RADON DISCHARGE LOCATIONS THAT ARE SHOWN TO AFFECT INTERIOR RADON CONCENTRATIONS NEGATIVELY

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Abstract

Passive radon mitigation systems installed as RRNC during new home construction were found to have discharge locations close to walls extending vertically above them. Radon concentrations larger than the EPA action level were measured even after activation of these systems and various tests were done to lower the concentrations further. By process of elimination, the discharge locations were the last potential cause. Rerouting the vent pipes to bring the discharge location in compliance with current standards lowered the radon levels on multiple floor levels. We will first review discharge locations in mitigation standards, then review the differences between flue gas exhaust and radon mitigation discharges as well as typical attic venting methods and its link to re-entrainment. Lastly, the radon measurements in these houses will be discussed in detail. Documenting these re-entrainment cases may serve as an example that even after activation of passive radon mitigation systems, homes with radon problems above the EPA action level can exist merely due to the fact that the discharge location requirement in US standards for new homes had not been followed.

Discharge Locations in Standards and Guidelines

There is a disparity between requirements for the discharge location in radon mitigation standards for existing and new residences implemented in the US starting with the EPA document (USEPA, 1993) permeating through all other US radon mitigation standards (USEPA, 1995; IRC, 2006; AARST, 2006) and the rest of the world, such as Canada and countries in Europe. The EPA required the radon discharge location to be above the eave line of the roof with the discharge pointing vertically upwards, preferably above the highest section of the roof, at least 10 feet above ground, 10 feet from reentry points into the conditioned space of the building, and if the latter is not possible, at least two feet above any nearby reentry point. Later chimney flues were added to the re-entry distance requirements (ASTM, 2013; ASTM, 2008) and the requirement that the discharge was not allowed within 10 feet from a vertical wall that extends above the discharge (ANSI/AARST, 2013). To be clear, in certain regulated states in the US this is mandated, and in unregulated states this only rises to a voluntary self-regulation in the industry by professionals who hold specific radon industry certifications. Furthermore, this is formulated to an even weaker level in current guidelines outside the US, such as in Canada (CMHC, 2010) and countries in Europe (Roserens, 2000; WHO, 2009; Scivyer, 2012), which merely give an advisory guidance in the sense of a ‘best practice’, to discharge radon above the roof, yet allow radon in some of these guidelines to be discharged as low as the rim joist near ground level. Where applicable, the mandated or voluntary industry standards hold in the US for Active Soil (or Membrane) Depressurization. On the contrary, H(E)RV type whole house ventilations systems may have rim joist discharges in all of the US. It has also been pointed out that in the US such stringent requirements in industry standards are not in place for heating and furnace flue exhaust discharges. These used to be placed above roofs but more recently with high energy efficient furnaces are seen near ground level in many new buildings. Some have argued that the danger of a radon vent discharge is similar to flue exhaust gas and therefore the requirements on the discharge locations may be similar to the vent terminal clearances for combustion gases. Others have said that no significant differences were seen when discharging radon above roof and near ground (Scott, 2015). Therefore, the differences between flue exhausts and radon discharges will first be examined to see how severe the distinctions are.

In this paper we will not describe detailed model calculation about radon and RDP concentrations in the discharged air. That investigation has been done elsewhere with tracer gases in homes and with wind tunnel measurements on model homes, but we will concentrate on effects of nearby reentry pathways into the building. It will be supported with two documented cases of formerly ‘difficult to mitigate’ homes.

Differences Between Flue Gas Discharges and Radon Vent Pipe Discharges.

Let us first examine how flue exhaust gas discharges are different from radon vent discharges. Flue exhaust gas is exhausted intermittently in the winter and not in the summer, with water heater exhausts periodically throughout the year, whereas a radon vent pipe exhausts radioactive gas in the discharge continually. Flue exhaust gas discharge can be smelled, whereas radon cannot be smelled because it is a rare gas that is odorless, and the molar concentration of RDP’s present is below the lowest limit of detection of our biological sensor, our noses. Although in some cases other soil gases pulled from the ground may cause the air to have a musty smell in the discharge area that inherently does not have to do with the radon in it. Flue discharges produce substantial sound at the exhaust when the appliance is operating that can be easily heard at the discharge point, whereas radon systems are built to be as quiet as possible since they need to operate all the time and therefore ideally are designed to become part of the background noise. Flue exhaust gases create a condensate (‘smoke’) trail in winter due to their elevated temperature, whereas radon only does this in the most extreme winter conditions.

