

MEASURING AT-GRADE RADON MITIGATION EXHAUST

Bill Brodhead

WPB Enterprises, Inc., 2844 Slifer Valley Rd., Riegelsville, PA USA

wmbrodhead@gmail.com www.wpb-radon.com

ABSTRACT

In the United States (US) the radon exhaust from active soil depressurization (ASD) systems must be vented above the roof line of residential homes according to current US mitigation standards. In Canada and the European countries the radon system exhaust can be vented at-grade. Measurements of radon diffusion at-grade done with grab samples or averaging radon passive devices does not account for wind speed. The author was able over a six week period to measure hourly outdoor radon and wind averages at varying distances from a single radon system exhausting about 235 pCi/l (8700 Bq/m³) at-grade using nine continuous radon monitors and two weather stations. Ambient radon levels in the backyard were measured as a baseline. Weather data was collected at the exhaust location and at the roof top of the building. Continuous radon monitors were also placed on several levels of the home. In order to simulate other radon systems, the ASD system velocity was varied in each multi-day cycle from 20 to 40 to 69 CFM of airflow. The exhaust pipe outlet was also varied from 3 inch (75mm) to 4 inch (100mm). Hourly average wind speed was graphed in comparison to radon levels measured at each location. The average radon level at each location and sequence was tabulated. Elevated indoor radon originating from the ground based exhaust was not observed. Radon levels directly adjacent to the exhaust location averaged than 1.0 pCi/l (37 Bq/m³) higher than outdoor levels.

Radon System Exhaust Venting Requirements in US versus Canada

The US EPA published the interim Radon Mitigation Standards (RMS) in October of 1993 and the final version in April of 1994 ^{ref#6}. The requirement to vent ASD radon exhaust above the eave or roof was included in section 14.2.8 of the EPA RMS.

“14.2.8 To prevent re-entrainment of radon, the point of discharge from vents of fan-powered soil depressurization and block wall depressurization systems shall meet all of the following requirements: (1) be above the eave of the roof, (2) be ten feet or more above ground level, (3) be ten feet or more from any window, door, or other opening into conditioned spaces of the structure that is less than two feet below the exhaust point, and (4) be ten feet or more from any opening into an adjacent building. The total required distance (ten feet) from point of discharge to openings in the structure may be measured either directly between the two points or be the sum of measurements made around intervening obstacles. Whenever possible, the exhaust point should be positioned above the highest eave of the building and as close to the ridge line as possible.”

Since that time two other US standards, ASTM E2121 and ANSI/AARST SGM-2017, have been published that continue to require radon active soil depressurization (ASD) mitigation system exhaust to be vented above the roof.

The Canadian requirements for radon mitigation was published in 2017 and titled “Radon mitigation options for existing low-rise residential buildings” ^{ref#16}. The Canadian guidance includes the following in section 5.1.8..

“5.1.8 Mitigation system termination

Depending on the fan location, the termination of a soil depressurization exhaust can either be located:

- a) at low level lateral discharge usually passing through the rim-joint at right angles for a fan installed indoors in the basement or in an attached garage.
- b) above roof line level where the fan is typically installed in the attic or in an attached garage.”

Ground Based Exhaust Research prior to EPA RMS publication

The EPA “Radon Reduction Techniques for Existing Detached Houses, Technical Guidance (Third Edition) for Active Soil Depressurization Systems” by D Bruce Henschel ^{ref#5} was released at the same time as the EPA RMS in October of 1993. In this guidance the following statements were included about exhaust location of ASD systems.

“Very little data exist quantifying the effects of SSD exhaust re-entrainment, as a function of the key variables (including exhaust configuration, exhaust location, exhaust velocity/momentum, house characteristics, and weather conditions). Documented cases where exhaust re-entrainment in fact caused a significant deterioration in SSD performance all involve cases where: The exhaust was directed downward toward the soil immediately beside the house, as with a drier vent or with a 90 degree downward elbow on the fan exhaust (Clinton study); or where the exhaust was directed

straight upward immediately beside the house, or horizontally parallel to the house, especially when there were doors or windows nearby (PA 38 mitigated home study). The very limited data which are available directly comparing above-eave and grade-level exhausts suggest that **grade-level exhausts, directed horizontally to grade and aimed 90° away from the house, can result in re-entrainment no more severe than that experience when the exhaust is discharged vertically above the eave.** (PA 38 home study). Of course, the relative effects of the grade-level vs. above-eave exhaust might vary for differing weather conditions, exhaust velocities, etc.”

“Also, grade-level exhaust would not necessarily prevent exposure of persons in the yard immediately beside the exhaust. Limited data suggest that the radon in the exhaust will often be substantially diluted within a few feet of the discharge.”

In reviewing the EPA studies prior to the publication of the RMS and the referenced Technical Guidance in 1991 it appears that the early research done by Scott and Robertson^{Ref#1} at 40 homes in Pennsylvania starting in 1987 was the strongest evidence for the need to carefully vent ASD exhaust. After the initial radon systems were installed in all 40 homes, 18 of the homes were still above 4.0 pCi/l and 10 more were above 2.0 pCi/. In follow-up studies^{Ref#4,8} to determine why there was such a significant failure, Scott and Robertson realized that their initial ASD exhaust design of having the airflow directed parallel to the siding was causing significant re-entrainment. When the exhaust was either directed away from the building or up to the roof, the indoor radon levels were reduced below the 4.0 pCi/l level. Interestingly one of the study houses with the highest exhaust level of 8,000 pCi/l had at grade exhaust directed away from the house as its initial design and the post mitigation radon levels for this house was 2.4 pCi/l. Later wind tunnel and house studies^{Ref#7} found insignificant differences in re-entrainment from roof exhaust or at grade exhaust. Even though both Scott and Henschel declared that at grade exhaust would work for typical exhaust radon concentrations the EPA made the decision to require the exhaust to be vented above the roof.

Continuous Radon Monitor (CRM) Calibrations

This study used eight FTLab Radoneye RD200 plus detectors, two FTLab Radoneye Pro detectors, one FTLab FRD400, one Airthings Corentium Pro and one Niton RAD7. The FTLab detectors were chosen for this study because their sensitivity made it possible to measure very low radon concentrations. See the consistence of the radon measurements in the author’s radon chamber at 4 pC/l in Figure 2. Prior to the start of this study the FRD400 was cross checked at the Kansas State University (KSU) radon chamber in November of 2019 using KSU Pylon #0708. Figure 1 shows the three FTLab detectors used in this study were averaging close to each other but about 4% to 5% biased higher than KSU measured chamber level. KSU chamber is part of the international COIRA chamber level comparison. The three FTLab units were subsequently adjusted by modifying their calibration factors to more closely match the KSU chamber level. These three units were used to set the calibration of the authors Pylon AB5 #578 that was too fragile to ship to a chamber. See Figure 2. All of the FTLab detectors used in the study were then compared to the adjusted FRD400 and each detector used in this study had its calibration factor adjusted to closely match the FRD400 measurements. The results of adjustments are displayed in the comparison tests in Figures 3, 4 and 5. Figure 6 displays the results of the Corentium Pro. It was decided to use the Corentium Pro to only measure the radon in

the exhaust rather than the outdoor radon levels because of its ability to measure high levels of radon and run on batteries.

