USE OF SNIFFERS IN RADON MITIGATION

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ABSTRACT

The radon industry uses the term “sniffer” to refer to making quick, onsite radon measurements at locations that might indicate a radon source. In the past the only instruments for making these measurements cost five thousand dollars or more which was unaffordable for most mitigators. Several instruments are now on the market that cost less than two thousand dollars. These radon sniffers can be very helpful before or after a radon mitigation system is installed to find a radon source or rule out a possible radon source. Typically these instruments are most helpful to find a radon source after a radon mitigation system has been installed and the radon levels are still elevated. Another use is to measure the radon levels while a radon mitigation system is being installed to determine the workers exposure and radon reduction from ventilation. The author documented use of several currently available radon sniffers by having them measure a known radon concentration and make various measurements in two homes with elevated radon levels after a radon mitigation system was installed.

1.0 Radon SniffersTested

1.1 RadonAway GM1-2

The GM1-2 has a one minute initial start up followed by six minute sampling periods. During each sampling, the unit displays the time left in the six minute sampling period, the total number of alpha counts it is detecting, the counts per minute it measured during the previous six minute counting and the previous radon measurement it recorded based on the counts. See Figure 2.

Figure 1: GM 1-2

Because the GM1-2 only displays the radon levels from the previous 6 minute sampling it is necessary to always write down the levels recorded each time without missing one of the sampling period results which easily happens when one is performing other functions while the sampling is taking place.

The internal battery powered pump can run for hours and needs to be charged after continuous use. There is no battery indicator. The GM 1-2 also has a micro-monometer feature built in but this was not part of the study. The unit comes with a desiccant drying tube which starts off as a blue color and then changes to pink as the desiccant absorbs moisture in the sample air. Replacement desiccant tubes are sold by RadonAway and the desiccant drying function can be renewed by baking just the desiccant beads in an oven at 375 degrees for an hour.

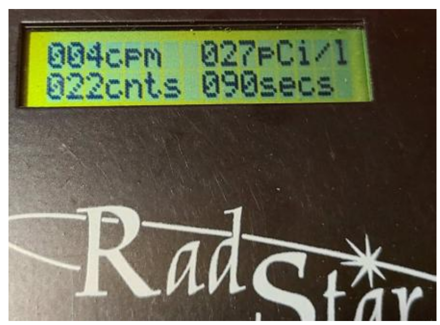


Figure 2: GM 1-2 display

The results can be in Bq/m3 or in pCi/l. The GM1-2 does not beep with each alpha count. The maximum radon concentration the GM1-2 can measure is 999 pCi/l. The sensitivity is about 10 counts per hour (CPH) per pCi/l.

Cost for this unit at time of this study was $1515 plus tax and shipping. The GM1-2 was calibrated by the manufacturer prior to the start of this study.

1.2 Environmental Instruments Canada CT007-R

The CT007-R is a scintillation cell instrument that has a built in battery and air pump, LCD display and bluetooth connectivity to a cell phone app. The display includes a battery indicator. There is toggle button to switch the display from short cycle average to long cycle average. As soon as the instrument is turned on it will begin providing results. The short cycle is the running 15 second average result. The long cycle is the running 5 minute average. You can toggle between short and long average at any time. 15 second average is useful for very high radon levels. Each alpha count can be set to beep.

Figure 3: CT007-R

Setting the CT007-R on smart mode using the cell phone app allows the algorithm to calculate the amount of background radon alpha counts from the previous sampling and subtract those counts in order to more accurately measure the current sampling concentration. This calculation is done with a cell phone app that needs to be continuously connected by bluetooth to the CT007-R during sampling. Figure 4 is the screen display of the current sniffer results. Figure 5 and 6 are the same running results in a graph. The graph average results can be varied from as little as each 15 second average results to 30 minute average results.

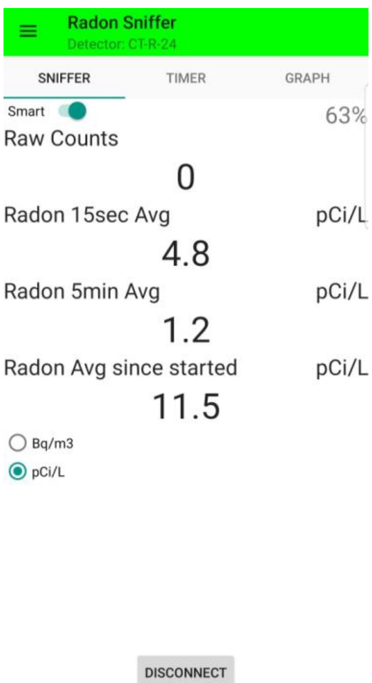


Figure 4: Results screen of CT007-R app

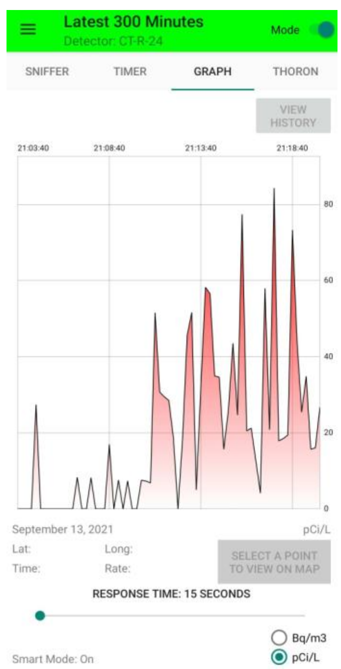


Figure 5: Graph screen set to 15 second interval

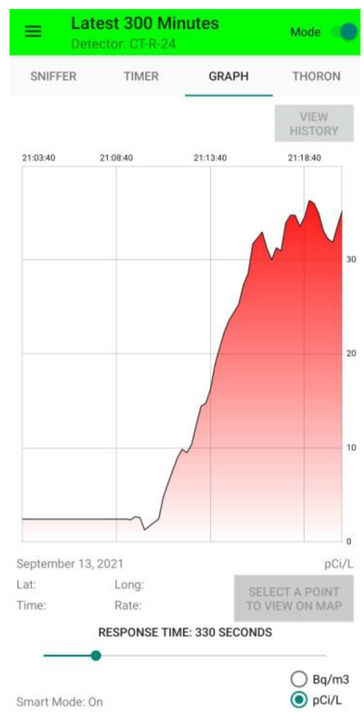


Figure 6: Graph screen set to 330 second interval

Figure 5 is the graph set to 15 second interval. Note the random results with this short interval. In Figure 6 by sliding the bar below the graph, the interval can be lengthened or shortened. At 330 second interval or 6.5 minutes the average smoothes out and the sampling result of about 32 pCi/l can be interpreted by the CT007-R results.

The CT007-R needs to be started in a low radon environment in order to minimize the background counts that the algorithm subtracts from the current counts. Once the CT007-R is started it operates best if it is always left on with the cell phone app working and connected to the CT007-R by its bluetooth connection. If the app or CT007-R is restarted it will assume the current alpha counts are the background not the sampling counts and will subtract them out giving an initial potentially false result. The benefit of this algorithm is it allows the CT007-R to be used for multiple sampling with shorter periods in between sampling when low radon air is used to flush out the sampled air.

In general it is a well known fact that radon sniffing needs to start with sampling what is assumed to be a lower radon level and then subsequent sampling is done in what is assumed to be increasingly higher radon concentrations. If higher radon level sampling is done first, such as sampling under a slab, before lower radon level sampling such as a crawl space is done, the background from the higher radon level will cause background alpha counts from the radon decay products left in the detection area of the instrument to give false high or greater measurement variability. The length of time the sniffer samples a higher concentration also increases background counts. Therefore the quick response of the CT007-R can allow less background counts if sampling is only 5 minutes compared to the typical sampling time of 10 or 12 minutes with the other two sniffers that were tested.

If a sniffer is sampling air that is in direct contact with soil such as under a slab or a crack or an opening that is adjacent to soil, there can be thoron as well as radon in the sampling. In Pennsylvania and New Jersey the soil can contain more thoron than radon. (ref 4) If thoron is sampled along with radon, a false high radon reading would be obtained. Thoron has a very short half life of about 55 seconds compared to radon's half life of 3.82 days. To minimize thoron influencing a radon measurement, the sample needs to be aged for at least ten minutes. This will cause the thoron concentration to be decayed in half ten times. If the thoron was 1000 pCi/l it would reduce it to 1 pCi/l. The CT007-R has a thoron measuring function that samples for 90 seconds to fill its scintillation cell and obtain alpha counts and then turns the pump off for 300 seconds or five minutes

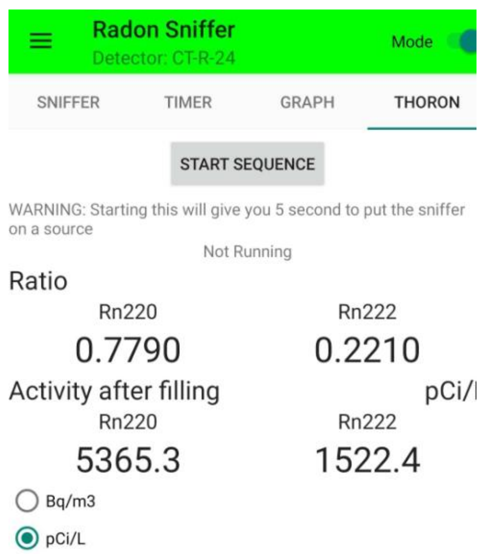


Figure 7: Thoron function

while continuing to measure. The fall off of alpha counts is then used to determine the thoron concentration of the sample and the radon level. See results in Figure 7.

Cost for the CT007-R at time of this study was $1750 plus tax and shipping. The maximum radon levels the CT007-R can measure is at least 10,000 pCi/l. The sensitivity of the CT007-R is about 47 CPH / pCi/l.

1.3 Ecosense EcoTracker

The ET100 EcoTracker is actually a group of four continuous radon monitors that can be programmed to provide radon average results every 5 minutes after start up. By placing these four detectors in suspect elevated radon locations a comparison of radon levels can be obtained in as little as eight to thirteen minutes. The EcoTrackers have no air pump and cannot measure radon levels greater than 255 pCi/l. They are not designed to measure high concentrations of radon below the slab or inside block walls. They are designed to measure small differences between different areas of a home or commercial building at the same time to allow easy comparison. They can however be placed directly near or in a suspected radon source such as a crawl space, sump pit, near a floor drain or open utility pipe. The opening to the chamber is on the bottom of the monitor so the bottom of the detector should be closest to the sampling location.

The Ecotracker uses the same radon sensor used in the Radoneye detectors sold by the same company. The Ecotracker uses a large pulse ion chamber to obtain 30 alpha counts per hour per pCi/l. This in combination with its open pathway to the ion chamber allows fast response to changing radon levels. The EcoTracker app can program each EcoTracker individually to provide radon averages every 5 minutes or every 10 minutes or every hour. The Ecotracker must be plugged into an outlet with the supplied charger or powered with a cell phone back-up battery attached to a 5 volt to 12 volt converter plug that is included with the basic package. There is no clock function so the start and stop time may need to be recorded if long term measurements are made. There is no beep when alpha counts are recorded.

Figure 8: Four EcoTrackers

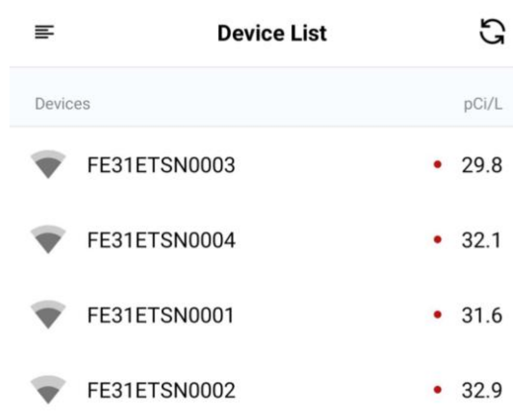


Figure 9: EcoTracker app display

Figure 10: EcoTracker battery setup

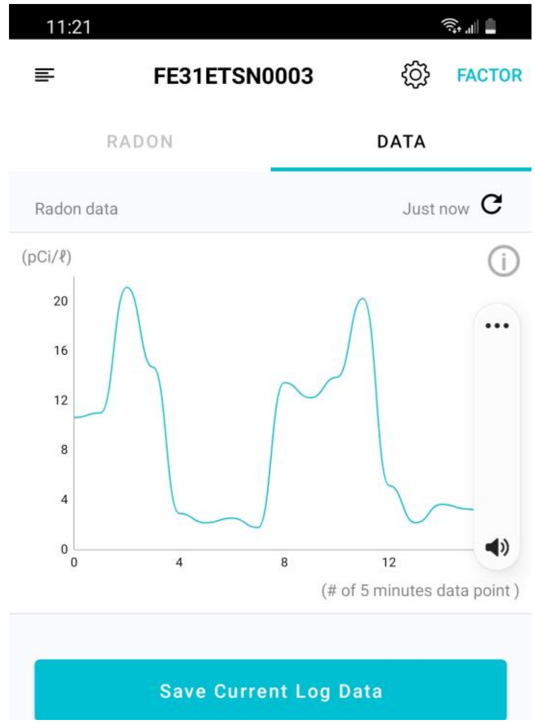


Figure 11: One hour of 5 minute averages

The EcoTracker takes three minutes to go through its start-up. The EcoTracker app connects with the Ecotrackers using blue tooth connection. The radon results of all four of the detectors are displayed in the app device listing. See Figure 9. The individual monitors can also display a graph of all of their measurements since the unit was turned on. See Figure 11. The average results whether they are in 5 or 10 or 60 minute averages are stored in the unit and can be uploaded to any cloud based storage or email address. These results can be converted into an excel table for graphing. After all the measurements are recorded the data in the EcoTracker can be cleared.

Cost for the four EcoTrackers at time of this study was $999 plus tax and shipping. The sensitivity of the EcoTrackers is about 0.5 CPM / pCi/l.