Flue gas discharge is warm or hot depending on the efficiency of the furnace, whereas air with radon is the same temperature as the deeper soil under the house that it originates from. They exhaust carbon monoxide (CO) and dioxide (CO_2), whereas radon causes a radioactive gas in the discharge plume. Most of these serve as easy indicators that allow people and even children to be aware of flue exhaust gasses in the immediate surroundings of the exhaust location and naturally

Table (1). Summary of noticeable differences of flue gasses and Radon with Radon Decay products in the discharge near the discharge location.

	Flue Gasses	**Radon and RDP’s**
Timing	Intermittently operating	All the time operating
Smell	Smelly, when on	Always Odorless
Sound	Considerable sound at discharge, when on	Part of low background noise
Visual	Cloud of smoke spewed out, when on	Transparent
Temperature	Warm or hot air, when on	Cool
Health Concern	CO at start, CO_2 when on	Radioactivity

will make them avoid these. Since none of these tell-tale signals exist for a radon discharge, their absence may cause members of the public to become complacent about the danger of radon, especially if they become familiar with a radon vent pipe in their backyard discharging what they perceive to be ‘clean air’. These are the reasons why discharge locations of radon vent pipes can be considered to be in a different category compared to flue exhaust locations.
It is counter-intuitive that the very attributes that radon professionals work hard to make systems be stealthy and have low visibility and low sound impact, works against signaling that there is a danger. Summarizing these differences, one can state that flue gas is very noticeable and an immediate deterrent when the public is around it, whereas radon discharge gas is not noticeable and thus not a deterrent for the unsuspected public.

Attic venting methods, radon standards and relevant research studies.

The passive venting of attics of single family homes in the US is usually accomplished by creating a natural air flow from certain entry vents that flows along the inside of the roof to the exit vent located higher on the roof. The entry vents are often register type vent openings below the soffit and the exit vents are low profile static vents tied-in with the roofing material higher up onto the roof, or more recently they can be a single ridge line vent that is a continuous array along the highest ridgeline of the roof. Another common attic venting type is venting through the length of the attic from the top of the gable-to-gable ends. This latter seems to be less effective, and is sometimes found to be augmented with soffit vents. Active exhaust venting may be added later when people determine that passive air venting is not sufficient and attic temperatures are observed to be too high in the mid to late afternoons during the summers. In the majority of existing single family homes in the US the attic is not a conditioned space. Therefore, as with a passive exhaust vent on the roof, an entry vent into a space that is not a ‘conditioned space’ of the house, is often ignored for the distance requirement to the radon mitigation system discharge location in new construction.

The EPA Radon Mitigation System standards were formulated having the principle ‘do no harm’ in mind. That led to the requirement of discharging radon above the eave of the roof in the US. This was interpreted by some to be above the ‘lowest horizontal line of the roof”, and thus gable end locations with the discharge above this line seemed acceptable under this definition also, even if gable end vent openings existed near or above the exhaust point. During subsequent standard discussions it appeared that the original requirement was meant to be ‘above the eave and above the rake’ of the roof, where the ‘rake’ is the first few feet of the inclined part of the roof material away from a gable end of the building. In subsequent standards this formulation has been modified to better reflect the intended meaning by requiring the discharge to be ‘above the plain of the roof’ and both gable ends and flue exhausts were in diagrams or words included in the 10 foot distance requirement, that was to be measured with a flexible tape measure over and around obstructions on the roof.

Shortly after the original EPA-RMS was released two relevant research articles were published addressing the exhaust location. One research studied model homes in a wind tunnel (Neff, 1994) under various conditions, wind strength and directions and using visible smoke streams on the one hand for qualitative analysis and on the other with a tracer gas for quantitative results. The other research studied tracer gases around real houses (Henschel, 1995). These simulations suggested larger radon levels near the outside of exterior walls for houses with ground and midlevel discharges and showed the least effect when discharges were high up or midway above the roof. The main mechanism pointed at as a cause for the increased exterior radon levels was the creation of stable vortices just below the soffit areas outside the exterior walls that are created under steady wind conditions and that could be observed in the wind tunnel simulations using smoke streams over model homes. In general, the concern in these studies was re-entrainment through natural venting of (closed) windows and other openings directly into the conditioned part of the house.