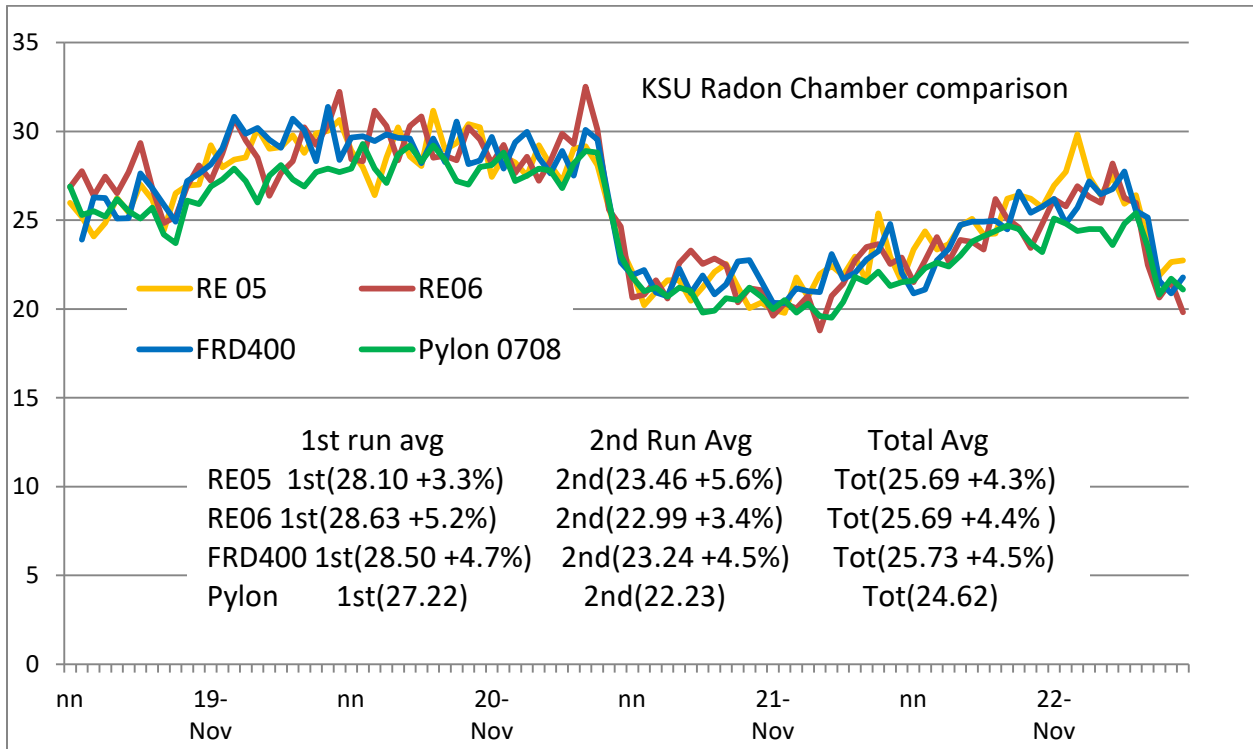


Figure 1 - KSU Chamber Comparison

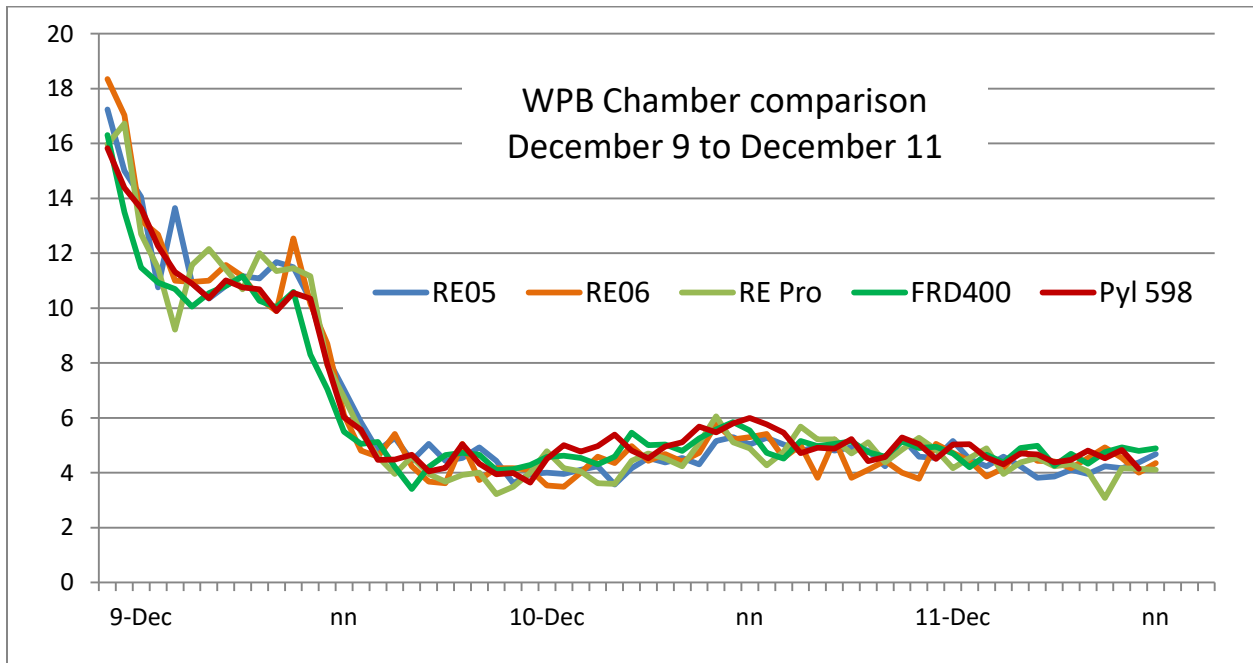


Figure 2 - FTLab adjusted Detector Comparison

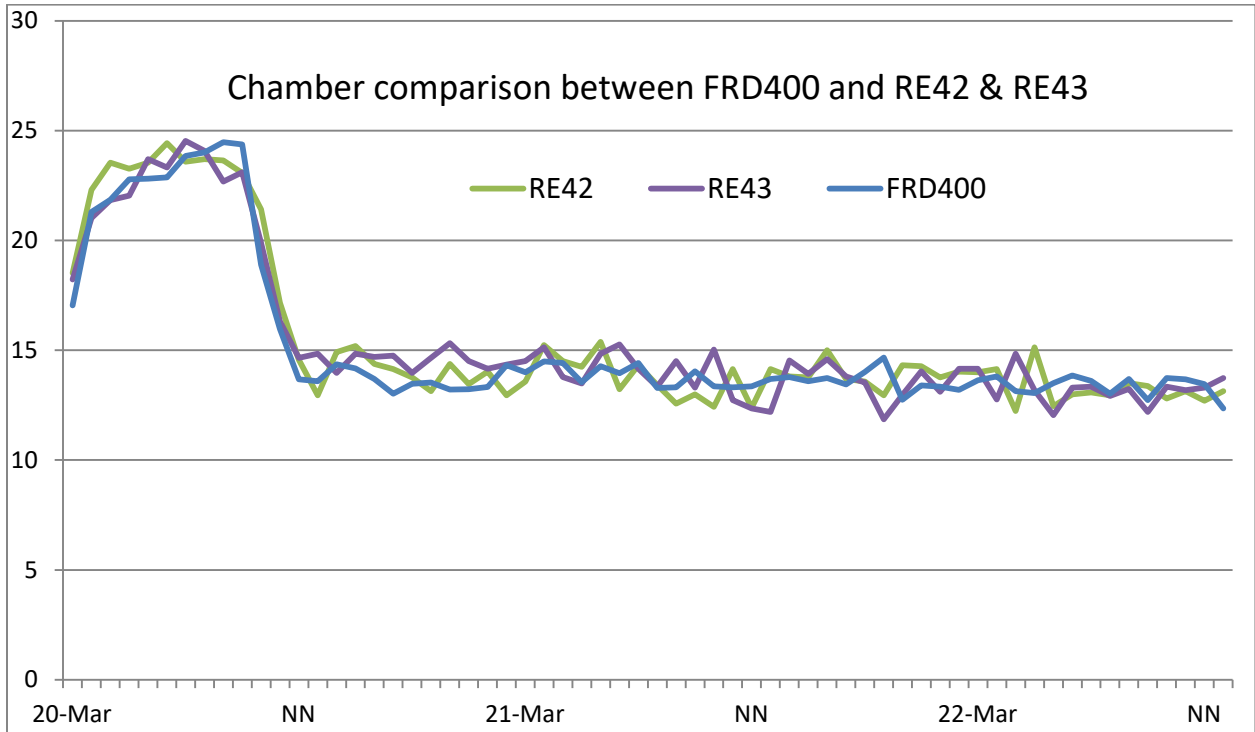


Figure 3 - RE42 & RE43 Compared to FRD400

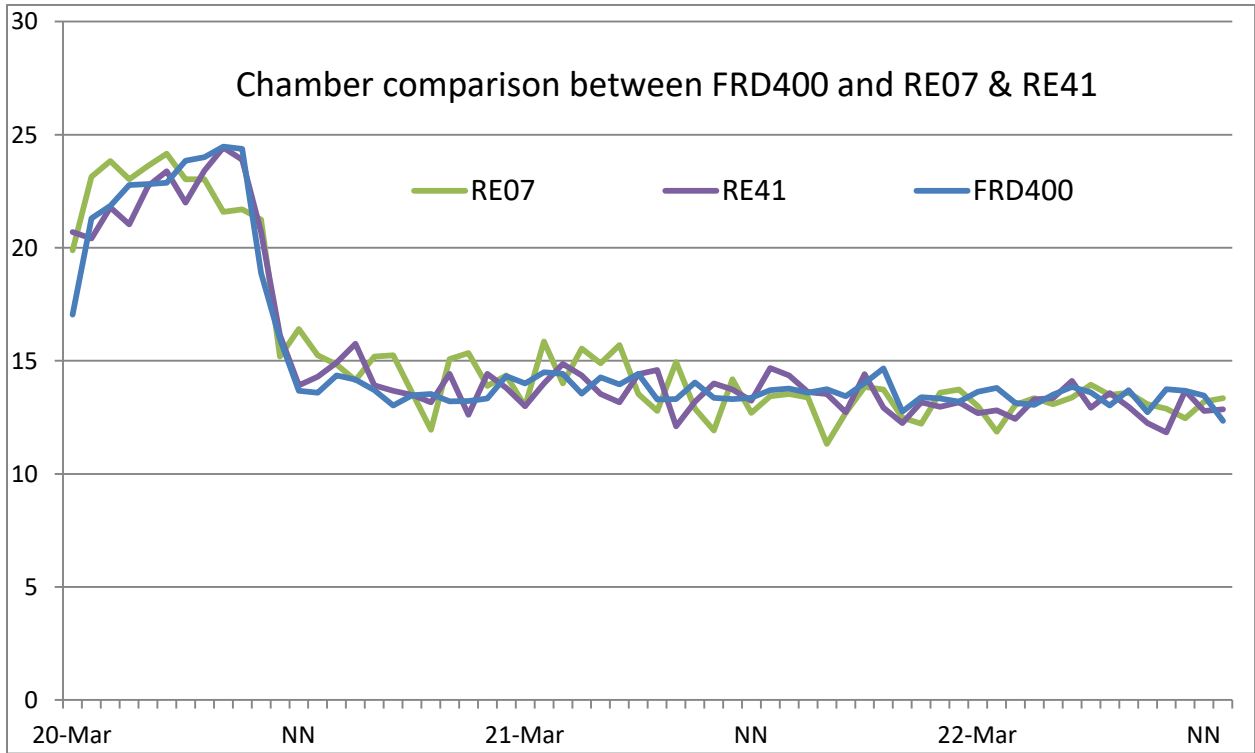


Figure 4 - RE07 & RE41 Compared to FRD400

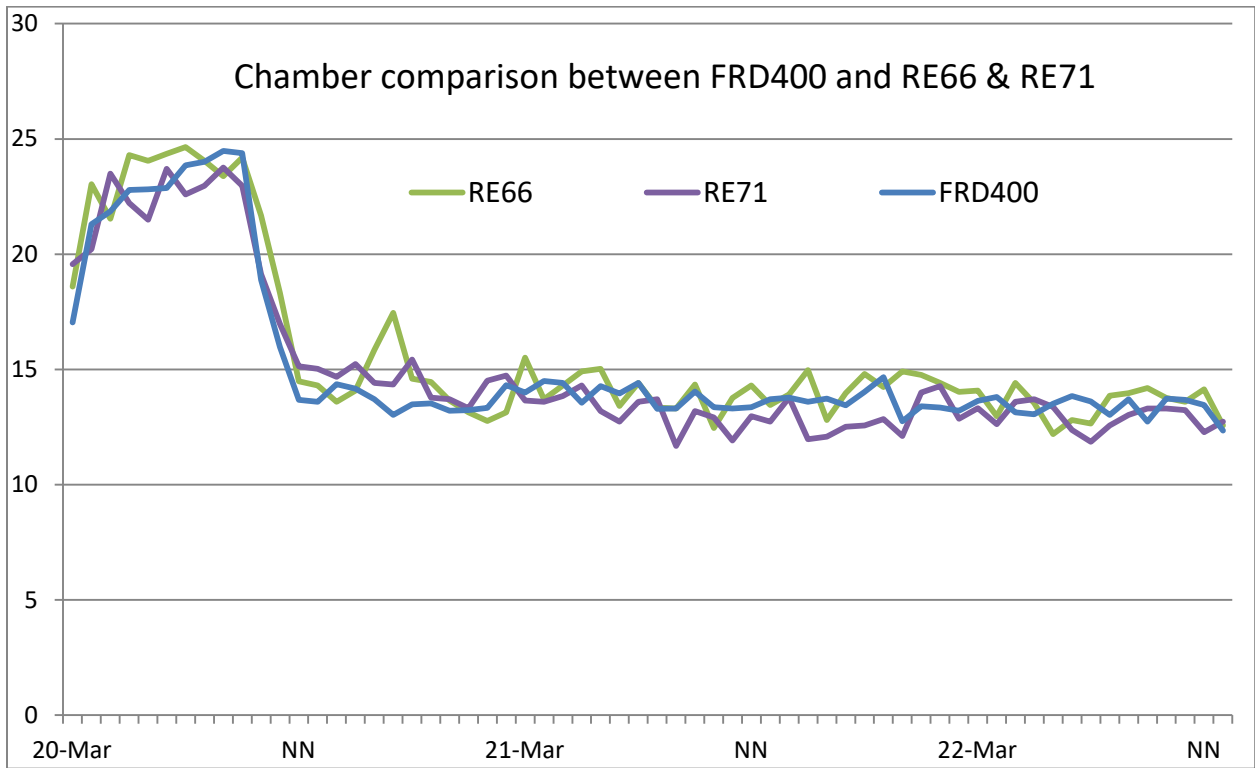


Figure 5 - RE66 & RE71 Compared to FRD400

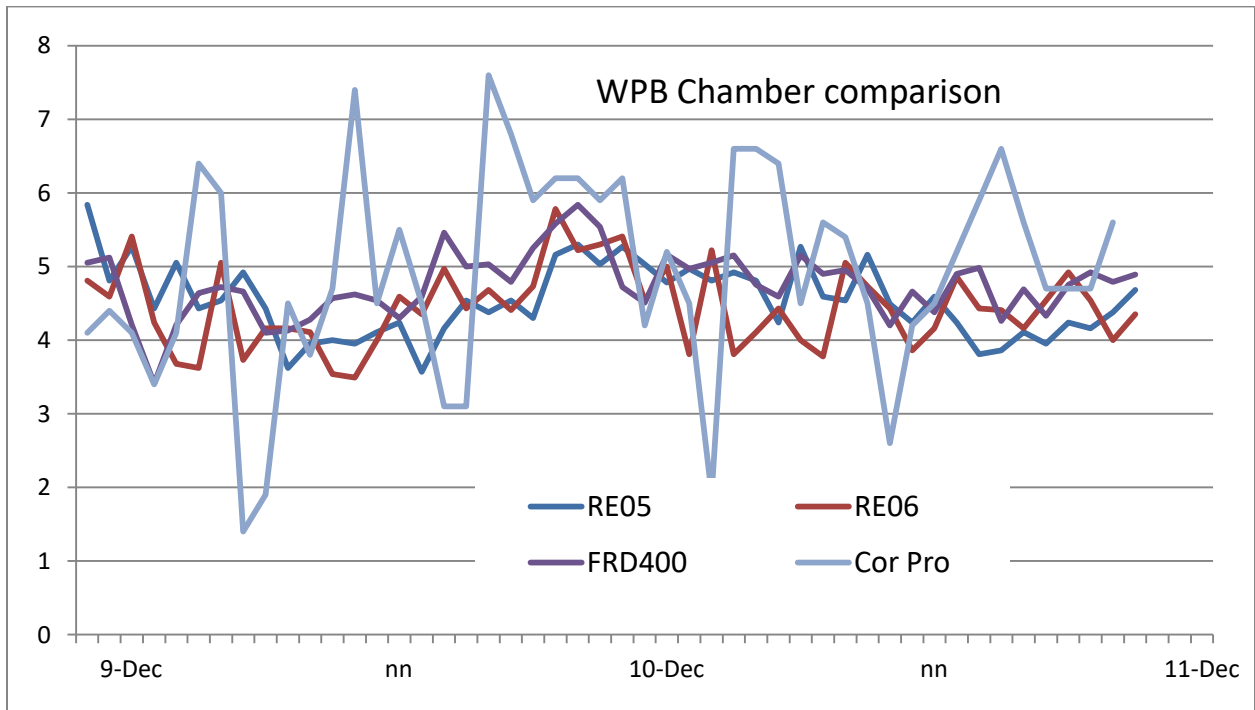


Figure 6 - Corentium Pro Compared to FRD400

Radon and Thoron in the System Exhaust

The study house is a three story residential home in Eastern Pennsylvania with about 700 square feet of basement slab and no crawl spaces. The home is over 100 years old and has a stone wall foundation. There is no gravel under the concrete slab in the basement. The radon levels with the radon mitigation system turned off for 7 days in June 2020 averaged 18.1 pCi/l (670 Bq/m³) in the basement and 4.1 pCi/l (152 Bq/m³) on the 1st floor and 3.4 pCi/l (126 Bq/m³) on the 3rd floor. The existing radon system has the fan outside and three center suction holes in the basement. The four inch radon piping to the outside fan was disconnected for this study. A new Fantech RN4EC-4 was installed in the existing basement suction piping. The exhaust from the RN4EC-4 was routed out the only basement outside window. The 4" exhaust piping was routed to about 18" above grade with a final 90 degree elbow discharging directly away from the house. After the study was completed the pre-study radon system was restored to its original configuration.

Initial radon measurements of the radon in the system exhaust were made with a RAD7. The RAD7 was set to sniff mode and used to measure the radon levels and the thoron levels in the system exhaust. The RAD7 measured about 226 pCi/l (8360 Bq/m³) of thoron and 221 pCi/l (8180 Bq/m³) of radon. Normally thoron is not an issue because its half life is only 55 seconds and decays away before it reaches a radon monitor in a basement. But even airflow of only 20 CFM (9.4 L/S) in a 4" (100mm) pipe is about 229 feet per minute (1.16 m/sec) which means it moves from soil to exhaust location in seconds. Continuous radon monitors (CRM) have different sensitivities to thoron depending on how long it takes for the thoron to diffuse into the detectors chamber. Previous testing by the author revealed that the Radon Eye might record as much as half of the thoron level as being radon. Slowing the entry of thoron into the detector would minimize this factor and not reduce the detectors ability to record the hourly radon average. The corentium pro was tested to have about a 2.5% of the thoron exposure being recorded as being radon. The slotted openings to the Corentium Pro were sealed with a 6 mil vinyl tape used to seal crawl space membranes. This reduced the thoron response to 0.7%. When the Radon Eye RD200 plus had its slotted openings taped as illustrated in Figure 7, the thoron response was reduced to about 2% to 3% of the thoron level. All of the Radon Eye monitors used around the radon system exhaust outside had their slotted openings taped.



