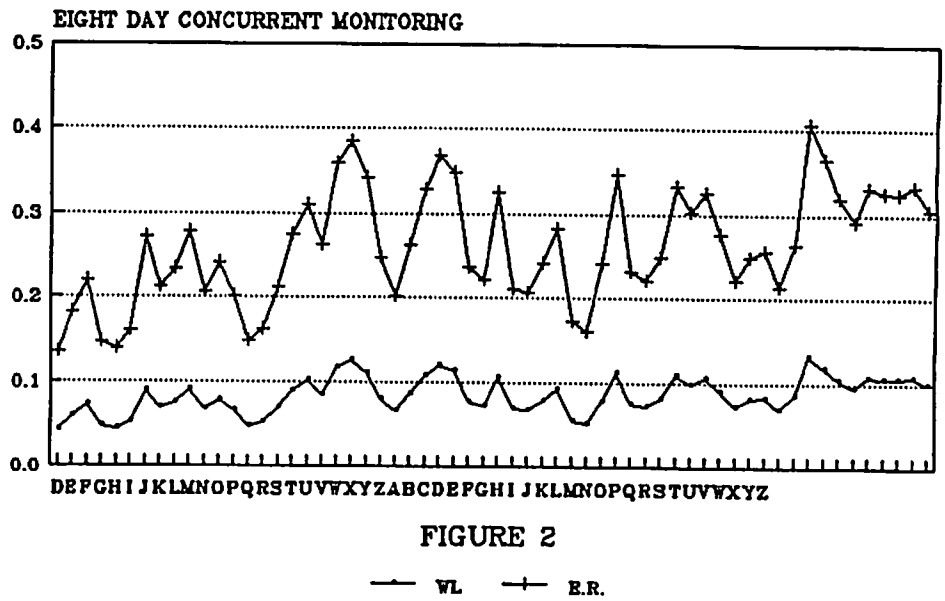

FIGURE 2

Figure 2 illustrates how variable the equilibrium range is. In this graph the equilibrium ranges from about 13 to 40% unattached fraction. In a nine hour period, the ER can change by a magnitude of 2. Here again, a conversion of WL to pCi/L using the assumed equilibrium factor would grossly underestimate radon concentrations. The following formula is often used to convert working level to picocuries per liter of air. pCi/L = (WL x 100)/ER. Where:

WL = Working Levels
ER = Equilibrium Ratio (the ratio of unattached to attached progeny)
pCi/L is the unit of measure representing 2.22 decays per minute or one trillionth of a curie.

16 DAY MEANS OF ATD AND WLM ~
ASSUMES 0.50 EQUILIBRIUM

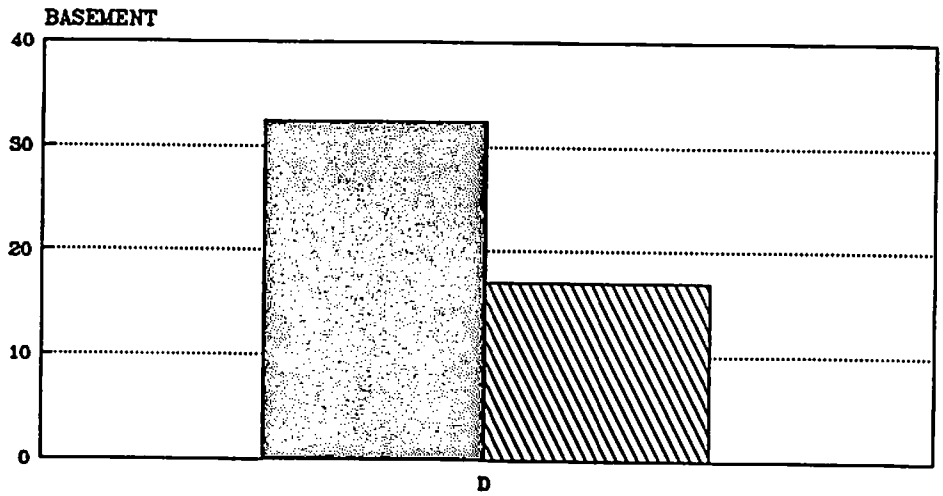

FIGURE 3

16 DAY ATD MEAN WL X 200

HOUSE 210, START 3/11/91, 11PM

Figure 3 illustrates the degree to which the working level converted to pCi/L underestimates the actual radon concentration when working level is converted based on an assumed equilibrium ratio of 0.50. In this case, the aformentioned conversion formula was applied and the results were plotted for the 16 day period against the mean of two alpha track monitors placed side by side and next to the working level continuous monitor. The mean ER was 0.26 which reveals a converted WL assuming an ER of 0.50 would underestimate radon concentrations by a factor of two. 0.26/0.50 = 0.52 or 52 per cent.

