# Measurement of Radon Variability in a Single Family Home Under Normal Living Conditions

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Weekly measurements were performed in both the basement and first floor of a small ranch home in the Harrisburg, Pennsylvania area using seven-day diffusion barrier charcoal canisters. Long-term E-PERM's and Alpha Track Detectors (ATD) were also deployed for 3, 6, 9, and 12 months. All measurements were performed under normal living conditions.

## Introduction

Fifty-two contiguous charcoal measurements were carried out, starting in February 1998 and ending in February 1999. Each Sunday evening at least one charcoal canister was placed on a storage shelf in the basement and one canister was placed on a first floor bedroom dresser. At the start of the experiment eight long-term E-PERM's and eight ATD's were also placed at the same locations as the charcoals. The long-term testing devices were pulled out in duplicate at 3, 6, 9, and 12-month intervals.

All testing devices were placed according to current US Environmental Protection Agency (EPA) protocols, with the exception of the short-term, charcoal measurements being done under "normal" living conditions. That is, in the winter the home was under closed-house conditions and in the late spring, summer, and early fall windows and doors were often open.

Long-term E-PERM's and charcoals were analyzed by Pennsylvania Department of Environmental Protection (DEP); Radon Division staff and ATD's were sent to Radon Environmental Monitoring, of Northbrook, Illinois for analysis.

The test site is a 1300 square foot ranch, single family home with a walkout basement. Only the back wall of the basement is exposed, and it is on this wall where there are two windows, including storm windows, which are never opened, and a door, also with a storm door. This door is primarily used during the spring, summer, and fall months. The house is heated by oil, hot water baseboard. There is central air conditioning but it is never used. The water supply is via a private well, with a radon level of 700 pCi/L.

The home is located in a valley, within several hundred yards of the base of a mountain, and the predominant geology is sandstone/siltstone. The home is located in an EPA Zone 1 county and statistical data (Personal Communication) shows that the average basement and first floor levels for this zip code are 15.7 and 8.9 pCi/L respectively.

## Quality Assurance

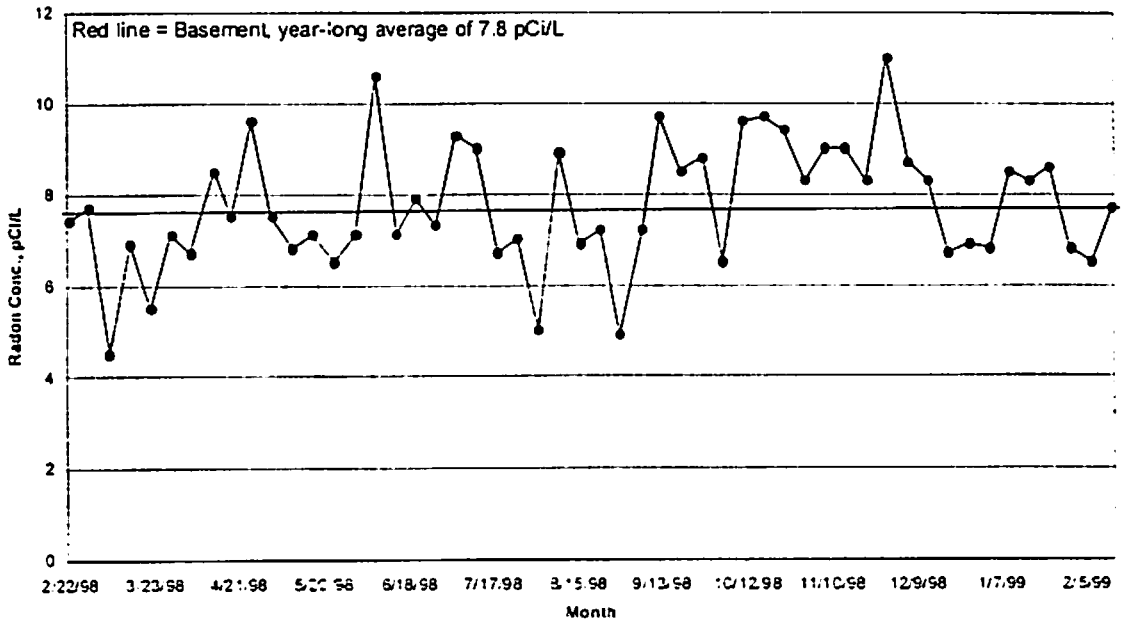
The Radon Division maintains a regular schedule of quality control measures on both our charcoal and E-PERM systems. Spikes, blanks, and duplicates are all well within established limits of acceptability. Additionally, during this study nine sets of duplicates were deployed with an overall average coefficient of variation of 4.4%, with a range from 10.8% to 0.7%. During six of the weekly exposure periods another test method was used as a crosscheck on the charcoal measurements. Four times short-term E-PERM's were used and three times continuous radon monitors were used. The E-PERM crosschecks showed an average (n=4) percent difference of 8.9% and the continuous radon monitors showed an average (n=3) percent difference of 15%. This 15% value would have been better had it not been for the fact that radon levels on two occasions dropped during the last day or two of the exposure period, and biased the charcoal results low.