Figure 7 - Radon Eye un-taped and taped to delay thoron

In order to quantify the radon continuously in the exhaust, two 4X6 adaptors were installed on the exhaust outlet with a short piece of 6" pipe between them. See Figure 8. This allowed the Corentium Pro to be installed in the piping to obtain hourly radon measurements. The radon level in the exhaust was measured when the airflow was varied from 20 CFM to 40 CFM to 69 CFM. (9.4 L/S, 18.8 L/S, 32.4 L/S)



Figure 8 - Corentium Pro installed in exhaust piping

The average radon concentration in the pipe did not vary significantly at 40 and 69 CFM airflow. See Figure 9. At 20 CFM airflow the averaged radon level was only about 5% lower than at the higher airflows. The consistence is likely due to the lack of stone base under the slab in combination with three center suction pits and permeable sub-slab soil. If the system was drawing air out of the basement then higher airflow would likely induce lower exhaust radon concentration. The measurements demonstrate there is not any significant dilution of soil gas with basement air at higher system vacuum and system airflow.

A 5 inch diameter flow grid was installed in the 4 inch PVC piping in the basement that allowed easy measurement of the airflow as the RN4EC-4 with its built in fan speed control was adjusted. The flow grid flow rate had been calibrated by the author in previous research work. The highest flow rate in this study of 69 CFM was achieved with the RN4EC-4 set at maximum speed.

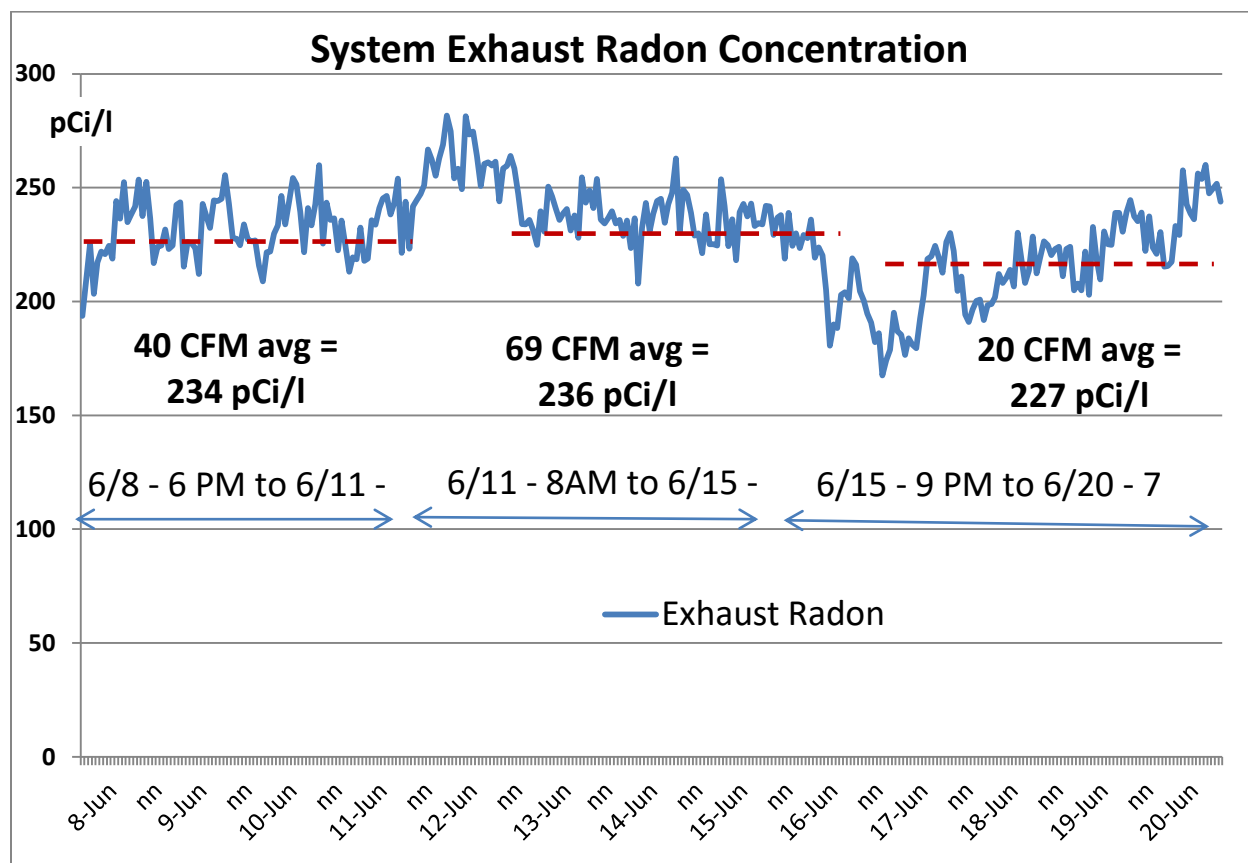


Figure 9 - Radon level of System Exhaust

Measuring Indoor Radon System Re-Entrainment

Prior to running the system exhaust outdoor diffusion measurements, six test runs were made that each had durations of five to seven days. Different CRM set-ups and placements were tried. During these initial test runs the CRM's outside were protected from rain by placing them in plastic mailboxes that had large holes drilled in the bottom of the mailbox. The system exhaust pipe size and location for four of the initial six tests was a four inch 90 degree elbow placed against the building siding at the rim joist location to simulate a typical at-grade system exhaust location. The other two tests were done with the exhaust port restricted to a 3" PVC pipe. The exhaust location was located under a window. See Figure 10.

The during five of the test runs two of the CRM's were placed about 18" from the exhaust outlet on either side of the exhaust location. See Figure 10. The average of these two CRM's for the five runs was 0.68 pCi/l to 0.99 pCi/l (25 to 37 Bq/m³) greater than backyard ambient radon levels. On one of the test runs the average of the side detectors was 1.45 pCi/l (54 Bq/m³) above backyard ambient radon levels. The total average of the six tests was about 0.4% of the exhaust concentration of about 235 pCi/l (8700 Bq/m³). These side detector measurements were slightly higher than the latter exhaust diffusion test total average of 0.5 pCi/l when the exhaust outlet was farther from the siding to accommodate the exhaust measurement detector. See Figure 12.