2.0 Radon Chamber Design

All of the sniffers were tested for their ability to respond to a locations radon concentration by sampling a radon chamber with a known concentration. See a picture of the chamber in Figure 12. The 530 liter radon chamber has two glove arms for moving items into and around the chamber and a side 28 liter air lock chamber to minimize influencing the current main chamber radon levels. The air lock chamber can be pre-filled with main chamber radon air but this was not done for this study as it would expose the EcoTrackers to radon before the test exposure was begun.

The chamber has two available radon sources. One radon source is manufactured by Pylon and can maintain the radon chamber at levels from 10 to 200 pCi/l. The other source is soil based and can maintain the chamber at levels up to 600 pCi/l. For this study only the Pylon source was used. The chamber relative humidity is maintained between 40% and 50% using desiccant columns. There is a computer fan in the chamber circulating air to maintain an even concentration in the chamber. The chamber system includes a positive pressure 3/8 inch tubing on the outside of the chamber to provide an inlet for the source and any dilution air as well as to circulate air through two Pylon scintillation cells. The two AB5 pylons which sample 0.5 LPM of air from the external chamber tubing are used to determine the chamber radon levels. The chamber has multiple ports for the sniffers to draw air directly from the chamber. Chamber is pictured in Figure 12 with the four Ecotrackers in the chamber.

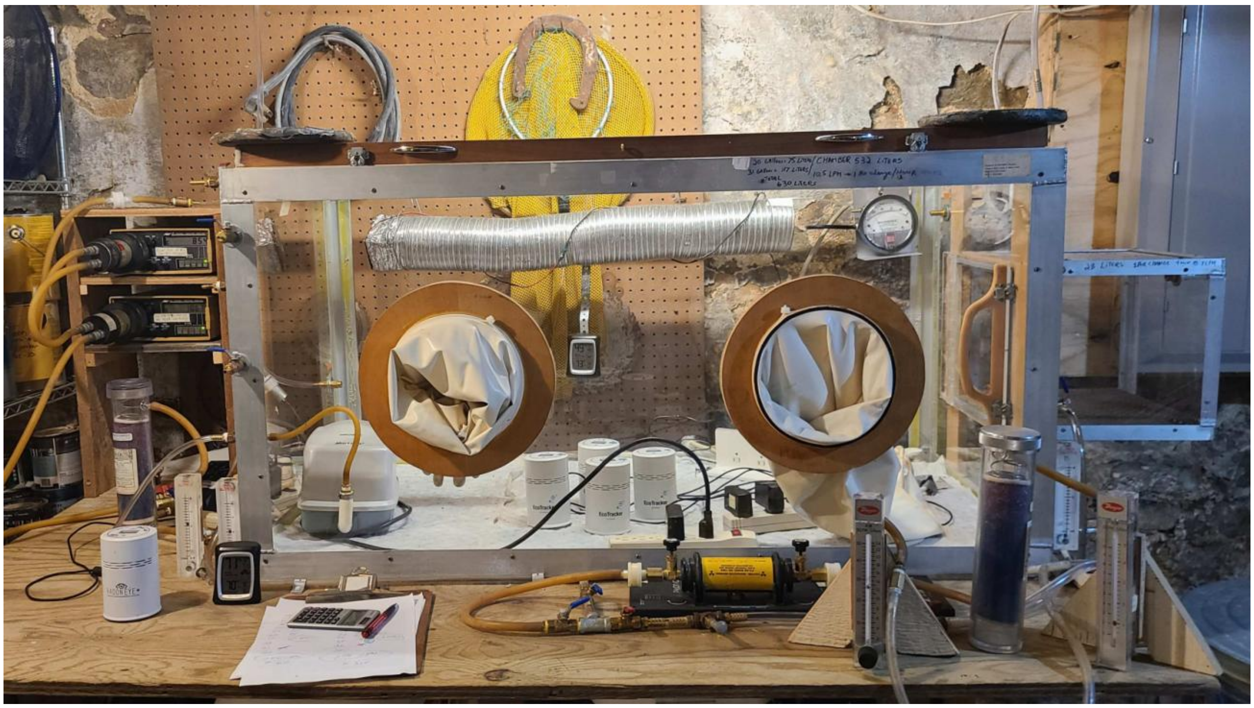
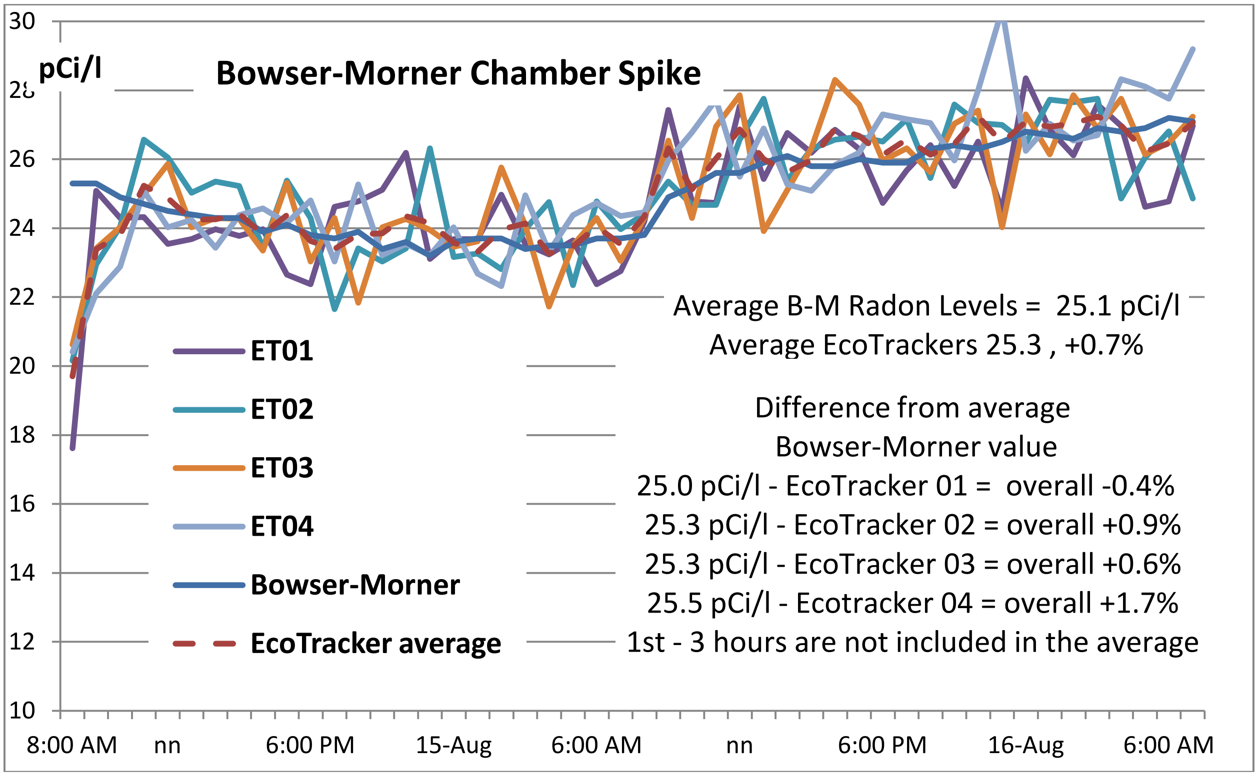


Figure 12: Radon Chamber

3.0 Radon Chamber Calibration

The radon concentration in the chamber is monitored by two AB5 Pylons that have flow through scintillation cells and by RadonEye radon monitors placed inside the chamber. To verify the accuracy of the radon levels measured in the chamber four of the EcoTracker radon monitors were spiked at Bowser-Morner radon chamber in August of 2021. The graphed results of the spiking are included in Graph 1. Three of the Eco-Trackers averaged within 1% of the Bowser-Morner average and a fourth EcoTracker was within 2%. The average of these four monitors were used in the chamber to set the calibration for the two Pylons and all of the Radon Eye monitors that are used in the study. This spiking was a good opportunity to test the Ecotrackers ability to measure hourly exposures.



Graph 1: EcoTracker spike results compared to Bowser-Morner

4.0 Testing the Sniffers using the Radon Chamber.

The radon chamber was set at three different levels to try and evaluate how well the sniffers performed at different levels of radon. The chamber was averaging about 8 to 10 pCi/l in the first run. The second run the chamber was averaging around 18 to 19 pCi/l. The third run the chamber was averaging about 85 to 87 pCi/l. In each run the GM1-2 and the CT007-R would sample the chamber from the outside. See Figure 13. The EcoTrackers required placing all four of the monitors in the air lock chamber and then using the chamber glove to move them from the airlock chamber into the main chamber and plug them in. See Figure 12. The reverse procedure was used to move them out of the chamber. All the monitors were moved outside after the radon levels had been sampled for 15 to 25 minutes. Sampling was continued outdoors for 15 to 20 minutes and then the monitors were placed in the chamber for a second exposure for the two higher level samplings. After the completion of each chamber level sampling all the monitors were placed outdoors for at least 30 minutes and the next sampling was not done until the following day.

4.1 Important Note about sniffers and the test results of this study

The results of these chamber sampling tests included one or two rounds of testing a known radon level for each monitor. The wide variation in results again illustrates that sniffing measurements are always an imprecise measurement especially when only one result is being considered. The results of the chamber testing are calculated as a percentage of the actual chamber radon levels to provide a method to compare the performance of each monitor but should not be considered an exact bias indicator of future radon sampling with these sniffers. The results indicate that differences of about 8 pCi/l and greater between locations can be identified with these sniffers but smaller variations were not tested and will likely require measurements spanning longer periods.

Figure 13: Chamber grab sample

4.2 GM1-2 results from Chamber exposure

The GM1-2 sampled the radon levels in the chamber at three different concentrations. The GM1-2 samples and records the counts every six minutes. It then displays the average count per minute and the radon levels. The results do not display tenths of a pCi/l which a sniffer measurement is not typically capable of measuring. In order to keep track of the variation in radon levels with the GM1-2 it is necessary to separately record the results and keep track of the six minute intervals as the data cannot be retrieved from previous recordings. It is very easy to get distracted with other work while waiting for the next result and not record an interval. Charts 4, 5, and 6 provide the results of the sampling of the chamber at about 8, 19 and 87 pCi/l levels. The sampling accuracy did not appear to significantly improve with the second and third interval. The GM1-2 tended to bias low as compared to the chamber level but to a lesser degree than the Ecotrackers. The Ecotrackers tended to report around 60% to 70% of the actual chamber radon level while the GM1-2 reported around 70% to 80% of the chamber value. The CT007-R averaged about 90% to 100% of the chamber value.

The display of raw counts does provide a quick indicator if very high radon or thoron levels are being sampled. When the GM1-2 was moved outdoors it generally took two or three intervals of 6 minutes each to get the results back to about 10% of the chamber sampling radon level although in the 8.1 pCi/l sampling the GM1-2 returned to 0 pCi/l after 18 minutes outdoors.

GM1-2 - Radon Chamber averaged 8.1 pCi/l		
Elapsed Time in minutes	**GM1-2 sampled Chamber**	**Percentage of Chamber**
6 min	7.0	**86%**
12 min	6.0	**74%**
18 min	8.0	**99%**
24 min	11.0	**136%**
6 min	**Moved GM1-2 to low radon area**	
6 min	3.0	**37%**
12 min	2.0	**25%**
18 min	0.0	**0%**
24 min	0.0	**0%**

Chart 1: GM1-2 Low-level sniff test

GM1-2 - Radon Chamber averaged 19.0 pCi/l		
Elapsed Time in minutes	**GM1-2 sampled Chamber**	**Percentage of Chamber**
6 min	16.0	**84%**
12 min	13.0	**69%**
18 min	9.0	**47%**
6 min	**GM1-2 sampled low radon area**	
6 min	3.0	**15%**
12 min	1.0	**5%**
18 min	2.0	**11%**
6 min	**GM1-2 sampled Chamber**	
6 min	11.0	**58%**
12 min	17.0	**90%**
18 min	20.0	**105%**
6 min	**GM1-2 sampled low radon area**	
6 min	5.0	**26%**
12 min	2.0	**10%**
18 min	8.0	**42%**

Chart 2: GM1-2 Mid-level sniff test

GM1-2 - Radon Chamber averaged 87.0 pCi/l		
Elapsed Time in minutes	**GM1-2 sampled Chamber**	**Percentage of Chamber**
6 min	45.0	**52%**
12 min	71.0	**82%**
6 min	**GM1-2 sampled low radon area**	
6 min	25.0	**29%**
12 min	9.0	**10%**
6 min	**GM1-2 sampled Chamber**	
6 min	60.0	**69%**
12 min	57.0	**66%**
6 min	**GM1-2 sampled low radon area**	
6 min	30.0	**35%**
12 min	10.0	**12%**
18 min	11.0	**13%**

Chart 3: GM1-2 High-level sniff test

4.3 CT007-R results from Chamber exposure

The CT007-R had the most accurate readings if the graph display was used and the response time of the graph was expanded. The display in the cell phone app displays a running 15 second and 5 minute average. The 15 second average could be useful to shorten the sampling time if very high levels were being sampled but in this portion of the study it displays too much variation to be helpful for the radon levels sampled from the chamber. The display of “Raw Counts” in the app also provide an on-going indicator if high or low concentrations of radon are being sampled. See Sniffer tab in Figure 14. The five minute running average provides a much better indicator after the sampling has been in place for at least five minutes. The app does provide a tab called “Timer” that provides a stop watch feature to allow tracking how long a sampling has been progressing. The timer interval can be adjusted but defaults to 5 minutes.

The graph function provides the best visual indicator of the level being sampled. See Figure 15 which is displaying 15 second averages and Figure 16 which is displaying 300 second averages. The length of the averages is easily changed by sliding the dot under the “Response Time” heading. This allows adjusting the average to provide an easier display to determine the approximate radon level the CT007-R is displaying for the sampling location of that time period. Figure 19 displays the fall off of radon levels the CT007-R is displaying when the monitor is moved to outdoor air. Determining the radon level by adjusting the graph was the most practical way to determine the sampling result. Cell phone screenshots of the graph are included to see the results obtained as the chamber levels were sampled.

