Radon Re-entrainment Study – An Initial Investigation

Final Report
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Introduction

Radon re-entrainment is the process whereby the exhausting gas from the terminal point of an active subslab depressurization (ASD) system finds its way back into a home or building. The home or building in question could be the same one where the ASD system is in place or it could be a nearby structure, and the terminal point of the ASD system could be at roofline, ground level, or any other location. Radon re-entrainment is not necessarily only associated with ground level exhaust.

This study was designed to look at the re-entrainment potential of ASD systems in single family homes with both roofline and ground level exhaust locations. The current national standards for exhaust point location for existing homes is that the exhaust point must be at roofline or above, where roofline is defined as the projecting edge of the roof. The roofline definition applies to both the gutter side and gable side of the home.

With only ten homes, all located in Central Pennsylvania we realize that this is just an initial and not conclusive investigation. Additionally, the exhaust gas concentration of radon was not very high. We would have liked the concentration to have been higher for it to be more of a re-entrainment "challenge" and to provide for a better signal to measure.

From the literature referenced however, we believe that this is the most conclusive and well-designed study to date. No other study collected yearlong radon data, and other data both inside and outside of the homes during their investigations.

It is the author's hope that we may be able one day to provide options for ASD installations that also include well designed ground level exhaust, in addition to the established roofline exhaust.

Background

There have been a limited number of studies that have looked at radon re-entrainment, some where the study was directly designed to look at re-entrainment and others where re-entrainment was just a part of a larger study on radon mitigation activities and effectiveness of installed systems. Five studies in the early to mid-1990's were Henschel and Scott 1991, Neff 1994, Penn State University (PSU) 1994, Colorado State University (CSU) 1994, and Maeda 1996. The Henschel and Scott work was part of the U.S. Environmental Protection Agency (EPA) early evaluation of installed active subslab depressurization systems and was known as the House Evaluation Project (HEP). Part of this work was to investigate why indoor radon levels remained high even after ASD systems were installed. One of the study's conclusions was that radon re-entrainment resulted in the continued elevated indoor radon levels. The CSU work was four model houses built to 1:35 scale and tested in a wind tunnel looking at variables such as house height, roof pitch, mid-roof exhaust, eave exhaust, and ground level exhaust. The PSU work involved an actual two-story house in State College, PA. A mock ASD exhaust was constructed which discharged tracer gas through 4" diameter pipe. Henschel published a lengthy report in Indoor Air, 1995 on both the Colorado and Penn State research. The Maeda work was not actually re-entrainment research but looked at exhaust gas concentration build-up outdoors, primarily correlating ambient radon concentration with wind speed. The exhaust stack for this system went through the roof of the house. The exhaust gas concentration was about 200 pCi/L. The ambient measurements were made at 2 meters above ground, where they measured 0.345 pCi/L, with a range of 0.168 to 0.482 pCi/L. The authors concluded that the measured ambient radon was due to the roof top exhaust. A more recent study by Brossard, 2012 looked at nine homes in Canada. Conclusions from these early studies were that radon can re-enter a building through attic vents, air leaks in door, windows, and building walls when the terminal discharge was near these entry routes. High system exhaust gas concentrations are an important consideration for design of the terminal discharge point. However, re-entrainment was <u>not</u> found to be a <u>common</u> problem even with ground level exhaust.

All the above references had some short falling in their investigation of radon re-entrainment; very high exhaust gas radon concentrations, inappropriate exhaust point location, not recording indoor radon concentration over a long enough period of time, or not measuring indoor radon concentrations at all.

<u>Study Design</u>

Procedure

Ten single family homes, nine in the Harrisburg area and one in Lancaster were selected for the project. We realize that more than ten homes would have been ideal, however both funding and available time committed to the project limited us to this number. With visits to the houses every two weeks and then subsequent data analysis a considerable amount of time on the project in addition to our staff's normal duties was invested.

To include all four Pennsylvania seasons the study and data collection ran for one year. The nine homes in Harrisburg started data collection in June-July of 2018 and the home in Lancaster October 2018.

Homes were all equipped to measure radon both inside and outside and on basement and first floors, and basement temperature and relative humidity. Two of the homes were more extensively monitored and they included the above plus differential pressure from basement to first floor, basement to outside, continuous radon monitoring of exhaust gas concentration, and weather stations.

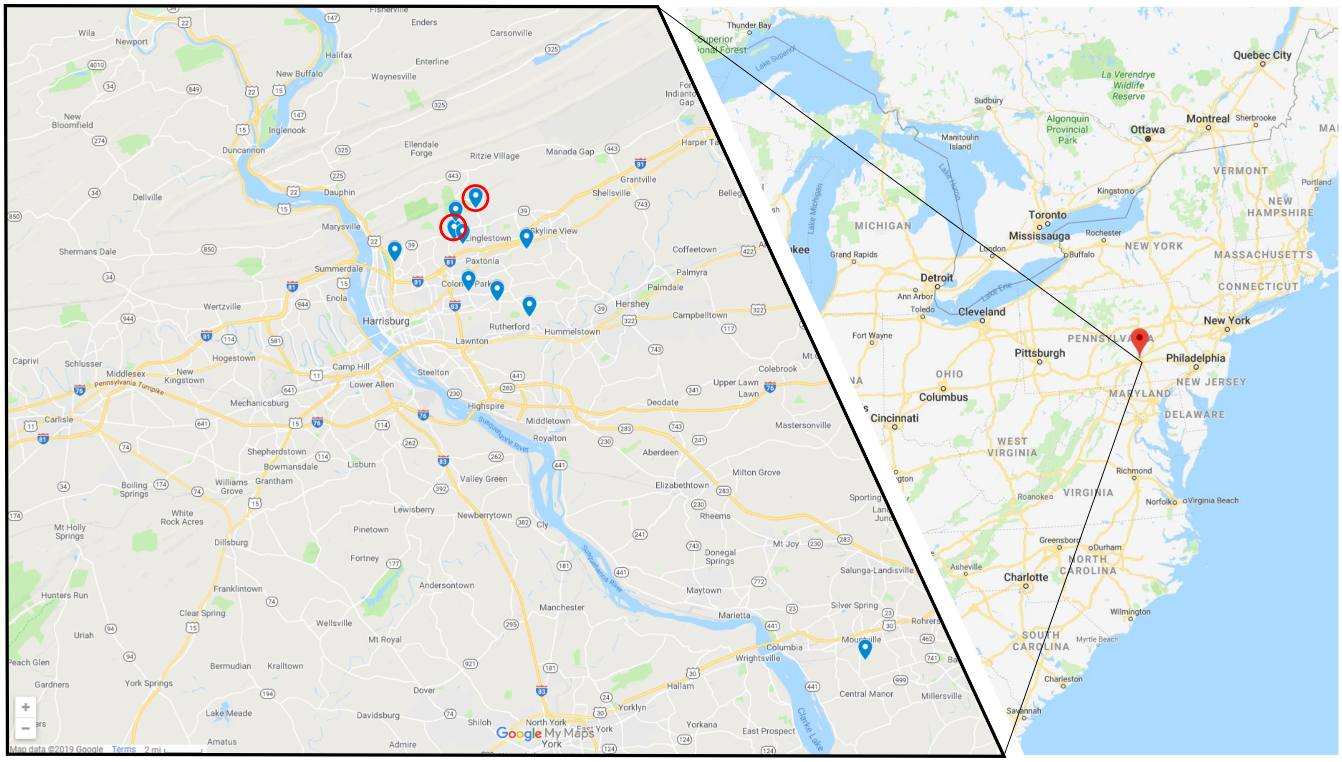
A cycling strategy was devised such that three different configurations would occur every six weeks; a baseline condition where the installed ASD system fan was turned off for two weeks and a valve was closed to isolate the system piping, a two week period where the ASD system fan was on and the exhaust was to roofline, and a two week period where the ASD system fan was on and the exhaust was several feet above ground level. Using this system, the house could act as its own control. This sequence ran for the entire yearlong study, except for one home. That home had our highest indoor radon levels of about 20-30 pCi/L in the basement and the family had small children which had a playroom in the basement. Because of this exposure we did not run the baseline (ASD off) configuration but only the roofline and ground level exhaust configurations. We felt that two weeks was more than adequate to allow each configuration to reach its own baseline conditions.

For all continuous radon monitor data analysis, when comparing the three configurations the first 24 hours of data from an initial cycle was eliminated from analysis to allow for equilibrium to be established.

It is important to remember that we did not require homeowners to maintain closed-house conditions during the study. There was a range of home conditions depending upon homeowner comfort and preference during the yearlong study. PA 01 in particular even though they had central AC rarely used it from spring through fall.

House Selection and Description, General

The map below shows study house locations in Harrisburg and Lancaster. Harrisburg is about 50 miles NW of Lancaster.



The nine homes in Harrisburg were from two different townships, Susquehanna and Lower Paxton Townships. We initially put an article in each township newsletter advising of the study, looking for research volunteers, and offering to cover the cost of ASD installation up to $1,000. From this advertising 40 responses of interest were received.

Selection of homes was based on several criteria. The two townships both are immediately outside of downtown Harrisburg and in proximity for the staff visits. The homes had initial radon levels between 4 and 30 pCi/L. All homes had full, unfinished basements. The homeowners were all able to allow us entry during normal working hours, and we typically visited homes anywhere from 8 AM to Noon. Upon initial review, all homes appeared that mitigation would be successful, without major investment of time or material. This indeed proved to be the case. With those criteria we were able to make our selection. The one home in Lancaster was a colleague who met all the criteria. We did visit all 40 homes with these criteria in hand.

Once the homes were selected a second site visit was arranged where more house specific data was collected, see Table1 below.

Table 1, House Characteristics

House ID	Levels	Style	Initial Rn Conc. (pCi/L)	Floor Area (Sq. Ft.)	Distance of ASD exhaust to nearest opening	Occupants (#)	Air Leakage (ACH50)
PA 01	2	Ranch	8	2,195	4’	1	2.11
PA 02	2	Ranch	10	2,200	3’	2	13.9
PA 03	3	Colonial	9	4,416	4’	6	2.59
PA 04	3	Colonial	12	3,380	12’	2	10.1
PA 05	3	Colonial	22	2.554	2’	1	7.2
PA 06	3	Colonial	11.5	2,440	4’	2	4.95
PA 07	3	Contemporary	15	3,825	7’	2	3.21
PA 08	3	Two Story	4.5	2,050	4’	2	14.3
PA 09	3	Colonial	32	3,312	8’	4	3.1
PA 10	2	Ranch	8	2,535	5’	2	1.33

Note: Levels and square footage include basement. Initial radon measurements all in basement.

For more details of individual house description, see Appendix A.

Radon Mitigation System Description, General

All radon mitigation systems were active systems employing one fan and one suction point. A suction pit was dug below each point of insertion through the slab and four-inch diameter PVC pipe was used. All systems used a RadonAway RP-145 fan, except for House PA 08 and PA 10, which used a high suction RadonAway GP-501. A U-tube manometer was installed on each four-inch pipe and an information packet was attached to the pipe. A post-test was run 24-48 hours after activation to assure that the radon levels were below 4 pCi/L. A unique design was employed outside on the exterior piping to allow for switching the system configuration from roofline exhaust to ground level exhaust, see Photo 1 below.

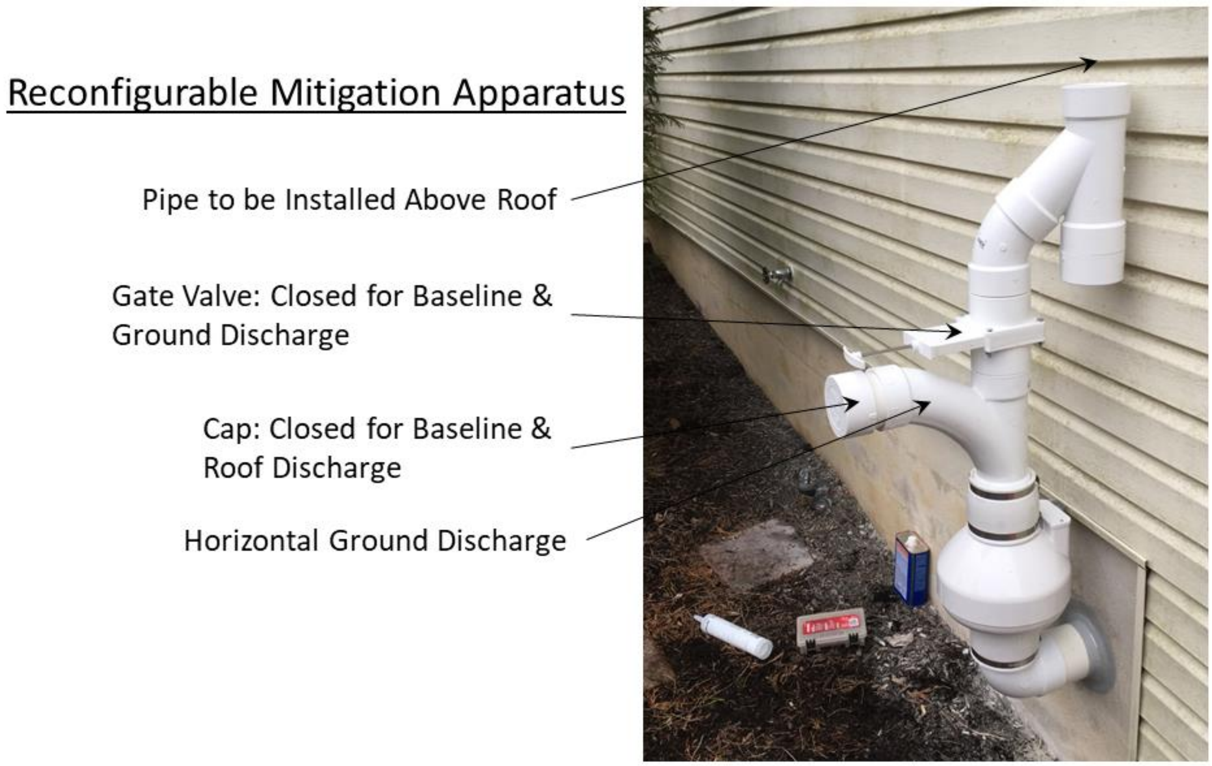


Photo 1. Reconfigurable mitigation system apparatus installed at all study houses allowing for changing between roofline and ground level exhaust configurations.

Radon Mitigation System Description, House Specific **– See Appendix A**

Appendix A contains a basic description of each study house such as house type, square footage, and heating/cooling system; an ASD system description describing fan type and number of suction points; and finally the type and location of the indoor and outdoor measurement device placement.

Testing and Monitoring

Testing consisted of devices left in the home for the entire study and spot measurements made during each two-week visit. Continuous radon monitors left in the home for the year were either Pylon AB-5 radiation monitors with flow through cells for measuring exhaust gas concentrations in system piping at PA 01 and PA 04, or Pylon AB-5 radiation monitors with the passive detector or the Sun Nuclear Model 1030 CRM's for measuring indoor radon. The continuous monitors were placed near to the suspected point of "maximal impact", where re-entrainment would most likely occur. Also left in the home for the year were Short Term E-Perms and HOBO temperature and relative humidity sensors. The spot measurements bi-weekly consisted of grab radon samples at various locations, both inside and outside the home. Using the micromanometer and pitot tube spot differential pressure measurements were taken from basement to outside, basement to first floor, and first floor to outside. Finally, sound measurements were made near the wall closest to the fan in the basement, on the first floor, on second floor, and outside ten feet directly in front of fan. Air flow and pressure were measured inside the ASD piping, using pitot tube and micromanometer. Table 2 below summarizes the continuous and periodic measurements.

In addition to all the above, two homes were instrumented more extensively than the other eight, PA 01 and PA 04. This was done in order to collect some additional and hopefully useful information. It was only done in these two houses due to costs, staff time, and equipment limitations. In addition to that mentioned above, PA 01 and PA 04 also had monitoring capability to continuously record differential pressure using Campbell dataloggers and Setra pressure sensors, from basement to outside, basement to first floor, and first floor to outside. The final instrumentation was a weather station at each of these two homes. The weather station was placed possibly closer to the home than the manufacturer recommended but the intention was to record weather near the ground level exhaust point.

Table 2, Measurements/Frequency

Houses(s)	Continuous Data		Bi-weekly Visits	
	Parameter	Location	Parameter	Location
PA 01 & PA 04	Temp./RH,	Basement	Grab Samples	See Figure 1 for locations
	Radon (CRM)-Indoors	Basement, 1st, 2nd Fl.	Differential Pressure	
	Radon (CRM)-ASD Exh. Gas	Basement	System Flow & Pressure	
	Differential Pressure	3 locations	Sound	
	Weather	Outside		
	E-perms	Inside all levels, outside		
PA 02, PA 03, PA 05- PA 10	Radon (CRM)-Indoors	Bsmt., 1st Fl.	Grab Samples	See Figure 1 for locations
	Temp./RH	Basement	Differential Pressure	
	E-perms	Inside all levels, outside	System Flow & Pressure	
			Sound	

A blower door was used initially in the study on each home to determine leakage points and to calculate the air changes per hour at 50 pascals (ACH50). To determine the leakage points the house was depressurized to minus 20 pascals and then using a smoke stick suspected leakage points such as doors, windows, vents, etc. were checked. These locations were noted in house notebooks. Blower door data can be found in Table 1 and Appendix J.

Measurement Location Details, General

Indoor radon measurements using the CRMs were made near a suspected point of maximal impact from the ground level exhaust; this could be a basement, first floor, or second floor window depending upon house characteristics. The two CRMs (PA 01 & PA 04) measuring the exhaust gas concentration in the system piping were immediately next to the four-inch riser for the ASD system in the basement. Short-Term E-perms were placed on each level of the home, and outside on the same side as the ground level exhaust, and outside on the opposite side of the house. The temperature/relative humidity sensor was placed in the basement. The weather stations at PA 01 and PA 04 were placed approximately eight feet away from the house near the ground level exhaust point, to record weather conditions nearest to the exhaust point. Grab radon samples were taken sub-slab through a floor test hole, outside in the ASD exhaust piping with the sampling tube 12-14" down the throat of the piping, along the side of the house approximately three feet from the ground level exhaust, on the opposite side the house, and one foot directly in front of the exhaust stream when the system was in the ground level exhaust configuration. Differential pressure measurements were made from the basement to the first floor, from basement to the outdoors, and from first floor to the outdoors. However, these pressure measurements were only cursorily evaluated. Finally, the sound measurements were taken during each of the three configurations, in the basement by the wall nearest the ASD system, on the first floor nearest the wall by the ASD system, on the second floor nearest the wall by the ASD system, and outside ten feet directly in front of the ASD discharge.

A three-page data collection form was used to record all the pertinent data and measurements collected during each two-week visit, see Appendix B.

The schematic below (Figure 1) shows the general pattern of device and measurement location placement inside and outside the house.

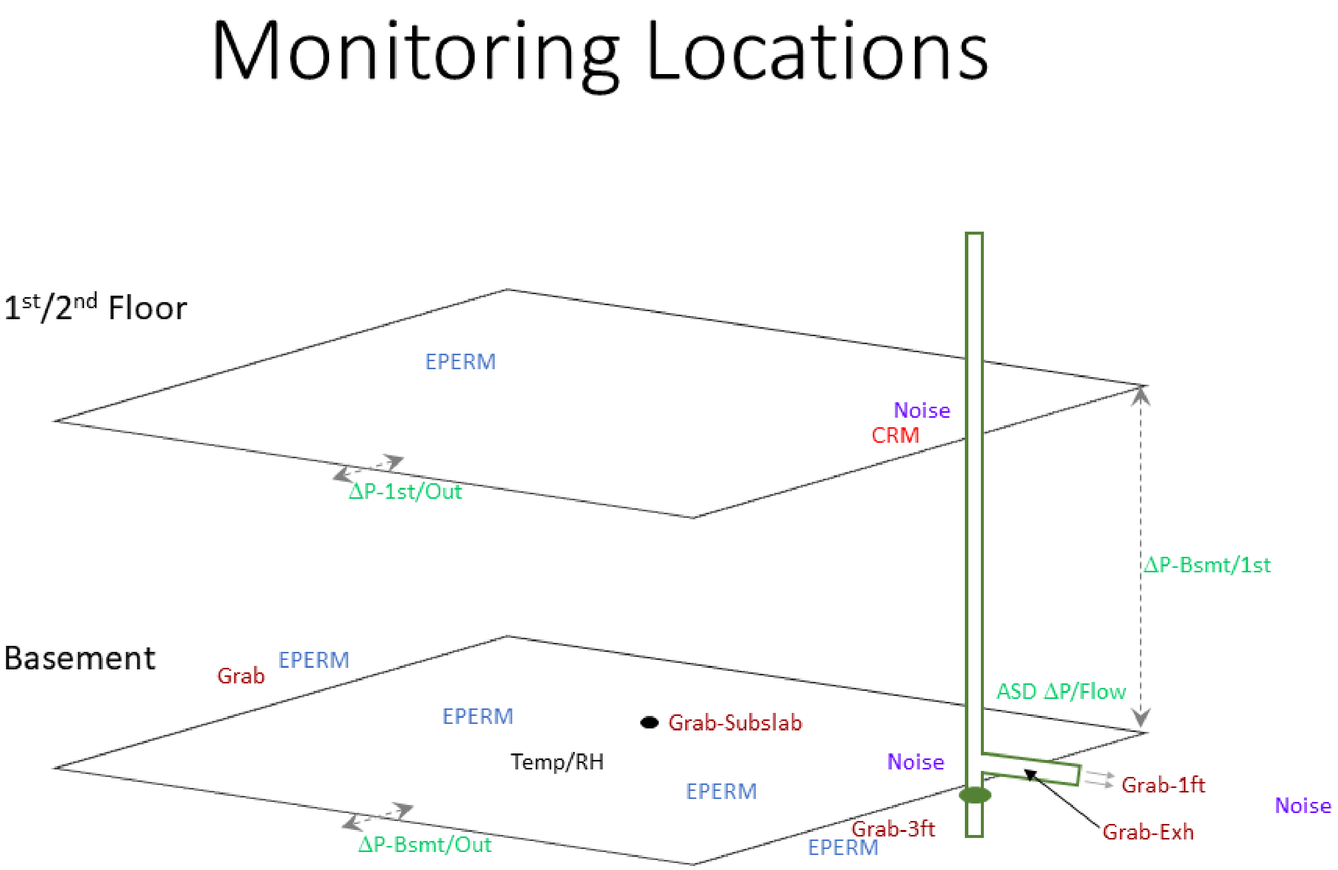


Figure 1. Monitoring Locations

***For House Specific Measurement Location Details,* – See Appendix A**

Results

The results section below contains data showing the indoor radon concentrations during the system cycling, in both graphical and tabular form. Indoor radon concentrations are also presented during system cycling by the season of the year. Presented also are indoor radon concentration transient spikes. These spikes in indoor radon <u>may</u> show short periods of re-entrainment that would be obscured by averaging of the data. Interesting data is shown for system exhaust gas radon concentrations, by both configuration and season. Two-week long average E-perm data is also shown for both indoor and outdoor locations. Radon grab sample data is shown for both indoor and outdoor locations, along with a very important graph of radon gas concentration discharge from the ASD exhaust point with distance. Next is a presentation of a theoretical radon gas dispersion model with its diagram and equations. Finally, ASD system air flow and pressure in the system piping is presented, as are sound levels both inside and outside the homes. It should be pointed out in the results section, data or graphs for house PA 01 or PA 04 are often presented as examples of the data. The remaining data for all other homes can be found in the appendices.

Indoor Radon Levels During Cycling of ASD Configurations

An example of basement CRM radon measurements (continuous 30-minute averages) as the mitigation systems were cycled on and off throughout the year-long study in house PA01 is displayed in Figure 2. This data shows the significant reduction in indoor radon levels during operation of the ASD system, regardless of system exhaust location.

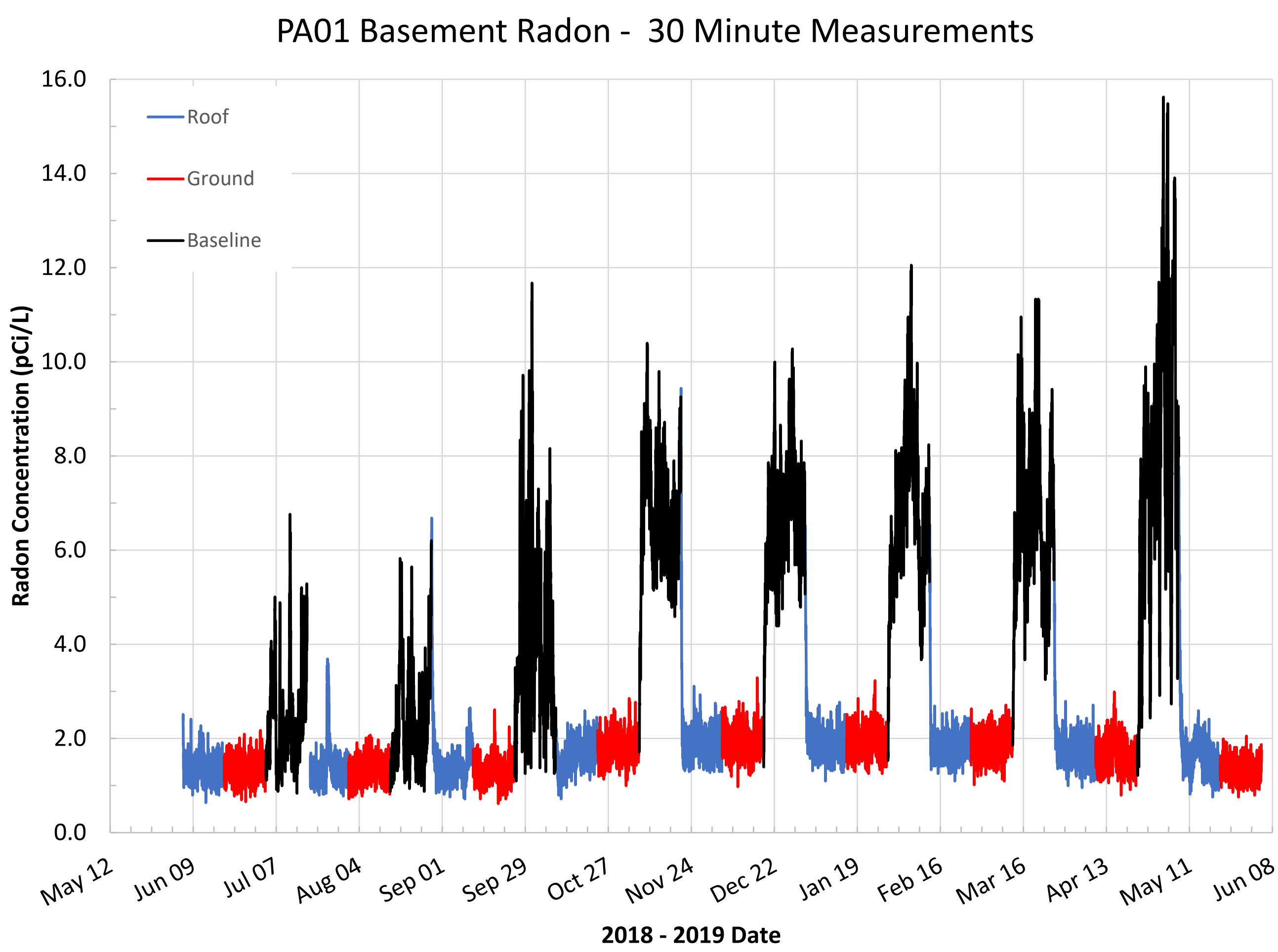


Figure 2.

Derived from Figure 2 (above), Figure 3 (below) shows CRM data for the basement of house PA01, where each bar represents a two-week average of 30-minute intervals of data for each configuration. The averages for each of the three consecutive configurations can be compared. Of particular interest is that the roof line and ground level configurations show almost identical average radon concentrations for the two-week intervals, for the entire year.