More recently a study was completed on nine homes (Brossard, 2012) and a follow up study on 85 homes (Brossard, 2015) that compared the effectiveness of interior radon mitigation systems with fans in the attic and the venting above the roof with exterior venting near ground level. The study, with pre- and post-mitigation measurements lasting two and a half to three months, concluded that ground level systems reduce levels to acceptable levels with respect to the Canadian standard of 200 Bq/m^3. More generally it concluded that no significant advantages were found in efficiency favoring one type above the other. It also mentioned that icing effects near the discharge of ground level systems was found less obstructive than with some systems with exhausts through the roof at the extreme low temperatures in the cold climates where these houses were located.

The contents of this document will give the details of the mitigation of two houses that were high in radon after RRNC systems had been installed during new home construction. Thus these are two case studies of two houses that were selected based on their past history and for which solutions for the intermittent or persistent radon problems were sought. Although the radon levels were reduced in the basement after activation of these systems they had not been reduced as much as usually measured after activation with a fan. In both houses the vent pipe discharge termination had not followed the standard in the sense that they were within 10 feet of a vertical wall that extended vertically above the discharge with a soffit entry vent. The radon concentration measurements discussed were measured inside real physical houses. Although the most common difficulties with activation of passive radon mitigation systems installed in RRNC are caused by high cavity resistances that are either caused by improper vent pipe connections to the sub-slab material or very low permeable sub material, it was determined neither was the case. That was verified with a sub-slab depressurization communication test during installation of the fan indicating there were no problems with the pressure field extension under these slabs, and by determining there was sufficient flow through the vent pipe for each system.

House #1, Discharge Under Soffit Vent

The first house is a two story stucco house located at 5400 feet elevation in a town at the foot of the front range of the Rocky Mountains in Colorado. The house has an unfinished basement with a one story utility and mudroom section connected perpendicularly to the main house that leads to a three-car garage. The roof is made of concrete tiles and the roof penetration has a sealed lead pipe jack through which the 4 inch PVC pipe fits as is common for this type of roofing material. The house has an open two story high entry hallway behind the front door with the bedrooms on second floor also connected to the same open hallway. The heating system of this house is forced air with the furnace located in the basement and vent ducts throughout the house and all three floor levels, a common heating system type in this area.

A simultaneous radon test with the passive mitigation system showed the house still had a high radon concentration in the basement after construction. During the activation of the system at the end of the year 2013 the single cavity of the system was relocated further towards the center in the unfinished basement slab near a furnace to achieve a better pressure field extension. The vent discharge was found to be through the roof over the one story utility area towards the main house and was located one foot below a soffit of the second story of the house, with an entry soffit vent register only one foot away from the vertical projection point of the pipe onto this soffit. An appropriate fan for the total friction of the system was added in the vertical pipe part in the attic. The sump pit through the slab was sealed with a transparent cover, and all expansion joints, grooves and cracks in the slab were sealed with an appropriate caulk. Subsequent short term simultaneous testing with three radon test devices showed that the described system decreased the radon concentration, but not below 4.0 pCi/L, as shown in the second window in Figure (1).

In an attempt to improve the system a side branch of two inches diameter with a ball valve (to be able to vary the flow through the side branch) was installed to take some of the air from a sump pit that was connected to an exterior drain pipe. A second set of two simultaneous tests were completed, whose results are shown in the third window insert of Figure (1). The test results were inconclusive, and since the post mitigation short term integrating E-PERM[1] test devices were left with the home occupant, and the test had been outside for a while before they had been picked up, another set of tests was proposed for confirmation. This time two independent test devices were used, a continuous radon monitor CRM510[2], and as a quality control check, it was decided to set up the same two tests that were used in the previous testing as well. Including the CRM device therefore five test devices were set up simultaneously. The results are shown in the fourth window of Figure (1). Four tests including the CRM showed levels below 4.0 pCi/L and one test was again high, close to 7 pCi/L. In addition, the CRM had more variability than is usually seen after a successful mitigation. On inspection the test that was high was the test device with the same serial number as the test that had been high during the earlier testing. Thus it was decided to send this device to the manufacturer for further investigation. Nevertheless, from a practical point of view the problem seemed to be solved since both independent E-PERM tests during this last test period SFB663, SGP705 and the CRM had shown comparable low average results in the basement (as well as the detector SFT688) as is shown in the fourth window of Figure (1).