## Results

All 112 charcoal canisters and all 16 long-term E-PERM's were successfully analyzed. One out of the 16 ATD's (9 month ATD) produced an anomalous result and was not included in the data, its duplicate also produced a questionable value, but was included.

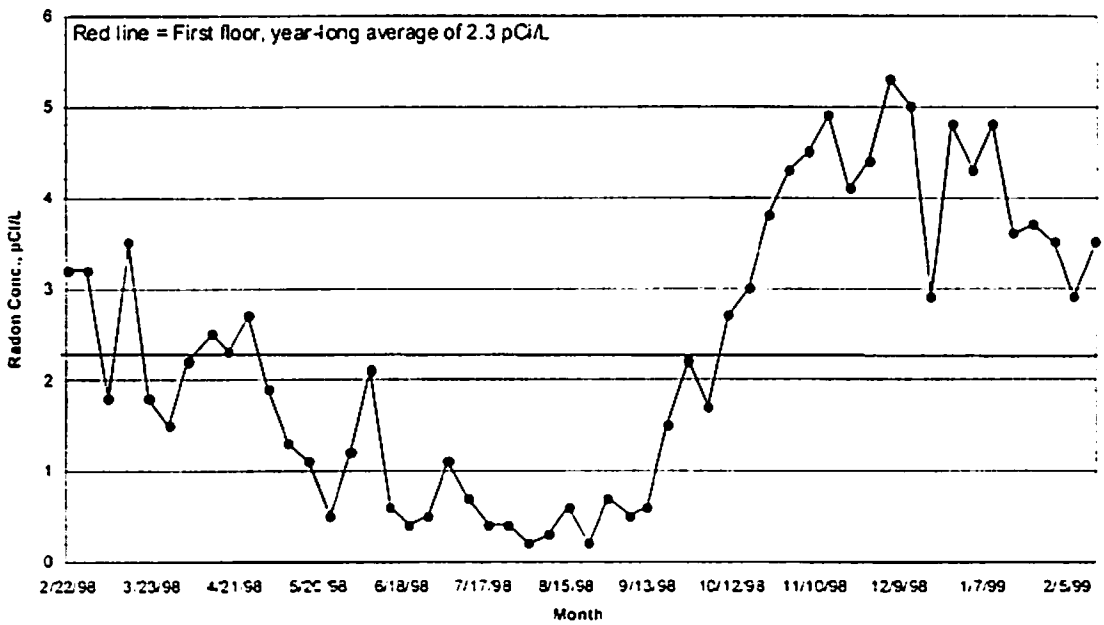
The average (- - 1 sigma) basement radon concentration based on the 52 charcoal canisters was 7.8 +/- 1.4 pCi/L. All but three of the 52 charcoal measurements were within two standard deviations of the mean. The data ranged from a high of 11.0 pCi/L (first week of December) to a low of 4.5 pCi/L (second week of March). See Figure 1 for basement radon variability over time.