The low-level sniff test was around 8.5 pCi/l. Figure 14 is the five minute results of 5.3 pCi/l while the graph results in Figure 16 display a result closer to 10 pCi/l. The two Figures display the difference in viewing the results at 195 second average and 330 second average in order to best determine the measurement the CT007-R is displaying for the chamber versus outdoor levels. The results in Chart 4 are based on the Graph results displayed in Figure 16.

CT007-R - Radon Chamber averaged 8.5 pCi/l		
Elapsed Time in minutes	**CT007-R sampled Chamber**	**Percentage of Chamber**
4min	10.0	118%
8 min	10.5	124%
2 min	**CT007-R sampled low radon area**	
5 min	5.0	59%
10 min	3.0	35%
15 min	1.75	20%
20 min	2.5	29%

Chart 4: CT007-R Low level radon sniff test

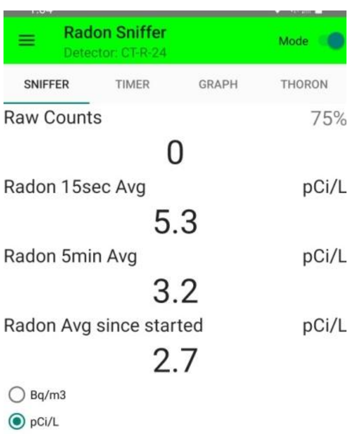


Figure 14: Sniffer tab running average display

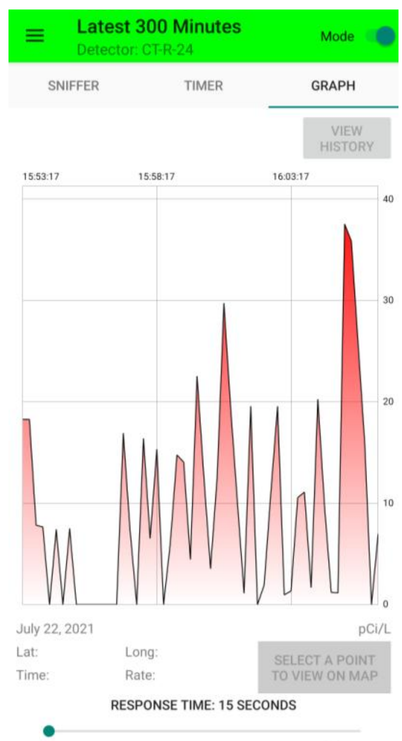


Figure 15: Graph tab displaying 15 second results for 19 pCi/l Chamber sampling

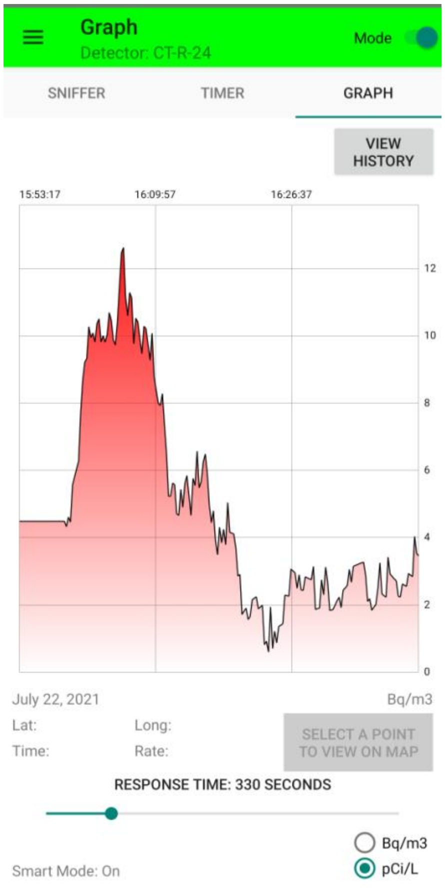


Figure 16: Graph tab displaying 330 second average results for 8.5 pCi/l chamber sampling

The second chamber sampling with the CT007-R is at 19 pCi/l. The graph results in Figure 18 appear to be an average of about 21 pCi/l. In this graph the second sampling of the chamber display initial average results of about 16 pCi/l and then about a jump to 22 pCi/l. The exposure outdoors after the second exposure were running much higher at an average of about 6 pCi/l. This is a good example why sniffers should be exposed in low radon environments after sampling to determine the background level before attempting another sampling.

CT007-R - Radon Chamber averaged 19 pCi/l		
Elapsed Time in minutes	**CT007-R sampled Chamber**	**Percentage of Chamber**
6 min	21.0	111%
5 min	**CT007-R sampled low radon area**	
14 min	2.0	11%
5 min	**CT007-R sampled Chamber**	
5 min	16	84%
5 min	22	116%
3 min	**CT007-R sampled low radon area**	
12 min	6	32%

Chart 5: CT007-R Mid level radon sniff test

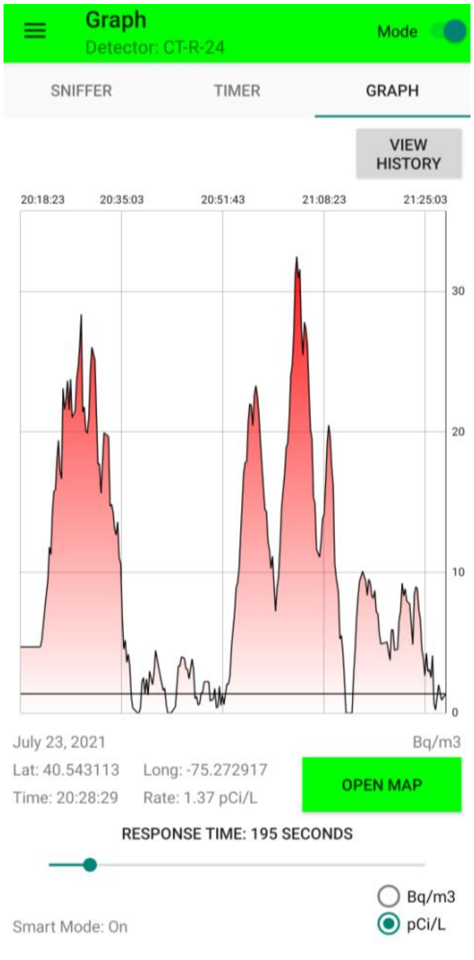


Figure 17: Graph tab displaying 195 second results over about 66 minutes

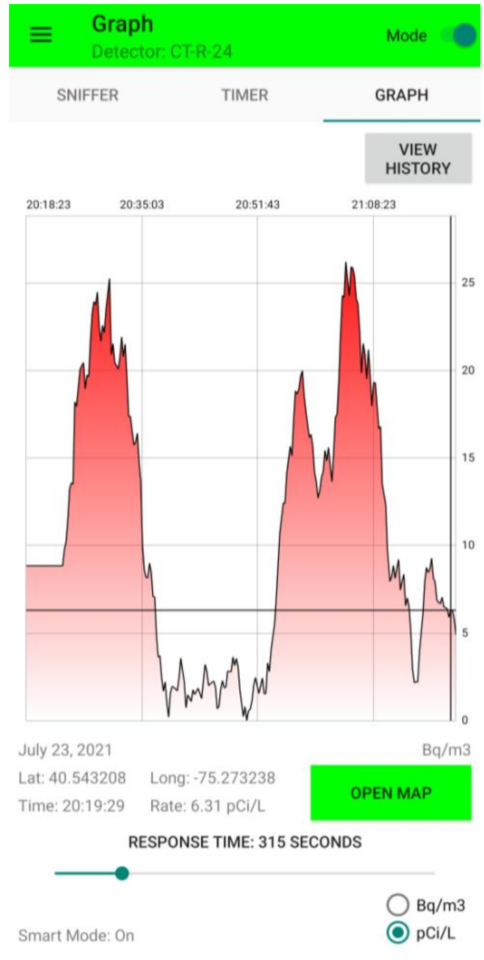


Figure 18: Graph tab displaying 315 second results over about 58 minutes

During the third chamber exposure the CT007-R was displaying results close to the chamber level of 88 pCi/l when the graph is average is increased to 315 seconds. When the monitor was moved outdoors after the 1st exposure the cell phone was moved out of range of the CT007-R and no data was collected for this period. What appears to be a zero reading at the start of the outdoor measurement in Figure 19 or Figure 20 is actually the loss of connection between the devices. The cell phone app re-established connection and continued recording data after that loss. The loss of connection may have influenced the CT007-R recording higher radon levels outdoors compared to the second outdoor exposure. During the final outdoor exposure the radon levels displayed returned to about 10% of the chamber exposure.

CT007-R - Radon Chamber averaged 88 pCi/l		
Elapsed Time in minutes	**CT007-R sampled Chamber**	**Percentage of Chamber**
4 min	78.0	89%
8 min	90.0	102%
5 min	**CT007-R sampled low radon area**	
5 min	N/A	
5 min	25.0	28%
5 min	14.0	16%
5 min	**CT007-R sampled Chamber**	
8 min	80	91%
3 min	**CT007-R sampled low radon area**	
5 min	5	6%
5 min	10	11%

Chart 6: CT007-R High level radon sniff test

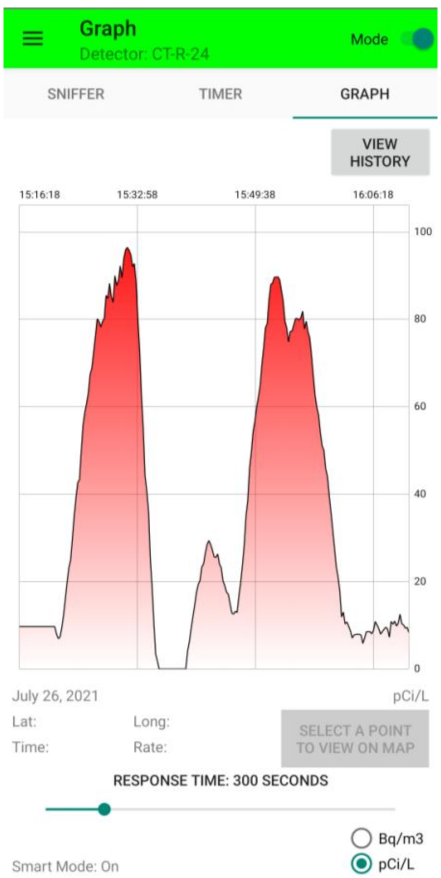


Figure 19: Graph tab displaying 300 second results over about 54 minutes

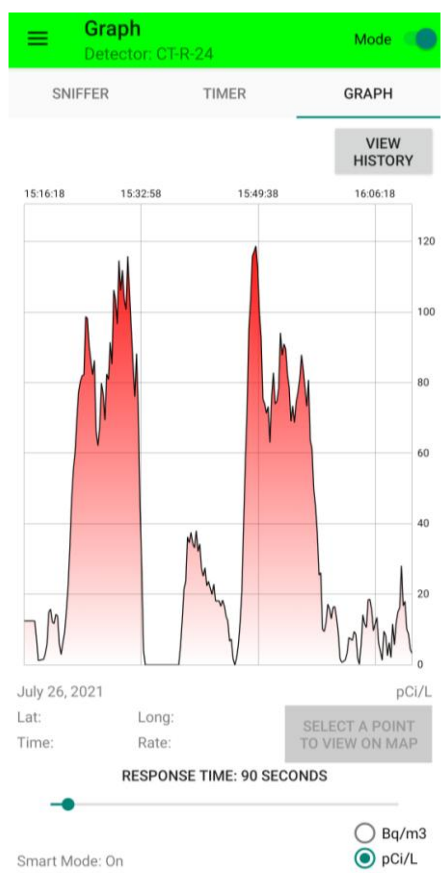


Figure 20: Graph tab displaying 90 second results over about 54 minutes

4.4 Ecotracker results from Chamber exposure

The Ecotrackers were obviously more difficult to test in this procedure because of the need to move them in and out of the chamber versus the other two monitors that have built in air pumps sampling air directly into their chambers. The data indicates that even though the Ecotrackers are passive devices they have a fast response time as the second five minute sampling did not vary consistently higher than the first 5 minute average. The Ecotrackers did have the larger low bias of the three sniffers tested. A more critical variable with sniffers is the precision as the bias can be accounted for. Sniffers used in post mitigation testing are typically a comparison of measurements made in different locations rather than an exact measurement of the location. The variation in results from one detector to the next is always greater at low sampling values especially under ten pCi/l.

In Chart 7, 8 and 9 the 5 minute results of each of the Ecotrackers is displayed at chamber concentrations of 9.4 pCi/l, 19.2 pCi/l and 85.4 pCi/l. After the Ecotrackers were removed from the chamber they were placed outdoors to determine how close they returned to outdoor radon levels. In each series it appears that the Ecotrackers are biased low about 60% to 70% reading of the actual radon level. This variation from the actual chamber result does not improve significantly after the first 5 minutes. This data implies that after the Ecotracker has been sampling at a given location for about ten minutes, it can be moved to a new location after exposing it in a low radon environment to air out the Ecotracker chamber first.

The Ecotrackers were moved to an outdoor open porch after being exposed in the chamber. The average measurement of the four detectors outdoors was 7% to 21% of the chamber level which is comparable to the other sniffers. The average result of the monitors exposed outdoors did continue to decrease up to about 15 minutes of outdoor sampling. Figure 21, 22, and 23 display the graph of the rising and falling of the radon levels as displayed in the Ecotracker cell phone app. This provides a visual graph of the change in radon levels and an easier way to see location to location change similar to the graph used with the CT007-R

During the 19.2 pCi/l exposure and the 85.4 pCi/l exposure, the Ecotackers were placed back in the same chamber a second time after being outdoors for about 20 minutes. In both cases the first ten minute average of all four monitors was 69% of the chamber radon levels. This second exposure had slightly higher percentage than the first exposure which would be expected from the background build up.

The data indicates that the Ecotackers can be exposed in a location for as little as ten minutes to determine an approximate radon level if the bias is taken into consideration. Exposure lengths of ten minutes at a sampling location were not tested for any of the monitors but in general would be preferable to minimize background counts. The background counts after a sampling even with airing the monitors out for ten minutes can still be 10% of the original sample reading for all the sniffers. Having sniffers sample what is assumed to be low radon levels first and high radon levels last is obviously preferable. Note that ten percent background reading of a high radon level sampling can be a higher concentration than other desired sampling locations. Having the monitors sample more than two testing locations was not tested.