However, when the manufacturer returned the test device it came with the message they had inspected and had found nothing wrong with the device, which was inconsistent with our experience in Figure (1). Nevertheless, because the RPD of our set of independent test devices passed our QA requirement the testing passed and it was recommended the home owner should test again in a year and thereafter every two years as is standard recommendation after each successful radon mitigation.

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[2] femto-TECH, Inc.,P.O. Box 8257, 25 Eagle Court, Carlisle, OH 45005

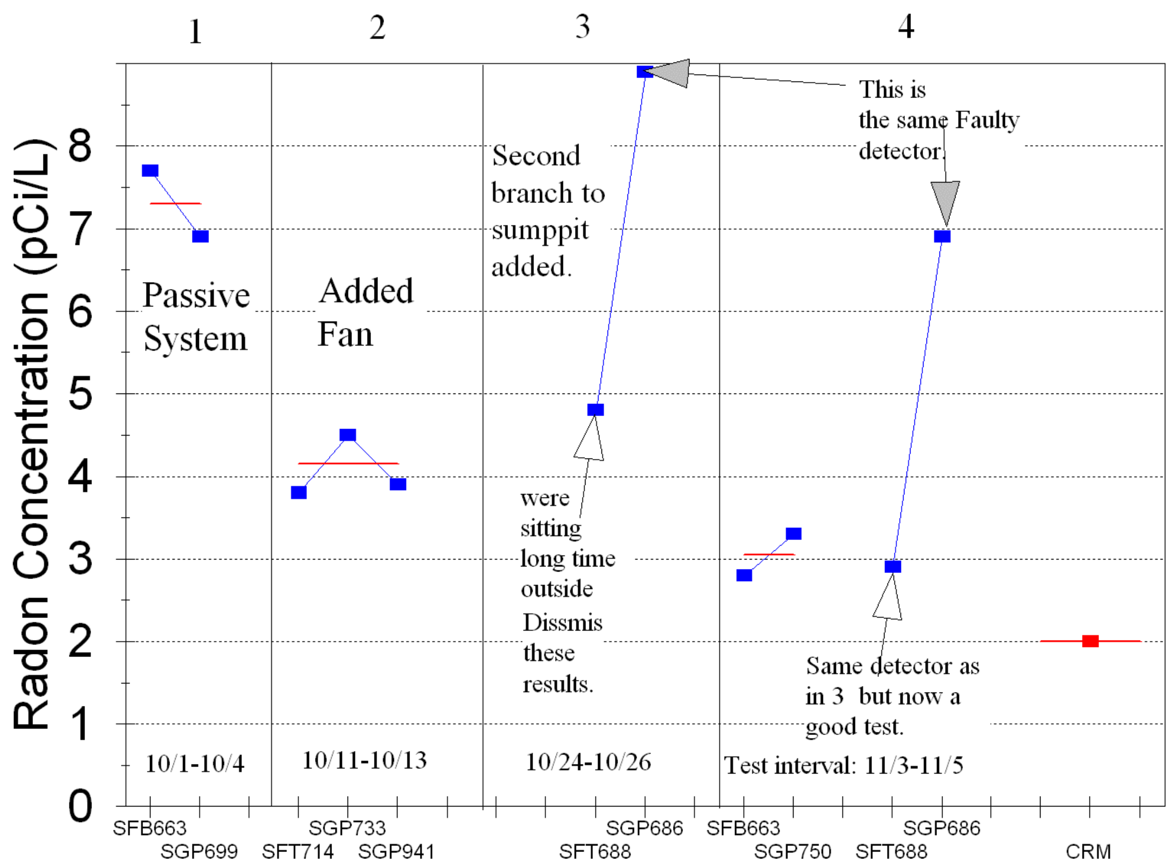

Figure (1). History of test results during the process of activation of House #1.