**Figure 1**
**Basement, Radon Variability**
**F&J R40VDB, 7 Day Diff. Charcoal**

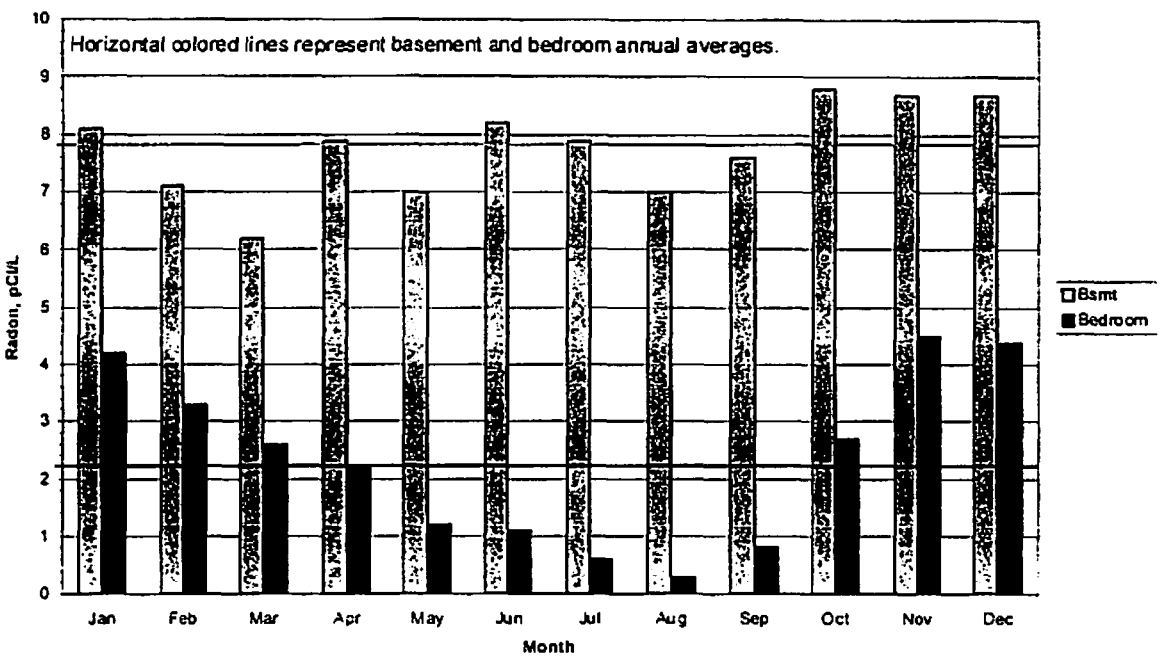



The average first floor radon concentration based on 52 charcoal canister results was 2.3 +/- 1.6 pCi/L. All 52 charcoal results were within two standard deviations of the mean. The data ranged from a high of 5.3 pCi/L (second week of December) to a low of 0.2 pCi/L (first and last weeks of August). See figure 2 for first floor radon variability over time.

**Figure 2**
**First Floor, Radon Variability**
**F&J R40VDB, 7 Day Diff. Charcoal**

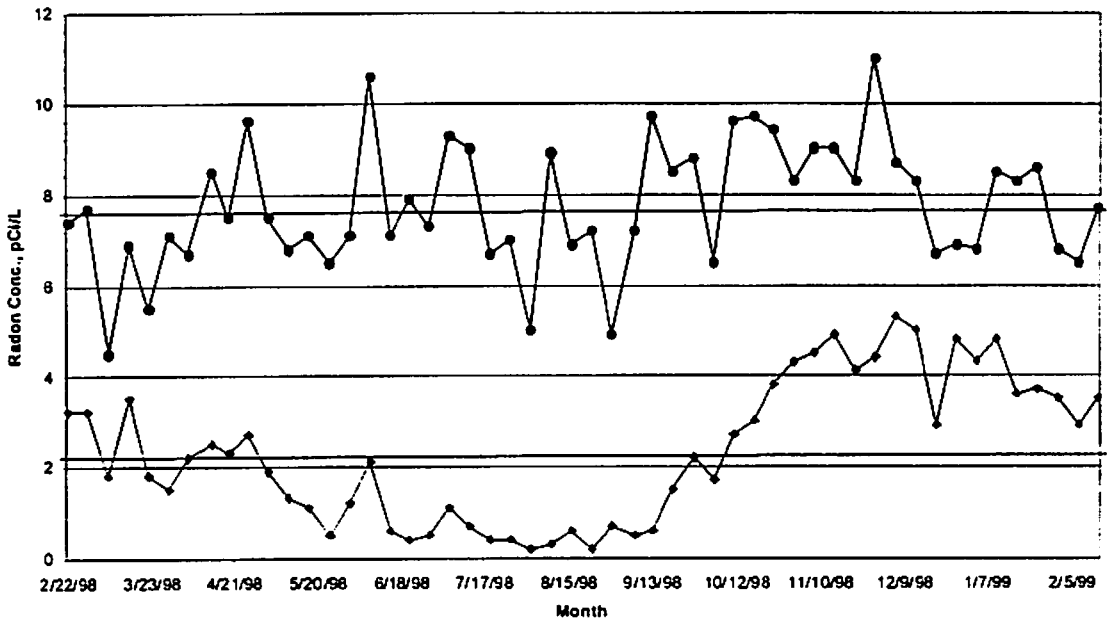



The inter-relationship between the basement and first floor radon variability can be observed in Figure 3.