Figure 10 - System exhausting 225 pCi/l at 40 CFM

During all the radon diffusion study test runs a CRM was placed indoors at the window above the exhaust. See Figure 10. During five of the test runs the window was closed with the radon system exhausting either 20, or 40 or 69 CFM of airflow. In all five of these tests the indoor CRM at the closed window measured averaged levels that were almost identical to a CRM on the same 1st floor about 20 feet away (6.5 meters) in the kitchen. This indicates there was no measureable re-entrainment during these tests. In one of the study test runs with the radon system exhausting 40 CFM, a window was left open for the entire 5 days of the exposure. See open detector and window in Figure 10. In this run the radon level average at the window was 0.4 pCi/l (15 Bq/m³) greater than the kitchen CRM (1.26 pCi/l versus kitchen 0.85 pCi/l). See the results graphed in Figure 11.

During the six pre-test runs a CRM was placed in the basement close to the plywood covering the window where the system piping was exiting the basement. A second basement CRM was placed in the center of the basement. During the six initial runs the radon level average at each of these basement locations was almost identical indicating no measureable re-entrainment into the basement from the window.

Outdoor radon levels in direct alignment with the system exhaust at two foot distance from the exhaust outlet had measured spikes of about 25% of the exhaust concentration or about 40 to 50 pCi/l (1480 to 1850 Bq/m³) when there was no wind movement. During measureable ground wind

speed the radon levels two feet out from the exhaust would drop to a low of between 3 and 5 pCi/l (111 to 185 Bq/m³) or about 2% of the exhaust concentration.

The conclusion from these six test runs is the slight increase in radon levels around the exhaust location (less than 2 pCi/l – 74 Bq/m³) and the relative small area of the increase as compared to the entire circumference of the building does not appear to be capable of creating a measurable or significant increase in indoor radon levels. Although the testing was not done in the winter when the stack effect is the highest, one of the test runs from April 25 to May 5 the temperature outdoors went down to the low 40's for four of the nine days and the 4" exhaust outlet was at its lowest airflow of 20 CFM. During this period the two basement detectors and two 1st floor detectors never showed a significant difference in their results and their average results were almost identical. Under these worse case conditions no re-entrainment could be detected. During this test run the backyard radon levels climbed to over 1.0 pCi/l during four of the nights indicating no wind movement and optimal conditions for re-entrainment.

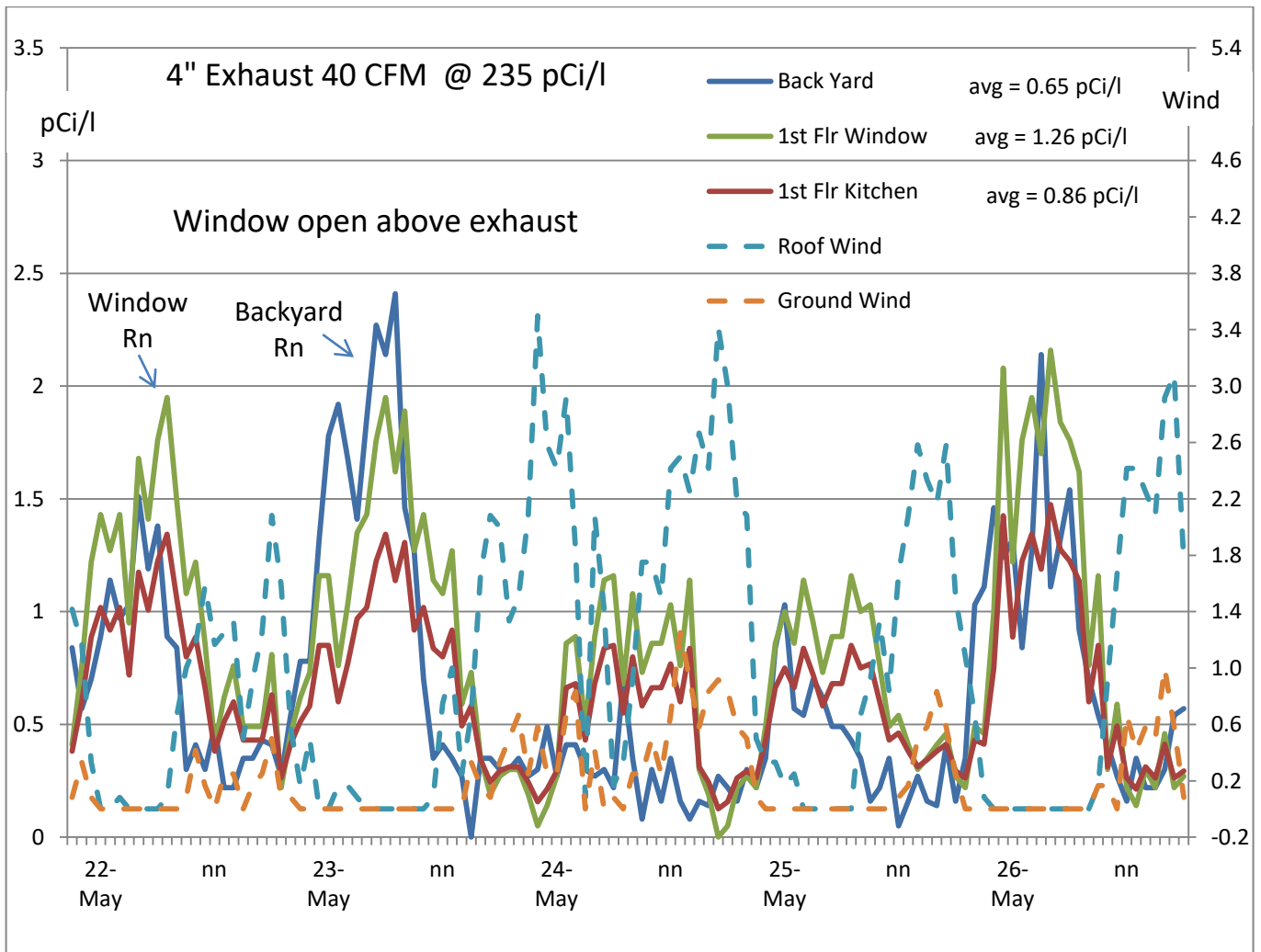


Figure 11 - System exhausting 235 pCi/l at 40 CFM with window open

CRM Location	CRM total average in pCi/l for each test run					
Test period	4/21/20 4/25/20	4/25/20 5/5/20	5/5/20 5/10/20	5/10/20 5/17/20	5/17/20 5/21/20	5/21/20 5/26/20
# Test days	4.125	9.46	4.96	6.96	4.42	4.92
Exhaust	40 CFM 4"	20 CFM 4"	69 CFM 4"	20 CFM 3"	40 CFM 3"	40 CFM 4"
Exposure days	4.125	9.46	4.96	6.96	4.42	4.92
Back yard	0.43	0.37	0.34	0.56	0.46	0.65
0.5 m left side	1.31	1.21	1.34	1.40	1.91	1.45
0.5 m right side	1.19	1.05	1.10	1.25	1.86	1.56
0.6 m out	25.5	7.3	33.1	14.8	39.4	8.3
Bas center	1.7	2.5	1.5	2.6	1.7	1.8
Bas window	1.5	2.4	1.5	2.4	1.9	2.1
1 st Flr window	0.8	1.2	0.7	1.2	0.8	1.3
1 st Flr kitchen	0.8	1.3	0.7	1.2	0.7	0.9
2 nd Floor	1.0	1.3	0.8	1.3	0.7	0.9
3 rd Floor	0.9	1.3	0.8	1.3	0.7	n/a
Notes						1 st Flr window open

Measuring Radon System Exhaust Diffusion At-Grade

In order to determine how radon diffuses in outdoor air around an at-grade ASD system exhaust, eight continuous radon monitors (CRM's) were placed in the locations indicated by the x in Figure 13. The CRM's were protected from rain exposure by placing them in tyvek envelopes and attaching them to wooden stakes. Tyvek envelopes have been demonstrated to allow easy movement of radon through the envelope while minimizing direct water intrusion from rain. During periods of predicted rain, a loose plastic bag was placed over each envelope to provide additional waterproofing while leaving the bottom of the bag open. One CRM was placed 0.5 meters directly to the side of the exhaust. The CRM's in direct alignment with the exhaust were placed at 1, 2, 3, and 4 meters from the exhaust outlet. Three CRM's were placed 1, 2, and 3 meters at a 45 degree angle from the exhaust outlet. All of the monitors distances were adjusted if the exhaust outlet distance from the building was varied to accommodate a change from 4" exhaust outlet size to 3" outlet size.



Figure 12 - CRM and weather station placement in ASD exhaust stream

Figure 12 displays the placement of the CRM's that were protected in Tyvek envelopes and mounted to wood stakes. The chargers for the CRM's were placed in plastic mailboxes on the ground. The farthest CRM in direct alignment with the exhaust is four meters (13 feet) away from the outlet. The furthest CRM's placed at a 45 degree angle to the exhaust is three meters (9.75 feet) away from the outlet. This CRM is not visible in the photo in Figure 12. There is one CRM that is 0.5 meters (19.5 inches) to the side of the exhaust location. A ninth CRM is 40 feet away from the exhaust on a picnic table in the backyard of the residence. The six inch, 200 mm, piping was used to place a CRM inside the exhaust stream to measure the radon levels in the exhaust continuously.