Radon Chamber averaged 9.4 pCi/l						
Elapsed Time in minutes	EcoTracker 01	EcoTracker 02	EcoTracker 03	EcoTracker 04	**Average of Chamber**	**STD**
5 min	5.0	5.4	7.5	4.9	**61%**	**1.22**
10 min	6.1	5.4	6.3	4.9	**60%**	**0.64**
15 min	5.0	7.8	8.7	8.8	**80%**	**1.77**
20 min	6.4	8.1	9.8	4.5	**77%**	**2.27**
25 min	6.1	6.5	5.5	6.0	**64%**	**0.41**
3 min	**Moved EcoTrackers to low radon level area**					
5 min	1.7	1.9	0.7	1.1	**14%**	**0.55**
10 min	0.6	1.9	1.4	0.3	**11%**	**0.73**
15 min	0.3	1.1	0.3	1.4	**8%**	**0.56**
20 min	0.6	1.5	1.4	2.6	**16%**	**0.82**

Chart 7: EcoTracker Low-level sniff test

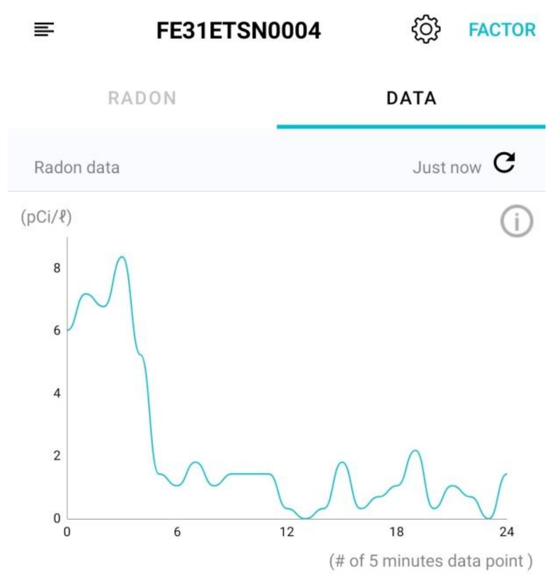


Figure 21: Graph of Ecotracker #04 results in a 9.4 pCi/l Chamber for 25 minutes and then outdoors for 90 minutes

Radon Chamber averaged 19.2 pCi/l						
Elapsed Time in minutes	EcoTracker 01	EcoTracker 02	EcoTracker 03	EcoTracker 04	**Average of Chamber**	**STD**
5 min	17.4	12.7	10.6	14.1	**71%**	**2.86**
10 min	15.8	14.8	11.0	16.6	**76%**	**2.48**
15 min	19.1	14.4	21.1	15.3	**91%**	**3.16**
20 min	16.2	13.9	14.7	15.8	**79%**	**1.05**
3 min	**Moved EcoTrackers to low radon level area**					
5 min	5.3	3.4	2.9	4.1	**20%**	**1.04**
10 min	2.4	4.2	2.2	2.2	**14%**	**0.97**
15 min	2.8	3.0	2.5	1.1	**12%**	**0.86**
20 min	3.9	2.6	1.8	2.2	**13%**	**0.91**
3 min	**Moved EcoTrackers back into chamber 19.4 pCi/l**					
5 min	13.4	11.0	13.5	16.2	**70%**	**2.13**
10 min	11.4	14.8	12.2	15.3	**70%**	**1.92**
15 min	18.6	24.2	13.9	14.1	**92%**	**4.85**
20 min	15.4	19.2	20.2	13.2	**89%**	**3.27**

Chart 8: EcoTracker Mid-level sniff test

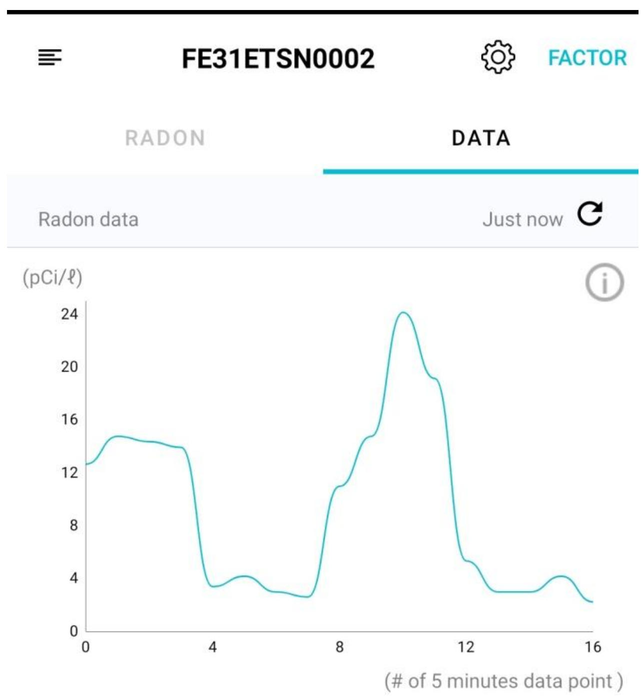


Figure 22: Graph of Ecotracker #02 results in a 19.2 pCi/l Chamber for 20 minutes and then outdoors for 20 minutes then in the chamber for 20 minutes and then outdoors for 20 minutes

Radon Chamber averaged 85.4 pCi/l						
Elapsed Time in minutes	EcoTracker 01	EcoTracker 02	EcoTracker 03	EcoTracker 04	**Average of Chamber**	**STD**
5 min	52.2	55.0	64.1	58.6	**59%**	**5.14**
10 min	49.4	73.8	60.3	66.2	**66%**	**10.29**
15 min	57.4	64.4	68.6	65.6	**66%**	**4.74**
3 min	**Moved EcoTrackers to low radon level area**					
5 min	9.5	18.7	16.8	12.8	**13%**	**4.12**
10 min	6.4	8.1	9.1	10.4	**10%**	**1.69**
15 min	5.7	6.6	5.2	6.8	**7%**	**0.75**
3 min	**Moved EcoTrackers back into chamber 19.4 pCi/l**					
5 min	55.1	53.8	62.2	60.5	**61%**	**4.08**
10 min	56.2	58.6	66.0	61.8	**62%**	**4.24**
15 min	53.3	67.6	66.7	65.6	**66%**	**6.72**
3 min	**Moved EcoTrackers to low radon level area**					
5 min	17.3	16.1	20.2	18.3	**18%**	**1.73**
10 min	11.4	7.8	8.3	10.0	**10%**	**1.65**
15 min	11.0	7.0	6.3	7.2	**7%**	**2.12**

Chart 9: EcoTracker High-level sniff test

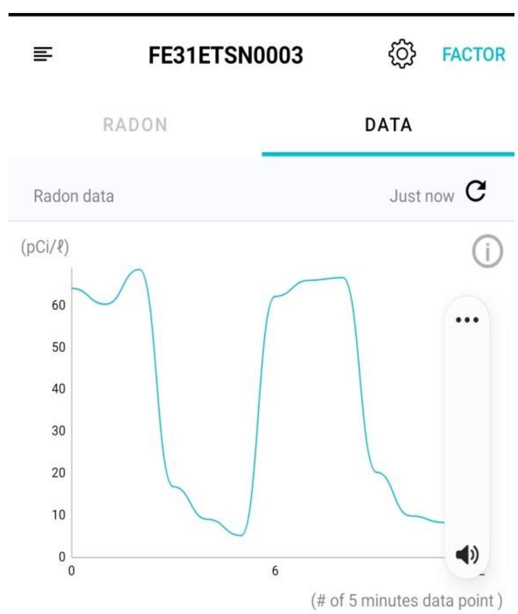


Figure 23: Graph of Ecotracker #03 results in a 85.4 pCi/l Chamber for 15 minutes and then outdoors for 15 minutes then in the chamber for 15 minutes and then outdoors for 15 minutes

5.0 Radon Dispersal from a Single Source

Radon dispersion from a single source was measured by the author in a previous paper in 2020 titled “Measuring at Grade Radon Mitigation Exhaust”. In that paper the radon levels at one to four meters from the exhaust either in direct alignment or at a 45 degree angle were measured. The exhaust volume was varied from 20 CFM, 40 CFM and 69 CFM. In that study it was shown that very little radon diffused directly to the side of the exhaust and significantly less at a 45 degree angle. If a basement foundation wall has an adjoining slab that is at or above the top level of the foundation wall, the adjoining sub-slab can be a significant radon source to the basement. Because basements are typically under a negative pressure during the heating season, radon can enter from under these adjoining slabs into the basement. The issue with using sniffers at this location is whether the measurement needs to be in the direct path of the source airflow or can be measured to the side of the path. Figure 24 demonstrates the use of Ecotrackers at a home to measure if the top of the foundation is a radon source. Sometimes the location of the airflow from under this adjoining sub-slab can be identified because fiberglass insulation is discolored or spiders have installed webs when they sense airflow. Other times it requires close inspection to locate openings under or between the wood sill plate and the foundation wall or the band or rim joist.

Figure 24: EcoTrackers placed in a basement near adjoining slab

A test was set up to measure radon levels in direct alignment with a flowing source or at a 45 degree angle or to the side or rear of the source flow. The source airflow was measure at 20 LPM or about 0.7 CFM. The radon concentration in the exhaust was measured with the CT007-R at about 175 pCi/l. The source which was from an existing radon system exhaust was routed through a delay chamber first to eliminate any measureable thoron in the exhaust stream. Radon Eye monitors were placed as displayed in Figure 25 and Figure 26 . The radon levels in the basement prior to the start of this test with the radon system operating ranged from 1.5 pCi/l to about 3.5 pCi/l in the basement air. The radon levels before the 20 LPM 175 pCi/l airflow was started was about 2.4 pCi/l in the basement. The levels in the entire basement rose to about 4.7 pCi/l with this airflow source. The total volume of the basement is about 130,000 liters. The source flow of 20 LPM times the 175 pCi/l times 60 minutes equals 210,000 pCi/hour. If the rise in radon was 2.0 pCi/l then the air change in the basement should be around 0.6 ACH which appears high but was not directly measured.

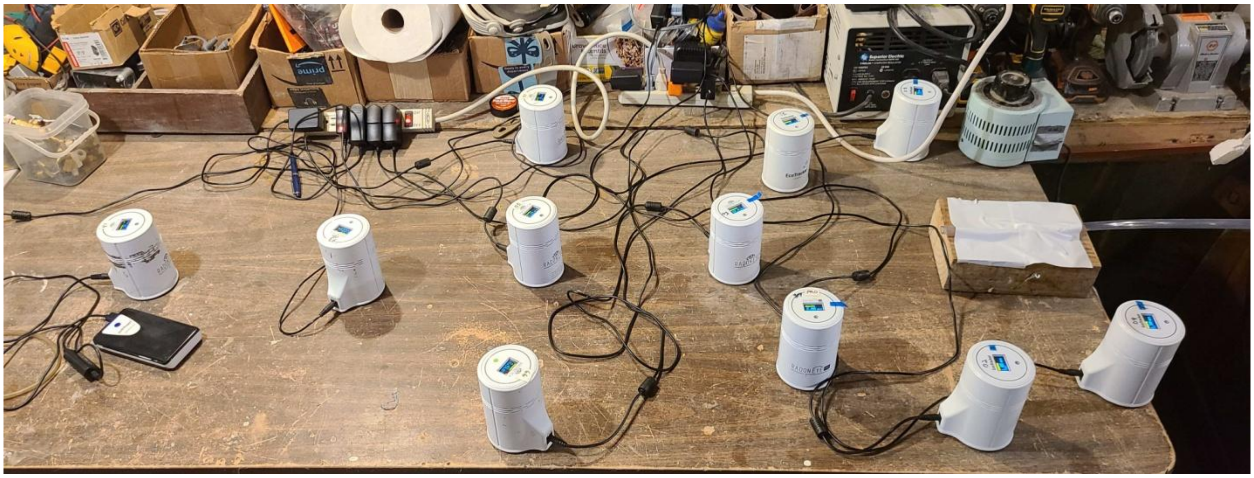


Figure 25: Diffusion of 175 pCi/l @ 20 LPM Flow

The radon levels induced by this source flow were allowed to reach their maximum level over 24 hours. The average of each of the monitors over 12 hours was then recorded. The results of each monitors average are displayed in Figure 26 with the approximate plume of increased radon also displayed. One foot in front of the radon airflow source the Ecotracker measured 9% of the source or 15.6 pCi/l which is 3.5 times higher than the radon levels behind the source airflow. Two feet from the source, the radon levels were measured at 6% of the source or 10.7 pCi/l. Three feet, four feet and five feet from the source measured 4.0% to 4.5% or 7.1 to 7.9 pCi/l. Eight feet away measured 5.1 pCi/l which was still higher than the basement radon levels.

The interesting results are one foot to the side, the rear and 45 degrees to the front of the airflow source there was no increase in radon levels over the basement levels. However one foot to the side of the radon monitors that were two feet in direct alignment with the airflow source the radon levels were elevated as if the velocity final dissipated and side dispersion happened. The results however do indicate that it is important to be in direct alignment with a flowing radon source in order to be able to measure increased radon over background radon levels.