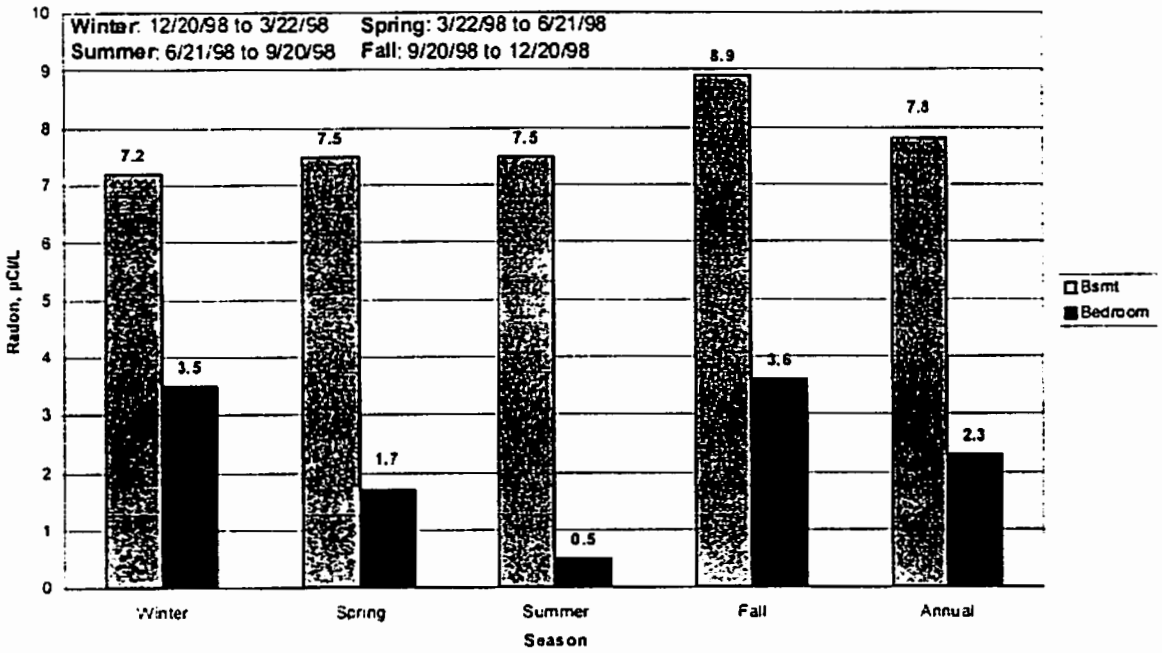

Radon levels in the basement do not appear to show any seasonal variation. The first floor radon levels do show a seasonal variation, with spring and summer levels below the annual average, and fall and winter levels above the annual average. This variation, I believe, is due mostly to increased house ventilation during the mild weather. Figure 5 compares basement and first floor radon levels by season.