HOME 212. WL AND ER
ONE HOUR INTERVALS. START AT 4PM

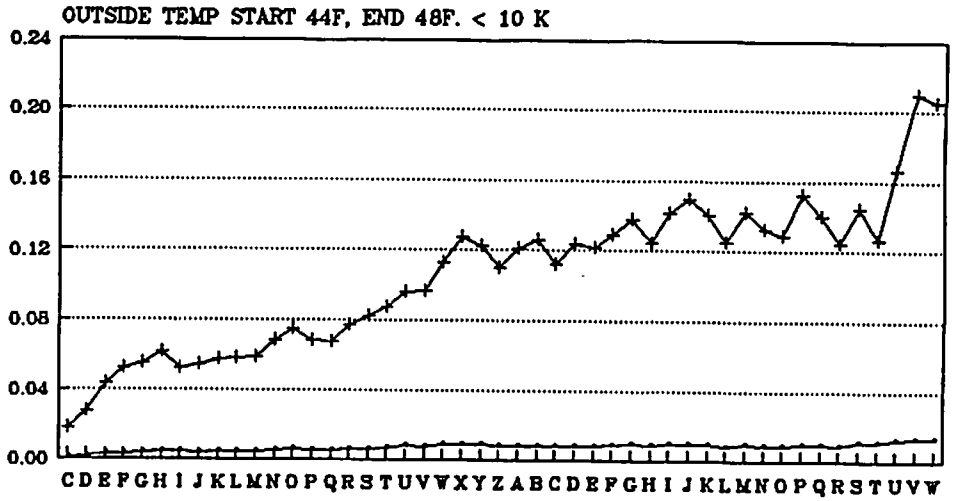

FIGURE 4

48 HR CONTINUOUS MONITORS. START 1/29/91

Figure 4 displays the change in ER and reveals a trend. Both ER and WL values doubled between day one and day two. No explanation to this change could be identified. Both indoor and outdoor temperatures remained fairly constant. The space being monitored was an unoccupied basement. A significant amount of dampness was noted, but indoor relative humidity measurements were not taken. Figure 4 demonstrates the probability of high inaccuracy for testing periods of less than two days.

HOME 212 ACTUAL V. CONVERTED
CONTINUOUS MONITORS. CRM AND WLM

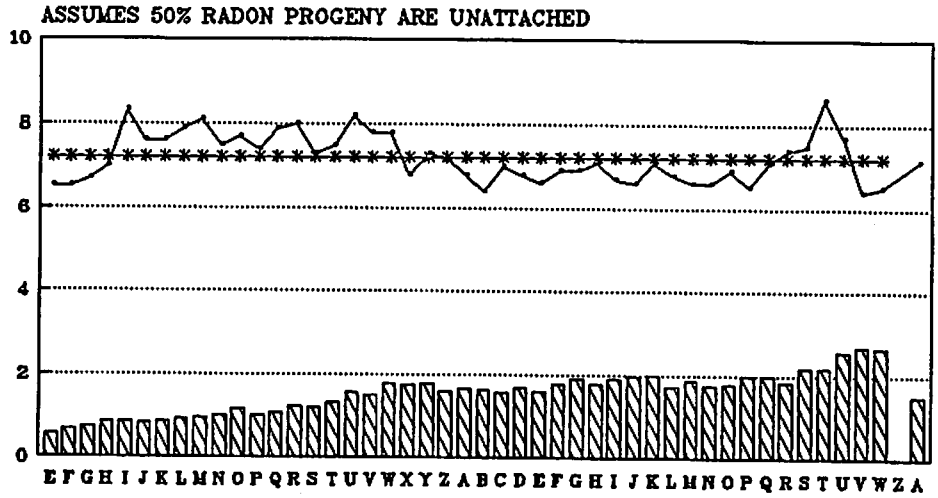

FIGURE 5

Figure 5 plots working level converted based on the assumed ER of 0.50. It reveals that the radon concentration as demonstrated by the Continuous Radon Monitor is about four times higher than the WL converted to Pci/L.