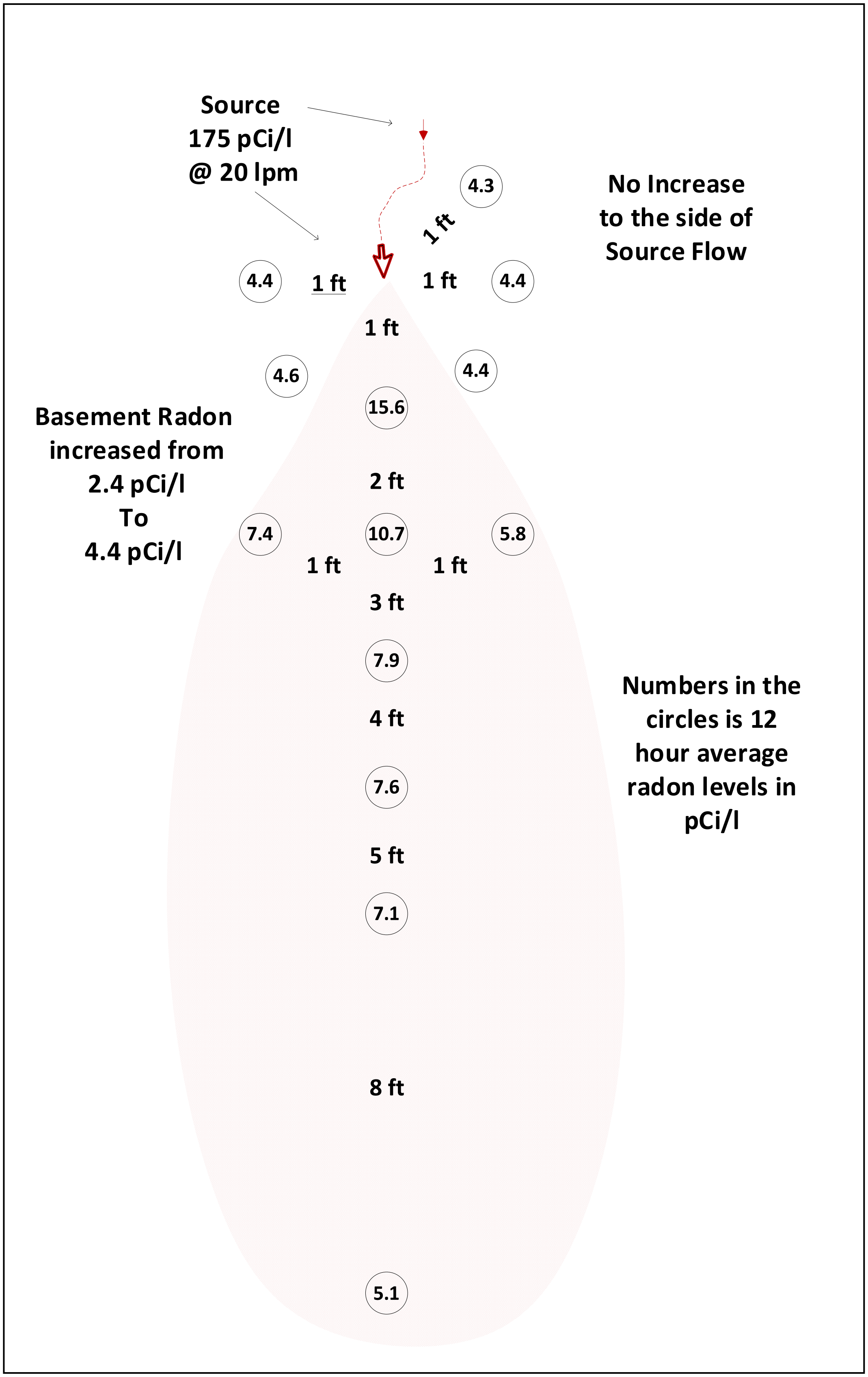


Figure 26: Diffusion of 175 pCi/l @ 175 LPM Flow

6.0 Post Mitigation Radon Diagnostics Case Study One

A home with an existing sub-slab depressurization system still had elevated radon levels of about 5.5 pCi/l. The original radon levels before the radon system was installed were about 17 pCi/l. Often post mitigation systems that are still elevated have marginally elevated radon levels that can be difficult to trace to a source. The important thing with any post mitigation diagnostics is to always 1st check the performance of the existing radon mitigation system. This requires a micro-monometer and a hammer drill to install small 5/16” test holes in the slab to make sure the sub-slab depressurization system is creating a vacuum under the entire slab. A test hole is typically installed in the slab at the far distance from any radon system suction pipes. Figure 27 illustrates the installation of the test hole prior to vacuuming the dust and measuring the sub-slab pressure. If the lowest level or basement is separated from the upper level by a door and there is an HVAC air handler in the lower area, the system should be checked for air balance. The micro-monometer tubing is run under the door that separates the lower level area (basement) from the upper level with the air handler running. The pressure difference should be close to neutral. A lower level negative pressure greater than 1.0 pascals (0.004”) is an additional pressure the radon system must overcome and also a driving force for radon to enter from other sources besides the lower level sub-slab. In this case the basement to 1st floor pressure was neutral.

Figure 27: Sub-slab pressure measured 1st

Figure 28: Basement to 1st floor pressure measured with HVAC fan on

A drawing of the lowest level of Case Study One is displayed in Figure 27. The ET# designations on the drawing represent the locations chosen to expose four separate Ecotrackers at the same time. Note that there is no radon mitigation system installed for the upper slab or crawl space at the time of the diagnostics testing.

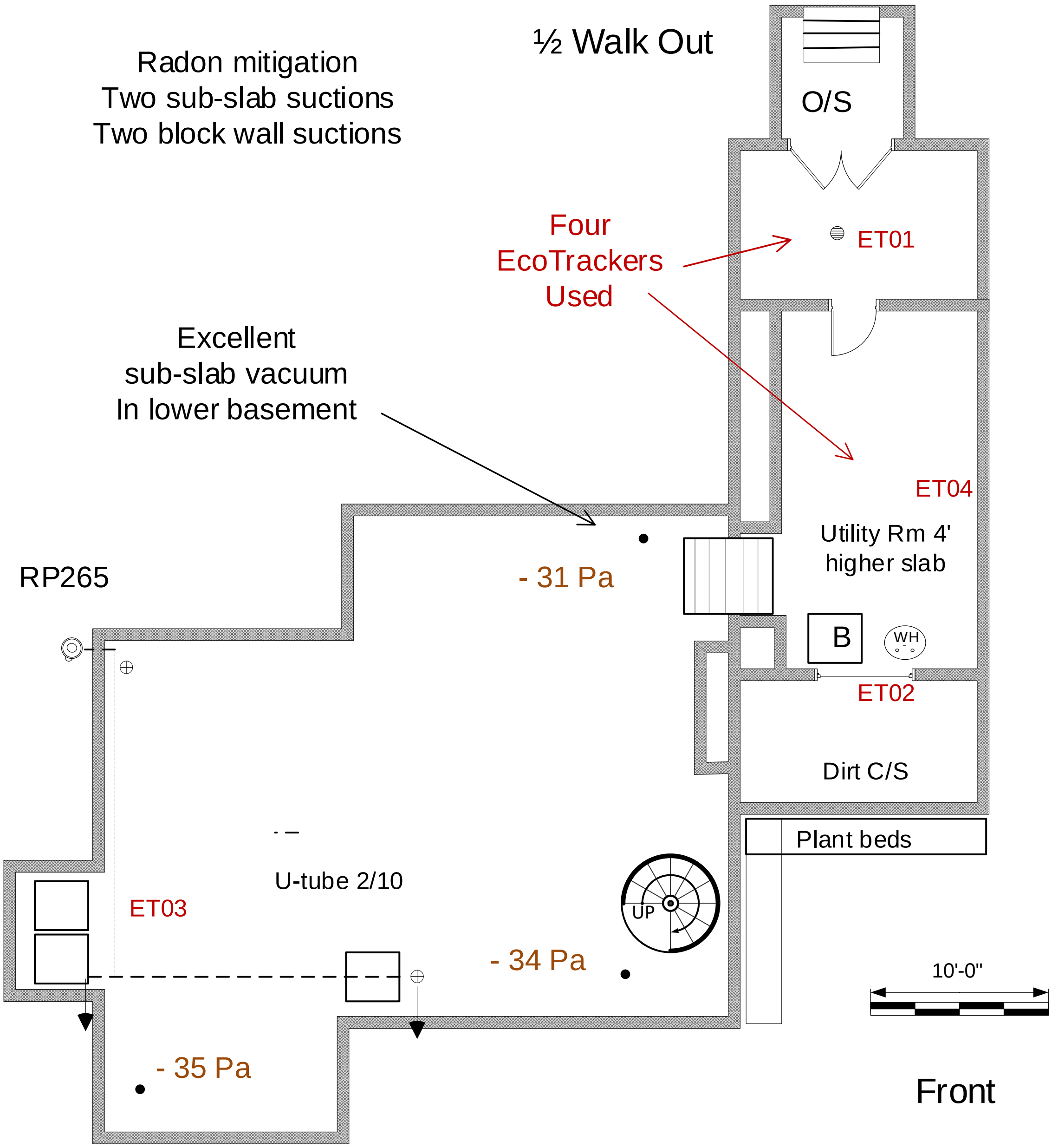
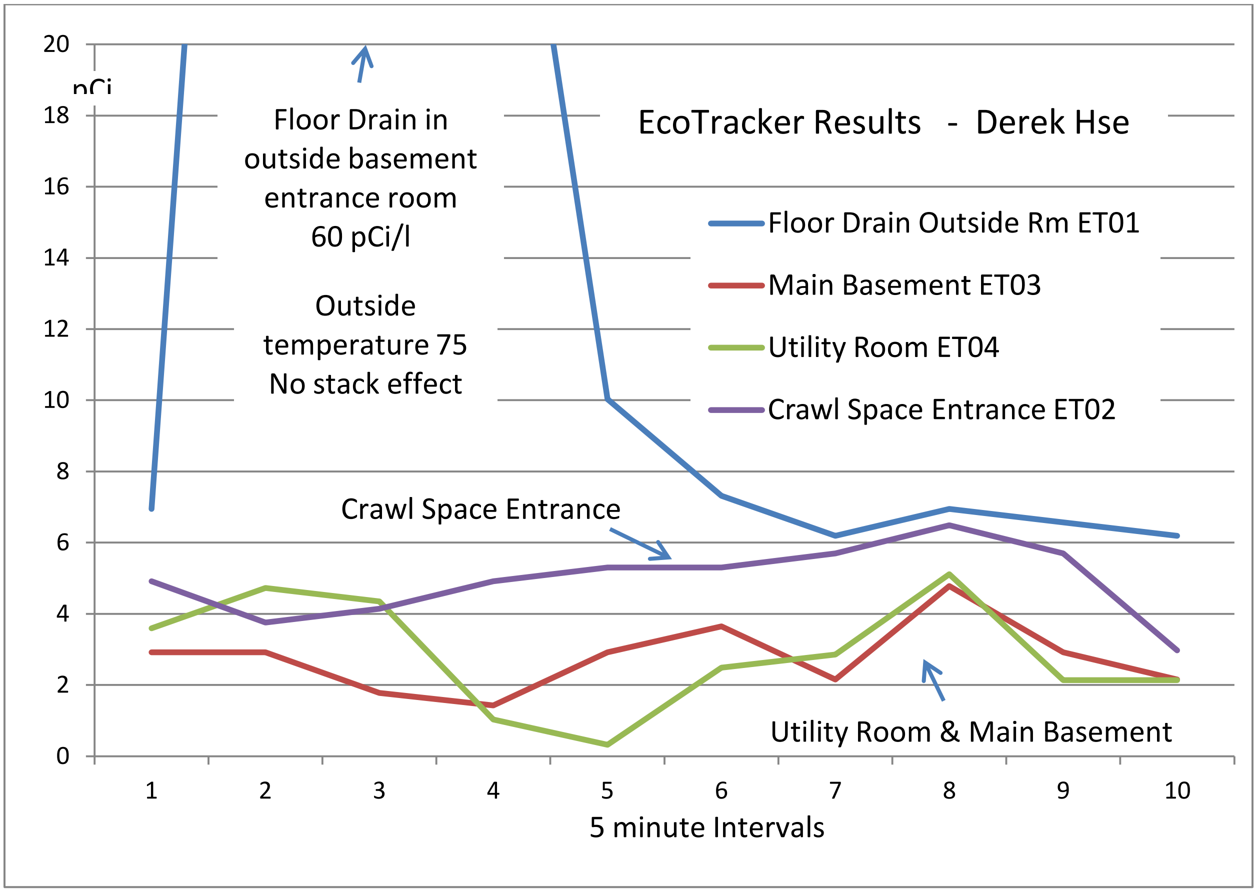


Figure 27: Field use of EcoTrackers



Graph 2: Variation in field exposure of EcoTrackers

The basement sub-slab had minus 31 pascals of negative pressure which ruled out the lower basement slab as a significant source. See the floor plan drawing in Figure 27. There was three possible sources of radon. An outside room had an open floor drain but an insulated steel door separating this room from the basement. There was an upper slab that had no suction piping installed in the slab. There was a crawl space that had an entrance covered with cedar boards and screening that prevented looking inside the crawl space. The screening above the crawl space entrance would allow radon to easily pass from the crawl space to the living area. Four Ecotrackers were used to measure the radon levels. Each location is indicated in the drawing in Figure 27 by the ET1 to ET4 numbers. The results of the Ecotrackers are plotted in Graph2. Figure 30 and 31 show the locations of two of the Ecotrackers.

Although the floor drain had very high radon levels, the drain is outside the conditioned space of the basement and not likely to be a source. ET04 was placed in the upper slab room while ET03 was placed in the basement. These two monitors read basically the same radon level although the upper level was being ventilated with outside air because it contained the basement entrance. This may explain why the upper slab started higher than the lower basement and then decreased to the basement level. See Graph 2. ET02 was placed at the entrance to the crawl space rather than in the crawl space. This produced a radon result that was about 2 pCi/l higher than the other two basement radon monitors. These results indicate the crawl space needs a membrane suction system. A revised mitigation plan recommended installing a suction hole to the upper utility slab since piping will need to be installed for the crawlspace through this area.

Routing the piping to the crawl space from the existing system is a long run. There were two suction pipes installed into the block wall without airflow controlling dampers. It was recommended to reduce the airflow into these block wall suctions to increase the vacuum under the basement slab so that a jumper pipe can be used for the additional suction hole and crawl space membrane suction system. A 3” jumper can be installed to accomplish this transfer of vacuum from the main basement sub-slab to the upper slab sub-slab and the new crawl space membrane system. See Figure 32.