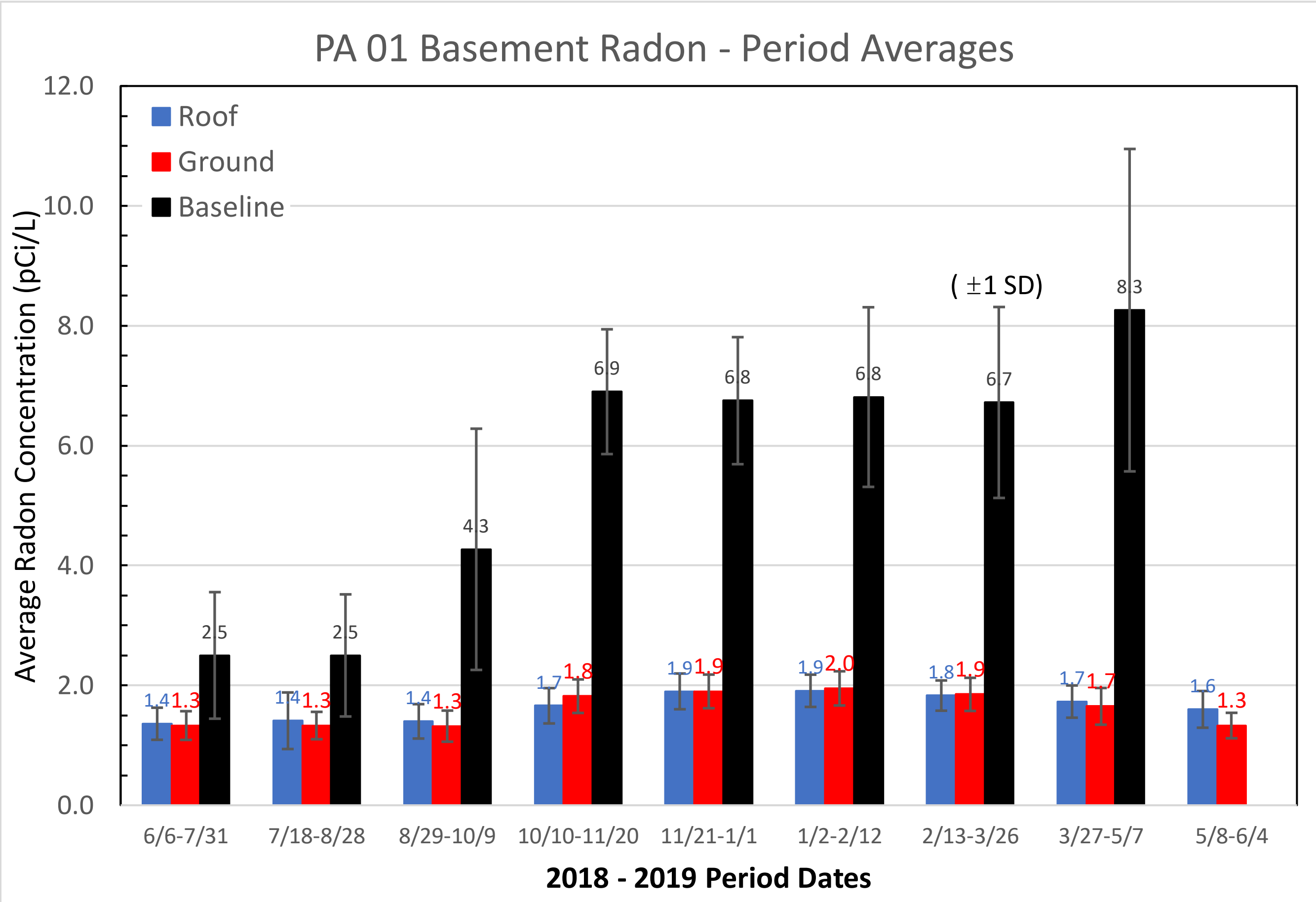


Figure 3.

Similarly, Figure 4 (below) shows the first-floor bedroom CRM data for PA 01. At this location, average radon levels for the paired periods of ground and roofline discharge configurations are equal five times, the roofline configuration is higher three times, and the ground level is higher once. However, in the case where one or the other configuration average is higher, the difference is small – typically by only 0.1 to 0.2 pCi/L. For PA 01 the first floor bedroom window would be expected to have the greatest likelihood of re-entrainment from the ground discharge location, since the window was directly above the ground level exhaust point, and this bedroom window was open often during the mild weather. The data for PA 01 indicate that ground level exhaust was not contributing to increased indoor radon concentrations over the course of the year. Graphs of period average summary data for the other study houses are presented in Appendix C.

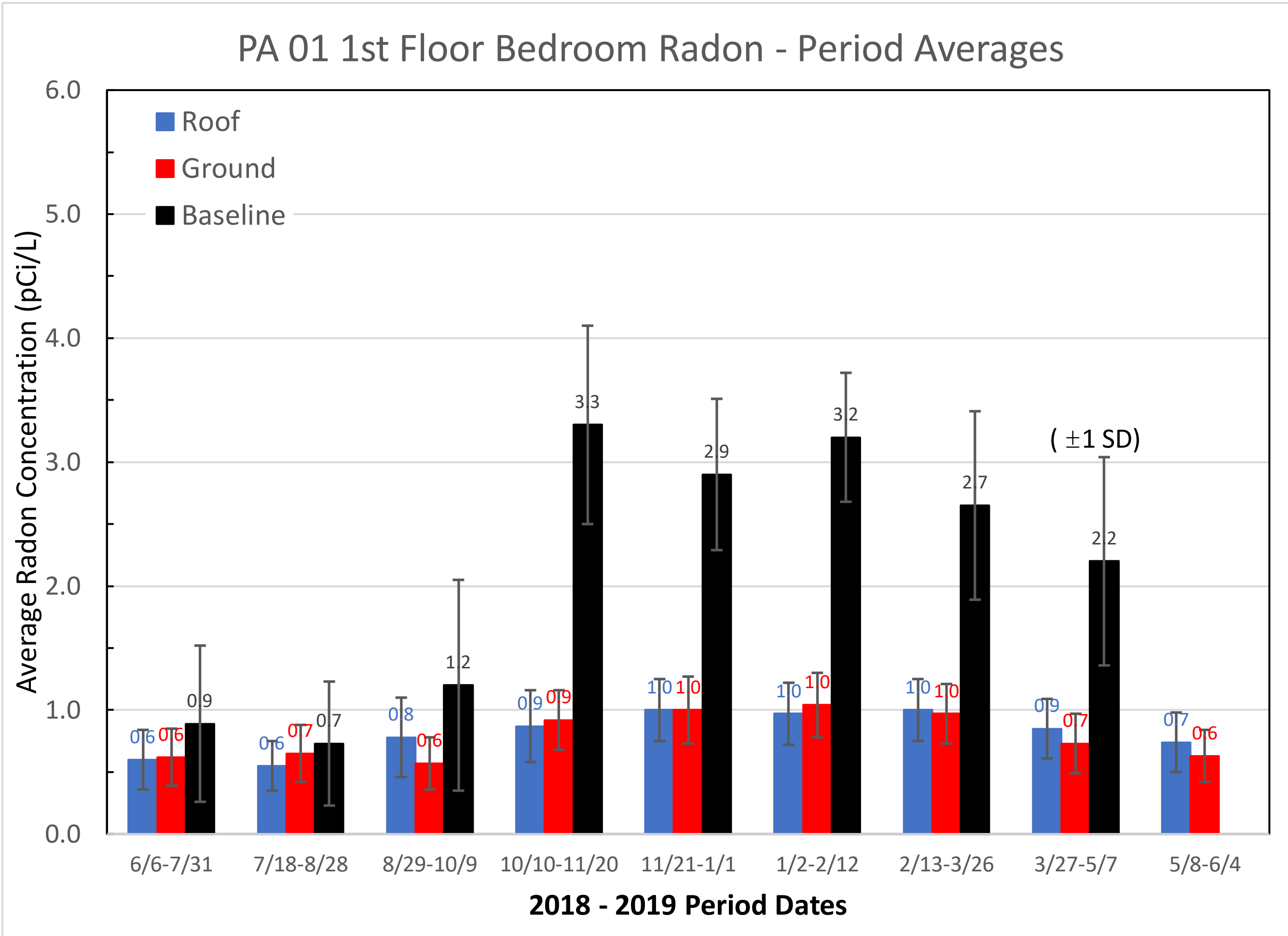


Figure 4.

Radon data from the CRMs were aggregated for each of the two-week periods throughout the year for each of the three mitigation configurations. The graphical summary of the data from the CRMs for all houses is shown in Figure 5, below.

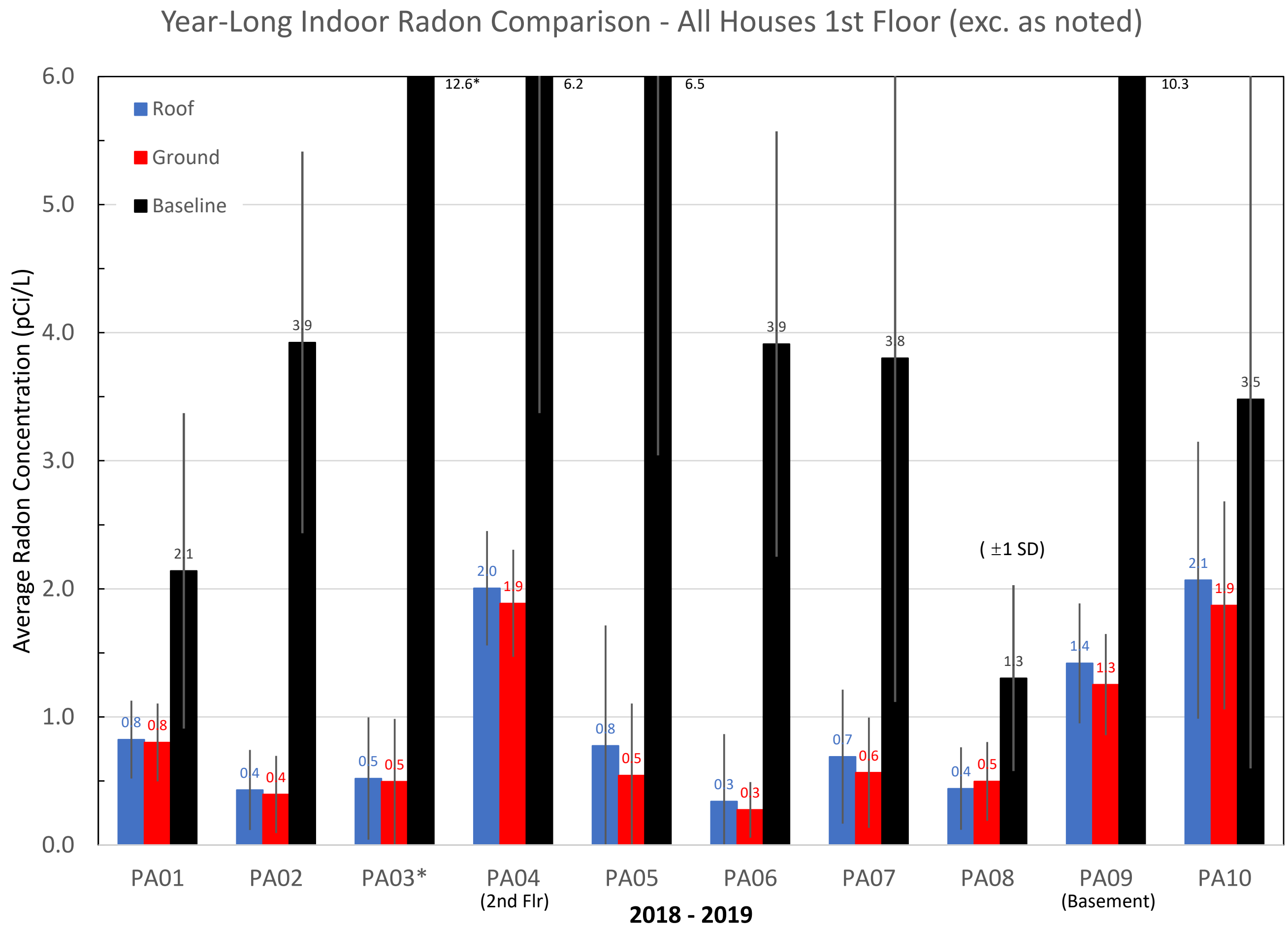


Figure 5.

All data are further summarized in Table 3. While overall averages for ground level and roof line exhaust are very similar, indoor radon levels from the CRMs and EPERMS for the roof-line configuration were higher than the ground level configuration in six of the 10 houses. As in PA 01, the data suggest that, for the entire group of study houses, the location of the ASD exhaust had little-to-no overall impact on indoor radon levels, and that in some of the houses the long-term indoor radon levels may have actually been higher during roof line operation. This may have been the result of measurably less negative pressure created by those systems due to the longer pipe requirement necessary to exhaust above the roof line. The baseline values, with the ASD fan off, do show elevated indoor radon concentrations, compared to roof and ground level configurations, as would be expected.

Table 3. Year-Long Average Radon Levels for Different Configurations Using CRMs and EPERMs

House	Location	Measurement Type	Roof Avg (pCi/L)/SD/#Periods[1]	Ground Avg (pCi/L)/SD/#Periods[1]	Baseline Avg (pCi/L)/SD/#Periods[1]
PA01	Basement (Unfin)	CRM	1.6 / 0.21 / 9	1.6 / 0.27 / 9	5.6 / 0.27 / 9
		EPERM	0.66 / 0.20 / 9	0.58 / 0.26 / 8	5.1 /2.6 / 8
	1st Flr Bedroom	CRM	0.81 / 0.16 / 9	0.79 / 0.18 / 9	2.1 / 1.0 / 8
		EPERM	0.48 / 0.12 / 9	0.43 / 0.20 / 8	1.8 / 1.2 / 8
PA02	1st Flr Bedroom	CRM	0.43 / 0.1 / 8	0.4 / 0.11 / 8	3.9 / 0.6 / 8
		EPERM	0.3 / 0.2 / 9	0.5 / 0.7 / 8	4.5 / 1.3 / 8
PA03	1st Flr Living Rm?	CRM	0.51 / 0.24 / 12	0.52 / 0.26 / 12	-------
		EPERM	0.4 / 0.21 / 12	0.4 / 0.24 / 12	-------
PA04	Basement (Unfin)	CRM	0.89 / 0.16 / 9	0.83 / 0.24 / 8	9.47 / 2.5 / 7
		EPERM	0.78 / 0.3 / 8	0.87 / 0.3 / 9	8.9 / 1.6 / 8
	2nd Flr Office	CRM	ND	ND	ND
		EPERM	0.88 / 0.34 / 8	0.7 / 0.26 / 9	4.7 / 2 / 7
PA05	1st Fl. Kitchen	CRM	0.77 / 0.54 / 9	0.51 / 0.38 / 8	6.4 / 2.5 / 7
		EPERM	0.71 / 0.61 / 9	0.46 / 0.3 / 9	5.64 / 2.2 / 8
PA06	1st Fl. Kitchen	CRM	0.34 / 0.19 / 9	0.27 / 0.06 / 9	3.9 / 1.2 / 8
		EPERM	0.23 / 0.27 / 9	0.13 / 0.05 / 9	3.68 / 1 / 8
PA07	1st Fl. Office	CRM	0.69/ 0.38 / 9	0.56 / 0.29 / 9	3.8 / 1.9 / 8
		EPERM	0.54 / 0.43 / 9	0.33 / 0.22 / 9	3.73 / 2.1 / 8
PA08	1st Fl. Bedroom	CRM	0.43 / 0.1 / 7	0.48 / 0.09 / 8	1.26 / 0.36 / 6
		EPERM	0.4 / 0.16 / 9	0.41 / 0.13 / 9	1.3 / 0.4 / 9
PA09	Basement	CRM	1.39 / 0.38 / 8	1.25 / 0.26 / 7	10.2 / 2.7 / 7
		EPERM	0.69 / 0.23 / 8	0.34 / 0.13 / 8	8.8 / 2 / 7
PA10	1st Fl. Bedroom	CRM	1.87 / 0.4 / 8	1.97 / 0.4 / 8	3.43 / 0.86 / 8
		EPERM	2.03 / 0.37 / 8	1.9 / 0.5 / 7	3.6 / 0.7 / 7

[1] Number of 2-week periods
CRM (continuous radon monitor) data excludes 1st 24 hours of continuous data after change in configuration to allow house to reach equilibrium
EPERM (integrating) data includes 1st 24 hours after change in configuration
Data are for room closest to system fan on each floor
Data collection for houses PA01-PA09 began June-July 2018 and concluded June-July 2019; and for house PA10 began October 2018 and concluded August 2019.
PA03, a baseline configuration was not run due to higher indoor radon, 32 pCi/L in basement, kids playroom.
ND (No Data) – Data for CRM on 2nd Flr Office of PA04 is suspect and not in agreement with side-by-side measurement results made with other devices (EPERMs)

To determine if there were seasonal effects on indoor radon levels when the systems were operated in the different discharge configurations – for example, due to more frequently open windows and exterior doors that would allow discharged radon to more easily re-enter the house, CRM data was aggregated by season for PA01 (Figure 6) and all houses (Table 4). Winter is defined as being December through February, spring being March through May, summer being June through August, and fall being September through November. Other than typical seasonal differences in radon levels, there appears to be very little difference between average radon levels for roof and ground level exhaust during each of the four seasons.

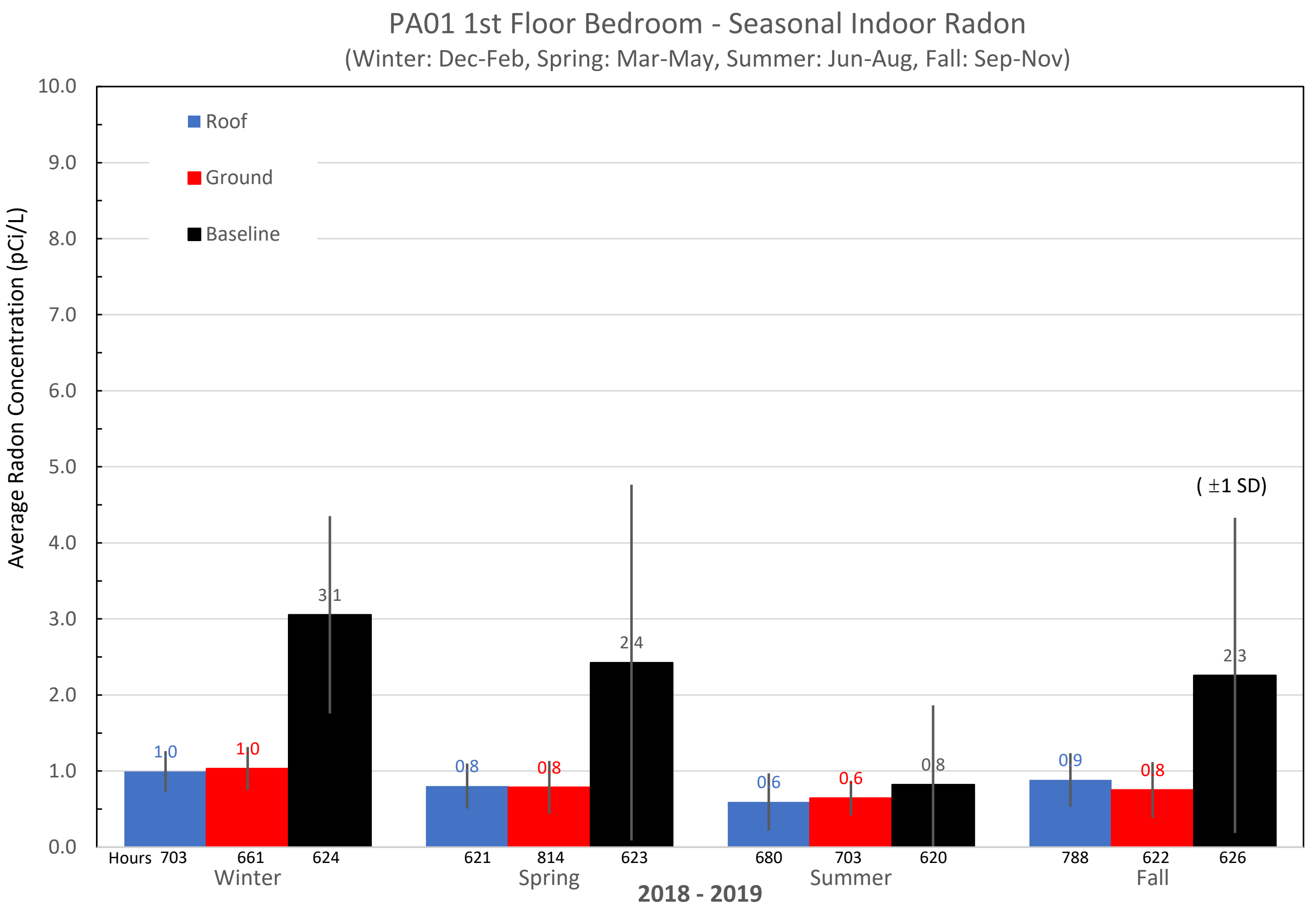


Figure 6

Table 4 below shows that, based on CRM data for all configurations, the winter season had the highest average indoor radon concentration 68% of the time, 17% of the time the high season occurred in the fall, 11% of the time the high season was spring, and only once did the high season radon average occur in the summer, which was in PA 04 with ground level exhaust. Closed house conditions may not have occurred during any of the mild season weather in any of the homes.

Table 4. Seasonal Average Radon Levels for Different Configurations From CRM Data

House	Location	Season	Roof Avg (pCi/L)//#Periods[1]	Ground Avg (pCi/L)//#Periods[1]	Baseline Avg (pCi/L)//#Periods[1]
PA 01	Basement (unfin)	Winter	1.88 / 1405	1.92 / 1320	6.78 / 1247
		Spring	1.67 / 1243	1.63 / 1626	7.49 / 1247
		Summer	1.38 / 1337	1.32 / 1408	2.49 / 1240
		Fall	1.64 / 1575	1.57 / 1242	5.59 / 1248
	1st Fl. Bedroom	Winter	0.99 / 1406	1.03 / 1321	3.05 / 1247
		Spring	0.8 / 1242	0.78 / 1627	2.42 / 1246
		Summer	0.59 / 1359	0.64 / 1405	0.82 / 1239
		Fall	0.88 / 1575	0.75 / 1243	2.25 / 1251
PA 02	1st Fl. Bedroom	Winter	0.53 / 1458	0.54 / 1227	4.35 / 1294
		Spring	0.38 / 1245	0.36 / 1215	3.57 / 1247
		Summer	0.33 / 1324	0.32 / 1343	3.28 / 1147
		Fall	0.46 / 1005	0.35 / 1248	4.44 / 1199
PA 03	1st Fl. Living Rm	Winter	0.8 / 2021	0.89 / 1852	--------
		Spring	0.48 / 1063	0.47 / 2203	-------
		Summer	0.4 / 1266	0.38 / 1502	12.57 / 517
		Fall	0.47 / 2110	0.38 / 1590	-------
PA 04	Basement (unfin)	Winter	0.99 / 1496	0.94 / 1243	6.05 / 7
		Spring	0.65 / 1192	0.62 / 1645	9.71 /1244
		Summer	0.89 / 1267	1.04 / 2126	10.35 / 1242
		Fall	1.00 / 1593	0.67 / 1247	10.43 / 1149
	2nd Fl. Office	Winter	ND	ND	ND
		Spring	ND	ND	ND
		Summer	ND	ND	ND
		Fall	ND	ND	ND
PA 05	Kitchen	Winter	1.34 / 1458	1.41 / 623	8.27 / 1225
		Spring	0.48 / 1606	0.38 / 1222	6.49 / 1242
		Summer	0.81 / 1251	0.4 / 1175	3.13 / 1237
		Fall	0.47 / 1417	0.39 / 1198	9.11 / 815
PA 06	Kitchen	Winter	0.55 / 1333	0.32 / 1245	4.10 / 1245
		Spring	0.23 / 1600	0.21 / 1243	5.10 / 1245
		Summer	0.3 / 1239	0.31 / 1869	2.23 / 1241
		Fall	0.31 / 1752	0.25 / 1248	4.28 / 1052
PA 07	1st Fl. Office	Winter	1.0 / 1245	0.93 / 1533	5.37 / 1244
		Spring	0.5 / 1865	0.39 / 2171	3.18 / 1866
		Summer	0.52 / 987	0.47 / 622	1.57 / 623
		Fall	0.76 / 1502	0.44 / 1279	4.26 / 1244
PA 08	1st Fl. Bedroom	Winter	0.53 / 1632	0.59 / 1866	1.62 / 794
		Spring	0.35 / 1386	0.41 / 1246	1.13 / 1534
		Summer	0.38 / 1246	0.48 / 1867	1.07 / 1263
		Fall	0.51 / 1562	0.42 / 624	1.49 / 1572
PA 09	Basement (unfin)	Winter	1.76 / 1538	1.44 / 1241	8.98 / 1244
		Spring	1.47 / 1554	1.37 / 1018	12.66 / 1244
		Summer	1.13 / 1363	1.09 / 1217	9.25 / 1208
		Fall	1.2 / 1099	0.99 / 626	10.25 / 1247
PA 10	1st Fl. Bedroom	Winter	2.21 / 678	2.07 / 1241	4.54 / 1439
		Spring	2.06 / 1320	1.66 / 1268	2.65 / 1485
		Summer	1.23 / 615	1.56 / 1053	3.07 / 677
		Fall	2.4 / 1243	2.38 / 650	2.96 / 52

[1] Number of 30-minute CRM intervals over the 2-week measurements

CRM (continuous radon monitor) data excludes 1st 24 hours of continuous data after change in configuration to allow house to reach equilibrium.

Data are for room closest to system fan on each floor

Winter: Dec-Feb, Spring: Mar-May, Summer: Jun-Aug, Fall: Sep-Nov
PA03, a baseline configuration was not run due to higher indoor radon
ND (No Data) – Data for CRM on 2nd Flr Office of PA04 is suspect and not in agreement with side-by-side measurement results made with other devices (EPERMs)

Transient Radon Spikes

Overall radon averages for mitigation periods can cloak transient radon levels that might briefly spike higher if radon is re-entering the building through leaky house assemblies (walls, ceilings, windows, doors, etc.) and/or open windows or doors. To examine this possibility, the data was sorted to count the number of 30-minute CRM measurement averages where the average was greater than 3 pCi/L for the indoor location specified in Table 5 during ground level or roofline discharge configurations. This data is presented in Table 5, with the number of periods exceeding 3 pCi/L compared to the total number of periods for the year-long study. The results show that: 1) regardless of the discharge configuration, the ASD systems robustly controlled indoor radon levels, with very few 30-minute excursions above 3 pCI/L, and 2) for houses with excursions above 3 pCI/L, the ground exhaust configuration had even fewer excursions than the roof exhaust configuration. House PA 10 had the greatest number of periods above 3 pCi/L in either configuration: reaching a maximum of 12.3 pCi/L during roof discharge (with 102 periods > 4pCi/L), and a maximum of 6.3 pCi/L during ground level discharge (with 43 periods > 4 pCi/L). This may be a result of PA 10 having the highest post-mitigation average radon levels (1.9 pCi/L during roof discharge and 2.0 pCi/L during ground level discharge), and the highest exhaust gas concentration of any home.

Table 5. Transient Radon Spikes, CRM Measurement Periods > 3 pCi/L

House ID	Location	Roof (#>3 / total periods)		Ground (#>3 / total periods)	
PA 01:	Basement	24	/5560	2	/5596
	1st Floor	0	/5584	0	/5599
PA 02:	1st Floor	0	/4410	0	/5033
PA 03:	1st Floor	15	/6973	8	/7796
PA 04:	Basement	9	/5563	0	/6283
PA 05:	1st Floor	90	/5731	16	/4218
PA 06:	1st Floor	70	/5923	0	/5605
PA 07:	1st Floor	6	/5599	0	/5604
PA 08:	1st Floor	0	/4826	0	/5603
PA 09:	Basement	12	/5554	0	/4102
PA 10:	1st Floor	484	/3855	270	/4211

E-perm Results

Table 6, below, includes summarized E-perm data collected for each approximately two-week period at PA 01. The E-perm sampling devices were started when the ASD system configuration was changed and therefore include monitoring of transitioning radon levels from one ASD configuration to another at the beginning of each period. Table 6 also includes results for indoor locations but not for ASD exhaust streams or from below the basement slab floor. The E-perm results are consistent with those from both CRM and grab sample measurements – not showing a difference in radon concentrations for the different ASD configuration, either indoors or in the ambient air around the house. However, levels are repeatedly slightly higher for the ambient location on the west side of house. That E-perm location is within several feet of the ground level exhaust. However, when the system is at baseline, with a cap on the ASD exhaust opening, the E-perm value is still twice the value of the opposite side of the house. It could be that there is some radon leakage at this location from the piping/fittings or it could be a slight difference due to the soil/rocks at that location, or the building itself. This home is brick and that could be contributing slightly since that e-perm was directly next to the brick home. The complete listing of this data for all other houses is found in Appendix D.

Table 6, E-perm Sample Data for House PA 01, Annual Data

Location	ASD Configuration	Avg. (pCi/L)	1 SD (pCi/L)	Min. (pCi/L)	Max (pCi/L)	N (# samples)
Ambient, East	Baseline	0.3	0.4	0.1	1.3	8
	Ground	0.11	0.06	0	0.2	8
	Roof	0.3	0.08	0.1	0.3	8
Ambient, West (Exhaust side)	Baseline	0.67	0.5	0.4	1.9	8
	Ground	0.6	0.14	0.4	0.9	8
	Roof	0.55	0.11	0.3	0.7	8
Unfinished Basement	Baseline	5.1	2.6	1.5	8.3	8
	Ground	0.57	0.26	0.3	0.9	8
	Roof	0.65	0.22	0.3	1.0	8
Finished Basement	Baseline	3.8	1.9	1.1	6.2	9
	Ground	0.37	0.2	0.1	0.6	9
	Roof	0.45	0.12	0.2	0.6	9
1st Floor Living Rm	Baseline	1.6	1.2	0.2	3.8	8
	Ground	0.17	0.12	0	0.3	8
	Roof	0.24	0.12	0.1	0.4	8
1st Floor Bedroom	Baseline	1.7	1.2	0.5	4.1	8
	Ground	0.43	0.2	0.2	0.7	8
	Roof	0.47	0.12	0.3	0.6	8

Ambient and ASD Exhaust Radon Concentrations

To better understand and characterize the concentration of radon around the outside of the houses that might enter the building, radon levels in the ambient air and the ASD exhaust stream are reported in tables 7 and 8 below. Radon in the ASD exhaust is likely to be the largest source of radon re-entrainment into the houses and was measured at several locations. For house PA 01 with continuous monitoring of radon in the ASD exhaust, Figure 7 displays the average radon concentration for each approximately two-week period, ranging from 30 to 50 days in length. Radon exhaust gas concentrations were measured in the ASD pipe just prior to exiting the basement to the outside, for both PA 01 and PA 04. The Pylon AB-5 with flow-through cell monitored the gas concentration continuously over the year, using 30-minute sample intervals.