Figure 3
Bsmt. Vs First Fl., Radon Variability
F&J R40VDB, 7 Day Diff. Charcoal



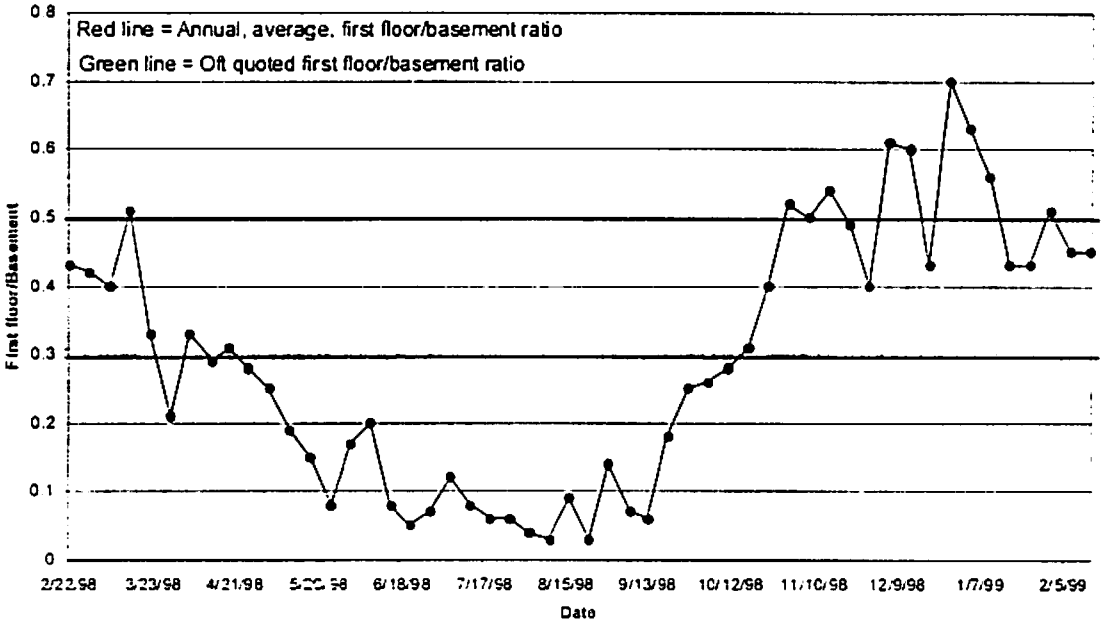

The basement and first floor radon levels can also be compared monthly. Each month the four charcoal canisters in the basement and on the first floor were averaged and graphed throughout the year. Figure 4 compares the monthly averages of basement and first floor radon levels. The basement shows fairly uniform levels, whereas the first floor shows a much more seasonal and open house effect.

**Figure 5**
**Radon Variability**
**R40VDB, 7 Day Diff. Charcoal**




The first floor to basement ratio is often quoted as 0.5, that is, the first floor tends to have roughly one-half of the radon concentration as found in the basement. This value is quoted for closed-house testing conditions. Figure 6 shows this first floor/basement ratio throughout the duration of this experiment, which includes both closed-house and open house conditions. An average ratio over the year of 0.3 was found.

**Figure 6**
**First Floor/Basement Ratio**
**F&J R40VDB, 7 Day Diff. Charcoal**




So far only charcoal results and data have been looked at, there is also interesting data from E-PERM's and ATD's to examine. These two methods and the charcoal are primarily examined in relation to one another. Overall, all three methods compared favorably over the yearlong experiment. The three test methods in the basement show a slightly better degree of precision than the three test methods on the first floor. The average coefficient of variation (COV) for the three basement methods for the year was 5.9%. The average COV for the three first floor methods for the year was 9.2%. Figure 7 compares E-PERM, ATD, and charcoal results for 3, 6, 9, and 12 month periods, in the basement.