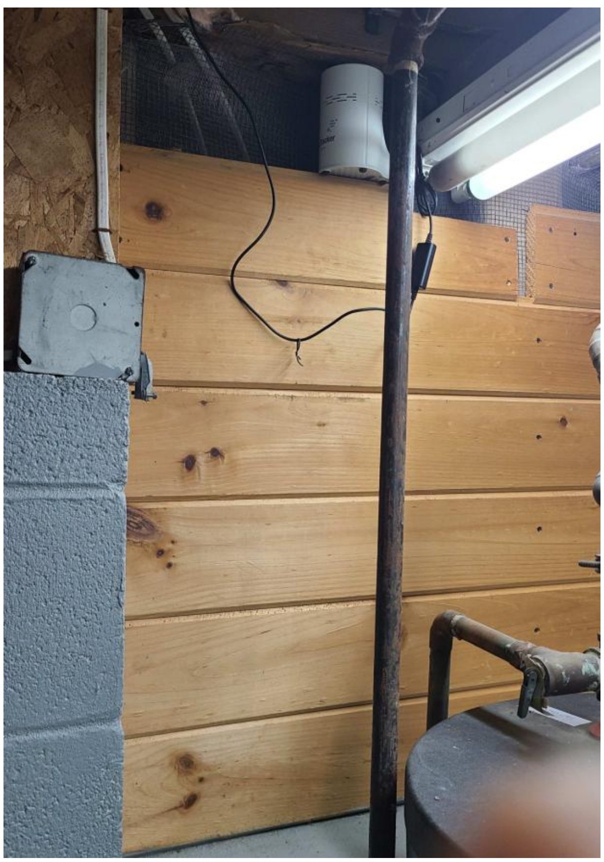


Figure 30: Crawl space entrance measurement with no direct access

Figure 31: Floor drain measurement

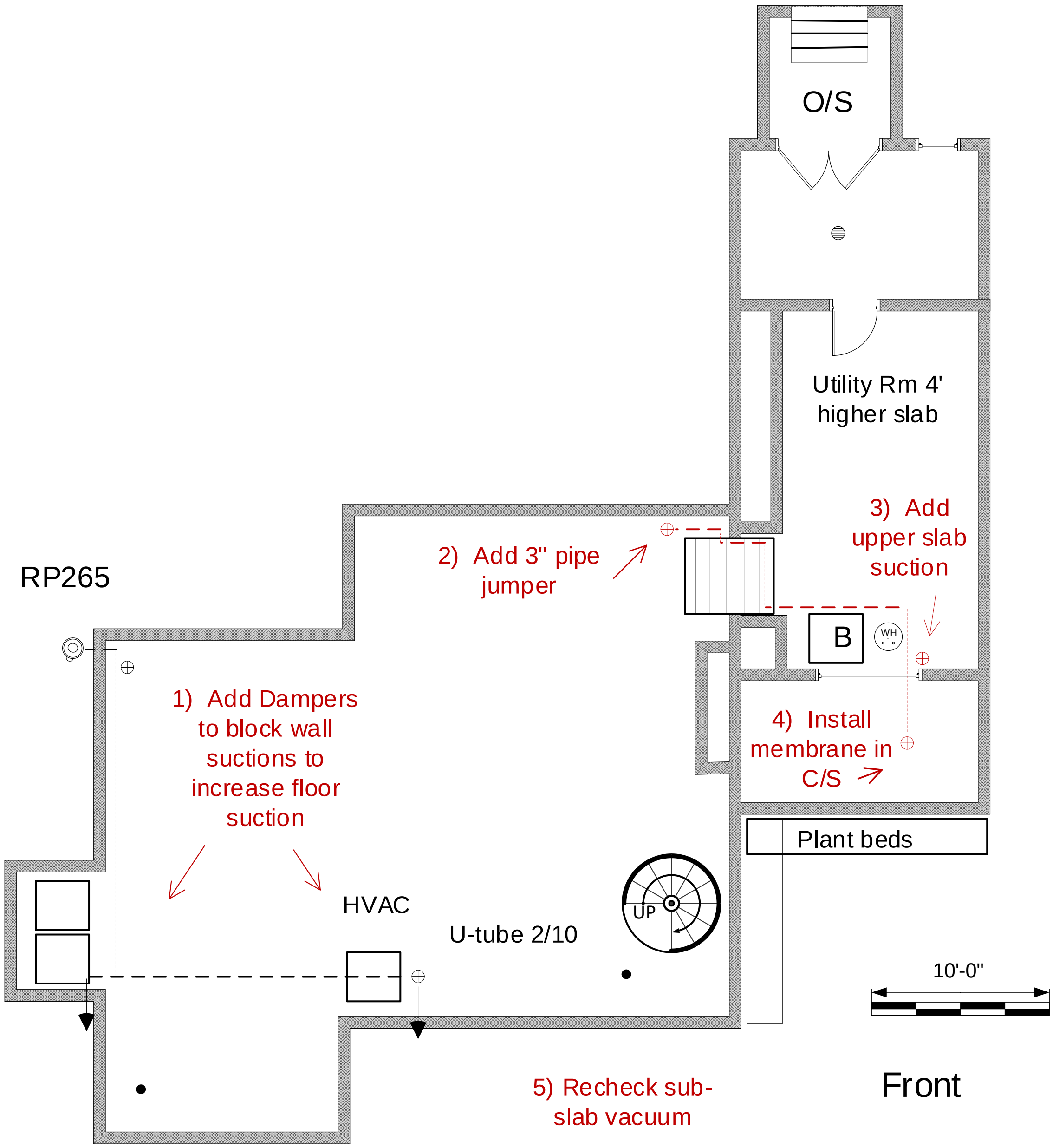


Figure 32: Revised mitigation based on diagnostic measurements

7.0 Post Mitigation Radon Diagnostics Case Study Two

Figure 33: Case Study Two - Outdoor levels measured at:
20” above grade under the deck & 10 feet above grade on the upper deck

Case study two is a traditional two story colonial house with a walk out basement. There is a very thorough ASD radon system installed that includes an attic radon fan venting through the roof that is attached to builders 3” piping routed into the sub-slab. A second exterior radon fan is vented up the outside of the house to the roof and has one 4 inch suction pipe into the basement sub-slab, one three inch suction into the garage sub-slab. The vacuum under the basement slab is about negative 40 to 50 pascals. There are two jumper pipes. One connects the basement sub-slab with the front porch with 3” piping. The other is an additional jumper pipe that routes a 3” pipe from basement sub-slab to the garage sub-slab. The garage sub-slab is 9 pascals negative. See the basement drawing in Figure 37.

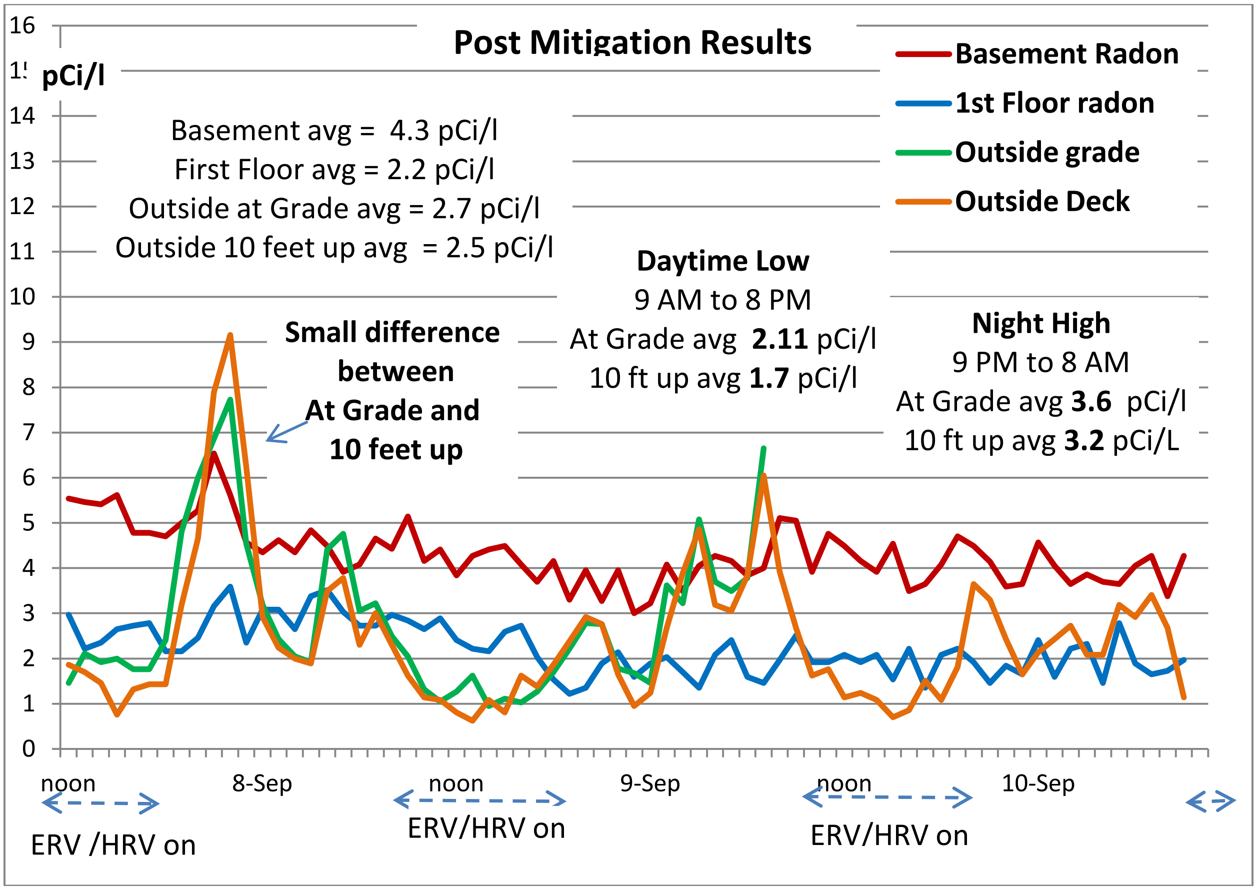
The initial pre-mitigation radon levels before the house was occupied were above a thousand pCi/l. The interior radon levels on the first floor are now primarily below 4.0 pCi/l but the basement levels tend to be in the 5 to 6 pCi/l range especially in the summer. The owner agreed to have extensive diagnostics done to reduce the basement level further.

Two methods were considered as options to further reduce the radon levels. One was to measure the radon flux of the basement slab to determine if reducing radon diffusion coming through the slab could reduce the basement radon levels. The other consideration was to add additional ventilation to the basement using and energy recovery ventilator (ERV) or an heat recovery ventilator (HRV). In order to determine the best option, flux measurements of the slab were done using Ecotrackers and a week long radon measurement of the basement, first floor and outdoors in two different locations was made. The results of that testing are included in Graph 3.

The radon levels outdoors at this development have been measured in the past and found to reverse correlate with wind speed. Increasing wind causes low outdoor radon levels and little or no wind allows radon levels to build up outdoors. Generally no wind periods happen at night. The outdoor testing included an outdoor measurement in the rear walkout basement of the house about 20" off the ground and an outdoor measurement on an upper floor deck about ten feet in the air. Radoneye RD200+ detectors were used because they included a time clock that confirms the syncing of all the indoor and outdoor measurements. The outdoor measurements housed the detectors in plastic mailboxes that had holes cut in the bottom. Ecotrackers could have been used with separate recording of the start and stop times and dates.

The original consideration for the HRV was to have the outdoor supply air inlet at the rim joist of the walk out basement so that it was ten feet above grade. The radon results however indicate there is little difference between 20 inches above grade and 10 feet above grade. It appears that when the wind stops, the radon levels emanating from the ground fills up the surrounding atmosphere like a swimming pool. See Graph 3.

The HRV or ERV could be run during optimal periods to avoid the evening times when radon levels are the highest outdoors. If the ventilator was to start at 9 AM and turn off at 8 PM and the air was obtained from ten feet above grade the average outdoor radon levels during that period would be 1.7 pCi/l. During the non venting period of 8 PM to 9 AM the average outdoor radon levels were still below 4 pCi/l but were higher with an average of 3.2 pCi/l. The suggested on times of the HRV are shown on the graph.



Graph 3: Radon results at case study house two.
Two outdoor measurement locations have identical levels

The radon levels under the slab were measured with scintillation grab samples taken in five locations under the slab by the PA DEP radon division. The same day the CT007-R was used to make similar sub-slab radon measurements at three of the DEP test locations. The results of those measurements are included in Figure 37. In two of the locations the CT007-R under predicted the radon levels as compared to the DEP results by 30% and 35%. In a third location the CT007-R was only 6% different. The PA DEP measurements would have excluded any thoron because they delayed the counting by at least 3 hours. The CT007-R was not run in its thoron mode so it is not know if there was thoron directly below the slab. Previous grab sampling indicated very little thoron under the slab. If there was thoron then the CT007-R reading would have biased higher which did not appear to be the case.

Flux measurements were made using E-Perm flux monitors and Ecotrackers or Radon Eye monitors under a metal bowl with a battery to power the monitor. See pictures of the flux monitors in Figure 34 and Figure 35. Figure 36 shows the flux test in operation with a weight to compress the gasket on the edge of the bowl. The results of the flux tests are displayed in Graph 4.