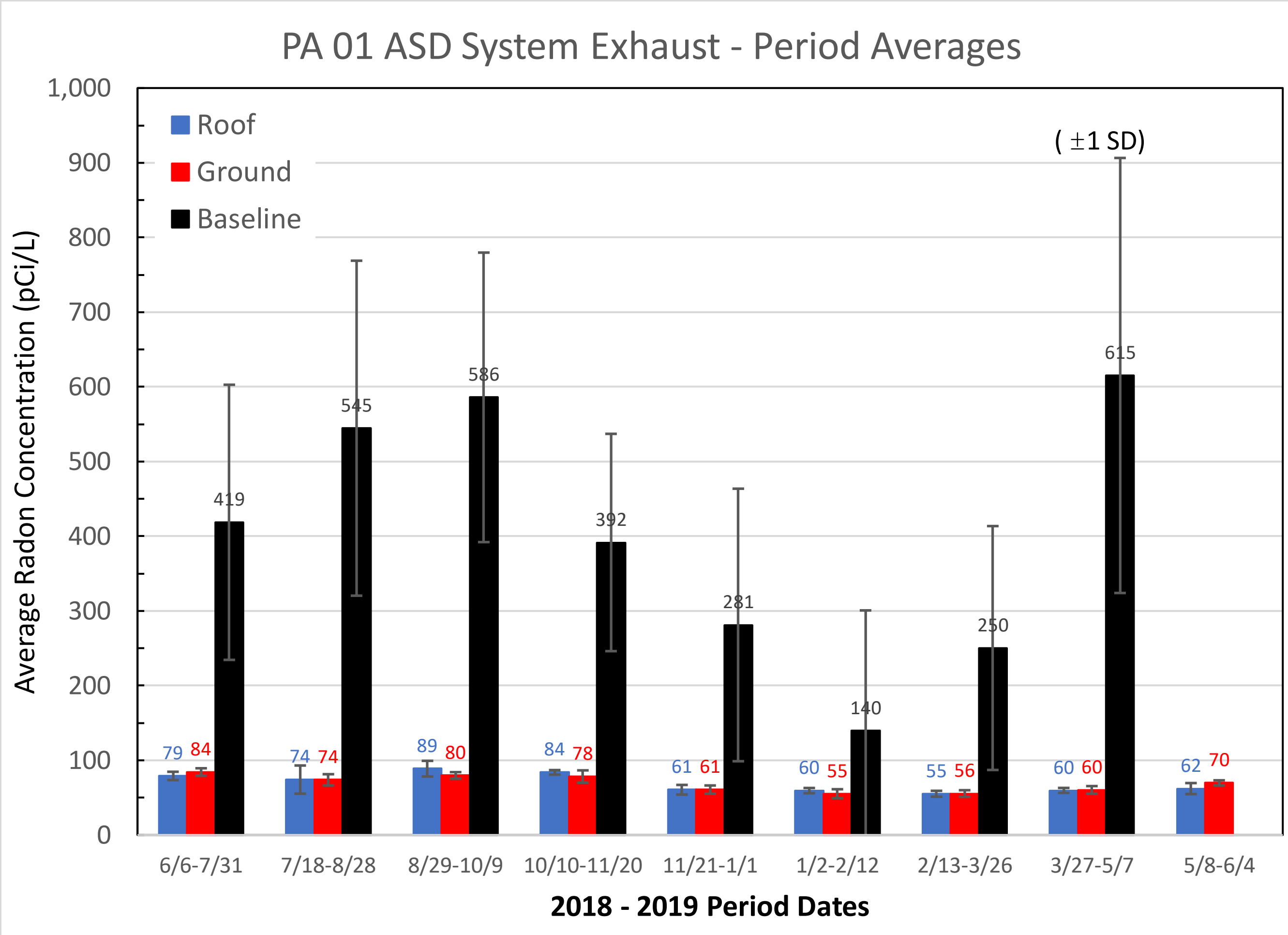


Figure 7.

Tables 7 and 8 below, summarize seasonal differences in radon exhaust gas concentrations for houses PA 01 and PA 04. The number of 30-minute periods for approximately three months of each season are included. Thus, there were approximately four cycling periods at roofline, four periods at ground level and four periods at baseline during a three-month period. As would be expected there is little to no difference between exhaust gas concentrations during the roofline and ground level discharge for both PA 01 and PA 04, however during the baseline period for PA 01 the exhaust gas concentration builds up within the piping even though there is no motive force in the piping.

Table 7, ASD Exhaust Gas Concentration from CRM, PA 01

Season	ASD Configuration	Average (pCi/L)	# 30-min Periods
Winter (Dec. – Feb.)	Roof	57.6	1404
	Ground	57.8	1319
	Baseline	210.2	1247
Spring (Mar. – May)	Roof	60.9	1243
	Ground	61.1	1626
	Baseline	432.7	1247
Summer (Jun.-Aug.)	Roof	77.8	1351
	Ground	78.4	1408
	Baseline	481.4	1240
Fall (Sep. – Nov.)	Roof	77.4	1575
	Ground	77.4	1242
	Baseline	488.2	1250

Table 8, ASD Exhaust Gas Concentration from CRM, PA 04

Season	ASD Configuration	Average (pCi/L)	# 30-min Periods
Winter (Dec.-Feb.)	Roof	23.4	1274
	Ground	21.3	1339
	Baseline	22.8	974
Spring (Mar. – May)	Roof	27.8	1935
	Ground	23.8	1350
	Baseline	15.3	1724
Summer (Jun. – Aug.)	Roof	28	1322
	Ground	27.2	2322
	Baseline	17	670
Fall (Sep. – Nov.)	Roof	28.2	1343
	Ground	26	1572
	Baseline	26.2	1273

There are significant differences in the characteristics of the PA 01 and PA 04 exhaust gas concentrations. The baseline for PA 01 is significantly elevated over the ground and roofline ASD configurations during all four seasons. The baseline exhaust gas concentration is also roughly half during the winter compared to the other three seasons. In PA 04 all three configurations have almost equal radon concentrations during all four seasons. These differences for each house and between houses could be explained by: 1) varying amounts of dilution of the radon concentration entering the pipe due to different amounts of house air leaking down through cracks and openings in the floor and foundation walls and/or outside air being drawn down along or within the exterior foundation wall, and/or 2) depletion of the radon source(s) near the bottom of the pipe, which could be due to a weak or constant source of radon near or far from the pipe, which would be dependent on the permeability and radon source in the soil.

For PA 01, Figure 7 on page 22 shows very similar exhaust gas concentration values during both roof line and ground level exhaust. This is obviously showing the sub-slab soil gas concentration being “controlled” via the ASD system. On the average there is about an 81% reduction in radon soil gas concentration during roof/ground level exhaust compared to baseline.

Table 9 summarizes radon concentrations in the exhaust and in the ambient air around PA 01 from grab samples collected throughout the year (see Appendix E for data for all houses). These samples were collected over five minutes and only represent a very small time period within the scheme of things. Outdoor samples can easily be affected by winds or lack thereof, soil moisture conditions, and barometric pressure. Radon levels in the ambient air drop dramatically even over short distances from the ASD discharge point. As seen earlier for PA 01, the exhaust stream and the samples collected below the slab show a buildup of radon during baseline (fan off) conditions.

Ambient and Exhaust Grab Samples

Table 9, Grab Sample Radon Data for House PA 01, Annual Data

Location	ASD Configuration	Avg. (pCi/L)	1 SD (pCi/L)	Min. (pCi/L)	Max (pCi/L)	N (# samples)
Ambient, East	Baseline	0.8	0.56	0.1	1.9	7
	Ground	0.25	0.03	0.1	0.6	8
	Roof	0.3	0.28	0.1	0.8	10
Ambient, 3' from Fan Alongside of house	Baseline	0.46	0.34	0.1	1.1	6
	Ground	0.34	0.33	0.1	1.1	9
	Roof	0.51	0.22	0.2	0.6	9
Exhaust Stream Inside 4" pipe	Baseline	253	433	0.4	1100	7
	Ground	44	10	29	48.4	8
	Roof	47	24	1.3	93.4	9
Ambient, Bedroom Window 4' above Exhaust	Baseline	1.1	1.34	0.1	3.7	7
	Ground	0.27	0.24	0.1	0.8	9
	Roof	0.37	0.19	0.1	0.56	10
1' in front of Exhaust	Baseline	-	-	-	-	-
	Ground	8.63	4.4	3.1	14.1	7
	Roof	-	-	-	-	-
Sub-slab	Baseline	404	87	346	584	7
	Ground	8.1	11	1.8	35	8
	Roof	68	165	3.1	35	9

A summary comparison of radon levels, from grab samples, in the ASD exhaust and near the discharge point during ground discharge configuration is shown in Figure 8. To avoid plotting on a logarithmic scale, the geometric mean concentration was calculated for each configuration at each house. The outdoor sample locations were at the one-foot centerline from the end of the exhaust and at three feet along the side of the house to one side of the fan or the other. As would be expected, the radon concentrations dropped dramatically at a distance away from the discharge point. At one foot the concentrations ranged from 1 to 48% of the exhaust point concentration, and at three feet the concentrations ranged from 0.5 to 3% of the exhaust point concentration. For the detailed results of gas dispersion, see Appendix K.

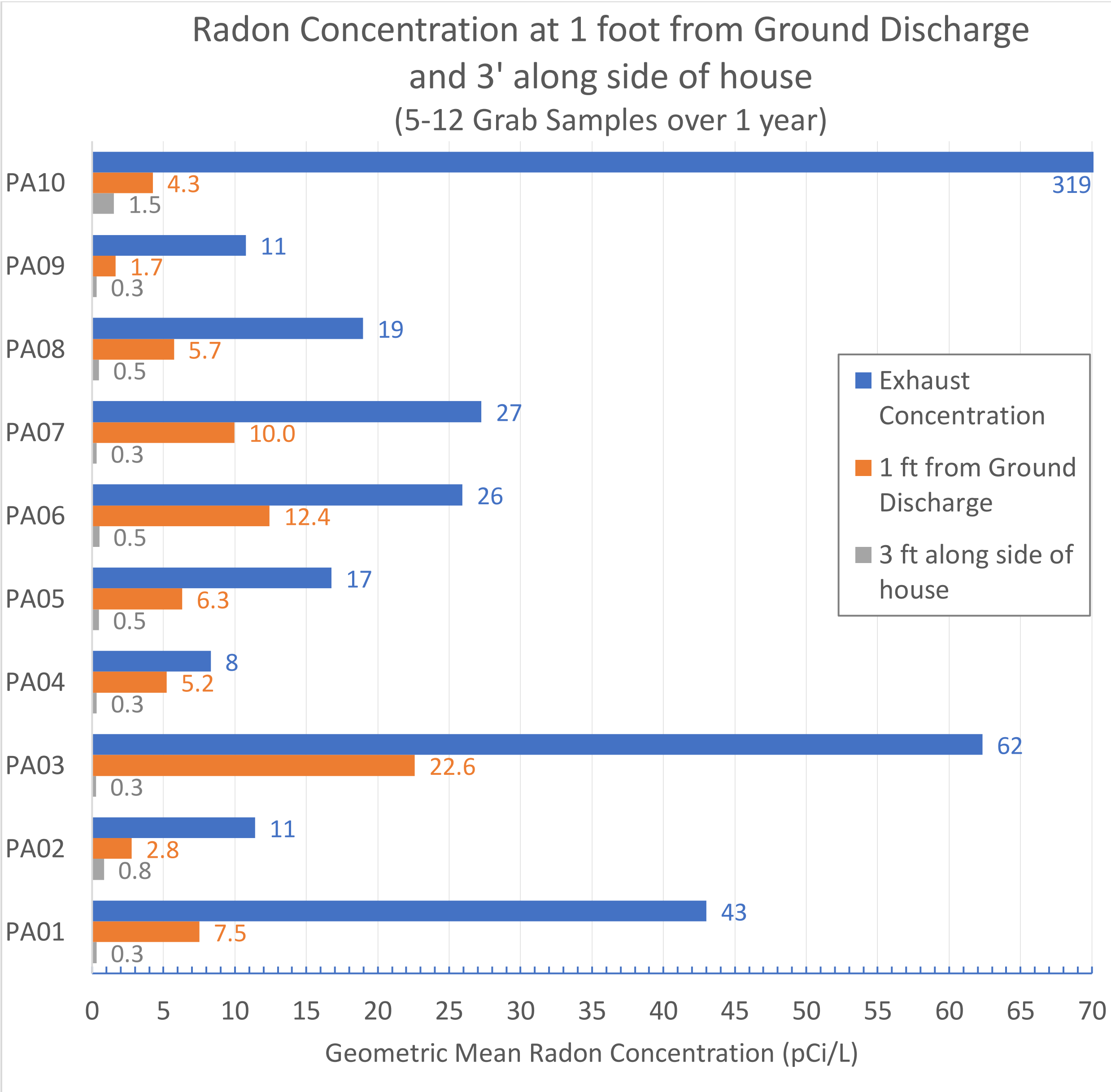
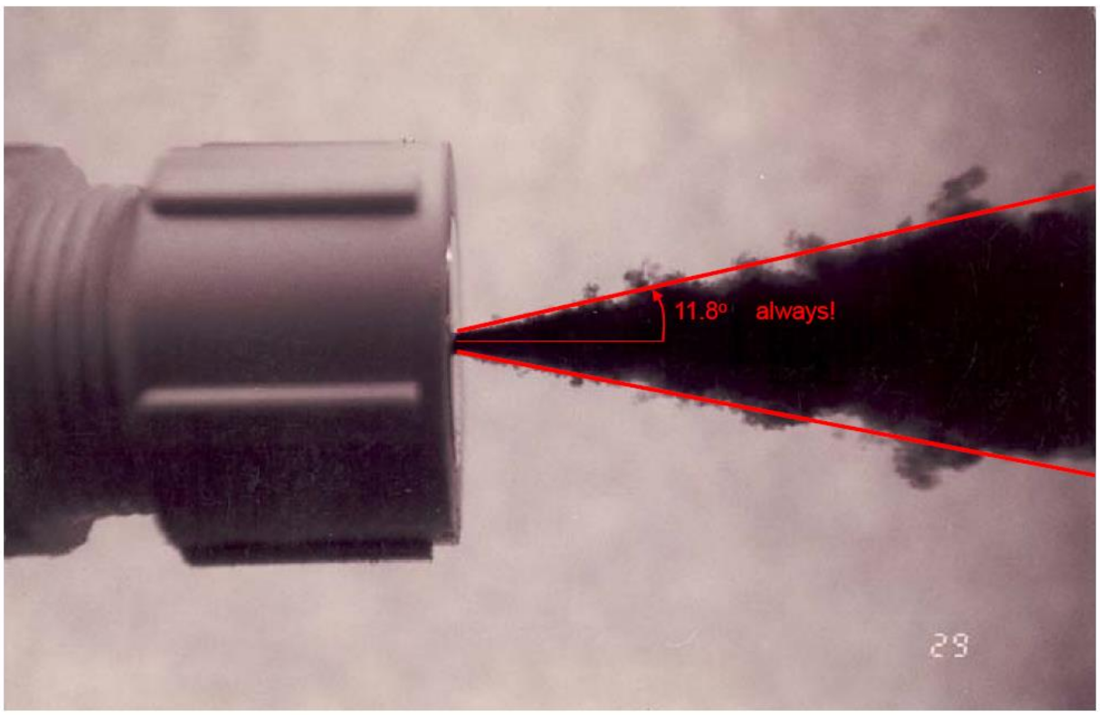

Radon Concentration at 1 foot from Ground Discharge
and 3' along side of house
(5-12 Grab Samples over 1 year)
PA10
319
4.3
1.5
PA09
11
1.7
0.3
PA08
19
5.7
0.5
PA07
27
10.0
0.3
PA06
26
12.4
0.5
PA05
17
6.3
0.5
PA04
8
5.2
0.3
PA03
62
22.6
0.3
PA02
11
2.8
0.8
PA01
43
7.5
0.3
Exhaust Concentration
1 ft from Ground Discharge
3 ft along side of house
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
Geometric Mean Radon Concentration (pCi/L)

Figure 8.

Radon Dispersion Model

The measurement results from the ASD exhaust discharge can be compared with calculations performed by Dr. Paul Houle, derived from a simplified analytical model by Dr. Benoit Cushman-Roisin to estimate and predict radon (or other pollutant) concentrations away from the discharge location. See Appendix K for more details. The calculations and model are based upon the experimentally confirmed result that the discharge from the ground level ASD pipe is a turbulent round jet analogous to that for plumes from factory smokestacks, underwater sewage release pipes, etc.



A fully developed turbulent round jet (Photo taken in Thayer School Fluid's Lab)

Figure 9. courtesy Prof. Benoit Cushman-Roisin, Ph.D, Dartmouth College, USA, 2012

In addition, the model ignores the effects of buoyancy, wind, and obstacles to the flow of the radon exhaust and assumes that at typical ASD discharge velocities (10 to 100 cfm) the air is considered incompressible (Mach below 0.3). Given these simplifications and based on empirical laboratory observations, all round turbulent jets (including the ASD discharge) will be in the shape of a cone with an opening angle of 11.8°, with respect to the centerline of the horizontal discharge axis. Thus, as the horizontal distance from the discharge point (open end of ASD pipe) increases, the diameter of the jet's cone increases. Because the mass of radon flowing from the end of the pipe is the same for any slice through the cone, the radon concentration in the discharge drops as turbulence along the edges of the cone cause ambient air to be entrained into the discharge cone – diluting the radon.

Houle's calculations were applied to grab sample data of radon concentrations in four-inch diameter ASD ground discharge exhaust pipes to estimate concentrations at one foot in front of the ground discharge point at each of the study houses. This data is compared to grab sample measurements collected at that distance.

Houle's calculations were also used to estimate radon concentrations at two and three feet from the horizontal discharge (Table 10, below).

Table 10. Comparison of Measured and Calculated Radon Concentration from Ground Discharge

House ID	Measured Radon Conc. (Geo. Mean)		Calculated Radon Conc.		
	at Discharge (C_0, pCi/L)	1 ft in Front of Discharge (C_1, pCi/L)	1 ft in Front of Discharge (C_1, pCi/L)	2 ft in Front of Discharge (C_2, pCi/L)	3 ft in Front of Discharge (C_3, pCi/L)
PA 01	43	7.5	20	13	9.4
PA 02	11	2.8	5.2	3.4	2.5
PA 03	62	23	28	18	15
PA 04	8.3	4.1	3.8	2.4	1.8
PA 05	17	6.3	7.6	4.9	3.6
PA 06	26	12	12	7.6	5.6
PA 07	27	10	12	8.0	5.9
PA 08	19	5.7	8.6	5.6	4.1
PA 09	11	1.7	4.9	3.2	2.3
PA 10	320	4.3	150	94	69

Notwithstanding the inherent variations in grab sample measurements in the ambient air around buildings, the calculated radon concentrations at one foot from the discharge are in reasonable agreement with the geometric mean measured concentrations for eight of the 10 houses. Grab samples were not collected at the two-and three-feet distances.

Because it's possible for radon concentrations in ASD exhaust to be higher than levels found in these 10 houses, concentrations in the discharge were also calculated for several hypothetical exhaust gas concentrations at even greater distances from the discharge point (Table 11). Radon levels for these scenarios can be much higher and could influence decisions about ground level discharge locations.

Table 11. Calculated Radon Concentration from Ground Discharge for Higher Radon Gas Exhaust Concentrations

Radon Concentration at Discharge (C_0, pCi/L)	Calculated Radon Conc. at 3 ft in Front of Discharge (C_3, pCi/L)	Calculated Radon Conc. at 6 ft in Front of Discharge (C_6, pCi/L)	Calculated Radon Conc. at 9 ft in Front of Discharge (C_9, pCi/L)
100	21.7	12.2	8.5
500	109	61	42.4
1,000	211	122	84.7

Applying the model to calm-wind data from a recent study by Brodhead in 2021 of horizontal, ground level ASD with discharge concentrations of approximately 230 pCi/L, calculated values were in good agreement with measured levels at two higher air flows (40 and 63 cfm). However, at the lowest flow (20 cfm), agreement was poor at all distances in front of the discharge point (1, 2, and 3 meters) – with the model consistently over-predicting radon levels in the discharge cone. A possible explanation for this may be that in the experimental configuration, the comparatively large, passive CRMs used to conduct radon measurements were, of necessity, directly in the exhaust stream – possibly disturbing the shape and profile of the plume/cone. The model is also expected to overpredict exhaust gas radon concentration since it does not account for wind, buoyancy effects, and obstacles to flow, as mentioned above.

While the radon concentration at a horizontal distance away from the house or discharge pipe is interesting and sometimes useful, it will often be more important to know the radon levels to the sides and perpendicular to the horizontal discharge, along the walls of the house with potential openings for re-entrainment of radon. Those calculations (Figure 10) show that near the boundary of the expanding cone of the pollutant under idealized conditions, the concentrations drop rapidly to background – where *x* is the distance from the discharge point, and *r* is the radial distance beyond which the concentration drops to background. They also comport well with the very low measurement results to the side along the house wall three feet away from the discharge as shown in Figure 8, page 26. Note that at 20 feet horizontally from the discharge point Houle's calculations estimate that the radon concentration along the centerline of the discharge has dropped to about 4% of the value it has at the discharge orifice. However, complicating this simple analysis is the unknown impact of the proximity and configuration of the house wall, height above ground of the discharge pipe, surrounding vegetation, topography, winds, etc. on the shape and dispersion characteristics of the plume of discharged ASD exhaust.

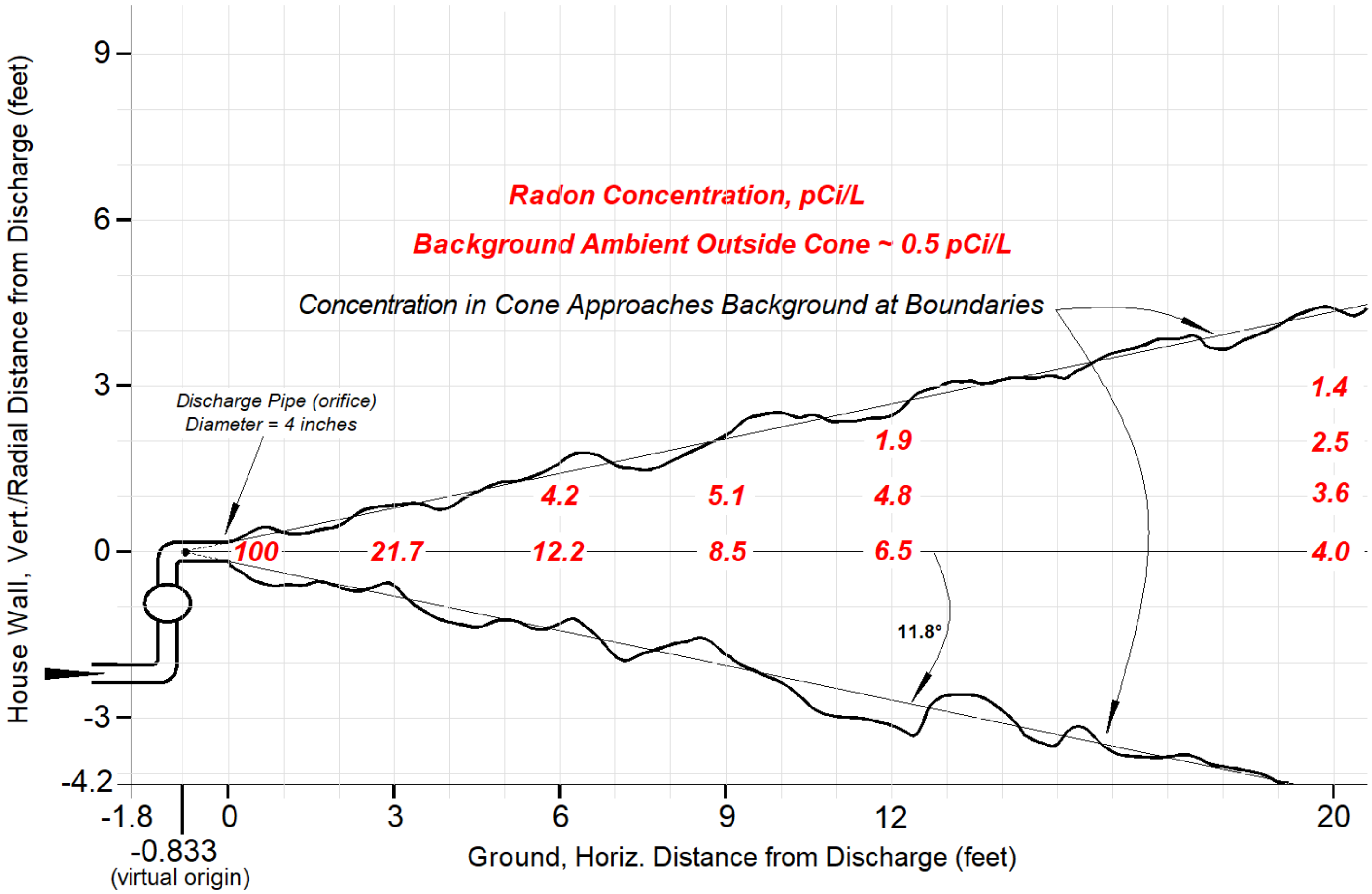


Figure 10. Radon concentration profile for a hypothetical ground level mitigation system discharge, based on the Houle and Cushman-Roisin model and calculations (Table 10). This assumes 100 pCi/L in the exhaust discharge and estimates radon concentrations both horizontally in front of the discharge and radially away from the centerline of the cone. Note that calculations of radon concentration in the plume are made using x as the distance from the 'virtual origin' (see Appendix L, eq'n L2 and L7, page 99). For example, with a pipe diameter of 4 inches, at a distance of 6 feet from the discharge, x = 6 + 0.833.

Along with measured radon levels in the system exhaust, the model will be helpful in considering the appropriateness of locations for ground level discharge, for example, open side yards next to buildings versus close-by neighboring properties or outdoor gathering areas (patios, picnic areas). However, for a better understanding of the effect of wind, obstacles, configuration of exhaust, etc. additional field validation should be conducted.

ASD System Flow and Pressure

Using the micromanometer and pitot tube in the vertical ASD pipe, pressure and air flow measurements were made during each visit where the system was either at ground level or roofline. This data for PA 01 is presented in Table 12 below.

Table 12, Flow (CFM) and Pressure (Pa) in ASD Piping, PA 01

ASD Configuration	Avg.	1 Std. Dev.	Min.	Max	N # Measurements
Flow (cfm)					
Ground	19	3.9	13	23	9
Roof	18	3.1	14	22	7
Pressure (Pa)					
Ground	467	20	441	501	10
Roof	458	16	441	479	9

PA 01 is characteristic of a high pressure and low flow system. Both the pressure and flow measurements over time were very consistent from week to week. There is also little difference in flow and pressure between the two configurations.

Figures 11 and 12 below show the average air flow and depressurization for all homes over the course of the study. The air flow during ground level discharge was higher than during roof line discharge in nine homes and was equal in one home. With less piping the ground level exhaust has less resistance to encounter and therefore slightly higher air flow. The pressure in the system pipe was higher during ground level discharge compared to roof line discharge in nine homes and was equal in one home. This can be explained by shorter lengths of piping for the ground discharge configuration, resulting in less resistance to air flow, thus generating more pressure, and possibly explaining the lower radon levels during ground discharge in some of the houses. The detailed flow and pressure data for all homes is in Appendix F.

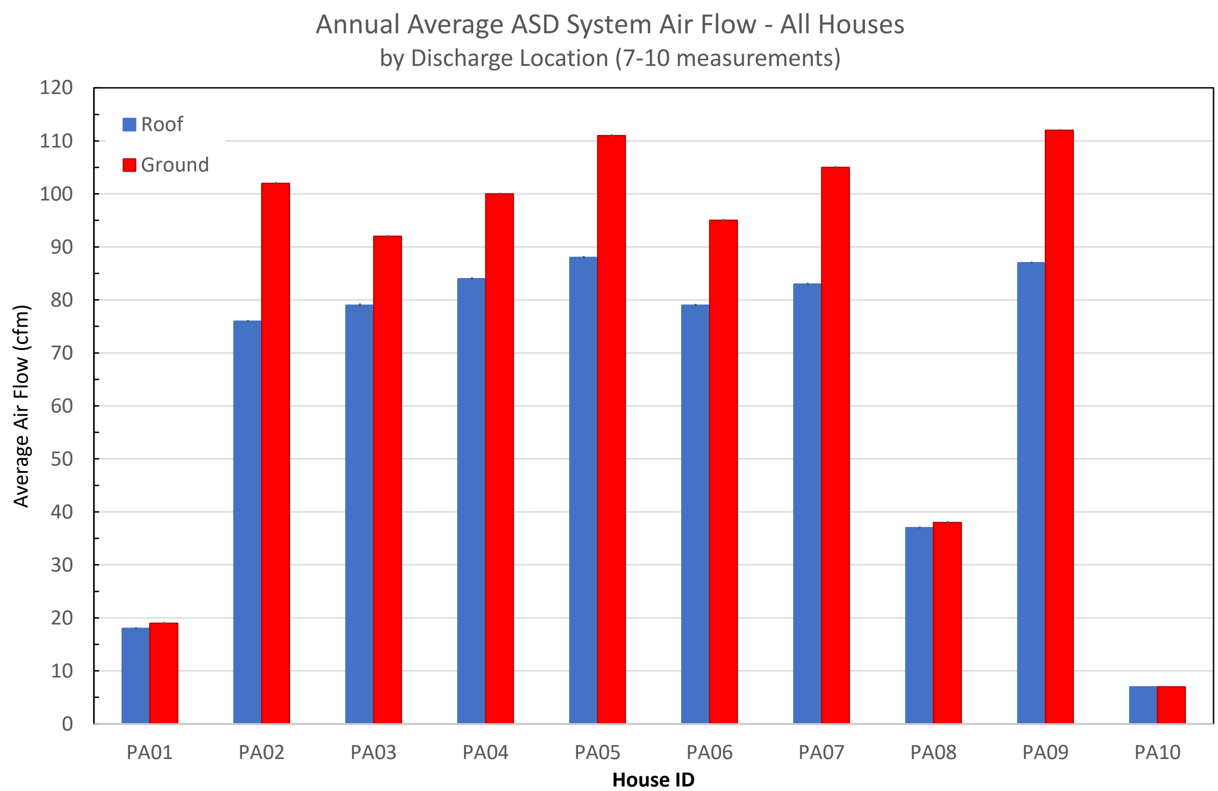


Figure 11.