About one and a half years later the home owner had completed their own independent test with a simultaneous double test kit and reported to us that the radon concentration value seemed to be higher than 4.0 pCi/L as is shown in Figure (2) in May, 2015. This time they had tested the level on the first floor, which is what had been discussed with them before, since that is where they were mostly living. A confirming set of tests was done as shown in Figure (2) (last set in the histogram) and found consistent with the home owner's tests of high levels on the first floor as well, and still low radon concentrations in the basement. Figure (3) shows a sketch of the second story of the vertical south elevation of the house. The lower roof is joined perpendicular onto the main house at the level of the second floor bedroom. The garage roof is not drawn on the right side outside the boundary of this sketch. As shown, the vertical radon mitigation discharge pipe stack is located under the main building's second floor soffit.

One more verifying radon test was done in the bedroom on the second floor with the CRM that found that the radon level was indeed higher than 4 pCi/L as well. It was decided to immediately modify the exhaust pipe discharge to bypass the soffit with a pipe stack, including two pipe bends, while making sure the top of the discharge would be at least two feet above the nearest opening at the bottom of the soffit per standard requirement as shown in the sketch in Figure (4).

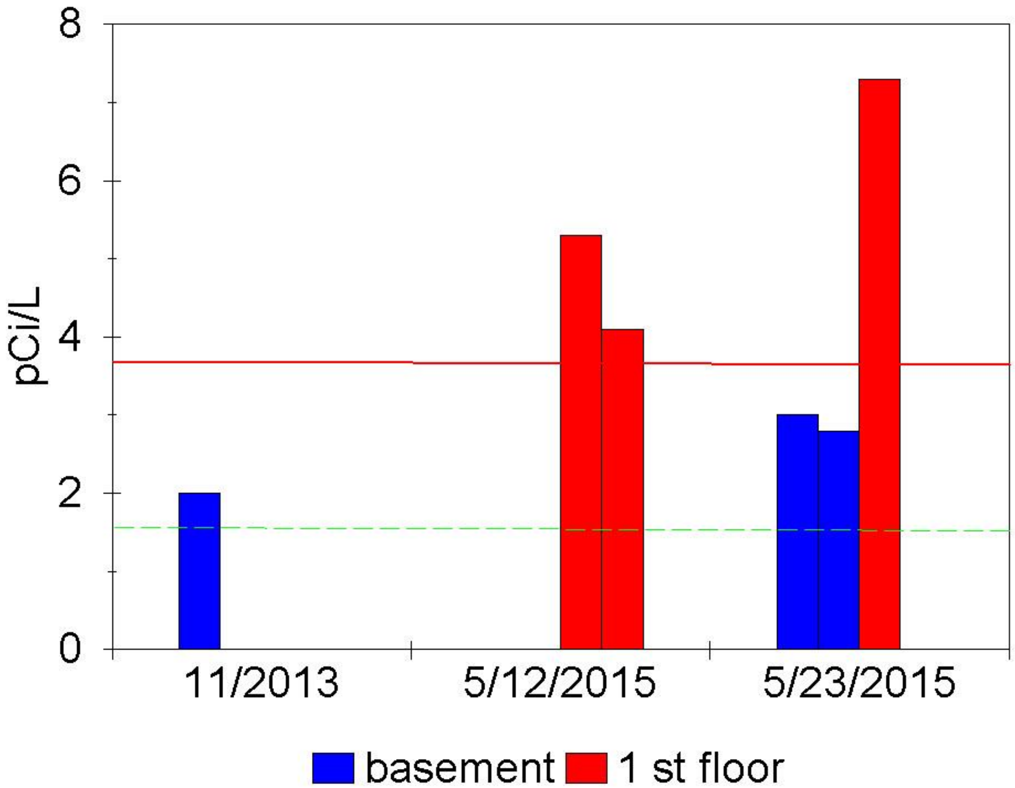

Figure (2). Follow up tests 1.5 y later of (#1) that showed the radon concentration is high on the first floor.