HOUSE 255 WL AND ER
3 HR INTERVALS FOR THREE DAYS

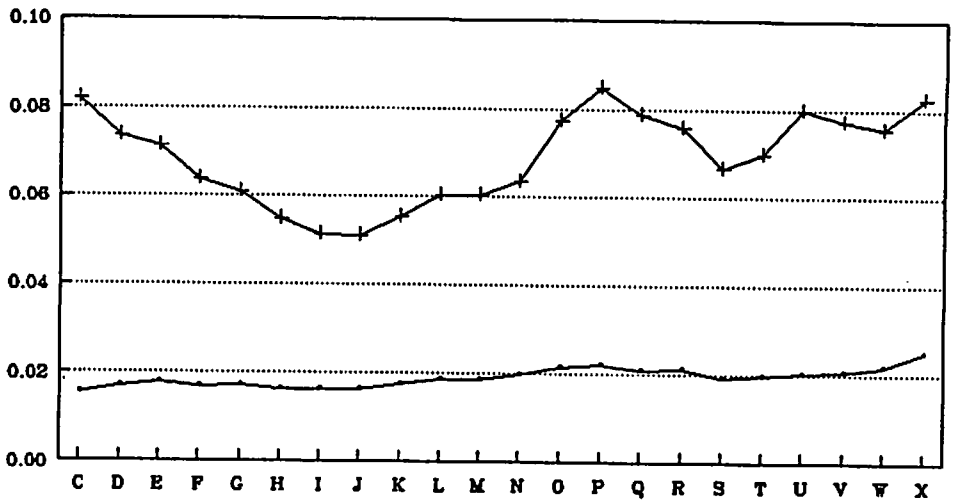

FIGURE 6

WLM ER

START 4/11/91 5PM. OT: 45/70F

Figure six illustrates a low ER for six day monitoring period. There were no fans or other air circulators to account for this low ratio. Since radon concentrations remained high (in the 18 - 31.9 pCi/L range) venting is an unlikely factor. More likely, this home as with others studied enjoys a low ER.

WL MEAN CONVERTED TO PCI/L
COMPARED TO CONTINUOUS RADON MEAN

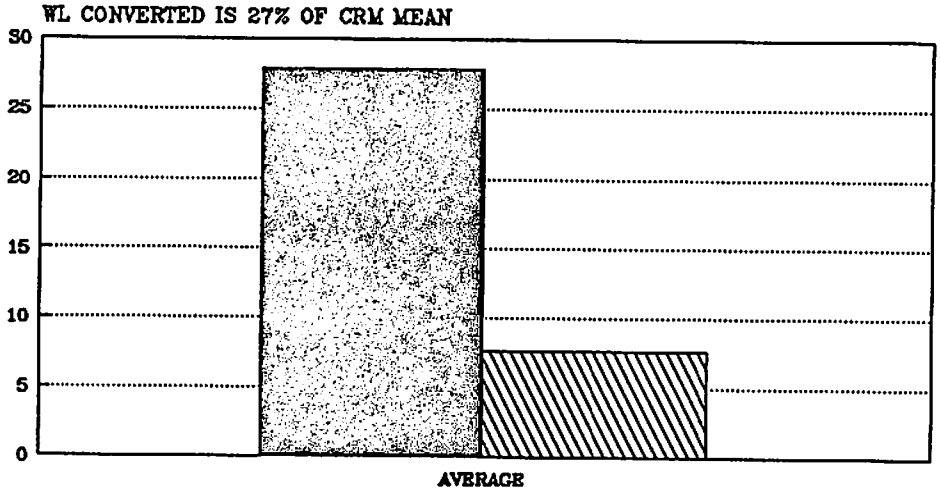

FIGURE 7

HOUSE 255. ASSUMES .50 ER

Figure 7 graphically underscores that a working level converted to picocuries in this home would underestimate the true radon concentration by a magnitude of nearly 4. Here the converted WL is only 27% of the actual CRM mean.

HOUSE 256

WL AND ER WITH ION EXCHANGER ON.