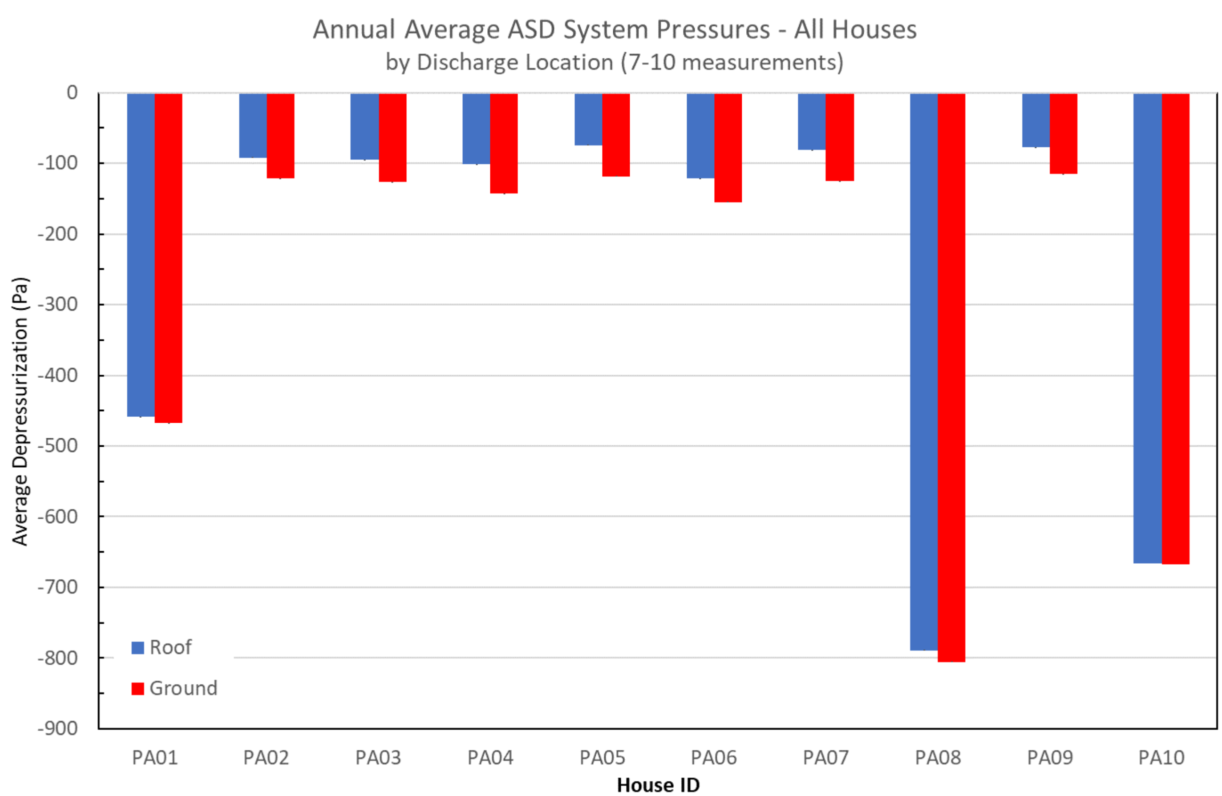


Figure 12.

Sound Levels

An example of sound measurement data is presented in Table 13 for PA 01. For this house, the ground level exhaust configuration sound levels are just marginally higher than the other configurations at each location, however the outside readings are considerably higher than the inside readings. It should be noted that outdoor sound levels can be significantly influenced by outdoor background noise, such as wind, traffic, birds, etc. Data for other houses are found in Appendix I.

Table 13. Sound Measurements for House PA 01.

Location	ASD Configuration	Avg. (dBA)	1 Std. Dev. (dBA)	Min. (dBA)	Max. (dBA)	N (msmts)
Basement, wall near ASD	Baseline	39.2	7.2	33.6	51	7
	Ground	40.6	5.3	36.4	51	8
	Roof	39.7	5.4	33.7	50	7
1st Fl. Bedroom wall near ASD	Baseline	39.6	6.8	36	55	7
	Ground	40.5	6.2	35	56	8
	Roof	38.3	3.9	34	46	8
Outside, 10' from fan	Baseline	48.2	9.8	37.6	60	7
	Ground	51	5.8	46	65	9
	Roof	45.7	4.9	38	52	8

Comparing the geometric mean of sound measurements for different discharge locations at all houses, Table 14 shows that the ground discharge was noticeably louder outside for the majority of the houses. For 1st floor indoor rooms near the system, the difference in noise levels is not as obvious.

Table 14. Comparison of Sound Levels for Ground vs Baseline and Roof Discharge (using year-long geometric mean of 5 to 10 measurements at each house)

Location	Comparative Sound Measurements
Inside, 1st Floor:	Ground Discharge > Baseline …. 6 of 9 houses
	Ground Discharge > Roof …. 5 of 10 houses
Outdoor, 10 ft Away:	Ground Discharge > Baseline …. 7 of 9 houses
	Ground Discharge > Roof …. 8 of 9 houses

Discussion and Summary

Figures 2, 3 and 4 (for PA 01) and the graphs in Appendix C, Period Averages, showing the indoor, continuous radon monitor (CRM) data provide the most conclusive evidence of any re-entrainment, if it is happening. The CRMs were placed indoors at the location expected to be most likely for re-entrainment, i.e. nearest to the point of discharge of the ground level exhaust. Table 1, House Characteristics, shows those distances and they range from three to 12 feet.

Some explanation of the graphs is in order. Each bar represents one, two-week period for the respective configurations. The bars follow the sequence of changes to the configuration of the ASD system, from roof to ground to baseline. Therefore, each grouping of the three colored bars represents approximately six weeks. This pattern is then carried through on the graph for the entire year of the study.

The period, seasonal, and annual average data of <u>indoor radon</u> concentrations during roof line and ground level exhaust show little to no differences, clearly indicating that no measurable radon re-entrainment was occurring during ground level exhaust. The period average graphs show very good indoor radon reduction from baseline to ground/roof discharge, as would be expected. This indoor radon reduction is also seen in the fact that most homes have basement post-mitigation radon less than 2 pCi/L.

These results are confirmed by the E-perm data, where for indoor locations there is very little, if any, difference between roof line and ground level exhaust configurations.

Analysis of transient radon maximums also indicate that regardless of the discharge configuration, the ASD systems robustly controlled indoor radon levels, with very few 30-minute excursions above 3 pCi/L, and for houses with excursions above 3 pCi/L, the ground exhaust location had even fewer excursions than the roof exhaust location.

Except for PA 10, radon levels in the exhaust of ASD systems for these houses were relatively modest (8.3 to 62 pCi/L) – measured after the systems had been operating for two weeks. It's possible that higher exhaust concentrations would be more likely to cause re-entrainment than was seen in these study houses, although results for PA 10 with the highest exhaust concentrations (320 pCi/L) showed no difference in indoor radon levels for ground and roof discharge locations. Measurements of exhaust radon levels from other houses and different parts of the country would be very helpful in determining if the exhaust radon levels in these study houses are atypical, and to better assess the range and distribution of radon levels in ASD exhaust.

The average sub-slab radon reduction for all ten homes was roughly 90% as observed after the systems had been running for two weeks, with a range from 70 to 99%. This clearly shows that active ASD systems remove, or dilute sub-slab radon faster than it can be produced by radium-226 decay. This may be dependent upon source strength and soil characteristics.

The ambient e-perm data does show that in three out of ten homes the fan side radon concentration is slightly higher than the side of the house opposite the fan. This increase however is only of several tenths of a picocurie per liter. In three cases the grab sampling does <u>not</u> confirm the same situation. Therefore, we do not see a significant difference of ambient radon on the fan side versus the non-fan side of the house.

Data from Figure 8 and Table 9 also show decrease of radon concentration with distance from an exhaust stack on the outside of the houses. In support of these measurements, a simple theoretical model was used to predict radon levels at various locations away from a ground level ASD exhaust. It shows that concentrations drop rapidly as the horizontal and radial distances from the discharge increase – especially to the side of the exhaust plume along the house wall, as confirmed by measurements. Disregarding wind, buoyancy effects, obstacles, and other factors, the model results are in reasonable agreement with ambient measurements in this study.

Air flows and pressures were typical for installed ASD systems, with the ground level exhaust configuration having slightly higher air flows than the roof configuration. This could be due to the shorter lengths of exhaust pipe in the ground level configuration causing less resistance to air flow – possibly explaining the lower radon levels during ground discharge in some of the houses.

Sound measurements recorded in Appendix I do show slightly higher decibel readings during ground level exhaust, as would be expected. At least one homeowner did notice an appreciable difference during ground level and roof line discharge since the ground level discharge was directly below the often-open bedroom window.

In summary, this study of 10 houses near Harrisburg, PA found that ground level discharge of ASD mitigation system exhaust did not increase indoor radon concentrations when compared with traditional roof top exhaust. The installations included locations near windows and exterior doors as well as along house walls without openings. While exhaust radon concentrations were modest, ambient measurements and model calculations suggest that re-entrainment of radon from properly located and installed ground level discharge would not be an important source of radon into a house.

Recommendations and Preliminary Guidance

Common sense is vitally important during any installation of any mitigation system. Based on the results of this study, it can be applied, along with appropriate guidance in standards, to locate ground level system exhaust locations away from windows, doors, and commonly used or trafficked outdoor spaces, and still provide suitable protection for the public while opening up more installation options for mitigators. In fact, personal communication with Bruce Henschel, retired from EPA and most responsible for the previous EPA radon Mitigation Standards, suggested that EPA may have considered ground level exhaust as feasible had more research data been available at the time.

Preliminary guidance for the installation of ground level discharge could include consideration of Canadian recommendations for pipe routing and discharge locations to limit condensation and freezing in system pipes that are influenced by the colder climate. In turn, the Canadian recommendations are adapted from their Natural Gas and Propane Installation Code (CSA-B149.1) for vent terminal clearances (CGSB 2017, 5.1.8.2), as follows:

> *Clearances from radon discharge should follow suggested minimal clearances and shall follow required minimal clearances listed in Table 2.*
>
> *a) A vent shall not terminate where it may cause hazardous frost or ice accumulation on building surfaces or any adjacent property surfaces.*
>
> *b) A vent shall not terminate directly above a sidewalk or paved driveway that is located between two single family dwellings and that serves both dwellings.*
>
> *c) The clearance for an openable window should also be applied for rooms that are occupied more than 4 h a day.*
>
> *d) Discharging no less than 100 cm (3.3 ft) under veranda, porch, deck, or balcony should be considered only if veranda, porch, deck, or balcony is fully open on a minimum of two sides.*

Table 2 — Clearances from radon discharge

Locations	***Suggested clearances m***	***Ft***	***Required minimal clearances m***	***Ft***
Clearance to a mechanical air supply inlet	*3.0*	*10*	*1.8*	*6*
Clearance to permanently closed window	*1.0*	*3.3*	*0.30*	*1*
Clearance to an openable window	*2.0*	*6.6*	*1.0*	*3.3*
Clearance from a door that may be opened	*1.0*	*3.3*	*0.3*	*1*
Clearance from a door that has an openable window	*2.0*	*6.6*	*1.0*	*3.3*
Clearance to outside corner	*0.3*	*1*	*0.3*	*1*
Clearance to inside corner	*1.0*	*3.3*	*0.3*	*1*
Clearance above paved sidewalk or paved driveway located on public property	*2.1*	*7*	*2.1*	*7*
Clearance above grade- from a veranda, a porch, a deck, or a balcony	*1.0*	*3.3*	*0.3*	*1*
Vertical clearance below soffits or from any attic venting component	*1.0*	*3.3*	*1.0*	*3.3*
Horizontal clearance from an area directly below the discharge where there is a risk of injury from ice falling	*2.0*	*6.6*	*1.0*	*3.3*

NOTE: The selection of the exhaust point should be made considering maximal available clearances from building openings and from outdoor occupancy areas.

Additional restrictions that would limit situations where ground level discharge could be considered might include:

- Don't discharge within 20 feet perpendicular to play areas or neighboring dwellings
- Don't discharge at ground level when radon concentrations in the system exhaust are greater than 500 pCi/L

These more restrictive specifications may be unnecessary or could be modified, but additional study of the issue may be required. For example, further investigations could include:

- Additional radon exhaust gas measurements from around the country would be helpful to model more carefully specified distances to potential re-entry locations or outdoor areas of exposure,

- Study of a broader cross-section of homes with different soils, construction, configurations, weather conditions, exhaust radon concentrations, having ASD systems installed with an apparatus similar to Photo 1, page 8. Measurements could be performed with alpha track detectors or long-term electret ion chambers at the locations of maximal potential impact from radon exhaust to look for re-entrainment. Other indoor locations in or around the homes distant from the point of maximal impact would serve as unaffected controls.

Areas of further study

If funding is available install ASD systems in other homes around the country. These systems would be designed with ground level exhaust. Placement of year-long radon test kits would monitor for potential re-entrainment. Placement of test devices would be discussed. This study would advance the current study by providing for other house types, soil conditions, meteorology, and possibly slightly different ASD design techniques.

Gather a larger data set on radon exhaust gas concentrations from ASD systems from around the country. This would be useful for modeling purposes to see the range and maximum exhaust gas concentrations that may be encountered.

Perform data and statistical analysis of the large data set for both PA 01 and PA 04 homes. This data was not closely examined in this current study. There is data from weather stations, pressure sensors, and other radon devices that could be more closely examined.

Acknowledgements

We would first and foremost like to thank all the homeowners who allowed us access to their homes for this yearlong study. They were all most gracious to us and I don't believe that we had any mishaps within the homes during the study. We thank Brad Turk of Environmental Building Sciences who provided a great deal of his technical expertise and guidance on initial house setup and instrumentation, for his building science and radon expertise, and for his invaluable help with the final report. Lastly, we thank Dr. Paul Houle, retired physics professor from East Stroudsburg University for his work on the theoretical gas dispersion from an open orifice.

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Appendices

Appendix A - House Description, System Description, Measurement Location

PA 01- Home built in 1960. A ranch style home with three bedrooms, no garage, and a large porch on a slab on the east side of the home. Full, walk-out basement with block wall foundation and poured slab in excellent condition. The south side is at grade level and has a walkout door. The first floor is 980 square feet and the basement is 1,215 square feet. There is no aggregate under the basement slab. There is attic access through the basement stair well, but the attic is not livable or useful for any storage, the AC air handler is in the attic. There is an oil boiler for the hot water baseboard heat in the basement.

PA 01- The suction point was through the basement floor on the west side of the house only away from the wall enough to miss the footer. The piping ran up the wall and a ninety-degree elbow took the piping through the rim joist to the exterior, where the RP-145 was located. Note: all houses have this same design. There are two bedroom windows on the west side of this house; one about four feet and the other about 16 feet away from the ground level exhaust point. Both windows are mostly open during mild weather from spring through the fall. The pressure/flow characteristics of this system tend to be high pressure and low flow, with an average pressure of 1.8" WC and a flow of 18 CFM. A floor test hole 44 feet away from the suction point shows -3.7 pa with the system operational.

PA 01- Pylon AB-5 CRM's with passive radon detectors to measure indoor radon were located on basement shelf on west wall of basement and on first floor bedroom dresser also on west wall. The Pylon AB-5 with the flow through cell was on a table top adjacent to the ASD pipe on the west wall of the basement to measure exhaust gas concentration. There were short-term E-perms placed next to each Pylon AB-5 unit measuring indoor radon, one E-perm located on the finished side of the basement, and two E-perms outside, one on the west side of the house attached to the ASD exhaust stack and one on the east side of the house attached to some fencing out in the yard. The temperature and relative humidity sensors were on the same basement shelf as the Pylon AB-5, on the west wall.

Many of the spring, summer, and fall measurements in PA 01 were not conducted under closed-house conditions, but rather the conditions of the occupant's choice. This homeowner did not often use air conditioning during the hot and humid weather and therefore windows and doors were often open, during seasonable weather.

PA 02 – Home built in 1991. A ranch style home with four bedrooms. Full, walk-out basement with entire back side exposed. The basement is divided by a framed wall dividing the finished from the unfinished side. Two thirds are unfinished, and one third finished. The first floor is 1,000 square feet and the basement is 1,100 square feet. The HVAC is in the unfinished basement.

PA 02- The suction point is through the basement floor on the west side of the house. The piping runs a third of the way up the wall, where two 45-degree bends jug around a window. One 90-degree elbow exits through the foundation to the exterior. At the outside exit is another 90-degree elbow which leads to the RP-145 fan. Four inch piping was used on the interior and 3-inch piping was used on the exterior of the home. There is a basement window within 2 feet of the fan. The spare bedroom window is approximately four feet from the fan. The piping runs up the side of the home and is vented above the roof.

This house is mostly closed with central air running in summer months. During the months of April, May, June, September, and October the homeowner did have the windows opened most of the time. Starting late

October, the heat was used. The average airflow through this system at ground discharge is 111 cfm. The average airflow through this system at roof discharge is 87 cfm. The overall air flow average is 91.5 cfm. The average pressure in this system is a 0.4-inch WC. When the fan was on, the floor test hole pressure was -23 Pa. This test hole is approximately 34 feet from the suction point.

PA 02- There were passive short-term E-perm devices used for the bulk of the testing in this location. One Sun Nuclear 1030 CRM was also used in this location on the first-floor spare bedroom.

In the basement there were two E-perms placed. One was located on a storage shelf, beside the temperature and humidity device. This was on the suction point side of the house, which was the west side of the home. The other electret was in the finished side of the basement at the east end of the house. It was placed on top of a cabinet.

On the first floor there was a Sun Nuclear 1030 CRM in the spare bedroom on the west side of the house, which was the fan side. There was an E-perm attached to the CRM. Also, on the first floor there was an E-perm placed in the dining room on top of the hutch at the east end of the house, opposite the fan.

There were two E-perm placed outside. One was located on the piping directly above the fan on the west side of the house. The other was placed on a down spout on the east side with no windows close to it.

PA 03 – Home built in 2008. Large, two-story colonial, with four bedrooms on second floor. Two car garage attached. Full, unfinished basement, with walk-out door in northeast corner. The first and second floors are 1,472 square feet each, and the basement is 900 square feet. There is a sump hole in the basement slab covered with a lid. The HVAC is located in basement.

PA 03- This house has a walk-out basement and was constructed with Superior Walls. The suction point is near the wall on the side of the house that has the family room and garage. The pipe immediately above the suction point has two 45 elbows to get pipe close to wall, and then goes vertically up to rim joist, with a 90-degree elbow to outside. The RP 145 fan is located on the side of the house that is facing the side yard. Above the ground level discharge there is a 45 degree elbow to get pipe close to house, pipe runs vertically until near the edge of the roof, and then two more 45 elbows to get pipe away from house so that discharge can be above the edge of the roof. This side of the house has no windows and has one door into the garage. The outdoor AC unit is a few feet away from the fan, and windows into the family room are around the corner on the side that faces the backyard. The average pressure of the system is 126 pascals at ground level discharge, and 94 pascals during roof discharge. The average flow of the system is 100 CFM at ground level discharge, and 85 CFM at roof discharge. The distance to basement floor test hole from suction point is about 49 feet. No pressure difference was detected in the test hole when fan was placed on suction point, yet smoke was still being pulled down into test hole.

PA 03- A Sun Nuclear 1030 was placed in the first-floor family room, on top of the entertainment center that sat along the wall that faces the side yard. There were four E-perms: one in the basement, attached to a shelf not far from the suction point, one in the family room near Sun Nuclear 1030, one attached to the vent pipe (outside), and one on the opposite side of the house, opposite corner (also outside). The HOBO (temperature/relative humidity) was placed in the basement, on the flange of an I-beam, between the central pole and air handler.

PA 04 – Home built in 1969.   Two story colonial, with four bedrooms on second floor. Unfinished basement under part of home and crawl space under remaining part. There is an attached two car garage. Large sun room attached at back of house.   The first floor is 1,417 square feet, and the basement is 546 square feet. The gas HVAC is in the basement. There is a covered sump in the basement slab.

PA 04- There was one suction point on the west side of the house 8-10" in from the wall using 4" pipe. Inside the basement were two 45's and one 90, and outside the house there were three 45's and one 90, and 13' of three-inch pipe for an exhaust stack to roofline.   Also, outside just above grade was the RP-145 fan.   In that the suction point was only 3-4' from the sump, the sump lid was sealed with silicone caulk. Adjoining the basement was a crawl space, and at grade was a slab on grade family. Neither of these zones were directly treated by the basement ASD system.

PA 04- Instrumentation for this house consisted of three Pylon AB-5 CRM's, one in the basement, one in the second-floor office, and one in the basement measuring the exhaust gas from the ASD piping. All were set to 30-minute intervals. There was a temperature/RH continuous device located in the basement. The remaining devices were all E-perms, two in the basement; one hanging and one by the Pylon, one on the first floor living room, one in the second floor office, and two outside; one by the fan and one on the other side of the house.

PA 05 – Home built in 1986. Two story colonial, with attached two car garage. Unfinished basement, with a crawl space underneath the garage. The crawl space is open to the basement. There is a sump in basement floor with a lid, but not well sealed. The basement is 985 square feet, and the first floor was not measured.

PA 05- The suction point is through the basement floor on the south side of the house. The piping runs up the wall, two elbows assist the piping to the rim joist, where an elbow takes the piping through the rim joist and to the exterior where the RP-145 fan is located. There are several windows located at this level. The kitchen window is approximately four feet from the fan. There is a breakfast nook that juts out right next to the fan. These windows are approximately 4 and 6 feet away from the fan. There is a bedroom window above the fan on the second floor of the home. This window is approximately 14 feet above the fan.

This house is mostly closed with central air running in summer months. During the months of March, April, and May the homeowner did have the windows opened about 50-75% of the time. The average airflow through this system at ground discharge is 111 cfm. The average airflow through this system at roof discharge is 87 cfm. The average pressure in this system is 0.3-inch WC. When the fan was on the basement floor test hole pressure was -6.7 Pa. This test hole is approximately 26 feet from the suction point.

PA 05- There were passive short-term E-perms used for the bulk of the testing at this house. One Sun Nuclear 1030 CRM was also used in this location on the first floor.

In the basement there were two E-perms placed. One was located on the table next to the suction point at the south end of the house. The other was located on the permanent shelving at the north end of the house. The temperature/humidity device was located on the staircase in the center of the basement.

On the first floor there was a Sun Nuclear 1030 CRM on the kitchen counter separating the kitchen from breakfast nook on the southside of the house. The ASD fan would be immediately outside this kitchen area. There was an E-perm placed directly next to the CRM. Also, on the first floor there was an E-perm placed in the piano room on a shelf at the north end of the house.

On the second floor there were two E-perms placed. One was in the bedroom closet directly above the fan on the south side of the house. The other electret was placed in the front bedroom on the north end of the house.

There were two E-perms placed outside. One was located on the piping directly above the fan on the south side of the house. The other was placed in a tree on the east side of the house approximately 5 feet away from the house.

PA 06 – Home built in 1996. Split level home with four levels including basement. Two car garage underneath the bedrooms. Relatively small, unfinished basement. Crawl space underneath family room. Sealed sump in basement slab. First floor 932 square feet, basement 540 square feet. Forced air HVAC located in basement.

PA 06- The suction point is in the basement, with block wall foundation. The main suction point is about a foot or two from the sump pit, near the exterior wall. There is also a jumper suction point that goes from the floor up along an interior wall then a 90 elbow takes it through the wall to underneath the family room, which is above a crawl space. The jumper is to the left of the main suction pit and has one 90-degree elbow and two 45-degree elbows. The pipe from the main suction pit has three 45-degree elbows and one 90 degree elbow: after the 90 on the main pipe, the pipe runs horizontally a few feet and goes through the block wall to the outside. There is a 90-degree elbow to the RP 145 fan, and a 45 degree elbow to get pipe to side of house. The Pipe runs vertically until it reaches near the soffit of the roof above the kitchen, then two 45-degree elbows take the pipe around the edge of that roof and pipe runs vertically and discharges above the edge of the roof. The fan is located on the backyard side of the house. The kitchen window is a few feet above and a few feet to the left of the fan and ground level exhaust. There is a bedroom window a few feet away from the roof discharge. The system pressure averaged 154 pascals at ground level discharge, and 121 pascals at roof discharge. The air flow in the system averaged 94 CFM at ground level discharge and 79 CFM at roof discharge. It is about 26 feet from the suction pit to the basement floor test hole. On February 14, 2020, the pressure difference in the test hole with no fan was plus 1.3 pascals, minus 38 pascals with fan on, minus 33 pascals at ground level discharge, and minus 24 pascals at roof discharge.

PA 06- There was a Sun Nuclear 1030 CRM placed on the kitchen corner, to the left of the sink, about two feet from the window (the kitchen is one level up from the ground level in this split-level house). In the basement (which is below the kitchen and living room), there were two E-perms, one hanging from the ceiling above and near the sump and radon pipe, the other E-perm being on the other side of the basement on a shelf. On the ground level floor (with the garage and family room) there was an E-perm in the family room on a small table. In the kitchen there was an E-perm near the continuous monitor. On the highest level of the house (one level above the kitchen level) there were two E-perms, one in the corner on a nightstand, near the wall that faces the backyard, and one in the master bedroom, near an interior wall, behind a TV. There were three E-perms outside, one attached to the vent pipe, one at the kitchen window near the exhaust, and one at the front corner of the house, garage side. The HOBO (temperature/relative humidity) was placed on a central pole in the basement.

PA 07 – Home built 2002. Two story contemporary, with attached two car garage. Full, unfinished basement, with door to outside. A wine cellar is also located in the basement, isolated from main basement by a door. The forced air HVAC is in the basement. The first floor is 1,943 square feet and the basement is 1,440 square feet.

PA 07- The suction point was through the basement floor on the west side of the house. There is 21 inches of piping inside with two 45-degree elbows and a 90-degree elbow that takes the piping to the exterior west side of the house, where the RP-145 was located. The exhaust stack then ran two stories to roofline exhaust. There are two windows on the west side of this house; one is the first-floor office, about eight feet above from the ground exhaust point. The other window is the second-floor master bedroom and is about 16 feet above from the ground level exhaust point. Both these windows were often partially opened during the milder spring and fall seasons. The system air flow during roofline exhaust was 84 CFM, and 111 CFM during ground level exhaust. The pressure in the piping was 0.32" WC during roofline exhaust and 0.51: WC during ground level exhaust. A floor test hole 37 feet away from the suction point shows -3.8 pa.

PA 07- One Sun Nuclear 1030 CRM was in the first-floor office on the south wall in front of the window adjacent to the ASD pipe. There were short-term E-perms placed in the following locations: one E-perm located on a shelf at the bottom of the steps in the unfinished basement; one E-perm located in the first-floor office; one E-perm located in the first-floor living room; one E-perm located in the second-floor master bedroom; and two E-perms outside, one on the south side of the house attached to the ASD exhaust stack and one on the north side of the house attached to a small tree by the deck. A HOBO temperature/humidity data logger was attached to a supporting pillar in the unfinished basement.

PA 08 – Home built in 1954. Two story, brick home with full, unfinished basement. There was a sunroom put on as an addition. The basement has no access directly to the outside, only via a stair way to the first floor. The gas forced air HVAC is in the basement. The first floor is 836 square feet and the basement is 800 square feet. There is a sump hole in the basement with cover.

PA 08- A brick house with a block wall basement. The suction point is located near the middle of the east wall (which faces the side yard). The inside piping has two 45 elbows and one 90 elbow: the pipe goes above the block wall and through brick to the outside. There's a 90 elbow to the fan (GP 501), a 45 elbow to get the pipe to the outside wall, and then a vertical run to the roof, with two more 45 elbows. The fan is centrally located on this wall. A chimney is about three feet to the left of the fan, and the first-floor bathroom window is about two feet from the ground level discharge. The roof discharge is at least two feet above a bedroom window, and the bedroom window is to the right of the roof discharge. The average pressure of the system is 805 pascals at ground level discharge, and 1094 pascals at roof discharge. The average air flow of the system is 38 CFM at ground level discharge, and 37 CFM at roof discharge. The distance from the suction point to the floor test hole is about 25 feet. On March 5, 2018, with the system complete, the pressure difference in the test hole was minus 2 pascals at roof discharge, and minus 2.4 pascals at ground level discharge.

PA 08- There was a Sun Nuclear 1030 continuous monitor placed in the first-floor bedroom, on top of a dresser, near the corner of the room (near an interior wall and a few feet from a front window). There was one E-perm in the basement, near a window to the east side (mitigation system side) of the house. There was an E-perm in the first-floor bedroom near the continuous monitor, and one in the sunroom on the opposite side of the house, on top of a stereo. There was one E-perm in the second-floor bedroom, near an east side window. Outside, there were three E-perms, one near the first-floor bedroom, one attached to the vent pipe, and one attached to downspout on the front left corner of the house (opposite side of the mitigation system). The HOBO (temperature/relative humidity) was in the basement on a support pole near the center of the basement.