Figure 34: Grab samples and Flux test

Figure 35: EcoTracker and battery placed in metal bowl

Figure 36: Flux test run for 6 to 12 hours

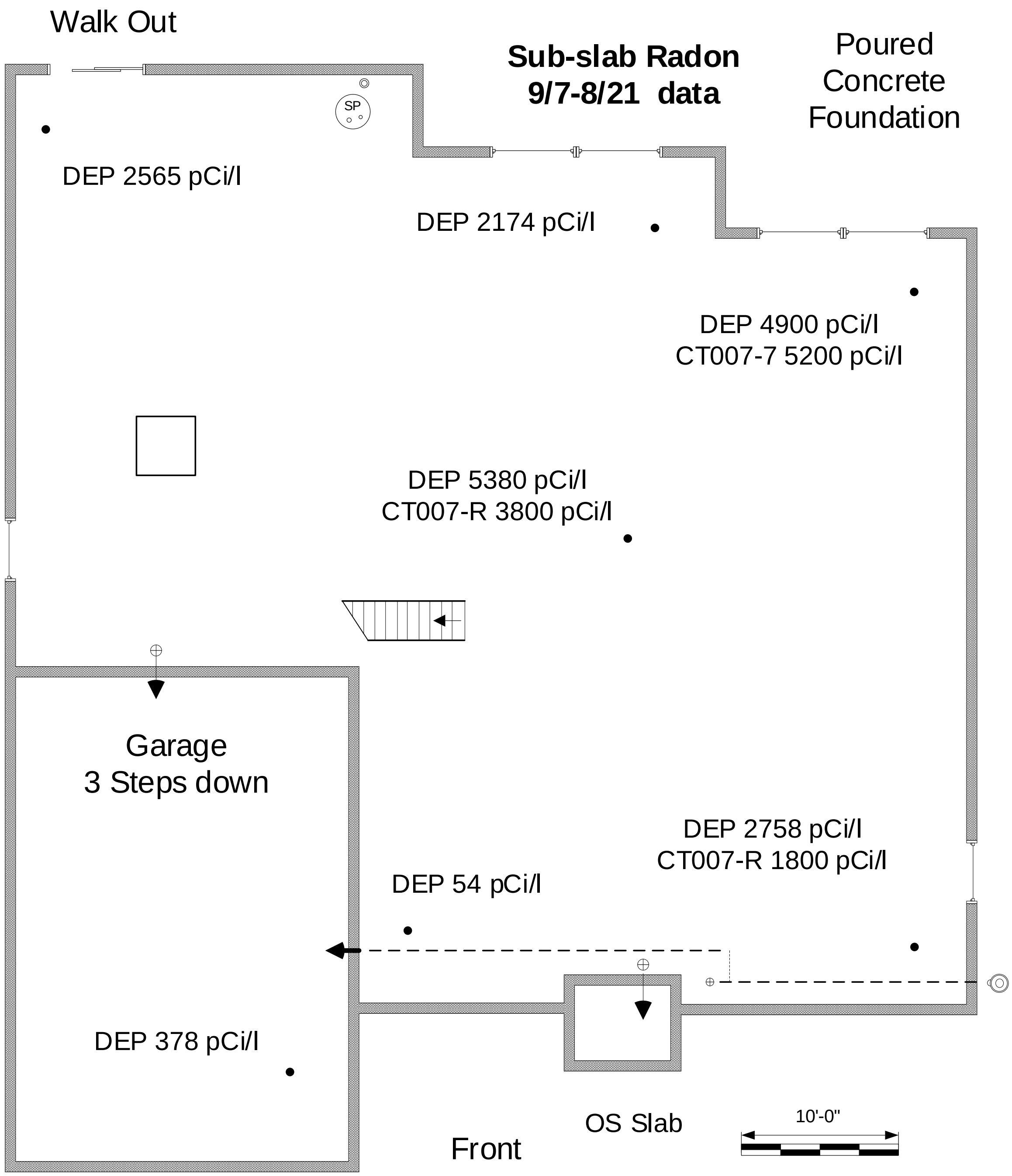
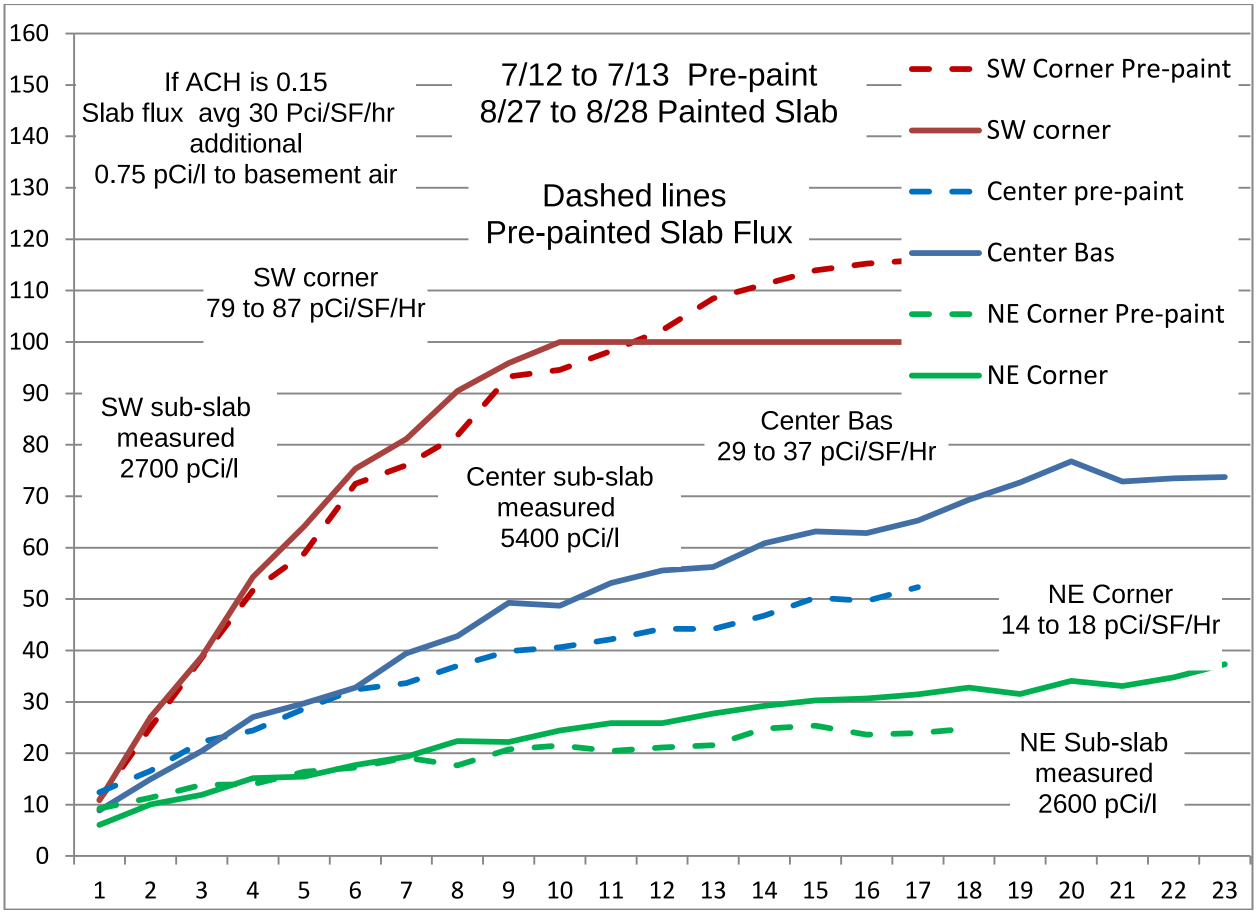


Figure 37: Variation in sub-slab radon between CT007-R and grab samples



Graph 4: Basement slab flux before painting slab (dash line)
And slab flux after painting slab floor

Flux measurements using either Radon Eye or Ecotrackers were made prior to any treatment being applied to the slab. During one of the rounds of radon testing a storm came through and the power was off for four hours. The radon levels in the basement went rapidly up. When the power resumed the radon levels began to fall. Extrapolating from the slow reduction of radon in the basement it appears that the air change per hour (ACH) in this basement is around 0.15 ACH which is considered low but not unusual for a basement of a new home. Using the this ACH and the results of the first round of flux tests it was determined that the radon flux through the slab was contributing 0.75 pCi/l of radon to the basement radon levels. The owner agreed to apply a coating to the slab to reduce this transmission. The owner purchased 20 gallons of Radon Seal coating and spray applied two coats to the entire basement slab. The flux measurements were repeated in the same locations after the sealant had a week or two to dry. The dashed lines in Graph 4 are the pre-paint flux results. The solid lines are the after slab was sealed with two coats. The graph indicates that no change in the flux was obtained by spray applying two coats of Radon Seal to the basement concrete slab. There are ongoing discussions of other slab coatings or vinyl sheet stock placed on the slab and the flux through the slab re-tested. The owner is planning to install either an HRV or an ERV. The HRV provides a higher efficiency than the ERV but the ERV reduces the moisture increase in the summer. The decision to use an ERV versus HRV involves determining if the heating load performance is more important with the HRV versus the ERV summer performance. The unit being considered offers the option to change the core from HRV in the winter to ERV in the summer.

Flux measurement calculation is done by obtaining the rise in radon levels inside the metal bowl that is air tight sealed to the slab. The rise in radon levels can be obtained by measuring the rise on the graph or by using the results from downloaded data obtained by the Ecotrackers. The rise in radon levels is then divided by the number of hours the rise happened during. Radon ingrowth inside a metal container will begin to decrease as radon levels back flow back into the slab. In general it is recommended to use the most consistent rise happening in the first 6 to 12 hours of the flux test. Once the pCi/l per hour level has been determined it needs to be multiplied by the volume of the container. In this case the bowl is 3 liters but the battery and Ecotracker take up about 0.5 liters so the true volume is 2.5 liters. This result then needs to be multiplier times the square foot or square meter area the bowl covers. This will give you the pCi per square foot or square meter per hour the flux test has measured. The result can be then multiplied times the area a similar flux through the slab is occurring to get the total contribution of radon coming from the concrete. If the air change rate of the basement is known or assumed, this ventilation rate can be converted to liters of ventilation diluting the radon emanation out of the slab to determine the approximate contribution to the radon levels in the area assuming the ventilation rate is correct. In Case Study Two the ventilation rate of the basement was calculated as 0.15 ACH. The flux through the slab could therefore add about 0.75 pCi/l to whatever other sources were happening.

8.0 Radon Sniffers and Thoron Levels

There is more thorium 232 in the earth's crust than Uranium 236. In a previous study by the author that included measuring radon in ASD mitigation exhaust pipes of 75 radon mitigation systems in New jersey it was not unusual to have more thoron than radon in the exhaust. Thoron is generally not considered an issue because it has a short half life of only about 55 seconds compared to radon's half life of 3.82 days. If however a sniffer is used to measure a radon source that is flowing directly out of the soil without a delay of at least five to ten minutes, thoron can be part of the sample. To test the response of the active radon sniffers to thoron, sampling was taken from an active ASD radon pipe and from a chamber that had high levels of thoron. Previous measurements of the ASD radon system exhaust had found equivalent levels of thoron compared to radon in the exhaust stream. If thoron is measured or contributes to the radon sampling it does in most cases however indicate a radon source since they both originate from the soil.

8.1 Measuring Thoron and Radon in ASD suction pipe

A small air pump was used to divert about 3 lpm of air from an existing ASD radon piping through a decay delay chamber and then through two AB5 pylon scintillation cells that had been previously calibrated. The average of the two Pylons produced a measurement of about 200 pCi/l of radon from the ASD pipe exhaust. A separate grab sample of the ASD pipe airflow was taken and aged in an older scintillation cell to exclude radon. This grab sample measured within 10% of the Pylon readings confirming the approximate result. A RAD7 was also used to measure the radon and thoron in the ASD pipe but it produced a level of radon that was half the concentration measured by the Pylons. The reason for this is unknown. See Chart 10. The GM1-2 and the CT007-R were then used to directly sample the same ASD pipe. See Figure 38. See Chart 11 and Figure 39 for CT007-R results. See Chart 12 for GM1-2 results. The CT007-R measured about 450 pCi/l in the ASD pipe. The GM1-2 measured about 350 pCi/l in the exhaust pipe. These measurements are about double the result of the Pylon measurement of about 200 pCi/l of radon in the pipe.

RAD7 set to 5 minute Thoron mode in ASD pipe		
Elapsed Time in minutes	200 pCi/l radon ASD pipe Radon results	Thoron results
5 min	49	99
10 min	93	92
15 min	94	87
20 min	100	79
Moved RAD7 to low radon area		
5 min	71	39
10 min	30	0
15 min	3.2	0

Chart 10: RAD7 ASD sniff results

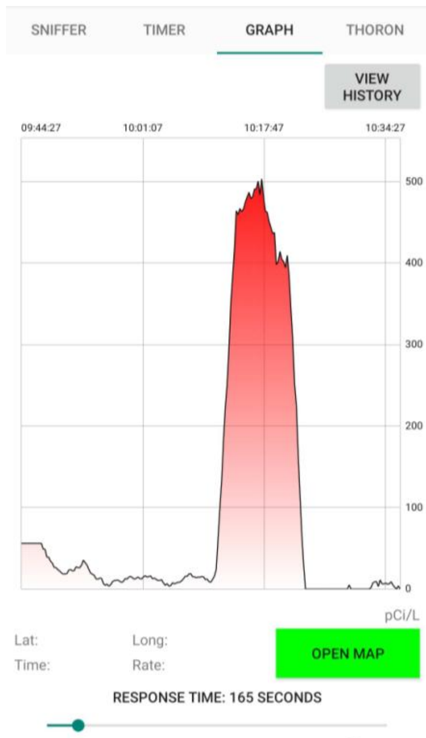


Figure 39: Graph of CT007-R measurement of ASD pipe

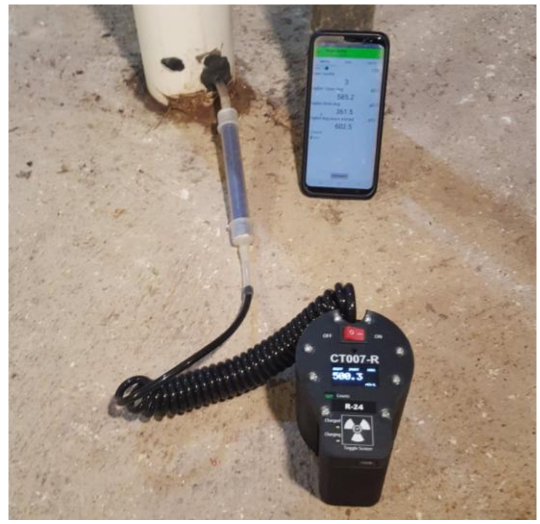


Figure 38: Using CT007-R to measure ASD pipe

CT007-R - ASD pipe measurement	Percentage of 200 pCi/l
450 pCi/l	225%

Chart 11: CT007-R ASD sniff results

GM1-2 results compared to 200 pCi/l Plyon		
Elapsed Time in minutes	Radon ASD pipe 200 pCi/l radon plus Thoron	Percentage of 200 pCi/l Pylon results
6 min	265.0	132%
12 min	370.0	185%
18 min	330.0	165%
	Moved GM1-2 to low radon area	
6 min	99.0	50%
12 min	29.0	15%
18 min	12.0	6%
24 min	6.0	3%
30 min	26	13%
36 min	8	4%
42 min	19	10%

Chart 12: GM 1-2 Sniff measurement of ASD pipe with 200 pCi/l radon

Figure 40: GM1-2 sniff

The CT007-R has a thoron function mode. In this mode there is a timed sequence which includes 90 seconds of sampling the air and 300 seconds when the pump is turned off and the instrument calculates the loss of counts in its scintillation cell versus any gain in alpha counts. The software then determines a thoron concentration based on the loss of counts from the decay of the short lived thoron atoms. See Figure 41 and Chart 13. The thoron concentration is listed as 263 pCi/l. The radon levels are displayed as 166 pCi/l. The 166 pCi/l is 83% of the actual radon level in the ASD pipe.