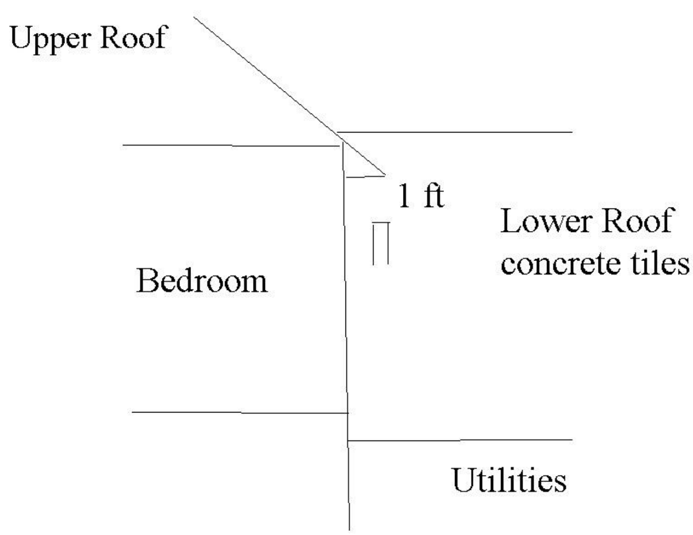

Figure (3). Sketch of vertical south elevation of the House # 1 with discharge pipe location of the passive system as installed during the construction of the house by others.

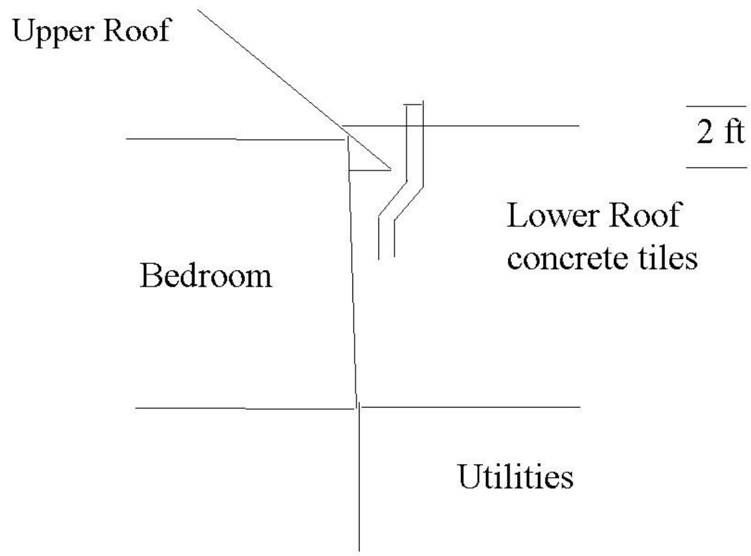

Figure (4): Sketch of same House #1 as in Figure (3), here with modified discharge.

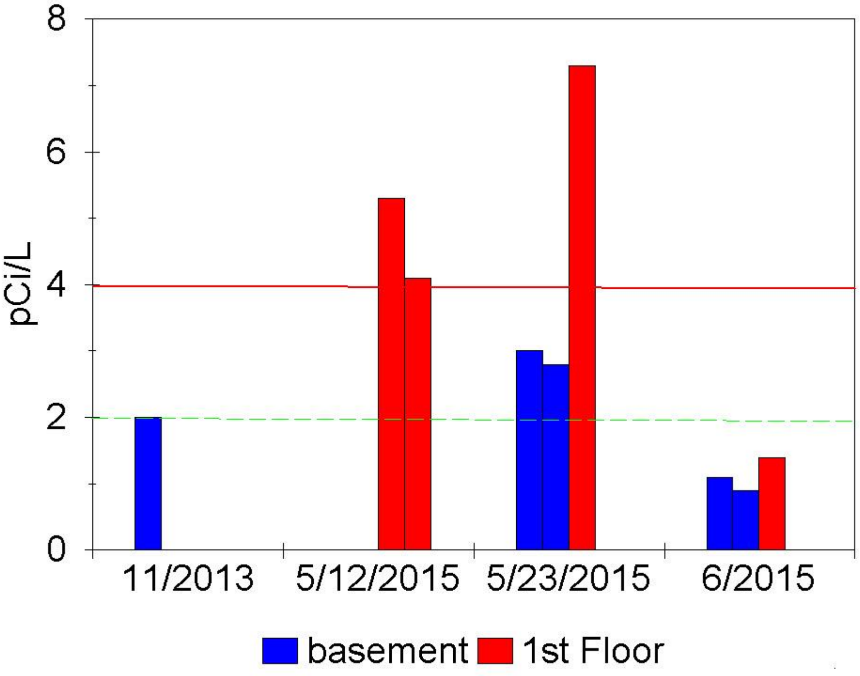

Figure (5). Test results showing high values measured by home owner and resolution after relocating the discharge point to two feet above the soffit vent.