PA 09 - Large, two story colonial, with full unfinished, walk out basement. Attached two car garage. Forced air HVAC system located in basement. There is a covered sump hole and next to that is a riser pipe for the RRNC system. The RRNC system was not used for this project since it went up through the house and out the roof. There was one other slab opening for a future plumbing rough in, but this was also covered. The first floor was 1,000 square feet and the basement 1,104 square feet.

PA 09- This house has an unfinished walk-out basement: there are sliding doors on the south side to the back yard. It has a floating slab: the perimeter channel is about one inch and was filled in with expanding foam during the mitigation installation. The suction point is in the southwest corner of the basement. There are two 45 elbows and one 90 elbow inside: the piping inside the basement is only about two to three feet high, and then it goes to the outside. The fan (RP 145) is on the west side of the house. There is one 90 elbow on the outside and four 45 elbows, the roof discharge is vertically above the fan and above the edge of the family room portion of the house. There are no windows on this side of the house except for two windows at the basement level. The ground level discharge was about one foot away from one of the basement windows, near the southwest corner. The average pressure in the system was 115 pascals at ground level discharge, and 77 pascals at roof discharge. The average airflow in the system was 112 CFM at ground level discharge, and 87 CFM at roof discharge. The distance from the suction point to the test hole is about 34 feet. On March 8, 2018, the pressure difference in the test hole with the system activated was -2.2 pascals at roof discharge, and -2.0 pascals at ground level discharge.

PA 09- A Pylon AB-5 CRM was placed in the basement, next to the vent pipe in the southwest corner. On the same basket that the Pylon was resting on, an E-perm was also placed. There was another E-perm in the basement, hanging from piping near the ceiling, in a more central location. There were two E-perms on the first floor, one in the dining room on the top of a china hutch, the other in the TV/family room (west side of house) on top of the TV cabinet. There was one E-perm in a second-floor bedroom, on the bookcase shelf. There were two E-perms outside, one attached to the vent pipe, and one attached to downspout on the southeast corner of the house, opposite side of house to the radon exhaust. A HOBO (temperature/relative humidity) was placed on a metal support pole in the basement, in a central location.

PA 10 - Home built in 1973. Ranch style home with three bedrooms, partly finished and partly unfinished basement, family room over a crawl space, and an integral two car garage. The basement has no access directly to the outside. A stairway from the garage leads down to the basement. There is an oil fired, forced-air furnace in the basement, along with central air-conditioning. The first floor is 1,395 square feet, and the basement is 1,140 square feet.

PA 10- There was one suction point in the laundry room on the south wall, about 8-10" in from the exterior wall. The pipe went up to the rim joist and outside, where the RP-265 fan was located just above grade. Above the fan was about 7' of 4" pipe leading to roofline.

PA 10- This house had one Sun Nuclear CRM located in the first floor, spare bedroom, which was also closest to the external radon exhaust point. The temperature/RH sensor was in the basement laundry room in the same room as the suction point but on the north wall of that room. There were seven E-perms; one in the basement near the Temp./RH monitor, one in a separate basement room, one in the first floor living room, one in the first floor family room on a slab, one in the first floor spare bedroom with the CRM, and two outside, one just above the mitigation fan housing, and one on the east side of the house by the garage.

Appendix B - House Routine Visit/Mitigation Cycling Log

House Routine Visit / Mitigation Cycling Log

Intensive Houses

HOUSE ID ____________________

ADDRESS ____________________

OCCUPANT NAME ____________________

DATE ____________________

Date/Arrival Time: ____________________

	Arrival	Departure
Mitigation System Configuration: Roof / Ground Level / Baseline (Off)		
Time Changed:		

Campbell 21X Data Logger #	Location/Connected Devices	Clock Update (Y/N)	Download Name & Data Check

Setra ΔP #	Location	Campbell 21X		Zero ΔP Volts Disconnect Tubing 21X: *6, A (to loc 5,6,7)
		Wire Loc #	Input Loc #	
	Basement-to-Outdoors			
	Basement-to-1st Floor			
	1st Floor-to-Outdoors			

CRM # /Cell #	Location	CRM Download Name & Data Check	Air Pump	
			Serial #	Flow Rate (ccm)
	ASD Exhaust			

HOBO T/RH #	Location	Download Name & Data Check

Weather Station #	Location	Download Name & Data Check

HOUSE ID ____________________

ADDRESS ____________________

OCCUPANT NAME ____________________

DATE ____________________

EPERM # Electret #	Location	Start			Stop			Radon (pCi/L)
		Date/Time	Volt	Temp	Date/Time	Volt	Temp	
EPERM Reader #:		**Background:**						

Grab Sample Cell #	Location	Collection Date/Time	Analysis Start Date/Time	Analysis Stop		Radon (pCi/L)
				Date/Time	Count	
	Outside by Fan*See note last page					
Pylon AB-5 # Counting Device:						
Sample Pump:						

HOUSE ID ______________________

ADDRESS ______________________

OCCUPANT NAME ______________________

DATE ______________________

Spot Differential Pressure Location	Reference Location	Pressure Difference (Pa)
Basement-to-Outdoors		
Basement-to-1st Floor		
1st Floor-to-Outdoors		
Spot ΔP Micromanometer #:		

Mitigation System	System Operating Pressure Pascal / Inches Water Column	Pitot Tube Flow Velocity (5 measurements w/pitot tube, fpm)	Volumetric Flow (cfm)
System Pipe	/		
Micromanometer #:			

Sound Measurement Location	Sound Level (dBA)	Sources of Background Noise
Basement Near Wall w/ASD		
1st Floor Near Wall w/ASD		
2nd Floor Near Wall w/ASD		
Outdoors 10' from ASD		
Sound Measurement Device:		

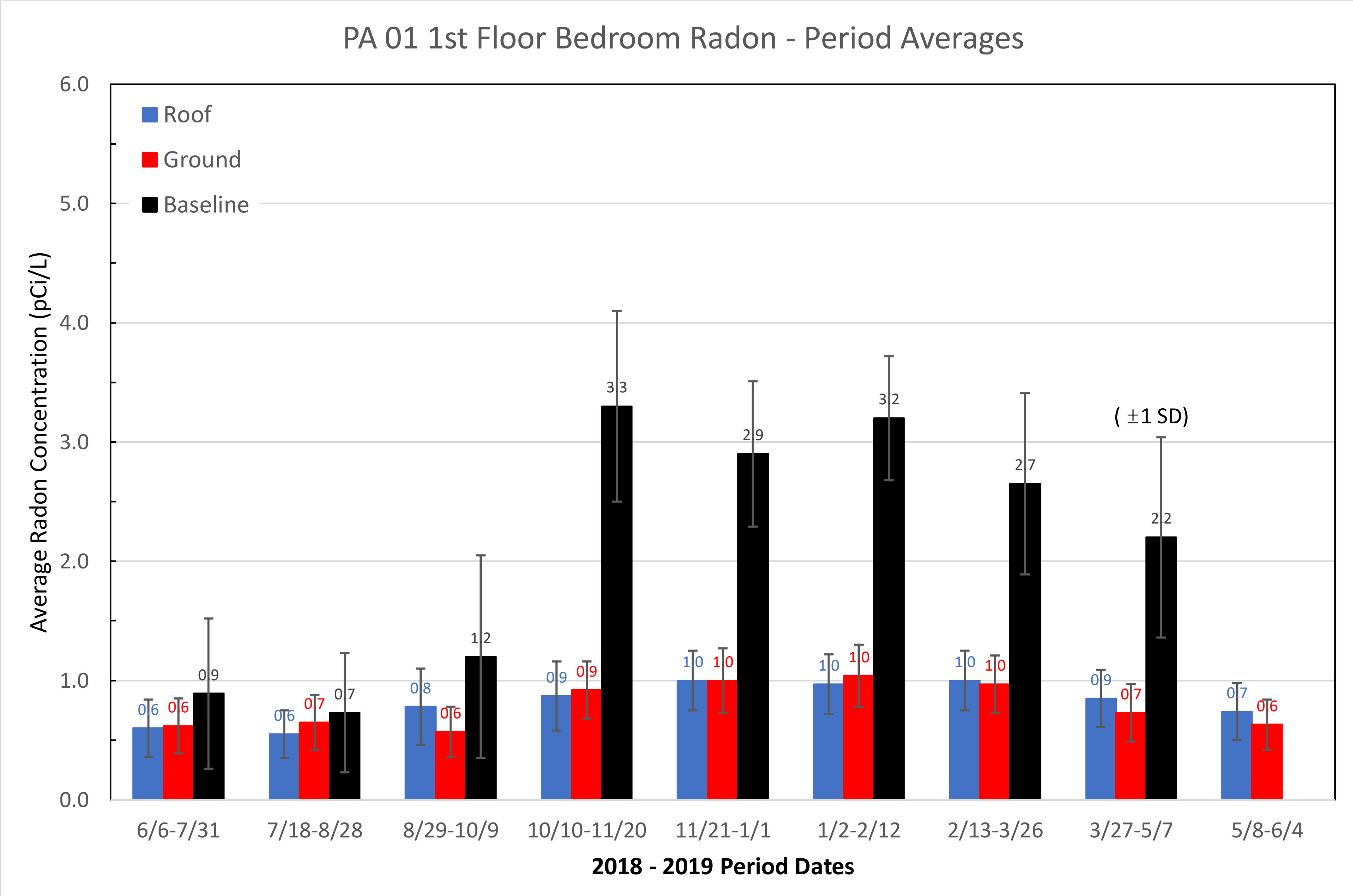
☐ Review 'Event & Activity Log' from Previous Mitigation Cycle, and Provide New Copy to Occupants

- *For outside grab samples collect along outside wall of house, and on fan side about 3 feet from fan also along outside wall of house.*

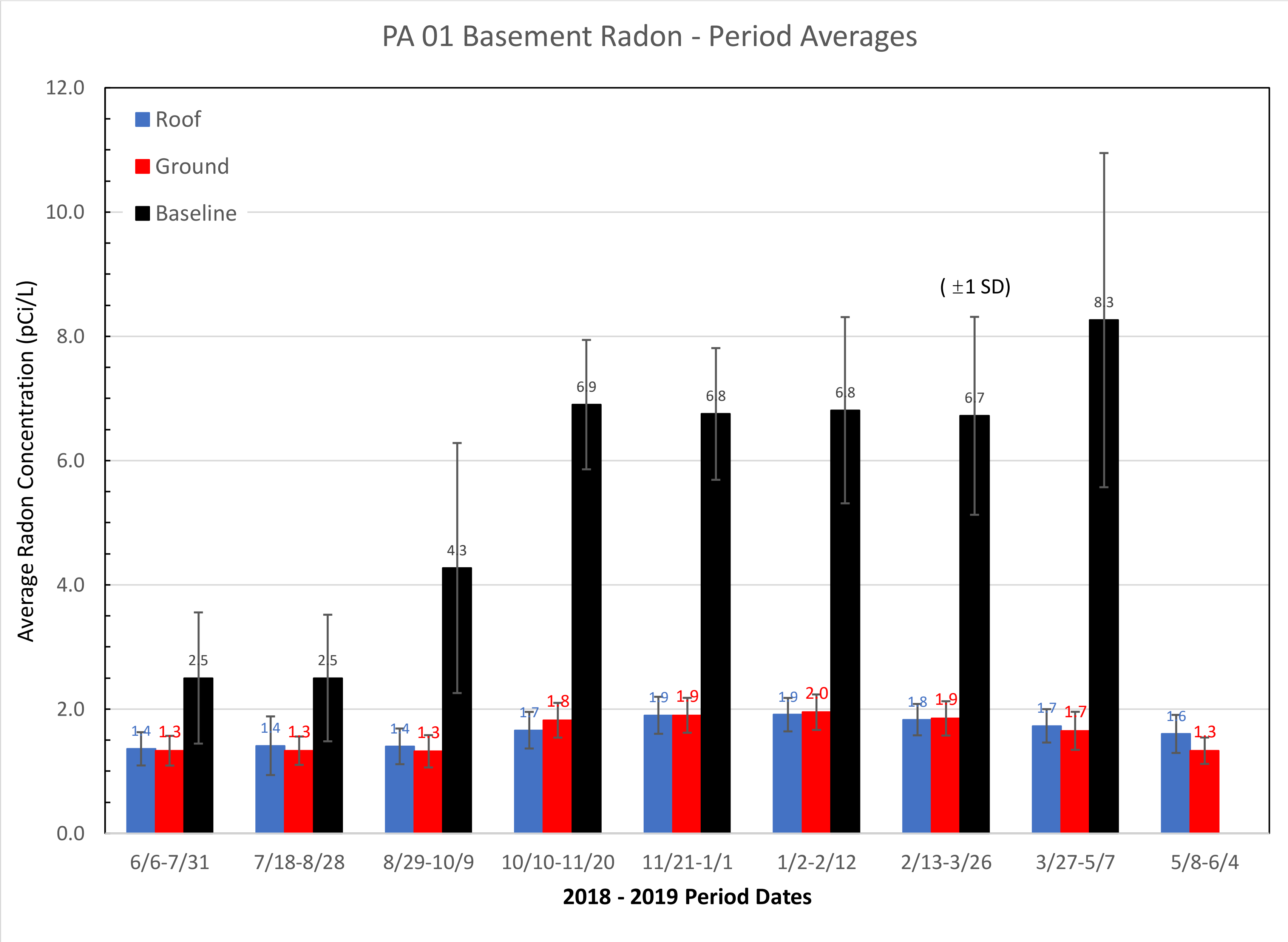
  For these samples collect before we change the configuration. This will have allowed the house to come to equilibrium.

Appendix C - Period Averages

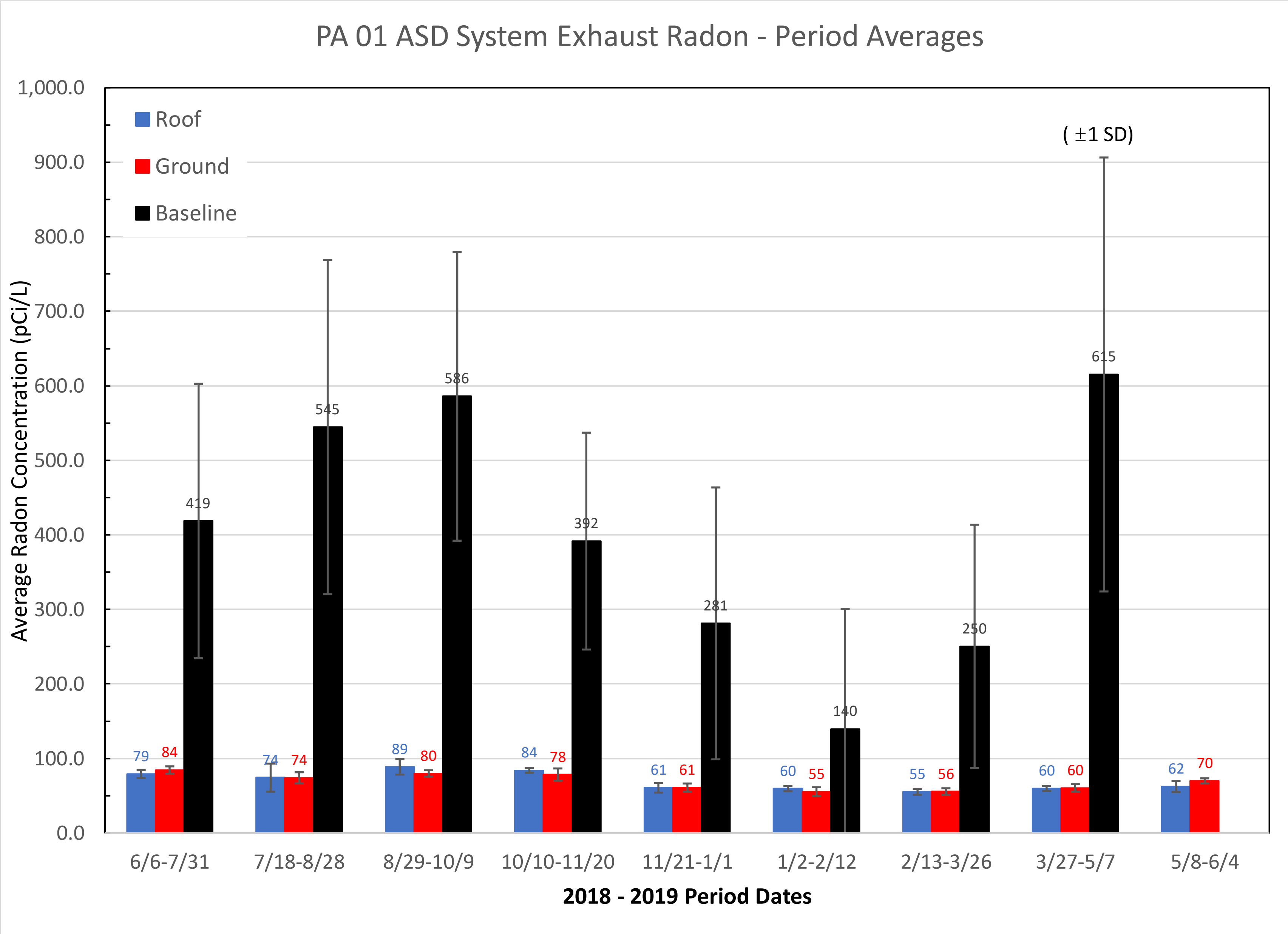
Continuous radon monitor, either Pylon AB-5 or Sun Nuclear 1030, Data for Indoor Radon, Basement, 1st and 2nd Floor (if applicable). ASD system exhaust gas concentration is shown for PA 01 and PA 04. PA 03 does not have baseline values since this home had the highest indoor radon levels in the basement, and the basement was used as playroom. Finally, there are some graphs that do not have bar graphs for each and every configuration. This was due to an instrument malfunction or some other mishap with that data collection.

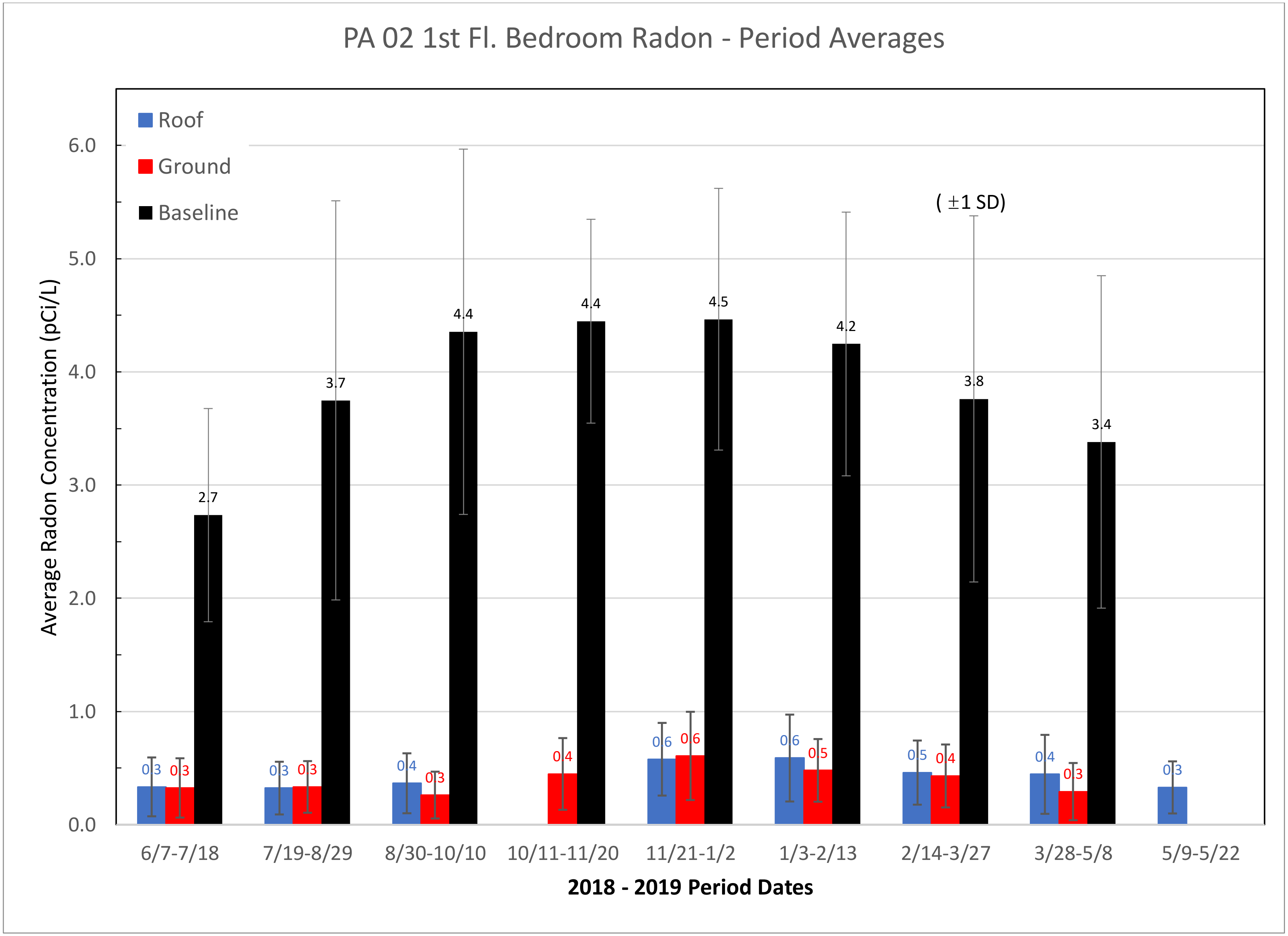


PA 01 1st Floor Bedroom Radon - Period Averages
Roof
Ground
Baseline
Average Radon Concentration (pCi/L)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.6
0.6
0.9
0.6
0.7
0.7
0.8
0.6
1.2
0.9
0.9
3.3
1.0
1.0
2.9
1.0
1.0
3.2
1.0
1.0
2.7
0.9
0.7
2.2
0.7
0.6
(±1 SD)
6/6-7/31
7/18-8/28
8/29-10/9
10/10-11/20
11/21-1/1
1/2-2/12
2/13-3/26
3/27-5/7
5/8-6/4
2018 - 2019 Period Dates

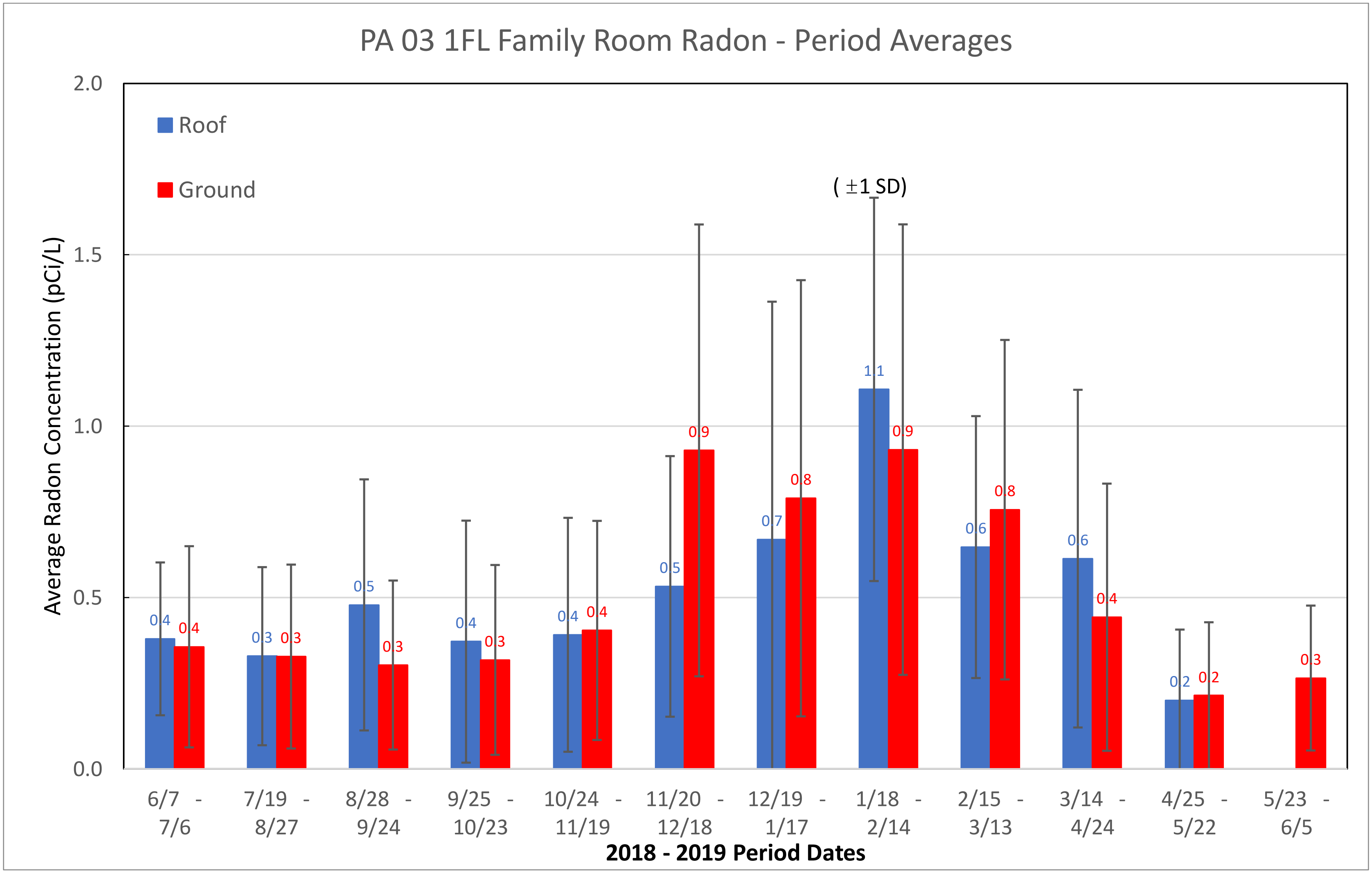


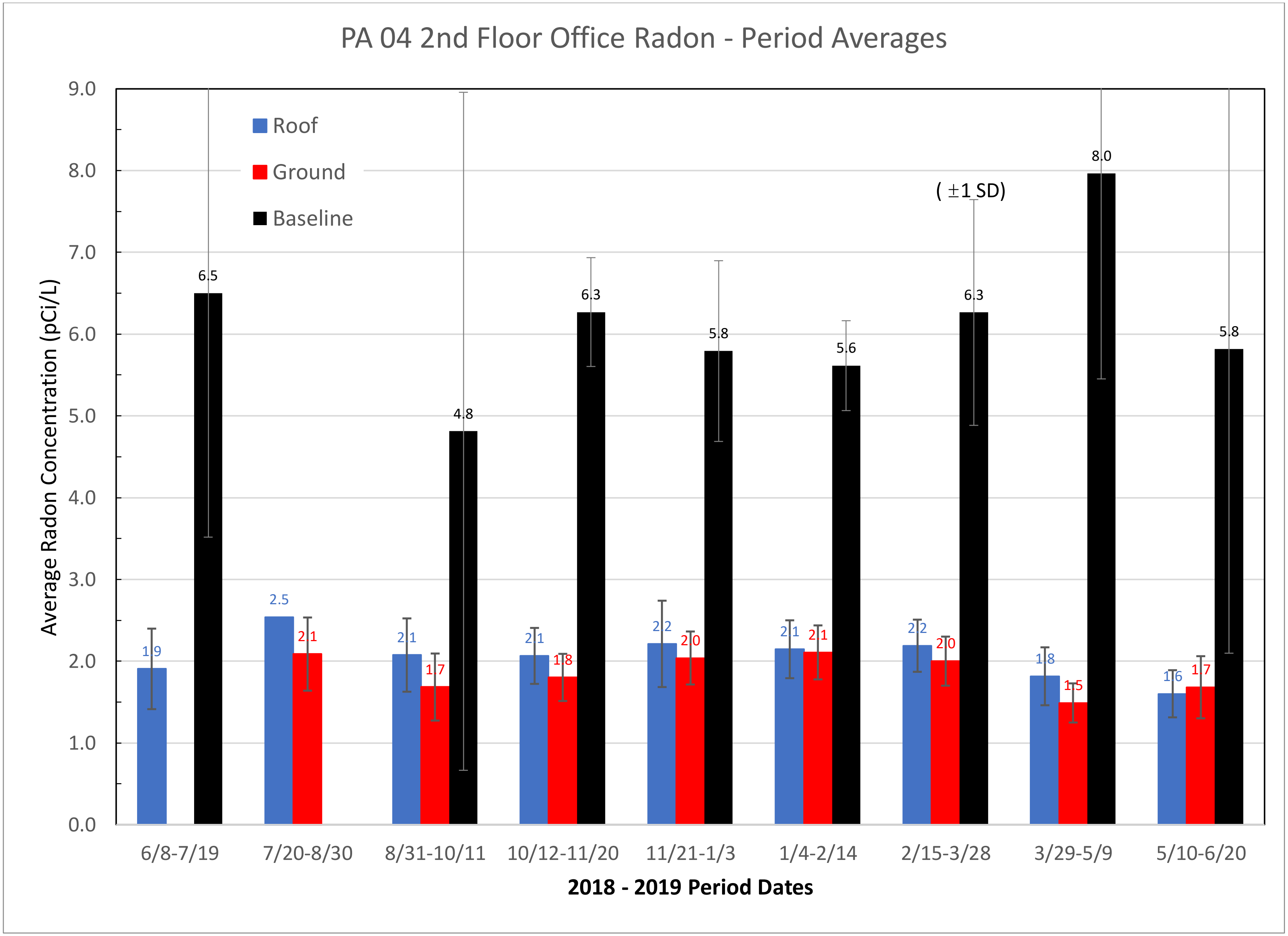
PA 01 Basement Radon - Period Averages
Roof
Ground
Baseline
(±1 SD)
Average Radon Concentration (pCi/L)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
6/6-7/31
7/18-8/28
8/29-10/9
10/10-11/20
11/21-1/1
1/2-2/12
2/13-3/26
3/27-5/7
5/8-6/4
2018 - 2019 Period Dates
1.4
1.3
2.5
1.4
1.3
2.5
1.4
1.3
4.3
1.7
1.8
6.9
1.9
1.9
6.8
1.9
2.0
6.8
1.8
1.9
6.7
1.7
1.7
8.3
1.6
1.3