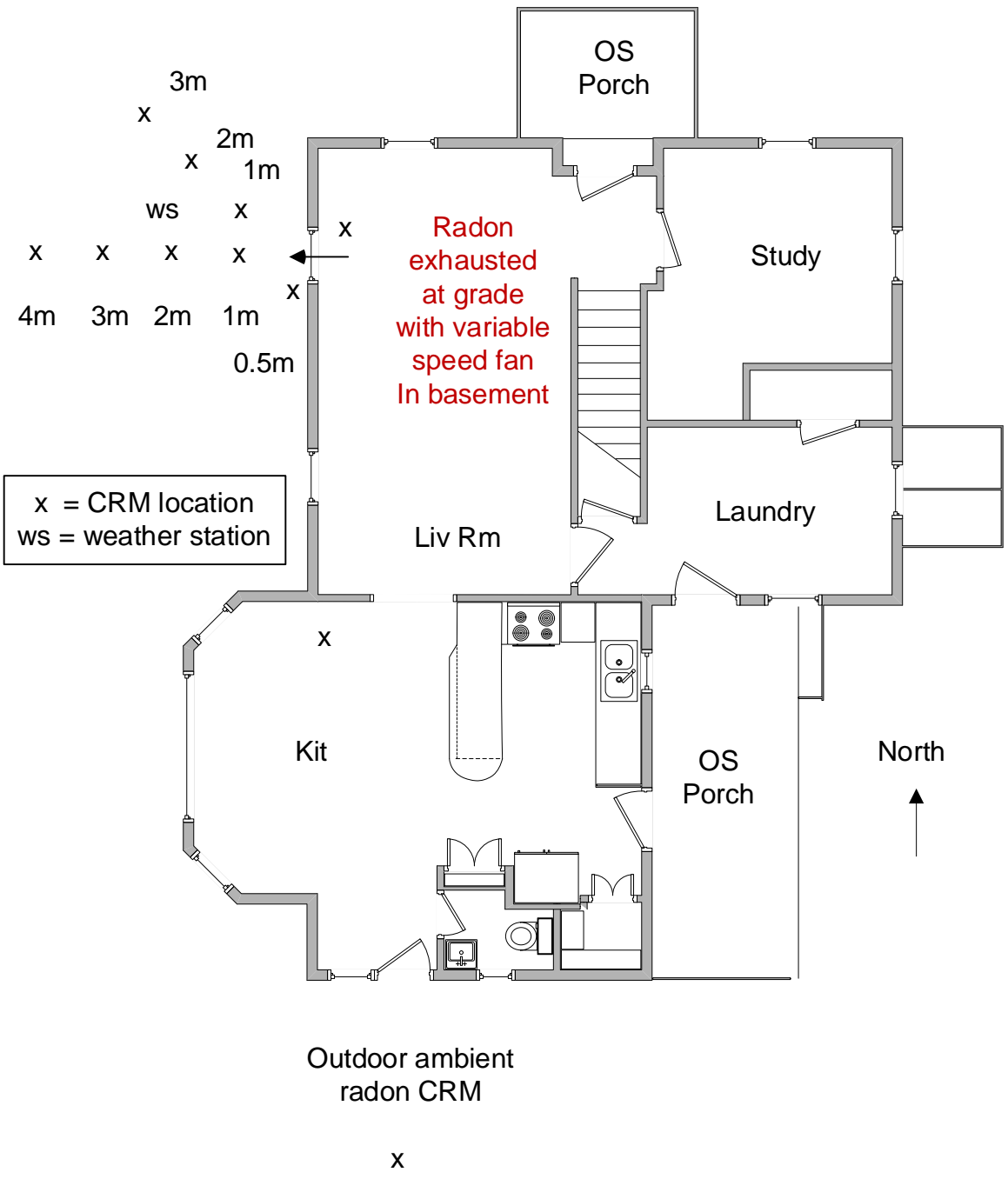


Figure 13 - CRM placements indicated by "x"
Weather Station indicated by "ws"

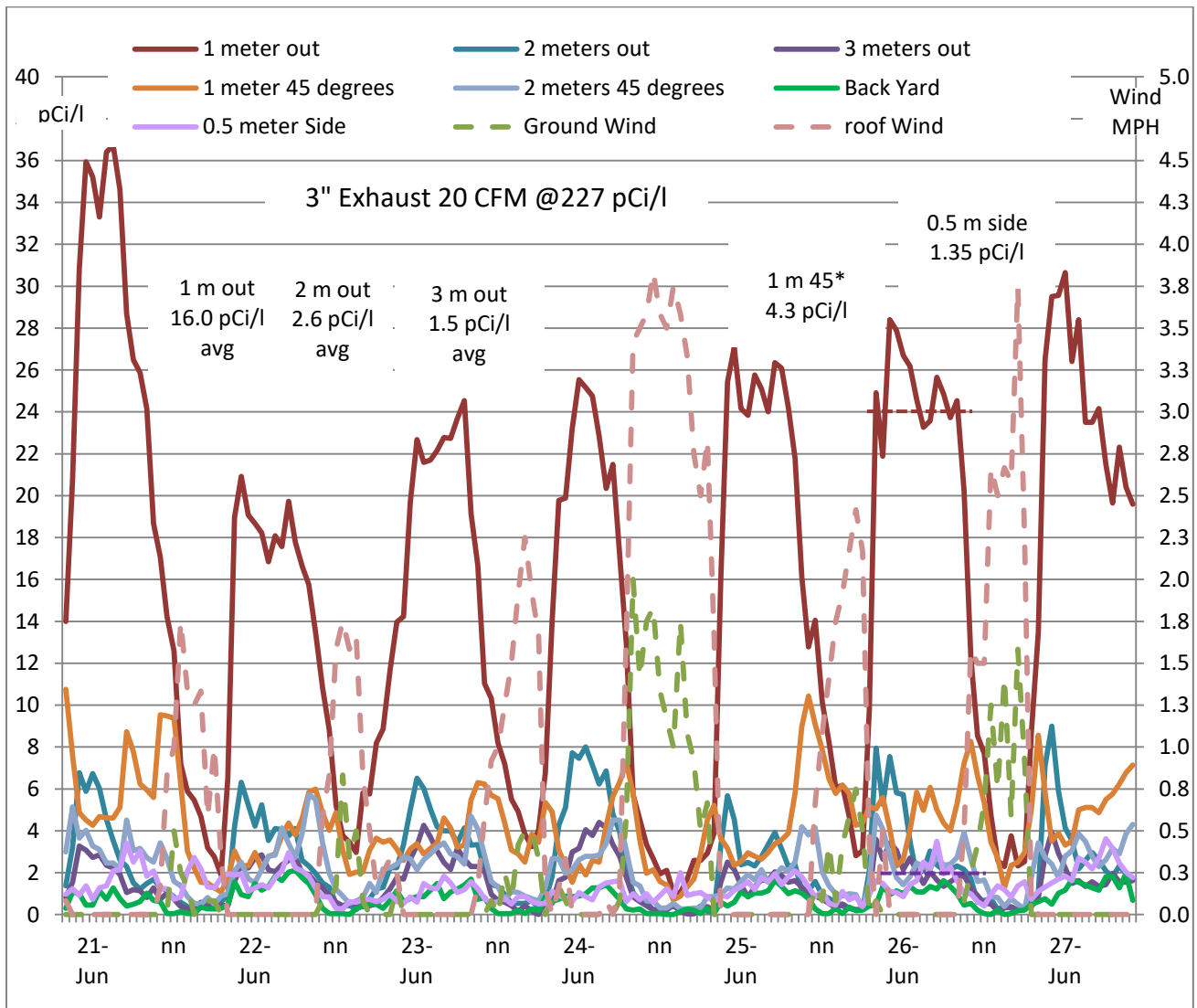


Figure 14 - Three inch exhaust at 20 CFM and 227 pCi/l (8400 Bq/m³)

Discussion of 3 inch (100mm) exhaust at 20 CFM (9.44 L/s) (Figure 14)

The pink dashed lines in Figure 14 depict the wind in MPH as measured by the roof top weather station. The green dashed lines are depicting the wind MPH as measured by the ground weather station. The weather station can be seen in Figure 12. Midnight is depicted by the date. Note that in every case there was no measureable wind from a few hours before midnight to about 8 AM. During these windless periods the red solid line depicting the radon levels at 1.0 meter in direct line with the exhaust would spike up to its maximum concentration of 21 to 36 pCi/l (780 to 1330 Bq/m³). At 2.0 meters out the green solid line spiked to a maximum of about 8.0 pCi/l (300 Bq/m³). At 3.0 meters out the purple solid line spiked to a maximum of about 4.0 pCi/l (150 Bq/m³). The orange solid line depicting the radon level at 1.0 meter at a 45 degree angle from the direction of the exhaust is spiking to about 4 to 10 pCi/l (150 to 370 Bq/m³) but the peaks are all happening just as the wind is

transitioning from no wind to some wind. This implies that the plume of spiked radon around the 1.0 meter area in direct line of the exhaust during the windless period is being spread towards the monitor set at 45 degrees when the wind starts moving it. When the wind on the roof is at its maximum of about 2 to 3 mph, the ground based wind is typically less than half the MPH speed of the roof or about 0.5 to 1.5 MPH. During the peak wind periods all the radon monitors are below 4.0 pCi/l (150 Bq/m³).

The dark green line on the bottom of the chart is the radon levels in the backyard which is considered the baseline radon level. See monitor locations in Figure 13. The pink line is the radon levels 0.5 meters directly to the side of the exhaust. The exhaust airflow in this run is at its lowest tested flow rate of 20 CFM (9.4 L/s) with a 3 inch orifice which is exiting the exhaust at about 400 feet per minute (2.03 m/s). Note that the pink and green lines track each other as the levels rise and fall. The side exhaust pink line is averaging 1.35 pCi/l (50 Bq/m³) while the backyard is averaging 0.73 pCi/l (27 Bq/m³) or a difference of 0.62 pCi/l (23 Bq/m³) for the entire six days of testing. The averages of 5 CRM locations are depicted on the chart in each of the charts. The total run average for each CRM in each run is also tabulated in Table 1 below and includes the difference between the CRM in the backyard and the CRM 0.5 meters to the side of the exhaust.

Discussion of 4 inch (100mm) exhaust at 20 CFM (9.44 L/s) (Figure 15)

Figure 15 depicts the same 20 CFM (9.4 L/s) flow but with a 4 inch exhaust outlet that has an exit flow rate of 229 feet per minute (1.16 M/S). This time the red line depicting the radon levels at 1.0 meter in direct line with the exhaust is peaking during windless periods at various radon levels ranging from about 18 pCi/l (666 Bq/m³) to about 42 pCi/l (1554 Bq/m³). The range of variation is similar to the previous discussed run at 20 CFM (9.4 L/s) using a 3 inch orifice. Once again the CRM at 1.0 meter at a 45 degree angle tends to peak just as the weather station records wind speed starts increase to increase. The pink and green lines representing the backyard and side exhaust CRMs again track each other with the side exhaust averaging slightly higher at 1.30 pCi/l (48 Bq/m³) than the backyard average of 0.61 pCi/l (23 Bq/m³) which is an average difference of 0.69 pCi/l (25 Bq/m³) for the entire four days of testing. The average level of the five CRM monitors included in the chart are very similar to the averages displayed in the Figure 14 chart.

The CRM at 2.0 meters in direct exhaust linement in Figure 15 did have one spike to 16 pCi/l (592 Bq/m³) versus the other windless periods during this test only spiking to 2.0 pCi/l to about 4.0 pCi/l. The previous test in Figure 14 had multiple spikes to 8.0 pCi/l (296 Bq/m³) at that location which appears due to the higher airflow velocity induced by the 3 inch orifice. The reason for this single 16 pCi/l spike at the lower velocity rate appears to be a heavy rainfall of about 1.5 inches from 3 PM until midnight. In general the 2.0 meter in line with the exhaust CRM had lower radon levels using the 4 inch exhaust than the 3 inch outlet. The 4 inch orifice has a 43% lower airflow velocity of 229 feet per minute (1.16 m/s) versus the 3 inch orifice velocity of 400 feet per minute (2.03 m/s) The overall average of the 3 inch orifice at 2.0 meters was 2.6 pCi/l (96 Bq/m³) versus 2.1 pCi/l (78 Bq/m³) average for the 4 inch orifice which does include the one rain induced spike. If the average radon results for the 4 inch orifice included the radon levels of the other windless period and not the one rain spike, the overall average would be 1.76 pCi/l.