The resulting radon test is for comparison added to the earlier test results and shown in Figure (5). The conclusion is that all radon tests on both first and second floor are now below 4.0 pCi/L and that the levels even in the basement have decreased, thus that the effect of soffit vent entry effected the whole house.

House # 2, Discharge Three Feet Away from Second Story Wall with Soffit Array Vent.

The second house is a two story home with wood siding located 40 miles away from House #1 on the side of a mountain in the Rocky Mountains at an elevation of 8500 ft. This house has a finished basement with a one story utility section attached to its side that also connects the house to a three-car garage. The roof is made of asphalt shingles and the roof penetration has a standard black plastic pipe jack through which the 4 inch diameter PVC pipe is routed using its rubber collar as a seal. The house is an open three story structure with an open stairway to the basement, and with the open living room reaching two stories up. There is a second story loft with a bedroom and bathroom on one side next to a lower section of the roof. The heating system was a boiler with heating registers along the edges of the floors including the basement, one of the common heating techniques for homes in the mountains.

A first radon test was performed with the passive mitigation system that indicated the house had a high radon concentration in the basement of 23.4 pCi/L. During the activation of the system in 2015 the fan was placed at the pre-destined location in the attic of the house next to a bathroom of the second floor loft area and one did not have to make other modifications because the pressure field extension tests showed good communication to all tested locations away from the pipe connection through the sub-slab material.

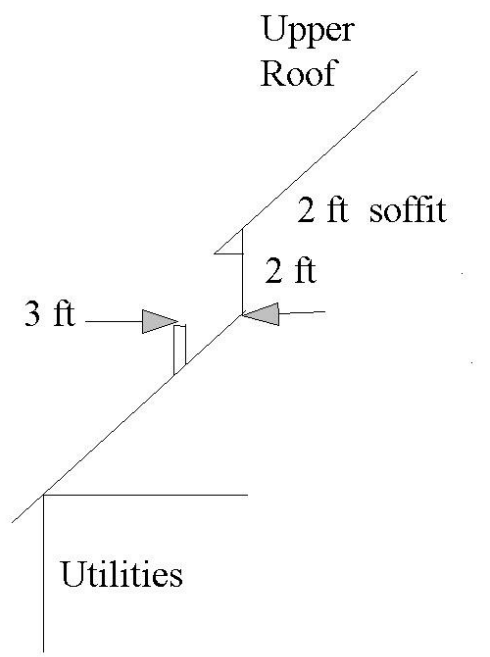

Figure (6). Sketch of discharge location with respect to main second story for House #2.

The vent discharge was found to be through the roof above the one story utility area towards the main house, three feet away from the second story exterior wall with bathroom on the side of the loft, and two feet below the soffit, as shown in Figure (6). The second story roof at that location has a soffit with vent line of openings. The fan was added in the vertical pipe part under the pipe penetration through the roof. Because the slab was finished in the basement, caulking of the slab could not be done except for a very limited area in the boiler room. Subsequent short term simultaneous testing with three E-PERM radon tests showed that this passive system decreased the radon concentration in the basement significantly as shown in Figure (7), but not below 4.0 pCi/L on the second floor in the bedroom located in the loft area next to where the fan was located. A suspicion of a possible entry pathway for radon from the garage into this area via the attic over the utility room prompted us to complete a second follow up test with simultaneous tested first floor, garage and second floor areas. As shown in Figure (7) the garage radon test result was lower than both other areas. This excluded the garage as the source for the high radon concentrations measured on second and first floor. Next, a third set of verifying radon tests comparing basement, first floor and second floor were done, yet again showing the same pattern with the higher values on first and second floor and a lower value in the basement. The existing discharge opening was capped off and the pipe routed to a new discharge location approximately 15 feet away from the main house on the other side of the ridge line of the garage, with the fan located in the attic of the garage immediately under the new discharge location. The four radon tests, two in basement, one on first floor and one inside the second floor loft at this point all measured radon concentrations below 2.0 pCi/L.