PA 01 ASD System Exhaust Radon - Period Averages
1,000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
Average Radon Concentration (pCi/L)
Roof
Ground
Baseline
(±1 SD)
79
84
419
74
74
545
89
80
586
84
78
392
61
61
281
60
55
140
55
56
250
60
60
615
62
70
6/6-7/31
7/18-8/28
8/29-10/9
10/10-11/20
11/21-1/1
1/2-2/12
2/13-3/26
3/27-5/7
5/8-6/4
2018 - 2019 Period Dates

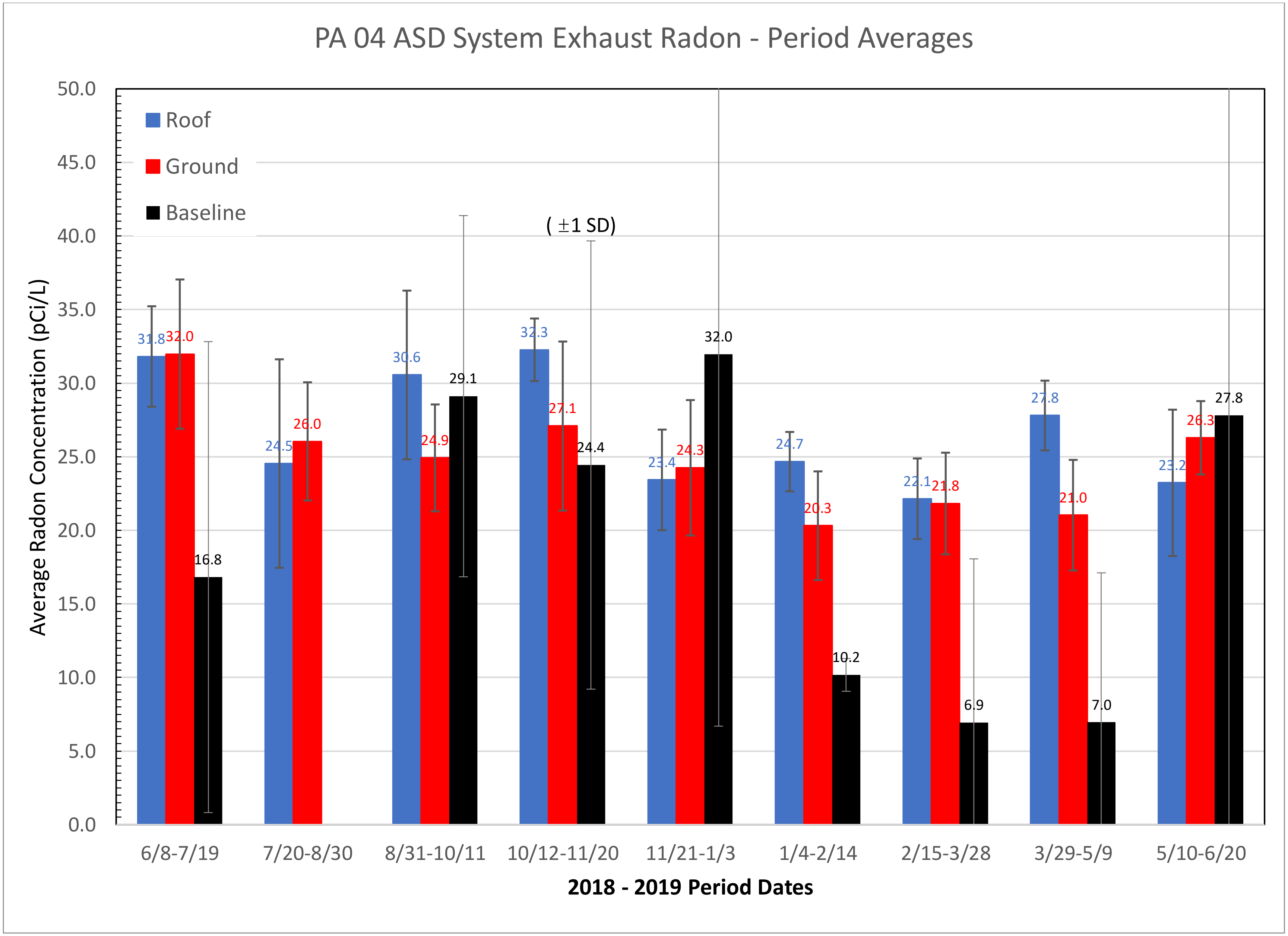

PA 02 1st Fl. Bedroom Radon - Period Averages
Roof
Ground
Baseline
(±1 SD)
Average Radon Concentration (pCi/L)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
2.7
3.7
4.4
4.4
4.5
4.2
3.8
3.4
0.3
0.3
0.3
0.3
0.4
0.3
0.4
0.6
0.6
0.6
0.5
0.5
0.4
0.4
0.3
0.3
6/7-7/18
7/19-8/29
8/30-10/10
10/11-11/20
11/21-1/2
1/3-2/13
2/14-3/27
3/28-5/8
5/9-5/22
2018 - 2019 Period Dates

Note: PA 03 did not use baseline configuration.

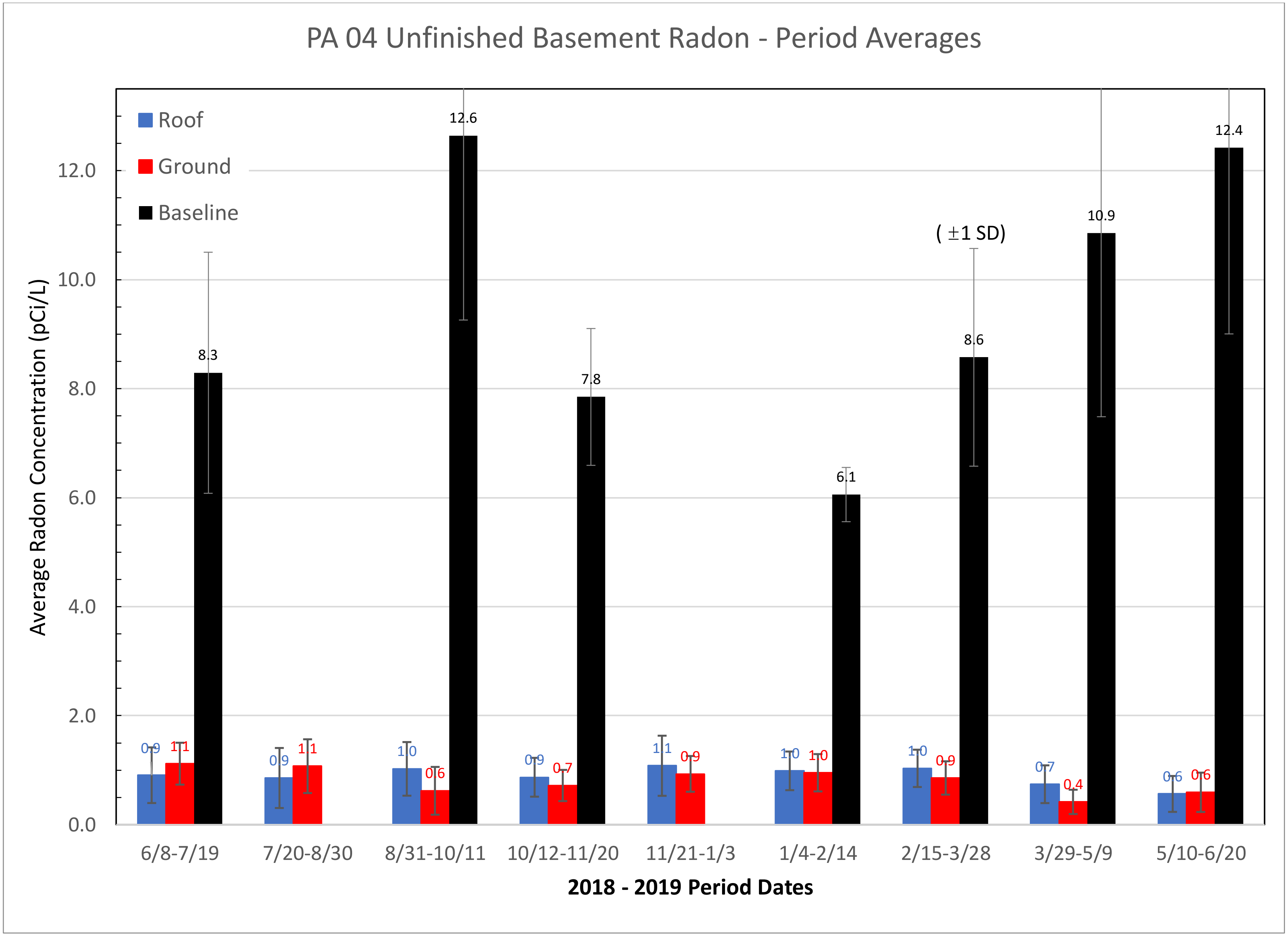




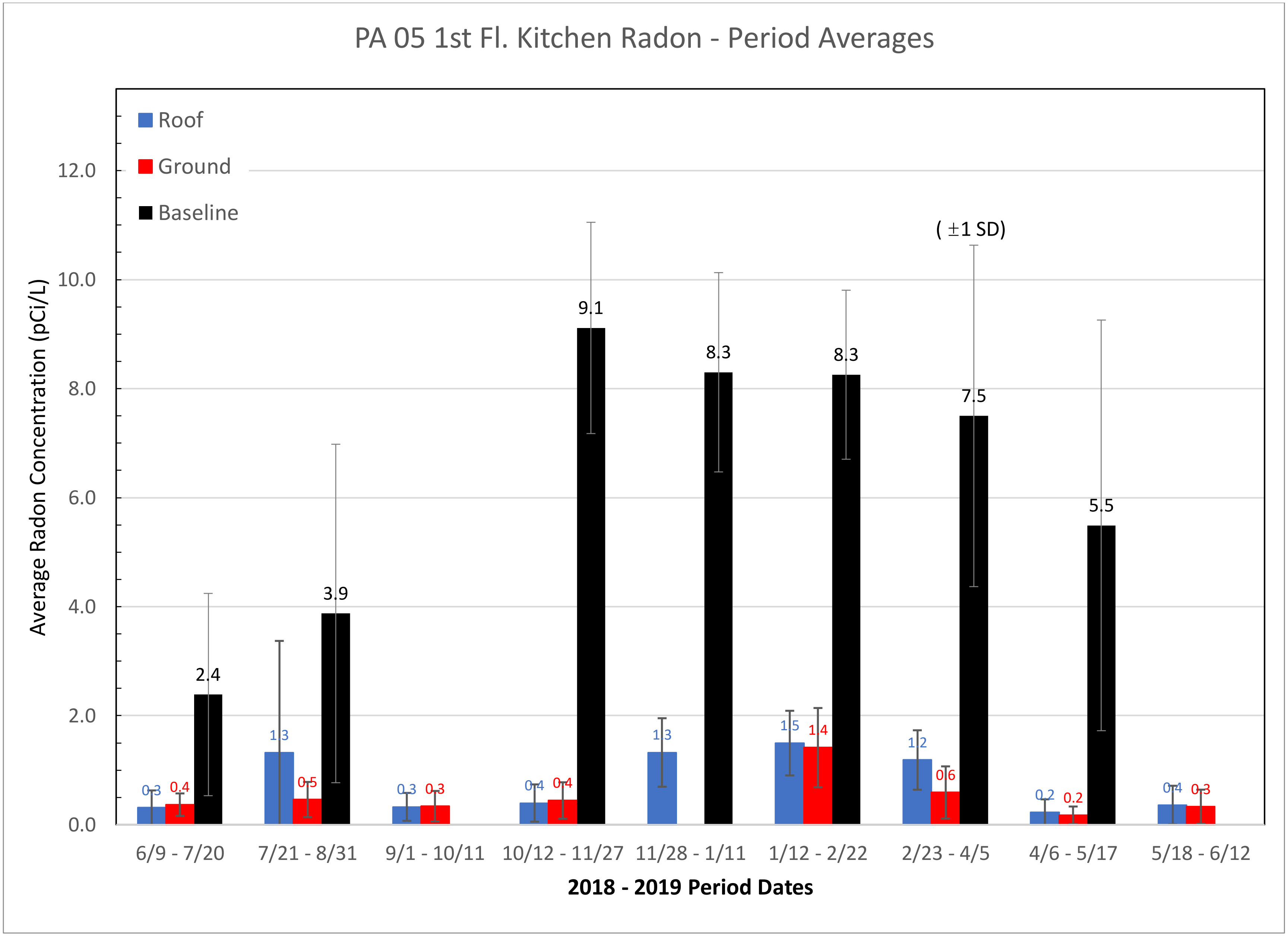
PA 04 2nd Floor Office Radon - Period Averages
Roof
Ground
Baseline
(±1 SD)
Average Radon Concentration (pCi/L)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
6.5
1.9
2.5
2.1
4.8
2.1
1.7
6.3
2.1
1.8
5.8
2.2
2.0
5.6
2.1
2.1
6.3
2.2
2.0
8.0
1.8
1.5
5.8
1.6
1.7
6/8-7/19
7/20-8/30
8/31-10/11
10/12-11/20
11/21-1/3
1/4-2/14
2/15-3/28
3/29-5/9
5/10-6/20
2018 - 2019 Period Dates



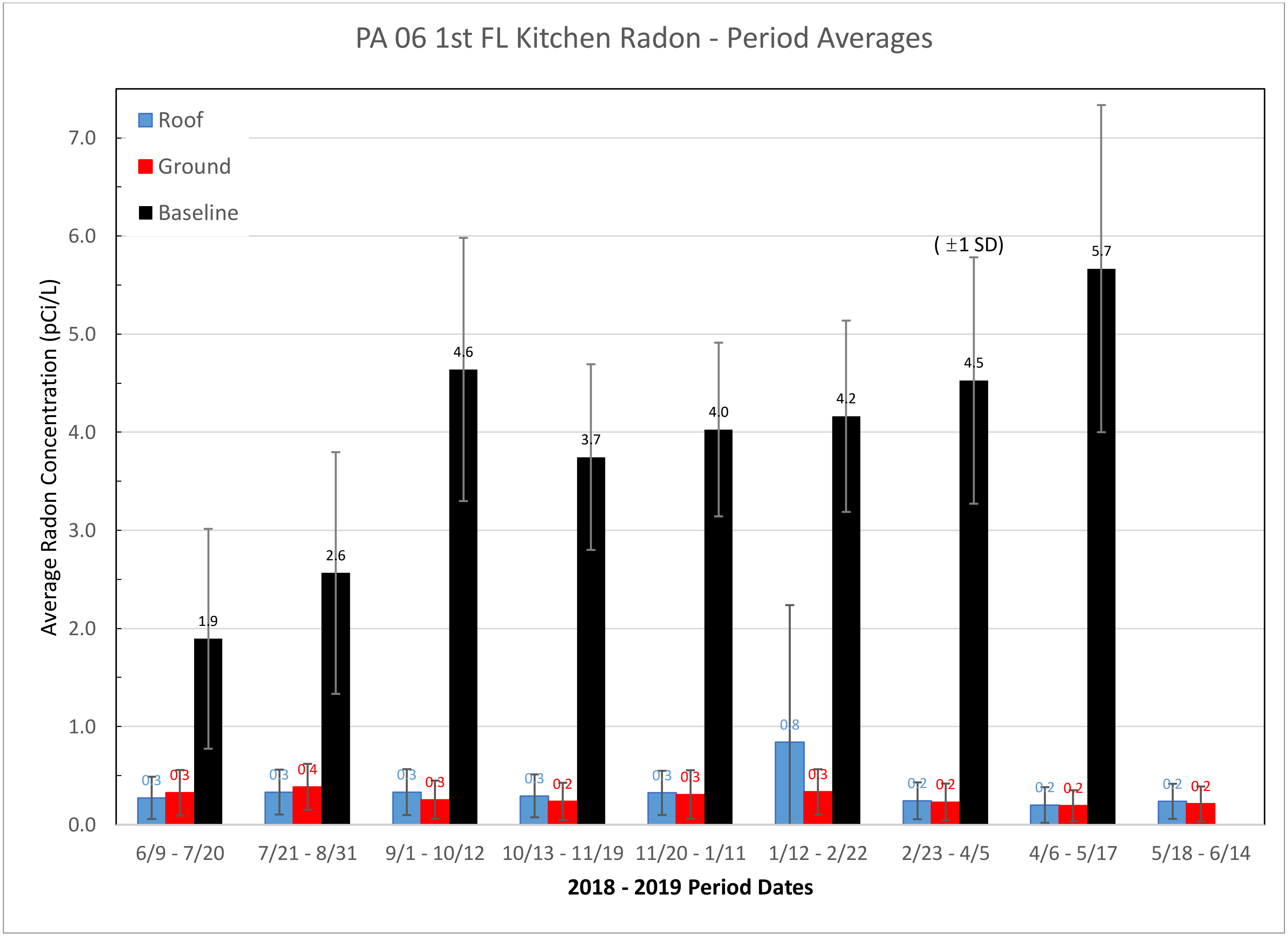
PA 04 ASD System Exhaust Radon - Period Averages
Roof
Ground
Baseline
(±1 SD)
Average Radon Concentration (pCi/L)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
31.8
32.0
16.8
24.5
26.0
30.6
24.9
29.1
32.3
27.1
24.4
23.4
24.3
32.0
24.7
20.3
10.2
22.1
21.8
6.9
27.8
21.0
7.0
23.2
26.3
27.8
6/8-7/19
7/20-8/30
8/31-10/11
10/12-11/20
11/21-1/3
1/4-2/14
2/15-3/28
3/29-5/9
5/10-6/20
2018 - 2019 Period Dates

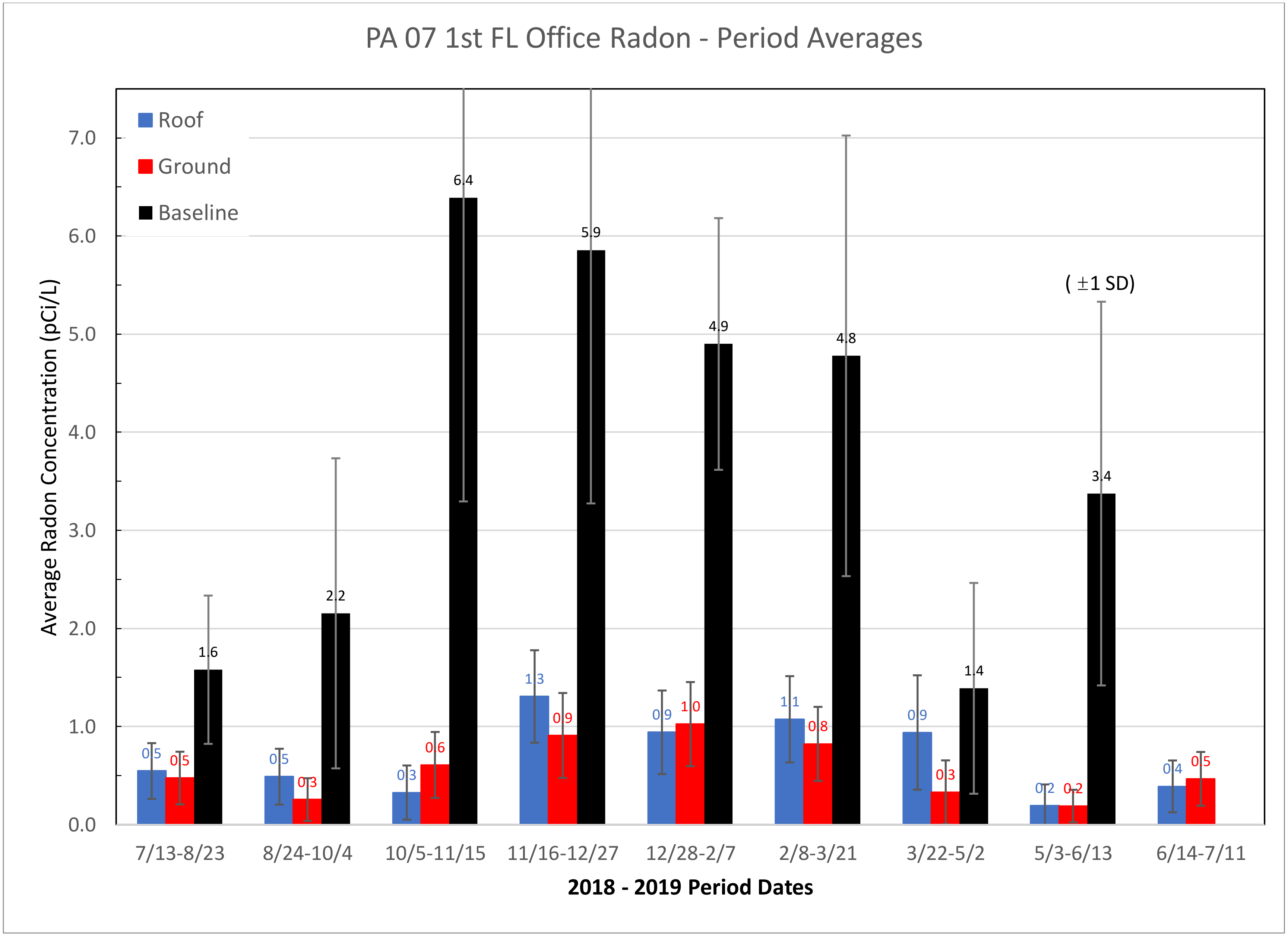


PA 04 Unfinished Basement Radon - Period Averages
Roof
Ground
Baseline
(±1 SD)
Average Radon Concentration (pCi/L)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
0.9
1.1
8.3
0.9
1.1
1.0
0.6
12.6
0.9
0.7
7.8
1.1
0.9
1.0
1.0
6.1
1.0
0.9
8.6
0.7
0.4
10.9
0.6
0.6
12.4
6/8-7/19
7/20-8/30
8/31-10/11
10/12-11/20
11/21-1/3
1/4-2/14
2/15-3/28
3/29-5/9
5/10-6/20
2018 - 2019 Period Dates

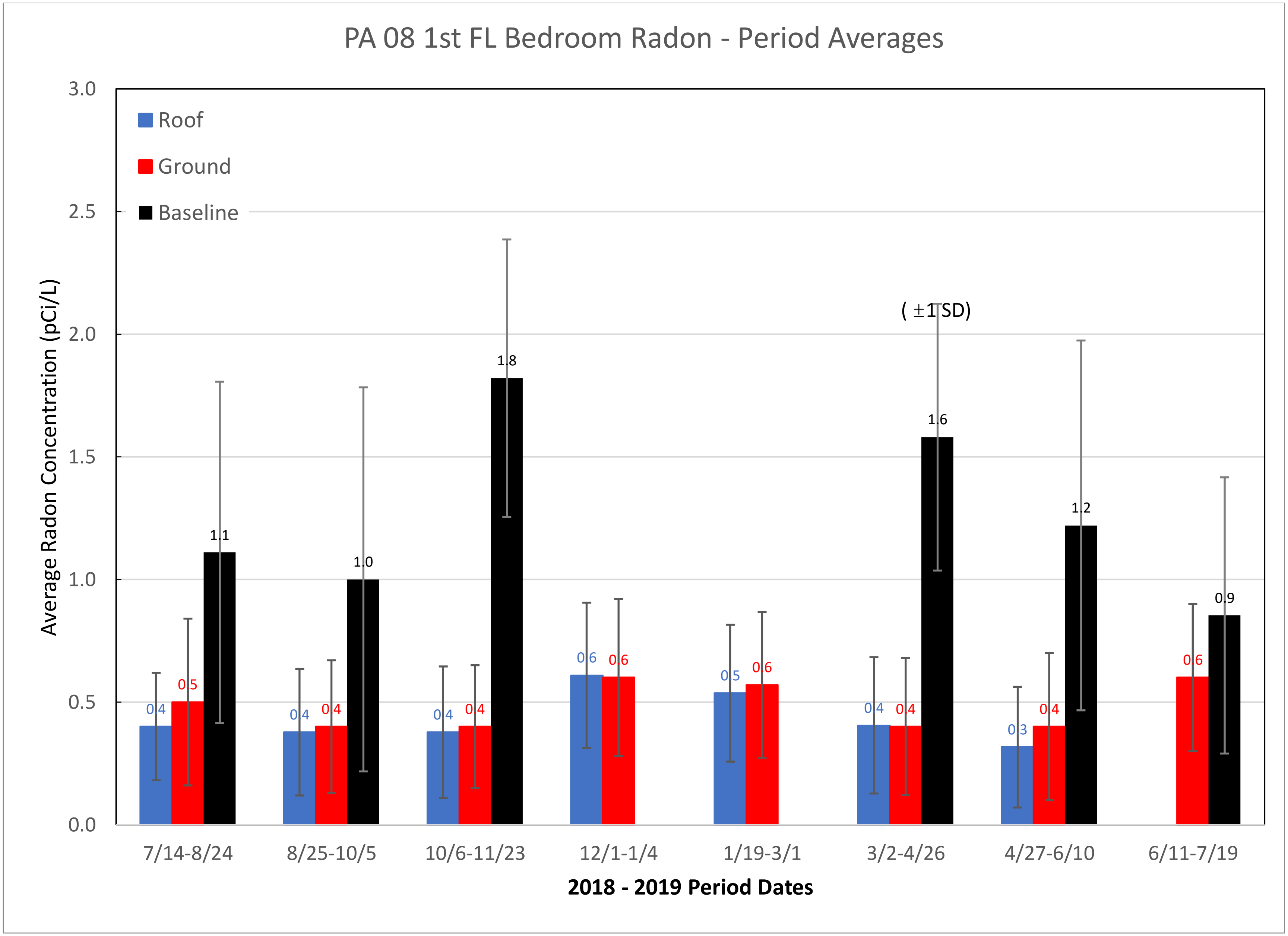


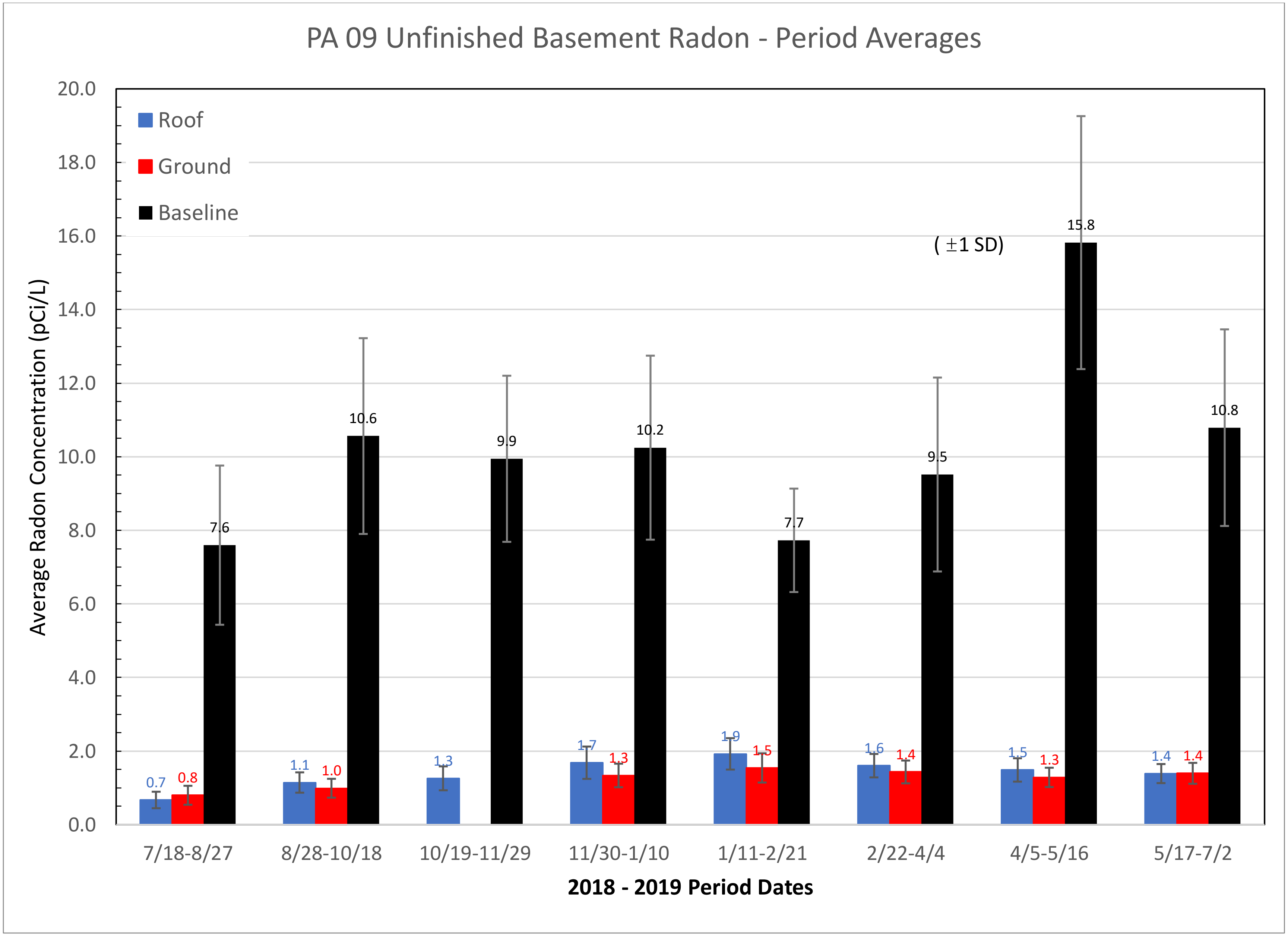
PA 05 1st Fl. Kitchen Radon - Period Averages
Roof
Ground
Baseline
(±1 SD)
Average Radon Concentration (pCi/L)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
0.3
0.4
2.4
1.3
0.5
3.9
0.3
0.3
0.4
0.4
9.1
1.3
8.3
1.5
1.4
8.3
1.2
0.6
7.5
0.2
0.2
5.5
0.4
0.3
6/9 - 7/20
7/21 - 8/31
9/1 - 10/11
10/12 - 11/27
11/28 - 1/11
1/12 - 2/22
2/23 - 4/5
4/6 - 5/17
5/18 - 6/12
2018 - 2019 Period Dates