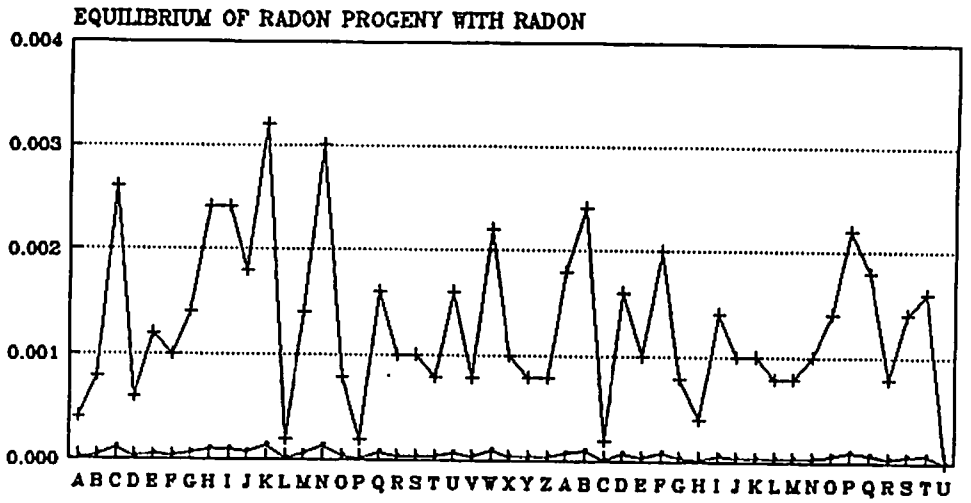

FIGURE 8

House 256 shows the dramatic affect of the operation of an electrostatic generator. The working level concentrations were nearly non detectable. This forced air system was capable of moving large volumes of air through this 10,000 square foot residence.

What is truly noteworthy about this home is that it would have been very easy to miss the fact that electrostatic generators were in use. All were attached to each of the three HVAC systems that climatized the house. The HVAC systems were in remote corners of this very large basement and the plates identifying these ion generators were covered with dust and unreadable to the eye. If a working level were converted based on an assumed ER of 0.50, virtually no radon would have been detected anywhere in the home.

Figure 9 demonstrates the elevated radon concentrations even in the absence of radon progeny. It would be interesting to study the health of a population exposed to radon in the absence of progeny - as in this case.

HOUSE 256

26 HOUR RADON BY CRM WITH IONIZER ON

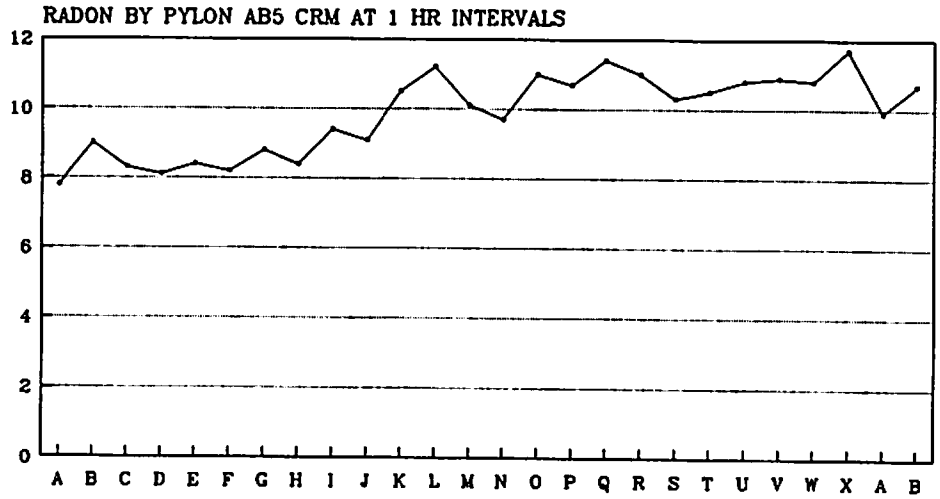

FIGURE 9

Figure 10, the control, shows the variation between working level converted to pCi/L based on an assumed ER of 0.50 in the EPA NAREL Las Vegas Radon Chamber. Again, converted radon grossly underestimates radon concentrations determined by continuous radon monitoring.