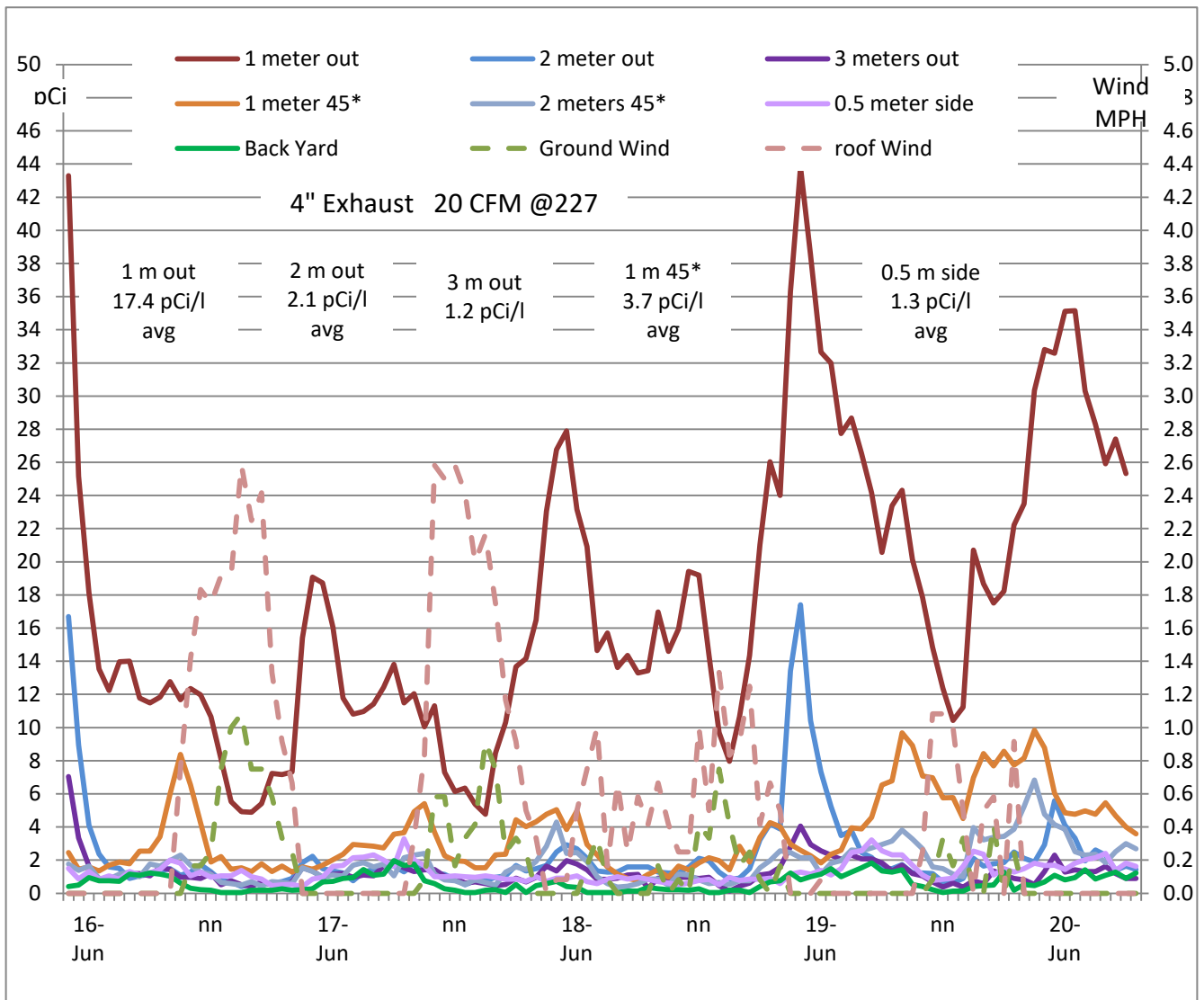


Figure 15 - Four inch exhaust at 20 CFM and 227 pCi/l (8400 Bq/m³)

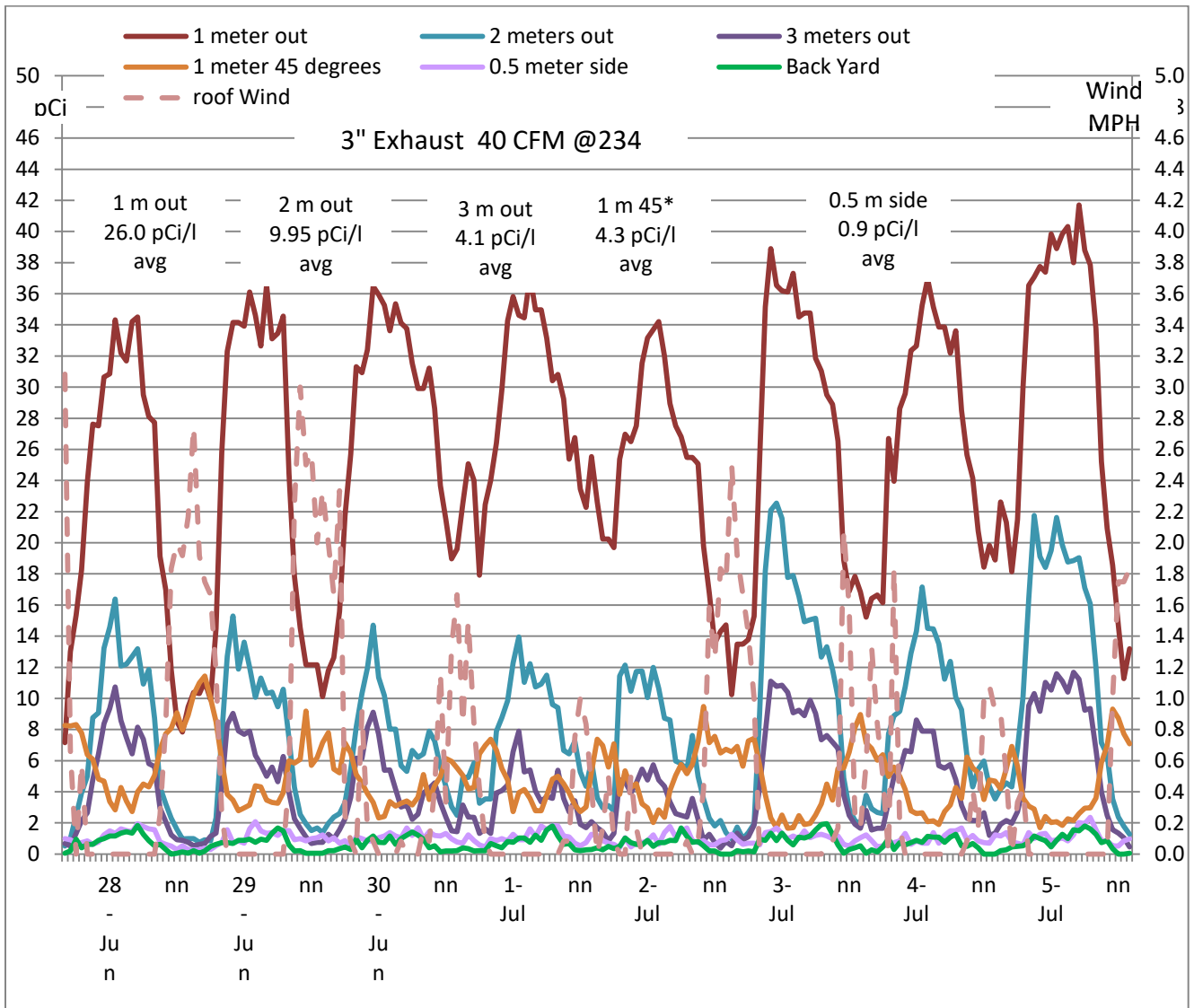


Figure 16 - Three inch exhaust at 40 CFM and 234 pCi/l (8660 Bq/m³)

Discussion of 3 inch (75 mm) exhaust at 40 CFM (18.88 L/s) (Figure 16)

Figure 16 depicts the 40 CFM (18.9 L/s) flow rate with a 3 inch (75 mm) exhaust outlet that has an exit velocity of 815 feet per minute (4.14 m/s). In this run the red line depicting the radon levels at 1.0 meter in direct line with the exhaust is peaking during windless periods at radon levels ranging from about 34 to about 40 pCi/l (1258 to 1480 Bq/m³). This is consistently higher than the previous 3 inch orifice at 20 CFM (9.4 L/s) with a range of 18 to 34 pCi/l (666 to 1258 Bq/m³). Higher velocity exhaust creates higher at-grade radon levels in the path of the exhaust. The averages at 2.0 meters and 3.0 meters in direct line of the exhaust averaged about 10% to 30% higher than the same setup at 40 CFM (18.9 L/s). The radon levels at 0.5 meters to the side of the exhaust once again measured lower at 0.55 pCi/l average (20 Bq/m³) than the same location at 40 CFM (18.9 L/s).

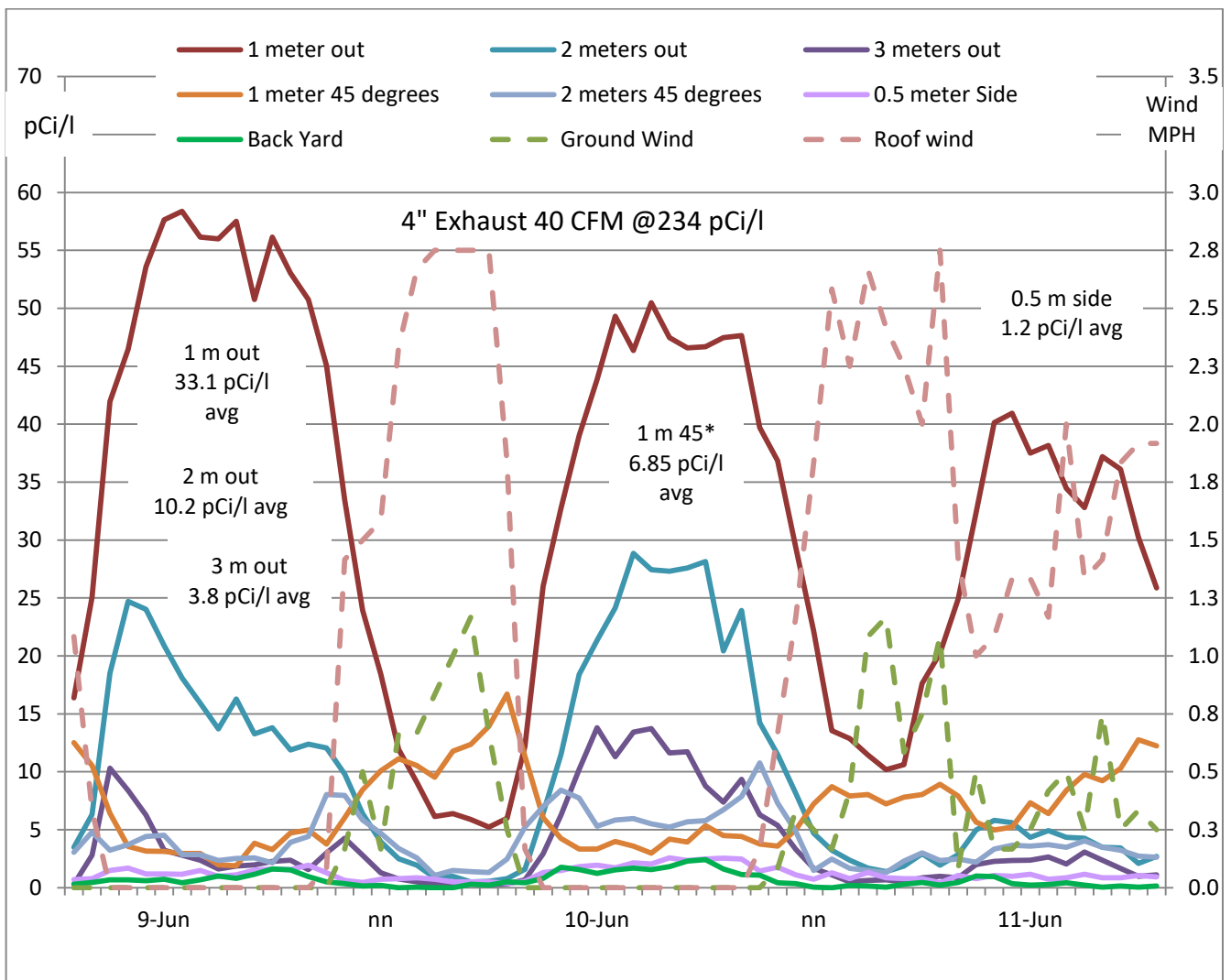


Figure 17 - Four inch exhaust at 40 CFM and 234 pCi/l (8660 Bq/m³)