Figure 7
E_PERM, ATD, Charcoal Quarterly Comparison
Basement

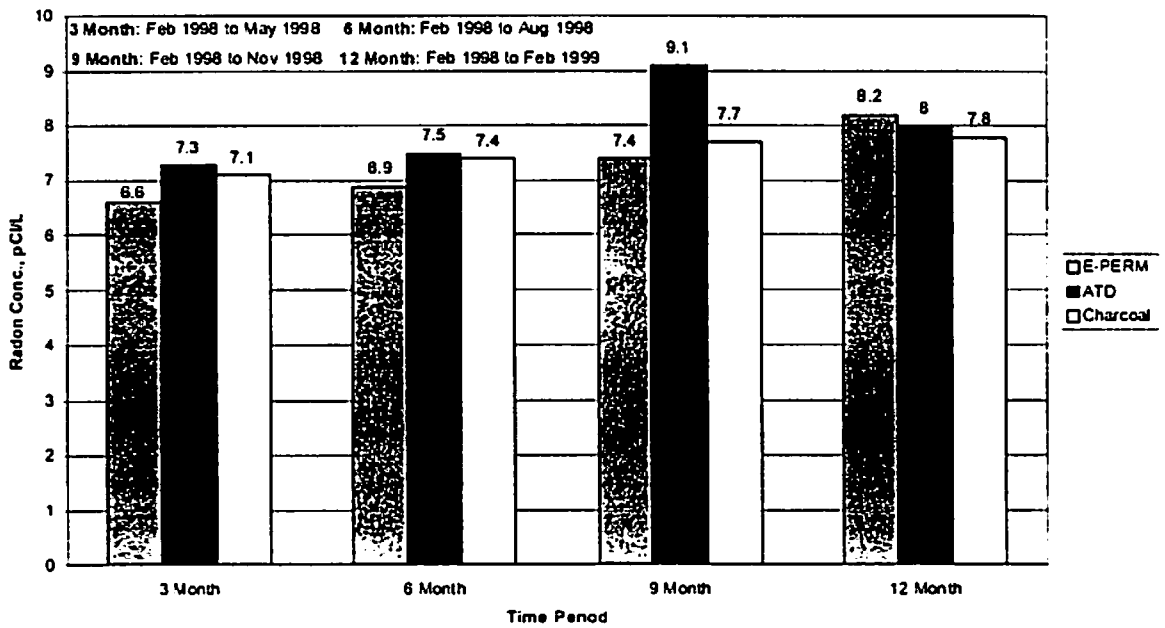
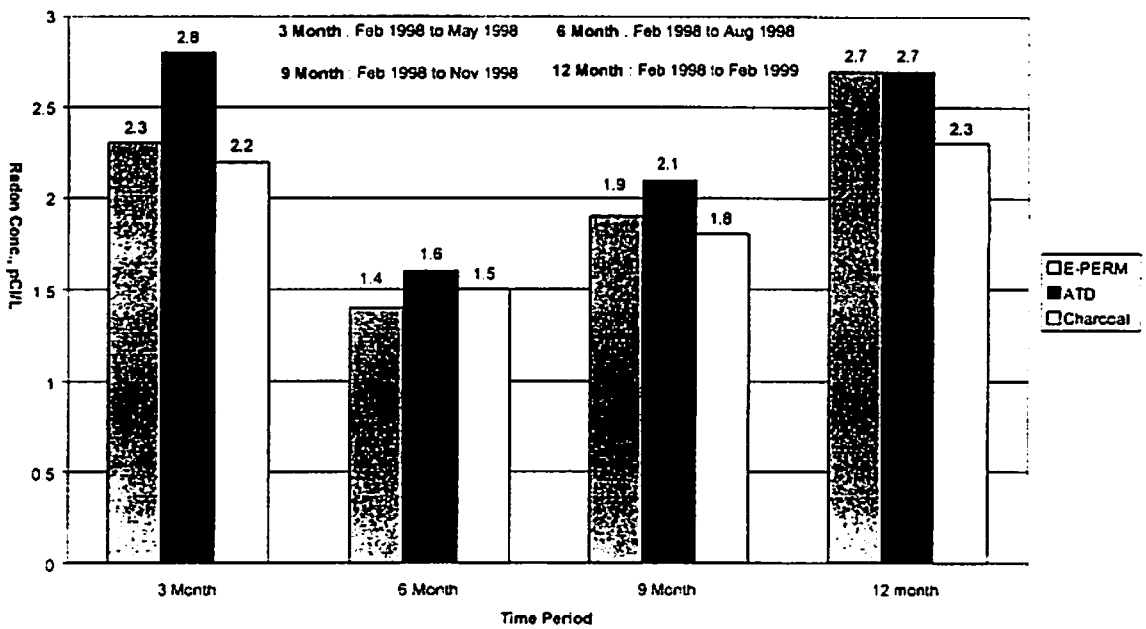



Figure 8 compares E-PERM, ATD, and charcoal results for 3, 6, 9, and 12 month periods for the first floor.

Figure 8
E-PERM, ATD, Charcoal Quarterly Comparison
First Floor




## Discussion

The basement radon data seems somewhat atypical in that it does not show a strong seasonal trend. There were 27 data points above the basement annual average and there were 24 points below the average, and there was one point on the average (See Figure 1). The points below the average are not associated with summer nor are the points above the average associated with winter. The magnitude of any one data point above and below the average was interestingly and probably coincidentally almost equal. The maximum value above the average was by 3.2 pCi/L and the minimum value below the average was by 3.3 pCi/L.

First floor data shows a clear seasonal effect. Data points from the beginning of May to the middle of October were all below the first floor annual average. Then from the middle of October to the end of February all data points were above the average. The data points were almost equally distributed above and below the average. There were 25 points above the average and 27 points below the average.

The basement to first floor radon seems to be moderately coupled. Sixty-seven percent of the time when the basement level was above or below the average the first floor level was also in the same direction above or below the average. That is, 67% of the time when the basement level was above the basement average the first floor was also above the first floor average, and vice versa.