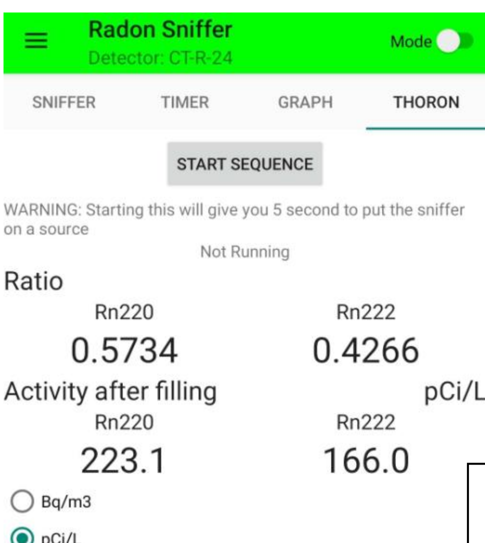


Figure 41: CT007-R ASD Thoron & Radon result

CT007-R - Thoron measurement in ASD pipe w/200 pCi/l radon		Percentage of 200 pCi
Thoron	Radon	
223.1	166.0	83%

Chart 13: CT007-R set to Thoron test

8.2 Measuring Thoron levels in a Thoron Chamber.

A 31 gallon 117 liter metal thoron chamber was set up with four Aladdin mantles made with thorium. Each of the mantles are placed in front of a small computer fan that circulated air around the inside of the chamber in a counter clockwise rotation. See Figure 42 and Figure 43. Sampling ports on the outside of the chamber allow samples to be extracted from the chamber. Thoron Eperms and a Rad7 were used to measure the thoron concentration in the chamber. The RAD7 average of the 2nd and third five minute sampling of the RAD7 produced an average of 168 pCi/l of thoron.

Twor EPerms designed to measure Thoron were exposed in the chamber to confirm the RAD7 results. The Eperms gave a value of 94 pCi/l of thoron. See results in Chart 18.

The radon sniffers were then used to sample the chamber which is assumed had the same radon concentration as the basement it was being used in. The basement had the radon equivalent of about 2.5 pCi/l.

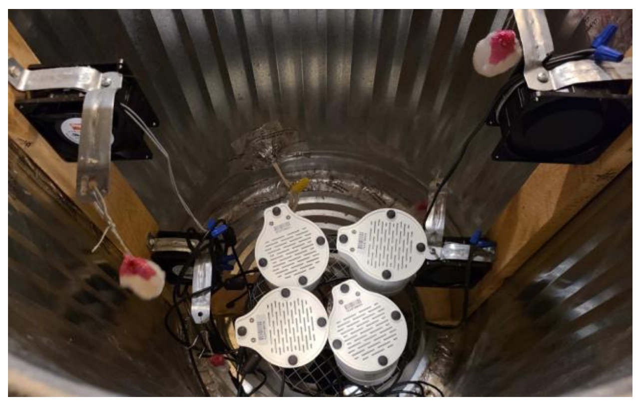


Figure 43: Ecotrackers in Thoron chamber with thoron mantles and circulating fans

Figure 42: RAD7 measuring Thoron chamber

RAD7 set to Thoron mode – Thoron chamber		
Elapsed Time in minutes	2 pCi/l radon in basement	Thoron results
5 min	4.8	97
10 min	4.1	180
15 min	3.3	157
Moved RAD7 to low radon area		168 pCi/l average
5 min	0.8	34
10 min	0.0	0.0
15 min	0.0	0.0

Chart 14: RAD7 set to Thoron sniff test

Average result of two thoron Eperms
94.5 pCi/l of thoron

Chart 15: Eperms used to measure Thoron Chamber

The GM1-2 sampled the thoron chamber and obtained the results listed in Chart 15 and displayed a result that was about 115% to 162%% of the thoron concentration recorded by the RAD7 even though there was less than 3 pCi/l of radon in the chamber.

GM1-2 measuring Thoron Chamber		
Elapsed Time in minutes	160 pCi/l Thoron Chamber	Percentage of 168 pCi/l Thoron
6 min	193	115%
12 min	273	162%
18 min	195	116%
	Moved GM1-2 to low radon area	
6 min	14	8%
12 min	0	0%

Chart 16: GM1-2 Thoron chamber results

The CT007-R sampled the chamber using its normal radon sampling mode and produced a reading of about 300 pCi/l which is 178% of the RAD7 measured thoron concentration. See Figure 44.

The CT007-R was then set to its thoron mode that samples for 90 seconds and then counts for 300 seconds with the pump off. In this mode it measured 295 pCi/l of thoron which is 175% of the RAD7 thoron concentration. See Figure 45 and Chart 17

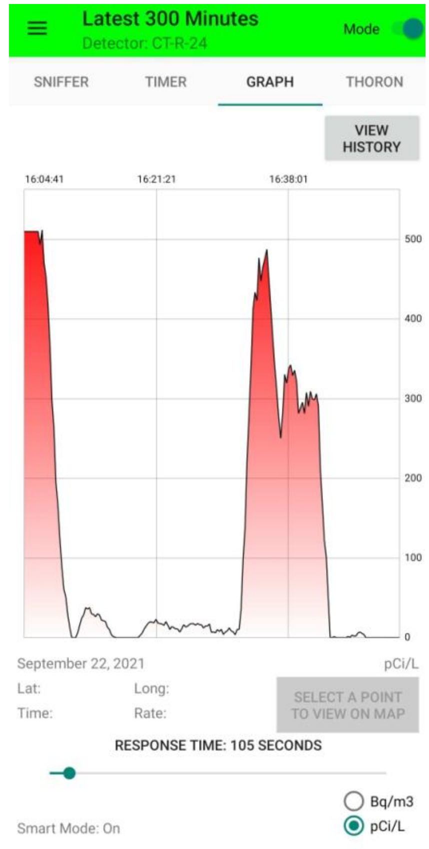


Figure 44: CT007-R Thoron and Radon chamber measurement

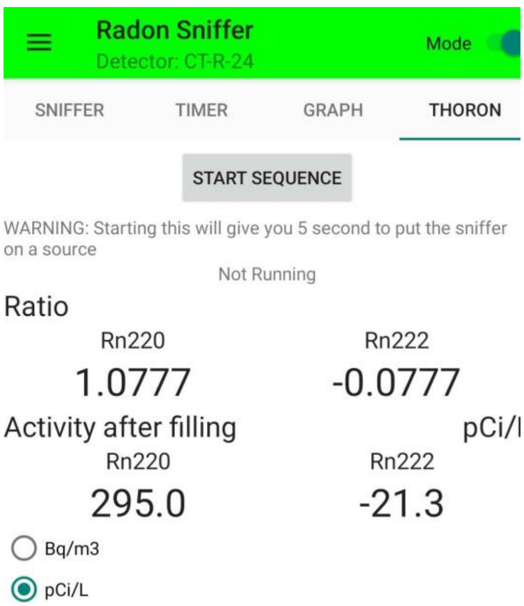


Figure 45: CT007-R radon only measurement of Thoron chamber

CT007-R - measurements of Thoron Chamber		Percentage of RAD7 168 pCi/l	Percentage of Eperm 257 pCi/l
Just Radon			
300 pCi/l		179%	117%
Radon	Thoron		
- 21	295	176%	115%

Chart 17: CT007-R set to Thoron test

Four Ecotrackers were placed in the thoron chamber to determine their response to thoron. They were placed in the chamber upside down because the entrance to the Ecotrackers radon chamber is on the bottom. See Figure 43. This placed the Ecotracker chamber entrance closer to the center of the thoron chamber. The results are listed in Chart 18. The average of all four Ecotrackers is used to give the approximate thoron response compared to the RAD7 thoron measurement.

Thorn Chamber averaged 160 pCi/l Thoron 2 pCi/l Radon					
Elapsed Time in minutes	EcoTracker 01	EcoTracker 02	EcoTracker 03	EcoTracker 04	Percentage of 168 pCi/l Thoron
5 min	106	106	115	121	69%
10 min	114	100	106	122	68%
15 min	126	120	107	138	76%
20 min	131	109	124	140	79%
25 min	146	134	138	132	85%
30 min	118	143	123	148	82%

Chart 18: Ecotracker performance in the Thoron chamber

9.0 - Sniffer Test Conclusions

Each of these three radon sniffers can make multiple measurements in different sampled locations if their individual response bias and minimum time requirement to take the sample is taken into consideration and enough time is allowed for background counts to dissipate in a low radon environment after sampling a source. Knowing each detectors limitations is important in evaluating the results obtained. Making sniffer measurements typically requires getting a rough idea if a sampled location is higher, the same, or lower than the room it is measured in or the adjacent room radon levels. Radon levels in the lower level of a building can fluctuate on a daily basis by as much as a factor of ten. Sniffer measurements cannot therefore be used to determine a multi-day average radon level. It was shown using the radon chamber measurements that the Ecotracker and the GM1-both biased low. The CT007-R was closer to the actual level. See Chart 19. The good point was this bias was fairly consistent whether the source was as little as 9 pCi/l or as high as 88 pCi/l. It is important to note that each of these bias tendencies could be different on another sniffer or vary over time. All of the sniffers used had been calibrated shortly before the study began.

Sniffer	Typical Percentage of actual chamber level
Ecotracker	55% to 100% avg 65%
GM1-2	70% to 100% avg 75%
CT007-R	90% to 120% avg 110%

Chart 19: Sniffer variance from radon chamber

When the sniffers were moved to the outdoors for 20 minutes they typically reported the outdoor radon levels in the range of 10% to 20% of the sampling they had just measured. There were however spikes or average=s with the GM1-2 and the CT007-R than with the Ecotrackers.

Sniffer	Approximate percentage of previous sampled level
Ecotracker	8% avg 20% avg 12%
GM1-2	10% to 40% avg 15%
CT007-R	11% to 35% avg 20%

Chart 20: Sniffer variance exposed outdoors

The Ecotrackers offer the advantage of having four sniffers in the package that allow simultaneous measurements at the same time and an app that displays all the four current measurements at the same time. The app also provides a graph of each interval result so new sampling locations can be compared with previous results. The Ecotracker as compared to the other instruments can also be used to make hourly measurements that can be downloaded for real time continuous hourly results. The Ecotracker does however require either a power cord or a separate battery in locations where having an outlet is not convenient. The use of cell phone batteries allowed the Ecotrackers to be used to measure multiple locations at Case Study One and Case Study Two. In Case Study One the GM1-2 and CT007-R were not used to determine how well they could determine a small 2 pCi/l difference. The Ecotrackers did see this difference between the crawl space entrance and the basement when the results were carefully reviewed. In Case Study Two the Ecotrackers could measure the very low outdoor radon concentrations and also measure two locations in the home to see all the small hourly variations. The Ecotrackers were also useful in measure flux coming through a concrete slab. It would be possible to measure flux by taking grab samples over time with the other sniffers but this method is difficult to set up and do.

The CT007-R and the GM1-2 have the ability versus the Ecotracker to measure radon inside block walls, under slabs or inside a radon ASD pipe.   Some radon mitigators will measure radon under the slab to determine the optimal location for sub-slab suction piping. The variation under the slab varied at Stucy Case Two houe from 54 pCi/l to over 5000 pCi/l. Using the CT007-R for this purpose was not tried during this study. The GM1-2 with a limit of 999 pCi/l would work for this purpose in homes with moderate levels under the slab.

In one part of the study it was demonstrated how obtaining a measureable increase in radon from a source required being in the path of the airflow rather than to the side of the airflow. A pump sniffer may have an advantage over the passive Ecotracker in slowly moving the sniffer inlet along a sill plate while listening for alpha counts or watching any increased counts take place. This technique was not tried during this study.

Sniffing in the airflow of the source or under a slab will often include thoron. In general if thoron is present then it can be assumed radon is traveling with it since they are both noble gases that originate from the soil. It is important to know that sniffers will respond to thoron as if it is radon. The CT007-R has the benefit of determining if thoron is a component of the sniff using its thoron function. This would be most important if sub-slab measurements are made.

The graph function of the cell phone app for the CT007-R and the Ecotrackers typically becomes the easiest way to track the variation in radon levels from one location to another. With the CT007-R the graph interval is easily adjusted to an amount that best displays the average radon value as well as the variation in counts the instrument is recording.

Ultimately the best choice may be having both multiple passive sniffers and a pump style sniffer to allow radon measurements in any location or multiple locations.

10.0 Reference Papers

1) Brodhead B. Measuring At-Grade Radon Mitigation Exhaust, Proceedings of AARST International Radon Conference; 2020

2) Brodhead B. Elevated radon levels in high rise condominium from concrete emanation, Proceedings of AARST International Radon Conference; 2008

3) Brodhead, Measuring radon and thoron emanation from concrete and granite with continuous radon monitors and E-PERMs. Proceedings of AARST International Radon Conference; 2008

4) Brodhead B. Initial results from Follow-up of New Jersey homes mitigated for radon, Proceedings of AARST International Radon Conference; 1993