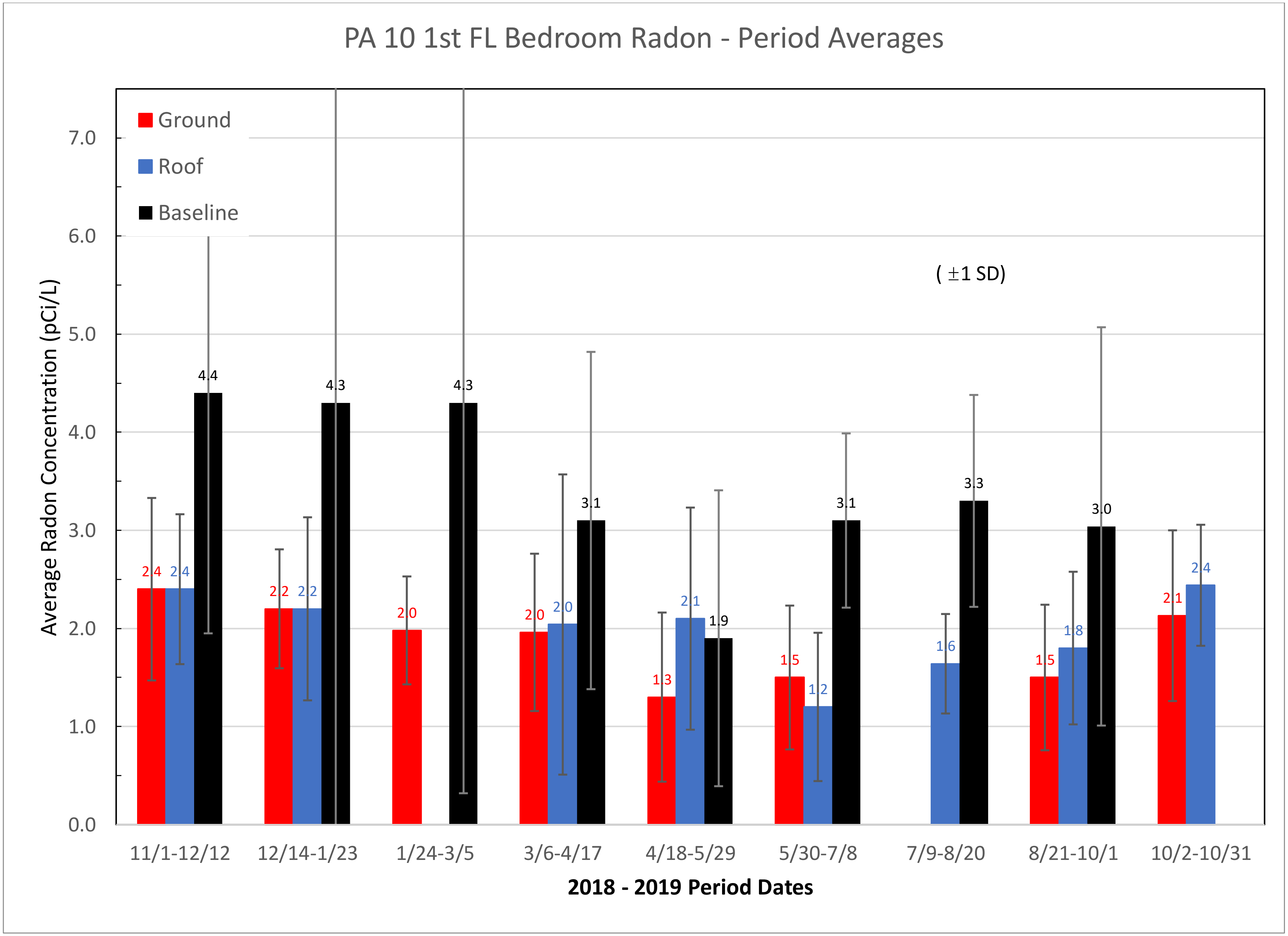

PA 06 1st FL Kitchen Radon - Period Averages
Roof
Ground
Baseline
(±1 SD)
Average Radon Concentration (pCi/L)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.3
0.3
1.9
0.3
0.4
2.6
0.3
0.3
4.6
0.3
0.2
3.7
0.3
0.3
4.0
0.8
0.3
4.2
0.2
0.2
4.5
0.2
0.2
5.7
0.2
0.2
6/9 - 7/20
7/21 - 8/31
9/1 - 10/12
10/13 - 11/19
11/20 - 1/11
1/12 - 2/22
2/23 - 4/5
4/6 - 5/17
5/18 - 6/14
2018 - 2019 Period Dates



PA 07 1st FL Office Radon - Period Averages
Roof
Ground
Baseline
Average Radon Concentration (pCi/L)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.5
0.5
1.6
0.5
0.3
2.2
0.3
0.6
6.4
1.3
0.9
5.9
0.9
1.0
4.9
1.1
0.8
4.8
0.9
0.3
1.4
0.2
0.2
3.4
0.4
0.5
(±1 SD)
7/13-8/23
8/24-10/4
10/5-11/15
11/16-12/27
12/28-2/7
2/8-3/21
3/22-5/2
5/3-6/13
6/14-7/11
2018 - 2019 Period Dates


PA 08 1st FL Bedroom Radon - Period Averages
Roof
Ground
Baseline
(±1 SD)
Average Radon Concentration (pCi/L)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.4
0.5
1.1
0.4
0.4
1.0
0.4
0.4
1.8
0.6
0.6
0.5
0.6
0.4
0.4
1.6
0.3
0.4
1.2
0.6
0.9
7/14-8/24
8/25-10/5
10/6-11/23
12/1-1/4
1/19-3/1
3/2-4/26
4/27-6/10
6/11-7/19
2018 - 2019 Period Dates


PA 09 Unfinished Basement Radon - Period Averages
Average Radon Concentration (pCi/L)
Roof
Ground
Baseline
(±1 SD)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.7
0.8
7.6
1.1
1.0
10.6
1.3
9.9
1.7
1.3
10.2
1.9
1.5
7.7
1.6
1.4
9.5
1.5
1.3
15.8
1.4
1.4
10.8
7/18-8/27
8/28-10/18
10/19-11/29
11/30-1/10
1/11-2/21
2/22-4/4
4/5-5/16
5/17-7/2
2018 - 2019 Period Dates


PA 10 1st FL Bedroom Radon - Period Averages
Ground
Roof
Baseline
(±1 SD)
Average Radon Concentration (pCi/L)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
2.4
2.4
4.4
2.2
2.2
4.3
2.0
4.3
2.0
2.0
3.1
1.3
2.1
1.9
1.5
1.2
3.1
1.6
3.3
1.5
1.8
3.0
2.1
2.4
11/1-12/12
12/14-1/23
1/24-3/5
3/6-4/17
4/18-5/29
5/30-7/8
7/9-8/20
8/21-10/1
10/2-10/31
2018 - 2019 Period Dates

Appendix D - E-perm Sample Data, Annual Averages

E-perm Sample Data, Annual Data, House PA 01

Location	ASD Configuration	Avg. (pCi/L)	1 SD (pCi/L)	Min. (pCi/L)	Max. (pCi/L)	n
Ambient, East, opposite side to fan	Baseline	0.3	0.4	0.1	1.3	8
	Ground	0.11	0.06	0	0.2	8
	Roof	0.3	0.08	0.1	0.3	8
Ambient, West, Fan side	Baseline	0.67	0.5	0.4	1.9	8
	Ground	0.6	0.14	0.4	0.9	8
	Roof	0.55	0.11	0.3	0.7	8
Unf. Bsmt	Baseline	5.1	2.6	1.5	8.3	8
	Ground	0.57	0.26	0.3	0.9	8
	Roof	0.65	0.22	0.3	1.0	8
Fin. Bsmt	Baseline	3.8	1.9	1.1	6.2	9
	Ground	0.37	0.2	0.1	0.6	9
	Roof	0.45	0.12	0.2	0.6	9
Living Rm	Baseline	1.6	1.2	0.2	3.8	8
	Ground	0.17	0.12	0	0.3	8
	Roof	0.24	0.12	0.1	0.4	8
Bedroom	Baseline	1.7	1.2	0.5	4.1	8
	Ground	0.43	0.2	0.2	0.7	8
	Roof	0.47	0.12	0.3	0.6	8

Appendix D, cont. - E-perm Sample Data, Annual Averages

E-perm Sample Data, Annual Data, House PA 02

Location	ASD Configuration	Avg. (pCi/L)	1 SD (pCi/L)	Min. (pCi/L)	Max. (pCi/L)	n
Ambient, East, opposite side to fan	Baseline	0.7	0.4	0.3	1.4	8
	Ground	0.5	0.6	0.1	1.8	8
	Roof	0.4	0.3	0.1	1.1	9
Ambient, West, Fan side	Baseline	0.4	0.3	0.1	1.1	8
	Ground	0.6	0.5	0.1	1.5	8
	Roof	0.9	0.9	0.1	1.7	9
Unf. Bsmt	Baseline	6.1	1.1	4	7.2	8
	Ground	0.8	1.0	0.1	3.4	8
	Roof	0.4	0.3	0.1	0.9	9
Fin. Bsmt	Baseline	4.7	0.8	3.1	5.9	9
	Ground	0.7	0.7	0.1	2.4	8
	Roof	0.5	0.3	0.2	0.9	9
1st Fl. Bedroom	Baseline	4.5	1.3	2.7	7.7	8
	Ground	0.5	0.7	0.1	2	8
	Roof	0.3	0.2	0.1	0.8	9
1st Fl. Dining Rm	Baseline	4.3	1.4	2.4	7.3	8
	Ground	0.5	0.6	0.1	1.9	8
	Roof	0.3	0.2	0.1	0.7	9

Appendix D, cont. - E-perm Sample Data, Annual Averages

E-perm Sample Data, Annual Data, House PA 03

Location	ASD Configuration	Avg. (pCi/L)	1 SD(pCi/L)	Min. (pCi/L)	Max. (pCi/L)	n
Ambient, East, opposite side to fan	Baseline	--	--	--	--	--
	Ground	0.88	1.7	0.1	0.7	11
	Roof	0.35	0.13	0.1	0.6	12
Ambient, West, Fan side	Baseline	--	--	--	--	--
	Ground	0.49	0.24	0.1	1	12
	Roof	0.47	0.2	0.3	0.9	12
Unf. Bsmt, next to ASD pipe	Baseline	--	--	--	--	--
	Ground	1.1	0.85	0.1	2.5	12
	Roof	1.2	0.7	0.4	2.6	12
1st Fl. Living Rm	Baseline	--	--	--	--	--
	Ground	0.4	0.2	0.1	0.8	12
	Roof	0.4	0.21	0.1	0.8	12

Did not run baseline in PA 03 due to higher radon levels.

Appendix D, cont. - E-perm Sample Data, Annual Averages

E-perm Sample Data, Annual Data, House PA 04

Location	ASD Configuration	Avg. (pCi/L)	1 SD (pCi/L)	Min. (pCi/L)	Max. (pCi/L)	n
Ambient, East, opposite side to fan	Baseline	0.19	0.14	0.1	0.5	8
	Ground	0.22	0.09	0.1	0.3	9
	Roof	0.16	0.09	0.1	0.3	8
Ambient, West, Fan side	Baseline	0.54	0.05	0.5	0.6	8
	Ground	0.58	0.05	0.3	0.7	9
	Roof	0.64	0.19	0.4	1.0	7
Unf. Bsmt, hanging	Baseline	10.5	1.8	8	13.5	8
	Ground	0.72	0.25	0.3	1.1	9
	Roof	0.85	0.21	0.6	1.2	8
Unf. Bsmt, by Pylon	Baseline	8.9	1.6	7.3	11.7	8
	Ground	0.87	0.28	0.6	1.4	9
	Roof	0.78	0.3	0.2	1.2	8
2nd Fl. Office	Baseline	4.73	2	2.4	5.8	7
	Ground	0.7	0.26	0.3	1.2	9
	Roof	0.88	0.34	0.4	1.4	8
Living Rm	Baseline	4.62	0.82	3.4	6.1	9
	Ground	0.88	0.27	0.6	1.4	9
	Roof	0.79	0.38	0.4	1.4	8

Appendix D, cont. - E-perm Sample Data, Annual Averages

E-perm Sample Data, Annual Data, House PA 05

Location	ASD Configuration	Avg. (pCi/L)	1 SD (pCi/L)	Min. (pCi/L)	Max. (pCi/L)	n
Ambient, East, opposite side to fan	Baseline	0.4	0.2	0.3	0.9	7
	Ground	0.3	0.13	0.2	0.5	9
	Roof	0.3	0.1	0.2	0.5	8
Ambient, West, Fan side	Baseline	0.13	0.05	0.1	0.2	8
	Ground	0.82	1.27	0.1	3.2	9
	Roof	0.21	0.26	0.1	0.9	9
Unf. Bsmt., next to ASD pipe	Baseline	15.44	4.58	9.2	23.9	8
	Ground	1.58	0.92	0.3	2.9	9
	Roof	2.43	1.06	1.1	3.7	9
Unf. Bsmt., top of shelf	Baseline	15.1	6.24	6.2	25.2	8
	Ground	1.5	0.7	0.9	2.2	9
	Roof	2.43	1	1.1	3.5	9
1st Fl Din. Rm.	Baseline	5.64	2.26	2.4	8.7	8
	Ground	0.46	0.33	0.1	1.1	9
	Roof	0.71	0.61	0.1	1.5	9
1st Fl. Piano Rm	Baseline	6.26	3.2	2.3	10.2	8
	Ground	0.5	0.36	0.1	1.2	9
	Roof	0.83	0.67	0.1	1.7	9
2nd Fl. Bedroom	Baseline	6.24	3.37	2.2	10.9	8
	Ground	0.46	0.42	0.1	1.2	9
	Roof	0.54	0.72	0.1	1.9	7
2nd Fl. Master Bedroom	Baseline	6.85	3.94	2.2	12.6	8
	Ground	0.48	0.48	0.1	1.3	9
	Roof	0.73	0.66	0.1	1.8	9

Appendix D, cont. - E-perm Sample Data, Annual Averages

E-perm Sample Data, Annual Data, House PA 06

Location	ASD Configuration	Avg. (pCi/L)	1 SD (pCi/L)	Min. (pCi/L)	Max. (pCi/L)	n
Ambient, East, opposite side to fan	Baseline	0.18	0.07	0.1	0.3	8
	Ground	0.17	0.09	0.1	0.4	9
	Roof	0.15	0.05	0.1	0.2	8
Ambient, West, Fan side	Baseline	0.15	0.05	0.1	0.2	8
	Ground	0.13	0.05	0.1	0.2	9
	Roof	0.12	0.04	0.1	0.2	9
Unf. Bsmt, near ASD pipe	Baseline	8.44	2.63	3.8	11.3	8
	Ground	0.27	0.09	0.1	0.4	9
	Roof	0.72	0.58	0.3	2.3	9
Unf. Bsmt., shelf	Baseline	8	2.62	3.8	10.9	8
	Ground	0.3	0.09	0.1	0.4	9
	Roof	0.72	0.46	0.3	1.9	9
1st Fl. Family Rm.	Baseline	4.2	1.42	1.9	7	8
	Ground	0.23	0.31	0.1	0.2	10
	Roof	0.27	0.3	0.1	0.3	9
1st Fl. Kitchen, near CRM	Baseline	3.68	1	1.6	4.6	8
	Ground	0.13	0.05	0.1	0.2	9
	Roof	0.23	0.27	0.1	0.2	10
2nd Fl. Spare Bedroom	Baseline	3.94	0.93	2.4	4.7	7
	Ground	0.36	0.55	0.1	1.8	8
	Roof	0.3	0.36	0.1	1.2	8
2nd Fl. Master Bedroom	Baseline	3.66	1.34	0.9	5.3	8
	Ground	0.16	0.05	0.1	0.2	9
	Roof	0.22	0.28	0.1	0.2	10
Ambient, window near exhaust	Baseline	0.16	0.07	0.1	0.3	8
	Ground	0.12	0.04	0.1	0.2	9
	Roof	0.12	0.04	0.1	0.2	11

Appendix D, cont. - E-perm Sample Data, Annual Averages

E-perm Sample Data, Annual Data, House PA 07

Location	ASD Configuration	Avg. (pCi/L)	1 SD (pCi/L)	Min. (pCi/L)	Max. (pCi/L)	n
Ambient, East, opposite side to fan	Baseline	0.16	0.07	0.1	0.3	8
	Ground	0.19	0.09	0.1	0.3	9
	Roof	0.16	0.09	0.1	0.3	9
Ambient, West, Fan side	Baseline	0.13	0.05	0.1	0.2	8
	Ground	0.16	0.07	0.1	0.3	9
	Roof	0.12	0.04	0.1	0.2	9
Unf. Bsmt	Baseline	8.6	2.1	3.7	10.8	8
	Ground	1.62	0.86	0.6	3	9
	Roof	2.2	0.98	0.7	3.3	9
Living Room	Baseline	3.6	1.9	1.2	6.3	8
	Ground	0.33	0.22	0.1	0.8	9
	Roof	0.59	0.4	0.1	1.1	9
1st Fl. Office	Baseline	3.7	2.2	0.9	7.1	8
	Ground	0.33	0.22	0.1	0.8	9
	Roof	0.54	0.43	0.1	1.3	9
2nd Fl. Master Bedroom	Baseline	3.6	2.3	0.8	6.8	8
	Ground	0.4	0.31	0.1	0.9	9
	Roof	0.58	0.44	0.1	1.3	9

Appendix D, cont. - E-perm Sample Data, Annual Averages

E-perm Sample Data, Annual Data, House PA 08

Location	ASD Configuration	Avg. (pCi/L)	1 SD(pCi/L)	Min. (pCi/L)	Max. (pCi/L)	n
Ambient, East, opposite side to fan	Baseline	0.6	0.1	0.4	0.8	9
	Ground	0.5	0.3	0.2	1.1	9
	Roof	0.7	0.4	0.4	1.6	8
Ambient, West, Fan side	Baseline	0.9	0.2	0.8	1.3	9
	Ground	0.8	0.1	0.7	1.1	9
	Roof	0.8	0.03	0.8	0.9	8
Ambient, 3’ from fan along side of house	Baseline	0.7	0.3	0.6	1.3	9
	Ground	0.7	0.1	0.6	0.8	9
	Roof	0.7	0.1	0.6	0.9	8
Unf. Bsmt.	Baseline	2.8	0.8	1.9	4.8	9
	Ground	0.8	0.1	0.6	1	9
	Roof	0.8	0.1	0.6	1	7
1st Fl. Master Bedroom	Baseline	1.3	0.5	0.4	1.9	9
	Ground	0.4	0.1	0.2	0.6	9
	Roof	0.4	0.2	0.1	0.6	7
1st Fl. Sunroom	Baseline	1.3	0.3	0.8	1.9	8
	Ground	0.7	0.2	0.6	1.2	8
	Roof	0.7	0.1	0.6	0.8	7
2nd Fl Bedroom	Baseline	1.3	0.4	0.5	1.9	9
	Ground	0.5	0.1	0.3	0.6	9
	Roof	0.5	0.1	0.3	0.7	8

Appendix D, cont. - E-perm Sample Data, Annual Averages

E-perm Sample Data, Annual Data, House PA 09

Location	ASD Configuration	Avg. (pCi/L)	1 SD (pCi/L)	Min. (pCi/L)	Max. (pCi/L)	n
Ambient, East, opposite side to fan	Baseline	0.1	0.04	0.1	0.2	8
	Ground	0.2	0.1	0.1	0.3	8
	Roof	0.2	0.1	0.1	0.4	8
Ambient, 3' from Fan	Baseline	0.2	0.1	0.1	0.4	8
	Ground	0.3	0.2	0.1	0.8	8
	Roof	0.2	0.1	0.1	0.5	8
Bsmt. By ASD pipe	Baseline	8.8	2	6.3	12.9	7
	Ground	0.34	0.1	0.1	0.5	8
	Roof	0.7	0.2	0.4	1	8
Bsmt. Hanging from ceiling	Baseline	7.9	2	6	12.8	8
	Ground	0.2	0.1	0.1	0.3	8
	Roof	0.5	0.2	0.2	0.7	8
1st Fl. TV Room	Baseline	3.5	1	2.1	5.1	8
	Ground	0.3	0.4	0.1	1.2	8
	Roof	0.3	0.2	0.1	0.6	8
1st Fl. Dining Rm	Baseline	3.7	0.9	2.6	5.2	8
	Ground	0.2	0.1	0.1	0.3	7
	Roof	0.3	0.2	0.1	0.7	8
2nd Fl. Bedroom	Baseline	3.4	0.8	2.2	4.6	7
	Ground	0.2	0.1	0.1	0.4	7
	Roof	0.5	0.8	0.1	2.7	8

Appendix D, cont. - E-perm Sample Data, Annual Averages

E-perm Sample Data, Annual Data, House PA 10

Location	ASD Configuration	Avg. (pCi/L)	1 SD (pCi/L)	Min. (pCi/L)	Max. (pCi/L)	n
Ambient, by bush opposite side to fan	Baseline	0.4	0.3	0.1	0.9	8
	Ground	0.7	0.7	0.2	1.2	9
	Roof	0.3	0.2	0.2	0.5	9
Ambient, 3' from Fan	Baseline	0.4	0.2	0.2	0.6	8
	Ground	0.6	0.4	0.2	0.7	9
	Roof	0.4	0.2	0.1	0.6	9
Bsmt. Laundry Rm.	Baseline	5.2	0.8	4.4	6.1	8
	Ground	2.1	0.5	1.9	2.7	10
	Roof	2.1	0.9	0.2	3.5	9
Bsmt. Work Shelf	Baseline	5.3	0.7	4.6	6.3	8
	Ground	2.3	0.4	2	2.8	9
	Roof	2.4	0.3	1.9	2.7	8
1st Fl. Spare Rm	Baseline	3.6	0.7	2.4	4.3	8
	Ground	1.9	0.5	1.1	2.6	9
	Roof	2.0	0.3	1.6	2.8	9
1st Fl. Living Rm.	Baseline	3.0	0.7	2	3.6	8
	Ground	1.6	0.4	0.7	2.3	9
	Roof	1.7	0.4	1.2	2.4	9
Room over crawl space	Baseline	3.6	1.0	2.1	5.1	8
	Ground	2.2	0.6	1.1	3.3	9
	Roof	2.0	0.5	1.2	2.6	9

Appendix E- Radon Grab Sample Data, Annual Averages

Grab Radon Sample Data for House PA 01, Annual Data

Location	ASD Configuration	Avg. (pCi/L)	1SD (pCi/L)	Min. (pCi/L)	Max (pCi/L)	n
Ambient, East	Baseline	0.8	0.56	0.1	1.9	7
	Ground	0.25	0.03	0.1	0.6	8
	Roof	0.3	0.28	0.1	0.8	10
Ambient, 3’ from Fan, alongside of house	Baseline	0.46	0.34	0.1	1.1	6
	Ground	0.34	0.33	0.1	1.1	9
	Roof	0.51	0.22	0.2	0.6	9
ASD Exhaust Stream	Baseline	253	433	0.4	1100	7
	Ground	44	10	29	48.4	8
	Roof	47	24	1.3	93.4	9
Ambient, Bedroom Win. 4’ above fan	Baseline	1.1	1.34	0.1	3.7	7
	Ground	0.27	0.24	0.1	0.8	9
	Roof	0.37	0.19	0.1	0.56	10
1’ in front of ASD Exhaust	Baseline	-	-	-	-	-
	Ground	8.63	4.4	3.1	14.1	7
	Roof	-	-	-	-	-
Bsmt. Sub-slab	Baseline	404	87	346	584	7
	Ground	8.1	11	1.8	35	8
	Roof	68	165	3.1	35	9

Appendix E, cont.- Radon Grab Sample Data, Annual Averages

Grab Radon Sample Data for House PA 02, Annual Data

Location	ASD Configuration	Avg. (pCi/L)	1 SD (pCi/L)	Min. (pCi/L)	Max (pCi/L)	n
Ambient, opposite side to fan	Baseline	0.6	0.2	0.3	1.9	8
	Ground	0.4	0.2	0.1	0.9	8
	Roof	0.4	0.3	0.1	0.8	10
Ambient, 3' from Fan, alongside of house	Baseline	0.6	0.5	0.1	1.1	8
	Ground	0.7	0.5	0.2	1.4	8
	Roof	0.8	0.5	0.3	2.2	10
ASD Exhaust Stream	Baseline	11.5	7.5	0.1	22.8	9
	Ground	16.6	9.3	0.6	30.4	8
	Roof	8.2	9.9	0.1	24.3	10
1' in front of ASD Exhaust	Baseline	-	-	-	-	-
	Ground	3.9	2.3	0.4	6.2	6
	Roof	-	-	-	-	-
Bsmt. Sub-slab	Baseline	4	3.5	0.2	10.5	7
	Ground	5.9	5	0.3	11.4	10
	Roof	65.9	70.6	6.9	163	10

Appendix E, cont.- Radon Grab Sample Data, Annual Averages

Grab Radon Sample Data for House PA 03, Annual Data

Location	ASD Configuration	Avg. (pCi/L)	1SD (pCi/L)	Min. (pCi/L)	Max (pCi/L)	n
Ambient, opposite side to fan	Baseline	--	--	--	--	--
	Ground	0.13	0.04	0.1	0.2	12
	Roof	0.22	0.19	0.1	0.8	12
Ambient, 3' from Fan, alongside of house	Baseline	--	--	--	--	--
	Ground	0.48	0.46	0.1	1.3	9
	Roof	0.19	0.22	0.1	0.8	9
ASD Exhaust Stream	Baseline	--	--	--	--	--
	Ground	65.9	18.67	26.2	85.5	12
	Roof	65.5	22.47	39.4	83.6	11
Ambient, window near exhaust	Baseline	--	--	--	--	--
	Ground	0.26	0.21	0.1	0.7	12
	Roof	0.23	0.21	0.1	0.7	13
1' in front of ASD Exhaust	Baseline	-	-	-	-	-
	Ground	24.77	10.5	12.7	42.3	10
	Roof	-	-	-	-	-
Bsmt. Sub-slab	Baseline	--	--	--	--	--
	Ground	6.61	6.51	0.1	20.9	12
	Roof	7.34	7.56	1.5	31.6	12

Did not run baseline in PA 03 due to higher indoor radon levels.