Discussion of 4 inch (100 mm) exhaust at 40 CFM (18.88 L/s) (Figure 17)

Figure 17 depicts the 40 CFM with a 4 inch (100 mm) exhaust outlet that has a flow rate of 458 feet per minute (2.33 m/s). In this run the red line depicting the radon levels at 1.0 meter in direct line with the exhaust is peaking during windless periods at radon levels ranging from about 38 pCi/l (1406 Bq/m³) to about 55 pCi/l (2035 Bq/m³). This is consistently higher than the previous 4 inch orifice at 20 CFM (9.4 L/s) with a range of 18 pCi/l (666 Bq/m³) to 42 pCi/l (1554 Bq/m³). The averages at 2.0 meters and 3.0 meters in direct line of the exhaust also averaged 4.8 and 3.1 times higher than the same setup at 20 CFM (9.4 L/s). The radon levels at 0.5 meters to the side of the exhaust measured about the same at the higher velocity 1.2 pCi/l (44 Bq/m³) as the lower velocity 1.3 pCi/l (48 Bq/m³) even though the quantity of radon atoms being released into the outdoors approximately doubled.

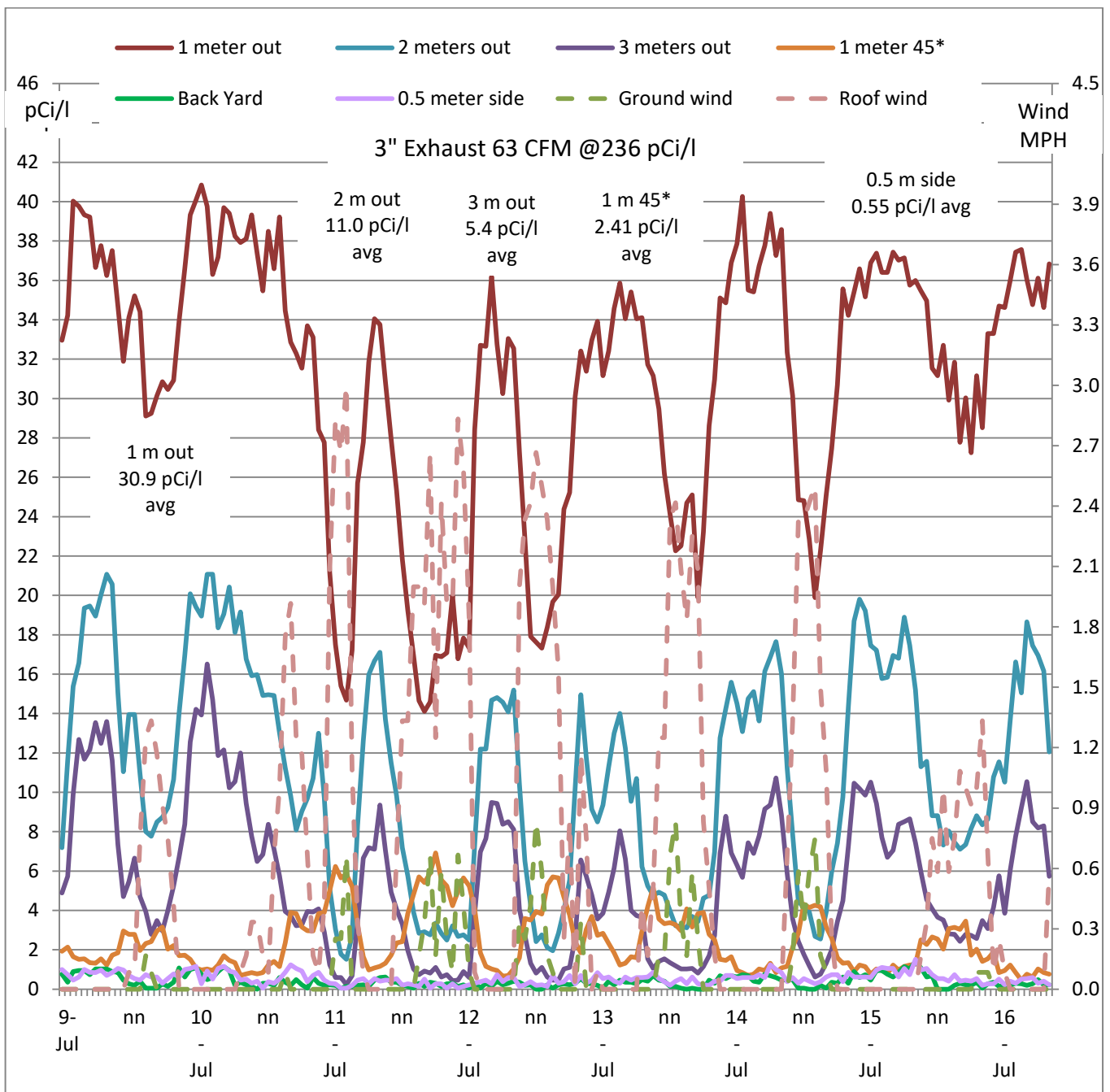


Figure 18 - Three inch exhaust at 63 CFM and 236 pCi/l (8730 Bq/m³)

Discussion of 3 inch (75 mm) exhaust at 63 CFM (29.7 L/s) (Figure 18)

Figure 18 depicts the 63 CFM (29.7 L/s) with a 3 inch (75 mm) exhaust outlet that has a flow rate of 1283 feet per minute (6.52 m/s). In this run the red line depicting the radon levels at 1.0 meter in direct line with the exhaust is peaking during windless periods at radon levels ranging from about 34 pCi/l (1258 Bq/m³) to about 40 pCi/l (1480 Bq/m³). This is the same peak range as measured when the 4 inch exhaust was at 40 CFM (18.9 L/s). Exhaust velocity increase from 815 feet per minute

(4.14 m/s) to 1283 feet per minute (6.52 m/s) did not appear to increase radon peak levels measured at 1.0 meter in the path of the exhaust. The average at 1.0 meter did increase about 19% so there was some increasing radon at 1.0 meter when the exhaust was increased. The averages at 2.0 meters and 3.0 meters in direct line of the exhaust also averaged 4.7 and 3.4 times higher than the same setup at 40 CFM(18.9 L/s) . The radon levels at 0.5 meters to the side of the exhaust however measured lower at the higher velocity even though the quantity of radon atoms being released into the outdoors approximately doubled.

Discussion of 4 inch (100 mm) exhaust at 69 CFM (32.6 L/s) (Figure 19)

Figure 19 depicts the 69 CFM (32.6 L/s) with a 4 inch (100 mm) exhaust outlet that has a flow rate of 790 feet per minute (4.01 m/s). In this run the red line depicting the radon levels at 1.0 meter in direct line with the exhaust is peaking during windless periods at radon levels ranging from about 55 pCi/l (2035 Bq/m³) to about 70 pCi/l (2590 Bq/m³). This is a slightly higher peak range than was measured when the 4 inch exhaust was at 40 CFM (18.9 L/s). Exhaust velocity increase from 458 feet per minute (2.33 m/s) to 790 feet per minute (4.01 m/s) did not significantly increase radon peak levels measured at 1.0 meter in the path of the exhaust. The average at 1.0 meter did increase about 34% compared to the average at 40 CFM (18.9 L/s). The averages at 2.0 meters and 3.0 meters in direct line of the exhaust averaged about the same as the averages at 40 CFM (18.9 L/s). The radon levels at 0.5 meters to the side of the exhaust did measure lower at the higher 69 CFM velocity. The radon levels in the outdoor area not in the path of the exhaust needs to be measured to be able to subtract out the background radon levels in order to determine the actual radon level increase at 0.5 the side of the exhaust. In table 1 with all the averages listed the bottom row gives the difference from these two locations.

69 CFM flow with 4" exhaust orifice

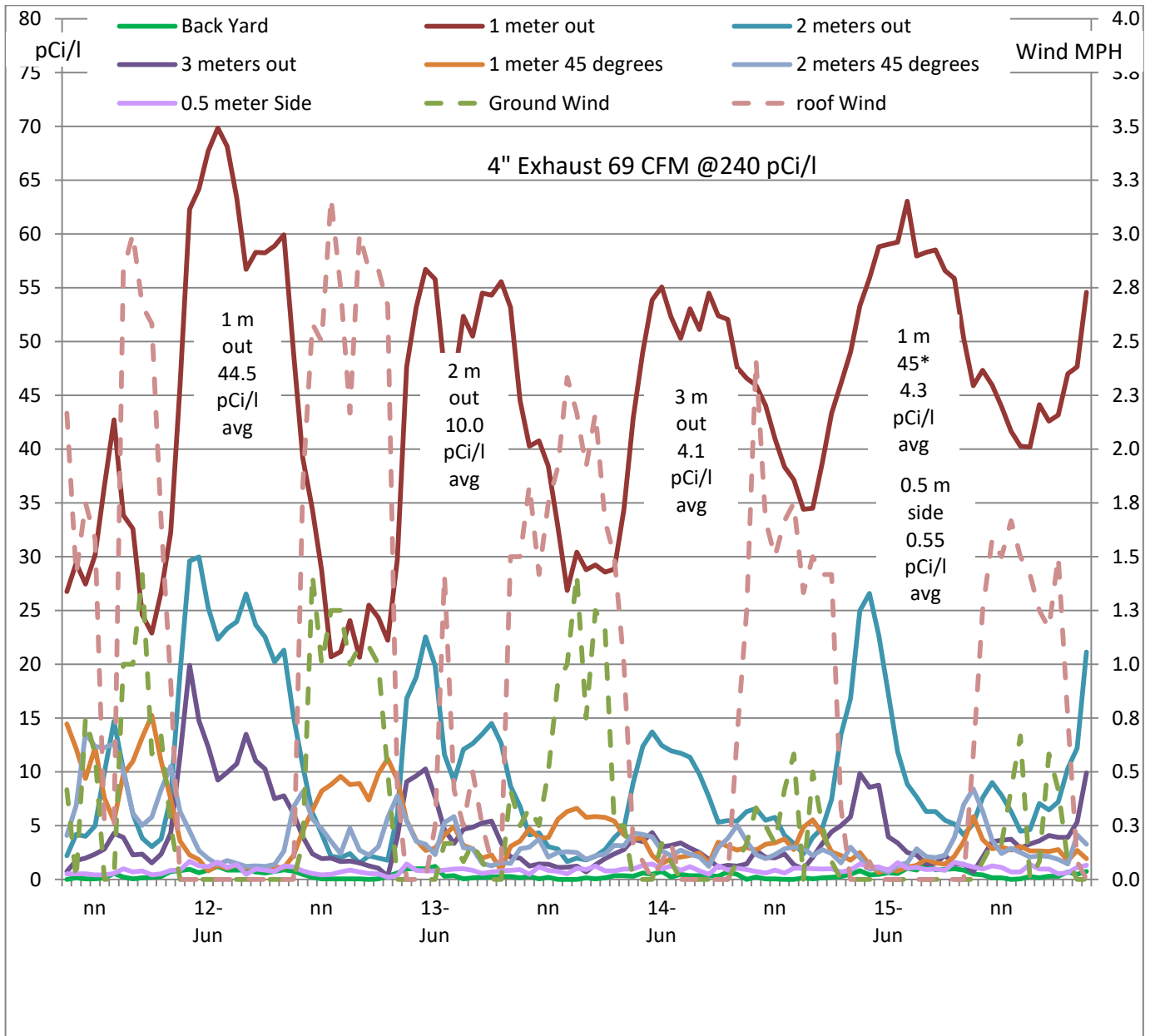


Figure 19 - Four inch exhaust at 63 CFM and 236 pCi/l (8730 Bq/m³)