Table 1 shows average radon concentration in basement and first floor under open and closed-house conditions and then compares these to the annual average.

## Table 1

| | Open House Radon | Closed House Radon | Annual Average Radon |
|---|---|---|---|
| Basement | 7.5 pCi/L | 7.8 pCi/L | 7.8 pCi/L |
| First Floor | 0.74 pCi/L | 3.3 pCi/L | 2.3 pCi/L |

The basement shows very little difference between open and closed-house radon levels compared to the annual average. The first floor under open-house conditions shows a much larger difference between open house, closed-house, and the annual average. This seems to show that the basement remains relatively isolated from the rest of the house.

Cohen et al. 1988 reported that open windows reduced radon levels by a factor of about 2.5. In this study open windows had a larger effect on radon levels, reducing them by a factor of about 4.4. This may have been due to a greater amount of ventilation during the exposure period.

First floor to basement ratios can be examined from the data. Table 2 shows this ratio for open-house measurements (n=20), closed-house measurements (n=32), and for the entire year (n=52).

## Table 2

| | Open House Average | Closed House Average | Annual Average |
|---|---|---|---|
| 1st Fl./Bsmt Ratio | 0.1 | 0.42 | 0.3 |

The closed-house result of 0.42 matches closely with the value from the EPA's national Residential Radon Survey of 0.4, as reported by Marcinowski et al. 1994. Other investigators (Fisher et al. 1998, Rahlenbeck et al. 1991, and Cohen 1991) have reported ratios from 0.5 to 0.61. Since most if not all radon surveys employ closed-house testing conditions little information is available showing first floor/basement ratios under open-house conditions. This study found 0.1 as the first floor/basement, open-house ratio. The overall annual average ratio combining both open and closed-house conditions was 0.3.

It is somewhat surprising and ironic that the winter season (See Figure 5) average charcoal results for the basement are lower than the other three seasons and also the annual average. Cohen et al. 1998 has reported winter measurements to be roughly 60 percent higher than summer measurements. An EPA study (EPA 520/1-86-015) of 20

homes in Butte, Montana reported minimum values in the warmer months and maximum values during the cooler months. In this EPA study the maximum levels occurred in December and the minimum levels were in August.

The first floor seasonal variation is more consistent with reported variations. Winter and fall seasons are roughly equal and higher than spring, summer, and the annual average. The first floor winter/summer ratio (3.5/0.5) of 7.0 is much larger than the value reported by Cohen of 1.86 for Pennsylvania houses. However, all of Cohen's measurements were done under closed-house conditions, which would have caused the summer time measurements to be significantly higher than for those of this study house for which summer measurements were done under open-house conditions. This study also showed data similar to the above EPA study, where the highest level occurred in December and the lowest in August.

Figure 7 compares the three test methods (E-PERM, ATD, and Charcoal) during four, three-month intervals in the basement. All three-test methods during the four intervals compare favorably. The percent difference for the three methods during the four intervals ranged from a high of +12.3% (9 month ATD outlier) to a low of –8.6%, with most differences better that +/- 5%. In Figure 7 the 9-month ATD value of 9.1 pCi/L is believed to be an outlier. The duplicate ATD for this 9-month interval was reported as 0.3 pCi/L. Conversation with the ATD laboratory could not resolve any problems with either result.

Figure 8 compares the three test methods during four, three-month intervals on the first floor. All three-test methods again compare favorably during the four intervals, particularly in light of the low radon levels. The percent difference for the three methods during the four intervals ranged from a high of +16.6% to a low of –10.2%. Eight of the 12 results had a percent difference of better than +/- 7%.

## Conclusion

A series of contiguous diffusion barrier charcoal measurements performed in a small ranch home showed that basement radon levels did not show the typical seasonal variability, but in fact remained relatively constant throughout the entire year. This was surprisingly true during the hot summer months when the first floor was maintained under open-house conditions. The first floor radon levels displayed the typical seasonal variability, with highs in the winter and fall, the low in the summer and an intermediate value in the spring.

First floor/basement radon ratios when analyzed under closed-house conditions showed a value of 0.42, quite consistent with current literature. Under open-house conditions this value drops to 0.1.

A comparison E-PERM's, ATD's and charcoals used in this study showed good agreement over the four different time intervals measured. The percent difference among

the test methods during any of the time intervals ranged from +16.6% to –10.2%, with most values better than +/-7%.

References

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