Appendix E, cont.- Radon Grab Sample Data, Annual Averages

Grab Radon Sample Data for House PA 04, Annual Data

Location	ASD Configuration	Avg. (pCi/L)	1SD (pCi/L)	Min. (pCi/L)	Max (pCi/L)	n
Ambient, opposite side to fan	Baseline	0.23	0.16	0.1	0.56	8
	Ground	0.27	0.03	0.1	0.5	9
	Roof	0.26	0.17	0.1	1.1	9
Ambient, 3' from Fan, alongside of house	Baseline	0.38	0.25	0.1	0.8	7
	Ground	0.41	0.31	0.1	1.1	9
	Roof	0.87	1.6	0.1	5.4	10
ASD Exhaust Stream	Baseline	20.54	32.4	0.1	87.9	7
	Ground	10.02	4	0.8	13.7	10
	Roof	13.35	4.39	5.8	18.9	10
2nd Fl. Office by window	Baseline	7.2	1.8	3.2	12.7	7
	Ground	0.89	0.27	0.5	1.3	7
	Roof	1.16	0.92	0.1	2.6	8
1' in front of ASD Exhaust	Baseline	-	-	-	-	-
	Ground	5.86	2.4	1.5	9.3	9
	Roof	-	-	-	-	-
Bsmt. Sub-slab	Baseline	156	140	70	459	7
	Ground	7.14	6.85	1.7	23.1	8
	Roof	6.8	4.6	0.2	13.2	11

Appendix E, cont.- Radon Grab Sample Data, Annual Averages

Grab Radon Sample Data for House PA 05, Annual Data

Location	ASD Configuration	Avg. (pCi/L)	1 SD (pCi/L)	Min. (pCi/L)	Max (pCi/L)	n
Ambient, opposite side to fan	Baseline	0.38	0.1	0.2	0.48	8
	Ground	0.58	0.75	0.1	1.9	5
	Roof	0.51	0.45	0.1	1.5	10
Ambient, 3' from Fan, alongside of house	Baseline	0.4	0.4	0.1	1.1	8
	Ground	0.53	0.29	0.3	1.1	8
	Roof	0.38	0.3	0.1	1.1	10
ASD Exhaust Stream	Baseline	73.52	113	1.2	306	7
	Ground	17.88	5.95	6.8	26.8	8
	Roof	23.1	6.58	13.4	32.5	10
1' in front of ASD Exhaust	Baseline	-	-	-	-	-
	Ground	11.36	3.65	10.3	16.6	6
	Roof	-	-	-	-	-
Bsmt. Sub-slab	Baseline	451	325	13.4	958	6
	Ground	137	193	1.1	531	7
	Roof	91	156	0.4	481	9

Appendix E, cont.- Radon Grab Sample Data, Annual Averages

Grab Radon Sample Data for House PA 06, Annual Data

Location	ASD Configuration	Avg. (pCi/L)	1 S (pCi/L)	Min. (pCi/L)	Max (pCi/L)	n
Ambient, opposite side to fan	Baseline	0.43	0.13	0.27	0.7	7
	Ground	0.34	0.18	0.1	0.56	6
	Roof	0.48	0.29	0.1	1.1	9
Ambient, 3' from Fan, alongside of house	Baseline	0.49	0.29	0.1	1.1	7
	Ground	0.67	0.44	0.1	1.5	7
	Roof	0.31	0.2	0.1	0.7	10
ASD Exhaust Stream	Baseline	0.2	0.1	0.1	0.3	7
	Ground	27.6	9.3	15.8	36.7	8
	Roof	33.4	7.45	22.1	43.2	10
1' in front of ASD Exhaust	Baseline	-	-	-	-	-
	Ground	13.42	4.61	5.3	18.6	6
	Roof	-	-	-	-	-
Bsmt. Sub-slab	Baseline	52	31	22.4	97.7	7
	Ground	0.53	0.41	0.1	0.9	8
	Roof	0.47	0.28	0.1	1.1	10

Appendix E, cont.- Radon Grab Sample Data, Annual Averages

Grab Radon Sample Data for House PA 07, Annual Data

Location	ASD Configuration	Avg. (pCi/L)	1SD (pCi/L)	Min. (pCi/L)	Max (pCi/L)	n
Ambient, opposite side to fan	Baseline	0.24	0.24	0.1	0.6	7
	Ground	0.26	0.18	0.1	0.5	8
	Roof	0.21	0.14	0.1	0.4	9
Ambient, 3' from Fan, alongside of house	Baseline	0.28	0.33	0.1	0.4	8
	Ground	0.4	0.5	0.1	1.3	8
	Roof	0.27	0.19	0.1	0.6	9
ASD Exhaust Stream	Baseline	0.15	0.12	0.1	0.4	6
	Ground	28.1	7.2	19	37	9
	Roof	22	15	0.1	36	10
1st Fl. Office, inside	Baseline	0.2	0.1	0.1	0.4	5
	Ground	0.5	0.5	0.1	1.3	6
	Roof	0.27	0.24	0.1	0.6	6
1' in front of ASD Exhaust	Baseline	-	-	-	-	-
	Ground	10.7	3.6	4.8	15	7
	Roof	-	-	-	-	-
Bsmt. Sub-slab	Baseline	65	52	9.8	157	8
	Ground	1.7	0.8	0.1	3.3	9
	Roof	2.3	1.1	0.1	4.8	10

Appendix E, cont.- Radon Grab Sample Data, Annual Averages

Grab Radon Sample Data for House PA 08, Annual Data

Location	ASD Configuration	Avg. (pCi/L)	1 SD (pCi/L)	Min. (pCi/L)	Max (pCi/L)	n
Ambient, opposite side to fan	Baseline	0.8	0.5	0.1	1.4	7
	Ground	0.5	0.3	0.1	1.1	9
	Roof	0.4	0.2	0.1	0.7	8
Ambient, 3' from Fan, alongside of house	Baseline	0.6	0.4	0.1	1.1	8
	Ground	0.7	0.4	0.1	1.6	9
	Roof	1.2	2.4	0.1	7.4	8
ASD Exhaust Stream	Baseline	61	141	0.9	433	9
	Ground	29	17	0.6	63	9
	Roof	33	20	5.8	62	8
1' in front of ASD Exhaust	Baseline	-	-	-	-	-
	Ground	14	7	7.7	25	5
	Roof	-	-	-	-	-
Bsmt. Sub-slab	Baseline	1408	659	617	2712	9
	Ground	16	14	1.3	41	9
	Roof	11	6	2.5	22	8

Appendix E, cont.- Radon Grab Sample Data, Annual Averages

Grab Radon Sample Data for House PA 09, Annual Data

Location	ASD Configuration	Avg. (pCi/L)	1SD (pCi/L)	Min. (pCi/L)	Max (pCi/L)	n
Ambient, opposite side to fan	Baseline	0.4	0.3	0.1	0.8	8
	Ground	0.3	0.3	0.1	1.1	8
	Roof	0.3	0.2	0.1	0.5	10
Ambient, 3’ from Fan, alongside of house	Baseline	0.3	0.1	0.1	0.5	8
	Ground	0.2	0.2	0.1	0.7	5
	Roof	0.6	0.4	0.1	1.1	9
ASD Exhaust Stream	Baseline	7.4	13	0.1	38	8
	Ground	11	2	8.2	13.4	7
	Roof	12.3	4	9.4	22.3	10
Bsmt. Sub slab	Baseline	37.4	26	4.4	70	8
	Ground	2.2	2	0.3	6.8	8
	Roof	4.4	2.6	0.7	9.5	10
1’ in front of ASD Exhaust	Baseline	-	-	-	-	-
	Ground	2	1	0.8	3.5	7
	Roof	-	-	-	-	-

Appendix E, cont.- Radon Grab Sample Data, Annual Averages

Grab Radon Sample Data for House PA 10, Annual Data

Location	ASD Configuration	Avg. (pCi/L)	1SD (pCi/L)	Min. (pCi/L)	Max (pCi/L)	n
Ambient, opposite side to fan	Baseline	1.8	1.4	0.8	4.6	8
	Ground	0.7	0.6	.01	0.9	10
	Roof	0.4	0.3	0.1	0.5	9
Ambient, 3' from Fan, alongside of house	Baseline	0.6	0.3	0.2	0.9	8
	Ground	1.7	1.7	0.5	5.5	10
	Roof	0.5	0.4	0.3	1.05	9
Basement	Baseline	4.7	1.2	2.5	6.9	8
	Ground	2.8	2.1	0.8	2.6	10
	Roof	2.5	0.7	1.6	3.4	9
ASD Exhaust Stream	Baseline	1491	1105	574	3549	8
	Ground	362	158	124	722	9
	Roof	269	232	59	683	9
Ambient, Bedroom Win.	Baseline	0.9	0.5	0.4	1.8	8
	Ground	0.5	0.4	0.1	1.05	10
	Roof	0.5	0.3	0.2	1.1	9
1' in front of ASD Exhaust	Baseline	-	-	-	-	-
	Ground	17	16	0.1	48.7	7
	Roof	-	-	-	-	-
Bsmt. Sub-slab	Baseline	2242	977	1828	3082	8
	Ground	75	31	31	101	8
	Roof	75	41	2.3	128	9

Appendix F - Flow and Pressure Data in ASD Piping

Flow (CFM) and Pressure (Pa) in ASD Piping, PA 01

ASD Configuration	Avg.	1 Std. Dev.	Min.	Max	Range	n
Flow (CFM)						
Ground	19.1	3.9	13.2	22.5	13.2-22.5	9
Roof	18.4	3.1	13.8	21.7	13.8-21.7	7
Pressure (Pa)						
Ground	467	20	441	501	441-501	10
Roof	458	16	441	479	441-479	9

Flow (CFM) and Pressure (Pa) in ASD Piping, PA 02

ASD Configuration	Avg.	1 Std. Dev.	Min.	Max	Range	n
Flow (CFM)						
Ground	101.6	3.2	99	108	99-108	7
Roof	76.3	15	41	93	41-93	9
Pressure (Pa)						
Ground	121.8	27	93	186	93-186	8
Roof	91.7	17	82.3	137.6	82-138	9

Flow (CFM) and Pressure (Pa) in ASD Piping, PA 03

ASD Configuration	Avg.	1 Std. Dev.	Min.	Max	Range	n
Flow (CFM)						
Ground	91.5	29.27	95.4	106.2	95.4-106.2	10
Roof	78.66	23.18	81.7	88	81.7-88	12
Pressure (Pa)						
Ground	126.5	2	122.5	130	122.5-130	12
Roof	94.6	1.6	91.4	97.1	91.4-97.1	13

Appendix F, cont. - Flow and Pressure Data in ASD Piping

Flow (CFM) and Pressure (Pa) in ASD Piping, PA 04

ASD Configuration	Avg.	1 Std. Dev.	Min.	Max	Range	n
Flow (CFM)						
Ground	99.56	3.35	93	105	93-105	10
Roof	83.88	2.43	78	85.9	78-85.9	10
Pressure (Pa)						
Ground	143	44	20	159	20-159	10
Roof	101	30	16.5	116	16.5-116	10

Flow (CFM) and Pressure (Pa) in ASD Piping, PA 05

ASD Configuration	Avg.	1 Std. Dev.	Min.	Max	Range	n
Flow (CFM)						
Ground	111	4	102	115	102-115	9
Roof	98	32	85	90	85-90	9
Pressure (Pa)						
Ground	118	17	96	157	96-157	8
Roof	74	4	70	84	70-84	9

Flow (CFM) and Pressure (Pa) in ASD Piping, PA 06

ASD Configuration	Avg.	1 Std. Dev.	Min.	Max	Range	n
Flow (CFM)						
Ground	95	2.2	91	98	91-98	8
Roof	79	6.9	71	98	71-98	9
Pressure (Pa)						
Ground	155	16	113	164	113-164	8
Roof	121	21	112	180	112-180	9

Appendix F, cont. - Flow and Pressure Data in ASD Piping

Flow (CFM) and Pressure (Pa) in ASD Piping, PA 07

ASD Configuration	Avg.	1 Std. Dev.	Min.	Max	Range	n
Flow (CFM)						
Ground	105	5	97	114	97-114	9
Roof	83	5	73	90	73-90	10
Pressure (Pa)						
Ground	125	2.2	122	129	122-129	9
Roof	81	2	79	83	79-83	9

Flow (CFM) and Pressure (Pa) in ASD Piping, PA 08

ASD Configuration	Avg.	1 Std. Dev.	Min.	Max	Range	n
Flow (CFM)						
Ground	38	2.7	33	42	33-42	9
Roof	37	4.4	30	42	30-42	7
Pressure (Pa)						
Ground	805	37	770	871	770-871	9
Roof	789	49	725	839	725-839	6

Flow (CFM) and Pressure (Pa) in ASD Piping, PA 09

ASD Configuration	Avg.	1 Std. Dev.	Min.	Max	Range	n
Flow (CFM)						
Ground	112	3	107	115	107-115	8
Roof	87	3	83	90	83-90	10
Pressure (Pa)						
Ground	115	2	112	119	112-119	8
Roof	78	7	72	89	72-89	10

Appendix F, cont. - Flow and Pressure Data in ASD Piping

Flow (CFM) and Pressure (Pa) in ASD Piping, PA 10

ASD Configuration	Avg.	1 Std. Dev.	Min.	Max	Range	n
Flow (CFM)						
Ground	7	2.6	4.1	13	4.1-13	8
Roof	7.3	5	2.5	17	2.5-17	8
Pressure (Pa)						
Ground	664	32	623	717	623-717	9
Roof	666	35	622	714	622-714	8

Summary Average Air Flow and Pressure for all 10 homes

ASD Configuration	Average	1 Std. Dev.	Min.	Max.	n
Flow (CFM)					
Ground	78	40	4	115	10
Roof	65	32	3	98	10
Pressure (Pa)					
Ground	218	238	20	871	10
Roof	189	243	3	839	10

Appendix G - ASD Exhaust Gas Concentration Data, Grab Sample, Avg. / 1 SD (pCi/L)

House	Baseline (pCi/L / 1 SD)	n	Ground (pCi/L / 1 SD)	n	Roofline (pCi/L / 1 SD)	n	1' in Frt. Exh. (pCi/L / 1 SD)	n
PA 01	253 / 433	7	44 / 11	8	102 / 176	9	9 / 4	7
PA 02	12 / 8	9	17 / 9	8	8 / 10	10	4 / 2	6
PA 03	N/A		66 / 18	12	66 / 22	13	25 / 11	10
PA 04	21 / 32	7	10 / 4	10	13 / 1	10	6 / 2	9
PA 05	74 / 114	7	18 / 6	8	23 / 7	10	11 / 6	6
PA 06	2 / 5	8	28 / 9	9	33 / 7	10	13 / 5	6
PA 07	0.1 / 0.2	6	29 / 7	8	22 / 15	10	11 / 4	7
PA 08	61 / 140	8	29 / 17	8	33 / 20	7	12 / 7	6
PA 09	8 / 15	7	11 / 2	7	12 / 4	10	2 / 1	8
PA 10	1491 / 1105	7	362 / 158	7	269 / 231	9	17 / 16	7

Baseline, ground, and roof values taken 10-12" down exhaust pipe.

Appendix H - CRM Indoor Seasonal Averages by Configuration, PA 01

House PA 01	*ASD Configuration*	*Bedroom*		*Basement*	
Season		Average (pCi/L)	Sample Size	Average (pCi/L)	Sample Size
Winter	Roof	1.1	1340	2	1339
Winter	Ground	1	1338	1.9	1336
Winter	Baseline	2.9	1584	6.7	1584
Spring	Roof	0.8	2005	1.7	1985
Spring	Ground	0.7	1400	1.5	1415
Spring	Baseline	2.3	976	7.5	977
Summer	Roof	0.7	1338	1.5	1289
Summer	Ground	0.6	1775	1.3	1779
Summer	Baseline	0.8	1335	2.4	1337
Fall	Roof	1	1333	1.8	1334
Fall	Ground	0.9	1505	1.8	1504
Fall	Baseline	2.2	1472	5.5	1469

Appendix H - CRM Indoor Seasonal Averages by Configuration, PA 04

House PA 04	*ASD Configuration*	*2nd Fl. Office*	*Basement*	
Season		Average (pCi/L)	Average (pCi/L)	Sample Size
Winter	Roof	ND	1	1283
Winter	Ground	ND	0.9	1338
Winter	Baseline	ND	7.3	321
Spring	Roof	ND	0.8	1928
Spring	Ground	ND	0.5	1340
Spring	Baseline	ND	10.7	1743
Summer	Roof	ND	1.0	1320
Summer	Ground	ND	1	2450
Summer	Baseline	ND	8	670
Fall	Roof	ND	1.1	1343
Fall	Ground	ND	0.8	1568
Fall	Baseline	ND	10.1	1246

ND (No Data) – Data for CRM on 2nd Flr Office of PA04 is suspect and not in agreement with side-by-side measurement results made with other devices (EPERMs)

Appendix I, Sound Measurements (dBA)

House PA 01. Sound Measurements (dBA)

Location	ASD Configuration	Avg. (dBA)	1 Std. Dev. (dBA)	Min. (dBA)	Max (dBA)	n
Basement, wall near ASD	Baseline	39.2	7.2	33.6	51	7
	Ground	40.6	5.3	36.4	51	8
	Roof	39.7	5.4	33.7	50	7
1st Fl. Bedroom wall near ASD	Baseline	39.6	6.8	36	55	7
	Ground	40.5	6.2	35	56	8
	Roof	38.3	3.9	34	46	8
Outside, 10’ from fan	Baseline	48.2	9.8	37.6	60	7
	Ground	51	5.8	46	65	9
	Roof	45.7	4.9	38	52	8

House PA 02. Sound Measurements (dBA)

Location	ASD Configuration	Avg. (dBA)	1 Std. Dev. (dBA)	Min. (dBA)	Max (dBA)	n
Basement near ASD pipe	Baseline	44	8	34.3	53.2	5
	Ground	44.2	4.8	39	53.2	5
	Roof	40.6	3	38.2	43.2	10
1st Fl. Bedroom near window	Baseline	37.3	3.6	33.3	43	5
	Ground	39.6	6	34.6	51	5
	Roof	37.4	2.3	34.7	41	9
Outside, 10’ from fan	Baseline	47.2	6.4	41	59	5
	Ground	55.6	5.4	50	66	5
	Roof	47.6	6	41	63	10

Appendix I, cont. Sound Measurements (dBA)

House PA 03. Sound Measurements (dBA)

Location	ASD Configuration	Avg. (dBA)	1 Std. Dev. (dBA)	Min. (dBA)	Max (dBA)	n
Basement near wall with ASD pipe	Baseline	--	--	--	--	--
	Ground	52.7	8.5	35.8	63.5	11
	Roof	48.2	6.9	39.3	57.9	13
1st Fl. Near wall with ASD pipe	Baseline	--	--	--	--	--
	Ground	45	6.5	35.8	53	11
	Roof	44	9.1	34.7	68.2	13
Outside, 10' from fan	Baseline	--	--	--	--	--
	Ground	56	7.3	46	75	12
	Roof	57	5.1	50	70	13

House PA 04. Sound Measurements (dBA)

Location	ASD Configuration	Avg. (dBA)	1 Std. Dev. (dBA)	Min. (dBA)	Max (dBA)	n
Basement near wall by fan	Baseline	49.14	5.6	42.2	60.1	8
	Ground	45.72	6.9	34.7	59.2	10
	Roof	43.03	6.6	35.5	55	9
1st Fl. Liv. Rm. Wall by fan	Baseline	41.2	5.2	34.1	47.3	8
	Ground	37.17	3.5	33.9	43.7	10
	Roof	38.21	5.1	34.9	51.6	9
2nd Fl. Office, above fan	Baseline	42.03	9.1	35.1	62.4	8
	Ground	37.85	5.1	34.8	52	10
	Roof	38.27	4.9	33.5	49.7	9
Outside, 10' from fan	Baseline	51.13	3.7	46.9	58.3	8
	Ground	50.33	3.1	46.6	53.5	10
	Roof	44.5	2	41.7	46.2	9

Appendix I, cont. Sound Measurements (dBA)

House PA 05. Sound Measurements (dBA)

Location	ASD Configuration	Avg. (dBA)	1 Std. Dev. (dBA)	Min. (dBA)	Max (dBA)	n
Basement near wall with ASD pipe	Baseline	45	5	37.6	51.4	7
	Ground	47	4.6	41	52	9
	Roof	47.4	5.4	40	56	10
1st Fl. kitchen	Baseline	46.5	7	38	59	7
	Ground	40	3.13	36.3	44	9
	Roof	42	3.3	37.7	47.1	8
2nd Floor	Baseline	38.8	2.5	36	43.4	6
	Ground	37.1	2.65	33.2	43.3	9
	Roof	38.7	4	33.2	47.8	10
Outside, 10' from fan	Baseline	49.4	7.3	35	56	6
	Ground	54	2.4	49	58	8
	Roof	51	5.3	43	60	10

House PA 06. Sound Measurements (dBA)

Location	ASD Configuration	Avg. (dBA)	1 Std. Dev. (dBA)	Min. (dBA)	Max (dBA)	n
Basement near wall with ASD pipe	Baseline	39	6	33	50	8
	Ground	42	7	36	54	8
	Roof	42	6	36	56	9
1st Fl. Near wall with ASD pipe	Baseline	44	4	41	54	8
	Ground	40	4	34	48	6
	Roof	44	8	32	60	9
2nd Fl. Near wall with ASD pipe	Baseline	36	1.9	34	40	8
	Ground	35	0.7	34	36	8
	Roof	35	2.4	31	36	8
Outside, 10' from fan	Baseline	45	2.8	40	48	8
	Ground	54	5.2	49	63	7
	Roof	47	9	39	62	9

Appendix I, cont. Sound Measurements (dBA)

House PA 07. Sound Measurements (dBA)

Location	ASD Configuration	Avg. (dBA)	1 Std. Dev. (dBA)	Min. (dBA)	Max (dBA)	n
Basement near wall with ASD pipe	Baseline	40	4.7	35	48	8
	Ground	41	3	38	47	9
	Roof	43	4	37	51	10
1st Fl. Office, near window	Baseline	38	2	34	40	8
	Ground	37	1	35	39	9
	Roof	38	2	36	42	10
2nd Fl., near wall with ASD pipe	Baseline	38	3.2	35	45	8
	Ground	38	4.6	34	47	8
	Roof	38	4	34	48	10
Outside, 10' from fan	Baseline	50	3	44	54	8
	Ground	55	4	51	62	9
	Roof	55	7	42	73	10

House PA 08. Sound Measurements (dBA)

Location	ASD Configuration	Avg. (dBA)	1 Std. Dev. (dBA)	Min. (dBA)	Max (dBA)	n
Basement near wall with ASD pipe	Baseline	47	5	38	53	9
	Ground	48	4	42	54	9
	Roof	49	3	44	51	8
1st Fl. Bedroom near window	Baseline	41	5	34	49	9
	Ground	42	4	36	49	9
	Roof	45	6	35	53	8
2nd Fl. Near wall with ASD pipe	Baseline	35	3	34	43	7
	Ground	36	2	34	42	9
	Roof	35	1	33	37	7
Outside, 10' from fan	Baseline	49	4	43	52	9
	Ground	53	6	37	57	8
	Roof	57	3	54	61	7

Appendix I, cont. Sound Measurements (dBA)

House PA 09. Sound Measurements (dBA)

Location	ASD Configuration	Avg. (dBA)	1 Std. Dev. (dBA)	Min. (dBA)	Max (dBA)	n
Basement wall near ASD	Baseline	39	5	33	46	8
	Ground	38	3	36	45	8
	Roof	41	4	35	47	10
1st Fl. Wall near ASD	Baseline	44	4	40	49	8
	Ground	45	5	40	55	8
	Roof	44	4	38	50	10
2nd Fl., wall near ASD	Baseline	38	4	35	46	7
	Ground	35	1	34	36	7
	Roof	37	3	35	42	7
Outside, 10' from fan	Baseline	53	10	42	70	8
	Ground	50	4	46	59	8
	Roof	50	6	42	59	10

House PA 10. Sound Measurements (dBA)

Location	ASD Configuration	Avg. (dBA)	1 Std. Dev. (dBA)	Min. (dBA)	Max (dBA)	n
Basement	Baseline	36	0.7	35.7	36.7	8
	Ground	39	2.4	37.9	43.5	10
	Roof	41	5.1	38	53.6	9
1st Fl. Bedroom nearest fan	Baseline	35	0.7	34.8	36.1	8
	Ground	36	0.6	35.4	37.2	10
	Roof	38	3.6	35.5	46.9	9
Outside, 10' from fan	Baseline	44	7.8	36.3	47	8
	Ground	57	3.5	53.5	56.5	10
	Roof	50	2	48	53.5	9

Appendix I, cont. Sound Measurements (dBA)

Average Sound measurements for all homes, with similar location

Location	ASD Configuration	Average (dBA)	1 Std. Dev. (dBA)	n
Basement	Baseline	42	4.4	10
	Ground	44	4.8	10
	Roof	44	3.4	10
1st Floor	Baseline	41	3.5	10
	Ground	40	3.1	10
	Roof	41	3.2	10
Outside, 10' from fan	Baseline	48	3.2	10
	Ground	53	2.3	10
	Roof	51	4.5	10

Appendix J House Air Leakage from Blower Door Testing

House ID	Air Flow		Leakage Area
	ACH50	CFM50/ft^2 Floor Area	(in^2) Canadian EqLA@10 Pa
PA 01	2.11	0.28	69.7
PA 02	13.94	2.1	498
PA 03	2.38	0.31	74.9
PA 04	10.13	1.35	300
PA 05	7.19	0.96	242
PA 06	4.95	0.66	157
PA 07	3.21	0.43	147.8
PA 08	14.34	1.91	395.7
PA 09	3.06	0.43	128.6
PA 10	1.33	0.17	32.8

Appendix K, Radon Gas Dispersion Model

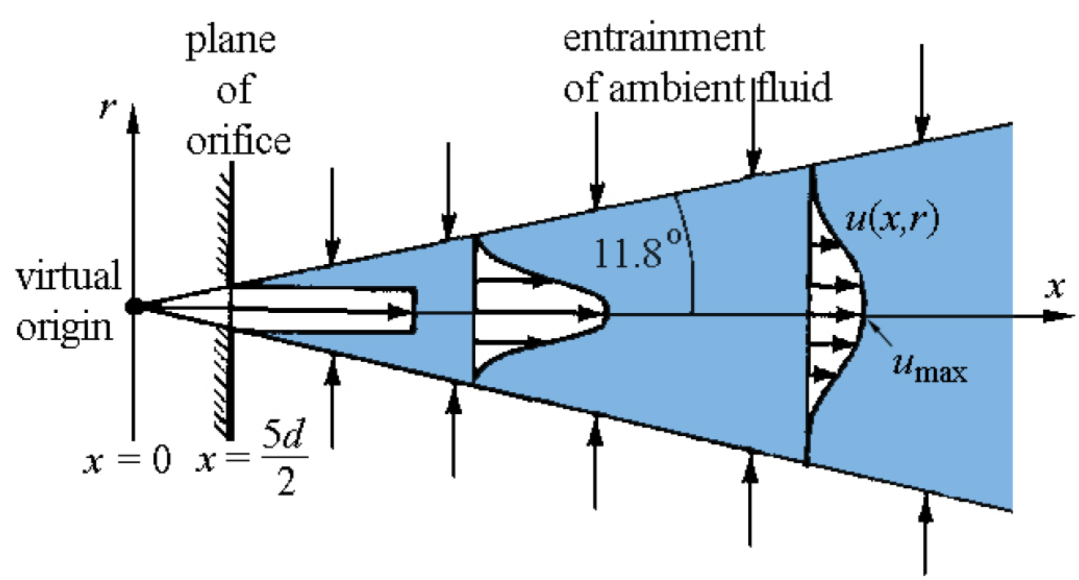
Following Cushman-Roisin[2], Houle[1] has derived calculations for radon concentrations along the horizontal discharge plume from an ASD mitigation system. The parameters to analyze radon gas dispersion from the horizontal discharge of an ASD system are shown in Figure L-1, below, where,

- *d* is the diameter of the orifice/discharge point,
- *u(x,r)* is the velocity of the gas at position (x,r),
- u_{max} is the centerline velocity,
- *x = 0* is established as the 'virtual' origin, and
- *x = 5d/2* is the distance of the orifice (discharge point) along the centerline from the virtual origin of the plume/cone,

and

$$R = \frac{1}{5}x \qquad \text{(L1)}$$

where *R* is the radius of the jet/plume/cone at distance *x*.



Notation for the turbulent round jet.

Laboratory observations reveal that all turbulent round jets possess the same opening angle, regardless of fluid (air, water, other), orifice diameter (d) and injection speed (U).
The universal value is 11.8°, yielding a ratio radius-to-distance of 1-to-5. ⟵ $\tan 11.8^0 \approx \frac{1}{5}$

Figure L-1. *courtesy Prof. Benoit Cushman-Roisin, Ph.D, Dartmouth College, USA, 2012*

Also based on Figure L-1, and after further derivation, the radon concentration as measured from the position *'x'* perpendicular to that central axis at distance *'r'*, and where *x* is the distance measured from the virtual origin is found to be:

$$c(x,r) = c_{max}\, e^{\left(-\frac{50r^2}{x^2}\right)} \qquad \text{(L2)}$$

C_{max} is the greatest concentration at $r = 0$ for any *x* along the centerline of the gas plume:

$$c_{max} = \frac{5d}{x} c_0 \qquad \text{(L3)}$$

where C_0 is the average concentration at the orifice (discharge point) and *d* is the diameter of the discharge orifice. Note that this relationship breaks down where *x* is taken at the orifice. To resolve this problem, Houle eliminated the constants in equation L3 by letting $C_{max,0}$ be the average concentration at the orifice and $C_{max,x1}$ be the value of the concentration at a distance *x1* from the virtual origin:

$$c_{max,0} = \frac{5d}{x_0} c_0 \qquad \text{(L4)}$$

and

$$c_{max,x1} = \frac{5d}{x_1} c_0 \qquad \text{(L5)}$$

then dividing equation L5 by L4

$$\frac{c_{max,x1}}{c_{max,0}} = \frac{\frac{5\,d}{x_1} C_0}{\frac{5d}{x_0} C_0} \qquad \text{(L6)}$$

so

$$c_{max,x1} = \frac{x_0}{x_1} \times c_{max,0} \qquad \text{(L7)}$$

Equation L7 was used to calculate values in Table 10 and 11. Note that Equation L7 assumes that the radon concentration will continue to drop with distance from the discharge point, without limit. However, at some point under real-world conditions the cone/plume will begin to distort and decay and the concentration profile will no longer apply. Figure L-1 implies that at higher discharge velocities, the jet of air will have greater momentum and will likely retain its characteristic shape and profile for a greater distance from the discharge location under conditions encountered in the field. Equation L7 does not account for those effects. It is expected that actual radon concentrations for conditions where the model and Equation L7 are no longer appropriate will be lower than those values predicted by that equation. Perturbations to the model by parameters such as wind, obstacles, ground reflection etc. are also likely to produce lower values of radon concentrations than those predicted by the model given here. For example, field studies of the effect of a steady wind have not been conducted, but it may not change the concentrations within the cone, instead bending the cone uniformly (as often seen in chimney exhausts).