CRM Location	CRM total average in pCi/l for each test run minus ambient radon					
# Test days	2.7	4.5	4.2	6.6	8.0	7.4
Distance from Exhaust	20 CFM 3"	20 CFM 4"	40 CFM 3"	40 CFM 4"	63 CFM 3"	69 CFM 4"
Back yard	0.73	0.61	0.68	0.68	0.53	0.4
1 meter out	15.3	16.76	25.34	32.48	30.39	44.14
2 meters out	1.85	1.5	7.61	9.54	10.44	9.55
3 meters out	0.78	0.56	3.75	3.08	4.89	3.72
4 meters out	0.15	0.17	0.85	1.06	2.15	0.65
1 meter 45*	3.59	3.11	4.32	6.17	1.88	3.91
2 meters 45*	1.46	1.21	3.87	3.37		3.28
3 meters 45*	0.18	0.19	1.44	1.25	1.19	1.34
0.5 meter side	0.62	0.69	0.35	0.53	0.02	0.5

Table 1 - Average radon level for each CRM in each run

Discussion of the averages of each CRM location for each test run

Table 1 depicts the change in the average radon levels at each location as the flow rate is adjusted and the exhaust outlet is varied from 3" (75mm) to 4" (100mm). Each of the results is the average that was measured over the entire test length that is indicated by # test days row. There is no factoring in the effect of wind which as shown in Figure 14 through Figure 19 to dramatically affects the results.

At 1.0 meter in direct alignment with the exhaust the higher flow for each orifice size produces a higher average radon level. In each case the 4 inch exhaust orifice produces a higher radon level at 1.0 meter than a 3 inch exhaust orifice even though the 4" orifice has a lower flow rate. At 2.0, 3.0 and 4.0 meters out the orifice size does not appear to make a consistent difference. The increased volume of air from 20 CFM to 40 CFM does dramatically increase radon average at 2.0 and 3.0 meters out. At 4.0 meters out the average radon levels are still elevated from the exhaust but with low amount of 0.15 to 2.15 pCi/l.

The average increase of radon to the side of the exhaust is less than 1.0 pCi/l (37 Bq/m³) in each test run with the average of all tests only being a 0.5 pCi/l (18 Bq/m³) increase. The radon levels 0.5 meters to the side of the exhaust are in fact less than the radon levels 4.0 meters in direct line with the exhaust.

Distance from exhaust	20 CFM	40 CFM	69 CFM
1.0 meter out	7.1%	12.4%	15.8%
2.0 meters out	0.7%	3.7%	4.2%
3.0 meters out	0.3%	1.5%	1.8%
4.0 meters out	0.1%	0.4%	0.6%
1.0 meter 45*	1.5%	2.2%	1.2%
2.0 meters 45*	0.6%	1.5%	1.4%
3.0 meters 45*	0.1%	0.6%	0.5%
0.5 meters side	0.3%	0.2%	0.1%

Table 2 - Radon level range as percentage of exhaust.

Exhaust Rn	300 pCi/l	1000 pCi/l	10,000 Bq/m ³	37,000 Bq/m ³
0.1%	0.3	1.0	10	37
1%	3.0	10.0	100	370
5%	15.0	50.0	500	1850
10%	30.0	100.0	1000	3700

Table 3 - Radon level range as percentage of exhaust.

Discussion of the percentage of exhaust levels for each CRM location

Table 2 lists the percentage of the exhaust concentration at each location if both the 3" orifice and 4" orifice average concentrations are averaged together to simplify the chart. This allows a crude extrapolating what the average concentration would be if the exhaust was a higher or lower concentration than was the test house. The average results for each location do not make any correction factors for the variation in wind direction or speed during each of the tests. See Figure 14 through Figure 19 to observe the effect of the wind.

An example of the variation you might see in other homes with higher exhaust levels is depicted in Table 3. The table lists the results you would have if the radon system exhaust was 300 or 1000 pCi/l

which is 4 times higher than the study house. The average concentration at 1.0 meter in front of the exhaust with a flow rate of 69 CFM would be an average of about 158 pCi/l (5846 Bq/m³). If the same radon concentration in the exhaust had an airflow of only 20 CFM the radon concentration at 0.5 meters to the side of the exhaust would be about 3.0 pCi/l (111 Bq/m³).

Study Conclusions

The results of the study indicate that radon system exhaust of about 234 pCi/l (8658 Bq/m³) vented at-grade directly away from the house produced on average radon levels around the exhaust location that were never greater than 2.0 pCi/l (74 Bq/m³) above the ambient radon levels. The average radon level beside the exhaust for the entire study was 0.5 pCi/l (18 Bq/m³) above ambient. When you consider that this portion of the exterior rim joist (about 1 meter) has slightly elevated radon as compared to the entire perimeter it appears from this study it is extremely unlikely that at-grade radon system exhaust could raise the indoor radon levels even if the exhaust concentration was four times or more higher. During the study no elevated indoor radon was measured that could be attributed to system exhaust except when a window directly above the exhaust was left open for four days with the system airflow of 40 CFM. During the open window test the indoor radon levels at the window was 0.4 pCi/l (15 Bq/m³) higher than another CRM twenty feet away. Lower exhaust rates did produce a higher though insignificant radon level to the side of the exhaust. Exhaust flow rates less than 20 CFM were not tested. This study was also done in the summer months when stack effect that causes outdoor to indoor rim joist flow rates was minimal. Further studies should be considered with a building with significantly higher radon exhaust in combination with low flow rates and significant openings into the building during periods of strong stack effect.

Although the radon levels to the side of the exhaust were very low there was significantly elevated radon levels at one meter in direct line with the exhaust of about 7% to 16% of the exhaust concentration. The average at 2 meters dropped to less than 5% and at 3 meters to less than 2% and at four meters less than 1% of the exhaust concentration. One meter away at a 45 degree angle the concentration was less than 2.5% of the exhaust concentration. At 2 meters at a 45 degree angle it was less than 2% and at 3 meters at a 45 degree angle it was less than 1% of the exhaust concentration. This study indicates the location of grade level exhaust should not be direct towards any occupied location within 3 to 4 meters of the exhaust outlet in a area that is less than 45 degrees angled from the exhaust direction.

References

- 1) Scott A - Project Summary Installation and Testing of Indoor Radon Reduction Techniques in 40 Eastern Pennsylvania Houses, EPA/600/S8-88/002 Feb. 1988, Arthur G. Scott
- 2) Scott A, Robertson A - Project Summary Follow-Up Alpha-Track Monitoring in 40 Eastern Pennsylvania Houses with Indoor Radon Reduction Systems (Winter 1987-88) EPA/600/S8-88/098 Jan. 1989, Arthur G. Scott and Andrew Robertson

- 3) Scott A, Robertson A - Project Summary Follow-Up Alpha-Track Monitoring in 40 Eastern Pennsylvania Houses with Indoor Radon Reduction Systems (December 1988 – December 1989) EPA/600/S8-90/081 Feb. 1991
- 4) Findlay W, Robertson A, Scott A - Project Summary Follow-Up Durability Measurements and Mitigation Performance Improvement Tests in 38 Eastern Pennsylvania Houses Having Indoor Radon Reduction Systems EPA/600/S8-91/010 May 1991,
- 5) Henschel D - Radon Reduction Techniques for Existing Detached Houses, Technical Guidance (Third Edition) for Active Soil Depressurization Systems. EPA/625/R-93/011 October 1993
- 6) Radon Mitigation Standards EPA 6402-R-93-078 October 1993 (Revised April 1994)
- 7) Neff D, Meroney R, El-Badry H - Project Summary, Physical and Numerical Modeling of ASD Exhaust Dispersion Around Houses. EPA/600/SR-94/115 August 1994
- 8) Henschel D, Scott A - Causes of elevated post mitigation radon concentrations in basement houses having extremely high pre-mitigation levels; Proceedings of the 1991 International Symposium on Radon and Radon Reduction Technology 2, U.S. Environmental Protection Agency; Research Triangle Park, NC. 1991. (Preprints IV.1-17)
- 9) Henschel D. - Re-entrainment and dispersion of exhausts from indoor radon reduction systems: Analysis of tracer gas data. *Indoor Air*. 1995;5(4):270–284.
- 10) Coughlin, R 1994 Field testing of effects of ASD exhaust on re-entrainment into a house (Masters Thesis), University Park, PA: Pennsylvania State University
- 11) Maeda, L and Hobbs, W 1996 Outdoor radon concentrations in the vicinity of an active home radon mitigation system, *Proceedings of the 1996 International Radon Symposium* (I1 -4.7), Fletcher, NC: AARST
- 12) M. Brossard, M. Brascoupé, C. Brazeau-Ottawa, R. Falcomer, W. Ottawa, and J. Whyte - Residential Radon Mitigations at Kitigan Zibi Anishinabeg: Comparison of Above Ground Level (Rim Joist) and Above Roof Line Discharge of Radon Mitigation Sub-Slab Depressurization Systems, *Health Physics*, V 102, pp S43-S47, May 2012.
- 13) Bernier, J and Brossard, M 2013 Outdoor Radon Dispersion: Comparison of Lateral vs. Vertical Exhaust of Radon Sub Slab Depressurization Systems, Maniwaki, QB: Kitigan Zibi Anishinabeg and Montreal, QB: Health Canada Quebec Regional Office (June 20 Teleconference)
- 14) M. Brossard, C. Brazeau-Ottawa, R. Falcomer - Radon Mitigation in Cold Climates at Kitigan Zibi Anishinabeg, , and J. Whyte, *Health Physics*, V 108, pp S13-S18, Feb 2015.

- 15) Summary Report on Active Soil Depressurization (ASD) Field Study
<https://www.canada.ca/en/health-canada/services/environmental-workplace-health/radiation/radon/summary-report-active-soil-depressurization-field-study.html>
- 16) National Standard of Canada “Radon mitigation options for existing low-rise residential buildings” CAN/CGSB-149.12-2017