EPA NAREL, LAS VEGAS, NV
CRM & WL CONVERTED TO PCI/L

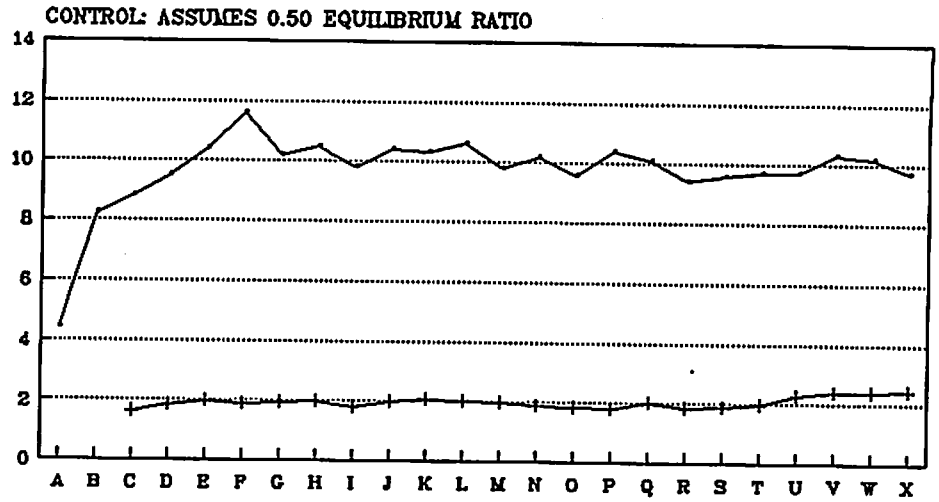

FIGURE 10

START 8/19/91, 24 HR CONCURRENT MONITORS

PRECISION CHECK

TWO CRMs RUN SIMULTANEOUSLY 5 DAYS

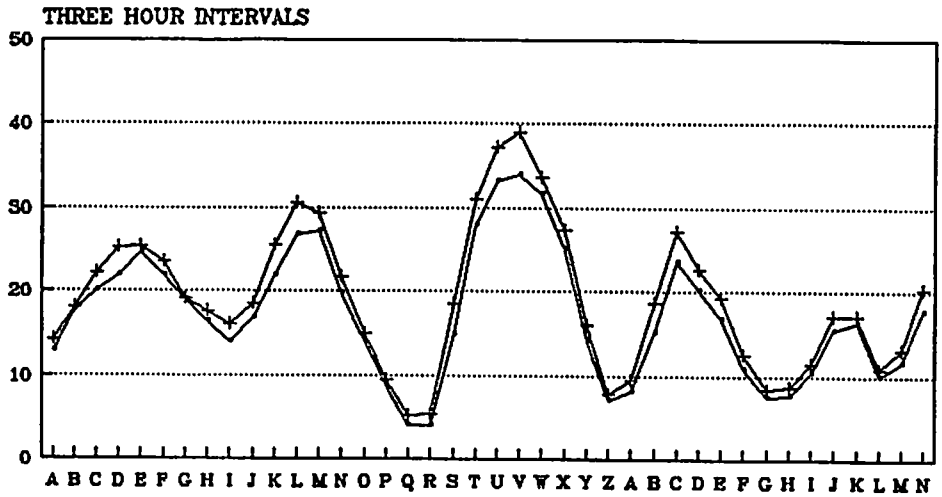

FIGURE 11

Figure 11 illustrates a five day precision check of two Pylon Continuous Radon Monitors run for five days set at three hour intervals. Such high precision is difficult, if not impossible to achieve with other methods of radon measurement. It also demonstrates the consistency of these devices.

DISCUSSION

These results demonstrate the true equilibrium ratios in homes to be four times lower that the assumed equilibrium ratio of 0.50. This study found the mean ER to all homes to be 0.126. For four homes without ion generators the ER mean was 0.158. This value is over three times lower than the often assumed ER of 0.50. ER mean was Conversions to picocuries from assumed ERs of 0.50 would underestimate radon concentrations by a magnitude of four in four of the five homes I studied. These same results were mirrored in the Control (Figure 11). The only significant variant from the ERs in the four homes was the fifth home, # 256, which had a nearly nondetectable ER due to the operation of positive ion generators.

The variability in radon concentrations from day to day as illustrated in figures one and four underscore the need to monitor radon for at least 48 hours in order to more accurately predict long term radon concentrations. It is also notable that short term test results compared well with continuous radon monitors and alpha track devices (Table 2).

In home #210, one ATD measurement was thrown out because it was reported at a concentration of only two thirds of the other two ATDs. Since this variant ATD was so far outside two standard deviations of all detectors of that location, I had little confidence in its accuracy. Such variations in values are more likely to occur due to gaps in quality control than environmental factors or the limitations of a given type of detector. For example, in this case the variant ATD was from company B while the other two which closely agreed in value, were from company A.

Outdoor environmental factors of temperature and relative humidity did not appear to influence radon concentrations sigificantly. Indoor temperatures and relative humidity were not studied in enough detail to draw any conclusions. More research is needed to learn the relationships between indoor and outdoor environments and radon, indeed for other indoor pollutants as well.

The limitations of all radon detectors warrant further study to answer the two important questions of: What are the variations and why do they occur?

SUMMARY

This five month study of radon and radon progeny has clearly demonstrates the unreliability of converting working level measurements to picocurie per liter based on an assumed equilibrium level of 50% unattached and 50% attached. In all homes studied, the highest ER detected was 41% unattached to 59% attached for one three hour sample. The mean ER for that home was 0.26 or 26% unattached. This indicates that at best, working level conversions to picocuries based on an assumed ER of 0.50 underestimated radon by half. At worst, the radon concentrations could be over a thousand times greater than a working level converted based on the assumed ER of 0.50 - as in the case of homes with electrostatic precipitators in operation.

Data from this study indicate extremely poor predictive power of working level conversions to picocuries based on an assumed equilibrium ratio.

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