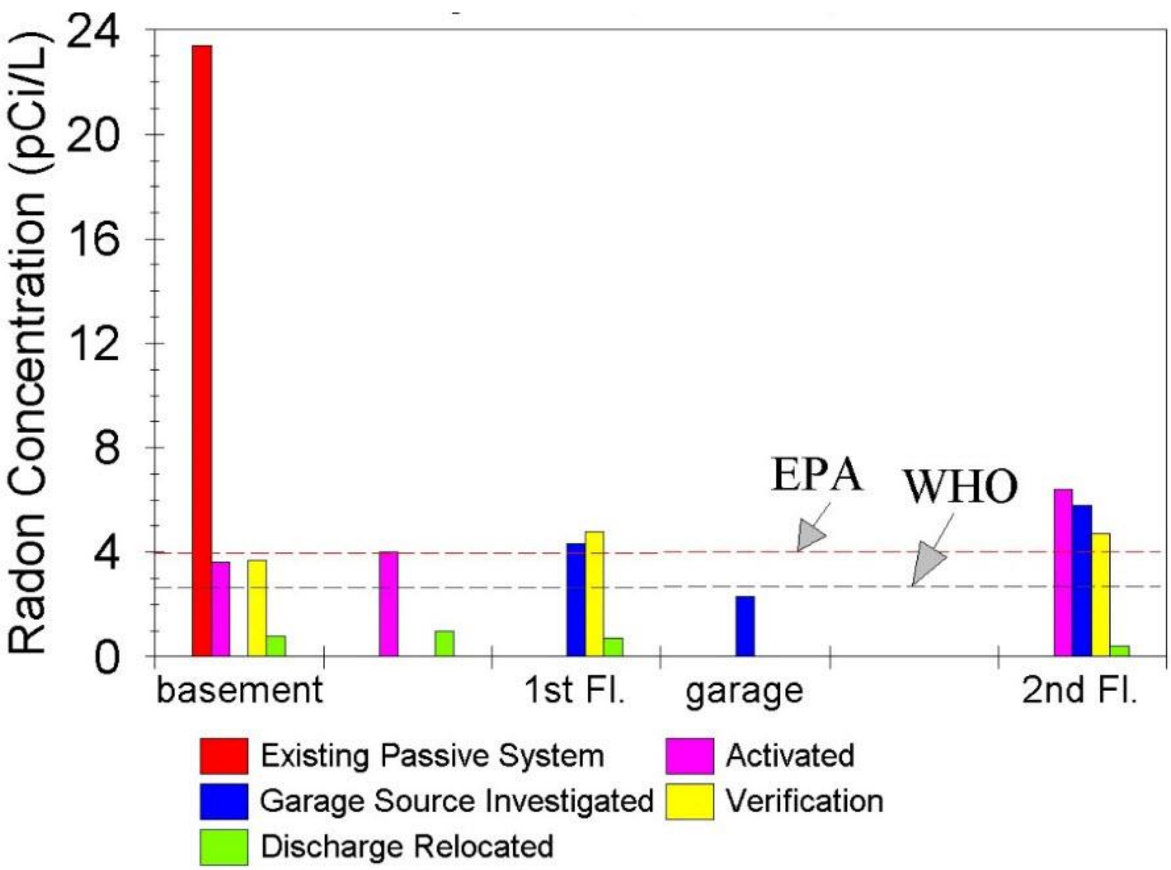

Figure (7). For House # 2, this shows the results of a sequence of radon measurements, each simultaneously done over various floor levels and garage, until resolution of the radon problem after the discharge was relocated.

Conclusions

Extra due diligence is required from standard writing in the radon community compared to standard writing for flue gas discharge location. The reason can be summarized by stating that flue exhaust gas is very noticeable and annoying, thus acts as a natural deterrent for the public but radon discharge gas is barely noticeable and thus does not have this deterring effect on the public when present. The testing in two houses described are cautionary tales and physical examples that sufficient distance of the radon discharge location from soffit entry vents are needed to exclude re-entrainment that can affect radon concentrations in homes, especially on higher floor levels, but potentially on other levels as well. These two documented cases with real radon and real existing houses support to require the “10 feet away or two feet above” rule and also the “10 feet horizontally away from a wall that extends vertically above it” for the allowable radon discharge locations, especially when entry soffit vents exist even into an unconditioned space such as an attic.

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