July 2018

Method for Radon Measurement in Residential Sewer Connections

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ABSTRACT

Radon gas is the most deadly indoor air pollutant. In the US, it is responsible for over 20,000 deaths per year. Residential exposure is typically the largest portion of a person's annual exposure, so a great deal of research has been done to understand the pathways that radon can follow to enter a house. Since radon emanates from the ground, it is present in high concentration in soil gas. Recent research on the vapor intrusion of volatile organic compounds from subsurface sources into a test house concluded that the sewer line is an important preferential pathway. Despite the potential for high concentrations of radon in sewers, there have been no studies examining correlations between sewer concentrations and indoor concentrations. One reason may be that it is very difficult to measure radon concentrations in sewers. To address this problem, the author has developed a method for testing radon concentrations in residential sewer connections, and conducted case studies to test and refine the method. The method uses the sewer cleanout cap as an access point, and addresses the problem of condensation from hot water discharge into the sewer system by heating a sampling chamber that holds the radon sampling device. Preliminary results show a large variation in sewer radon concentrations temporally, two measured values showed 133.3 pCi/L (4930 Bq/m³) and 636 pCi/L (23,500 Bq/m³). For context, the US EPA recommends taking action if indoor levels are above 4 pCi/L (148 Bq/m³). Future work will examine correlations between indoor concentrations and sewer gas concentrations.

1. INTRODUCTION

Radon gas is a naturally occurring radioactive isotope, designated ^{222}Rn, with atomic number 86. Radon is the in the decay chain of uranium-238, which is present in low concentrations throughout the Earth. The decay chain passes through five other isotopes – thorium-234, protactinium-234, uranium-234, thorium-230, and radium-226 – before decaying into radon. Radon is the first of these isotopes that is gaseous at standard temperature and pressure. This means that it has the potential to float up out of the ground, often carried with other soil gases or displaced by liquid, and to enter buildings. Buildings can collect radon, which potentially builds up to high concentrations.

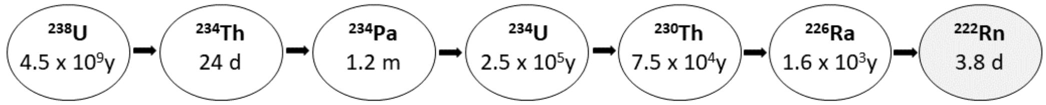

Figure 1: Decay chain from uranium-238 to radon-222, including half-lives of each isotope

Radon is not very stable, having a half-life of 3.8 days. By comparison, uranium-238 has a half-life of 4.5 billion years. Radon emits an alpha particle upon its decay to its immediate daughter product, polonium-218, which itself has a half-life of 3.1 minutes, and has several similarly unstable progeny among the 11 isotopes in the decay chain that ends in lead-206, which is stable. The emissions in this process cause radon and its progeny to be the source of about

1/3 of average human exposure to ionizing radiation (WHO, 2009). Alpha particle emissions are known to cause cellular damage, and human lung tissue is particularly susceptible to this damage. Thus, radon is a major contributor to lung cancer, responsible for about 21,000 deaths per year in the US (EPA, 2016). This makes it the single largest indoor air pollutant cause of death in the US.

Although radon is gaseous, its immediate progeny are solid. When a radon atom decays while it is mixed with air, the resulting solid daughter particles are suspended, and tend to bind to other suspended particulate matter because they are electrostatically charged. Thus, some reduction in concentration of radon progeny is possible by filtration (Chen *et al*., 1998). However, unattached decay products are more likely to cause cellular damage (Wang *et al*., 2011), so the overall effectiveness of filtration is unclear. Dilution has the potential to reduce radon concentrations, but it is costly in regions with significant heating or cooling loads. Nevertheless, commercial buildings are typically ventilated, and controlled to have positive pressure relative to outdoors, which is effective in maintaining radon at acceptable levels. Uncontrolled ventilation in houses, such as open windows or intentional openings in the building envelope also has potential to increase the entry of radon if not done correctly, because it can cause the building to be depressurized relative to the soil gas below (Boardman and Glass, 2015). Wind may be a contributing factor to this depressurization, and is typically unpredictable. Stack effect can also cause lower parts of a house, adjacent to the source of radon, to be depressurized. Therefore, the most effective approach to controlling radon exposure is to prevent entry into the breathing space.

Houses constructed above grade are typically not very susceptible to radon entry, since they are normally ventilated below the building envelope. Flow barriers, such as a concrete floor and concrete walls, are typically effective, except that they almost invariably crack, allowing flow of gas into the breathing space. Similarly, a vapor barrier can bel placed before pouring concrete, but these are often punctured or torn by shifting foundations, and are not considered reliable (Denman *et al*., 2005). Sealing cracks has not been found to be effective, so a common mitigation strategy is to depressurize the region below the basement slab, called a sub-slab depressurization system (Boardman & Glass, 2015). In this system, a fan continuously draws air and soil gas from below the slab, and diverts it through a pipe to a safe discharge location.

Although any exposure to ionizing radiation is believed to be harmful, the US EPA has set a recommended maximum indoor air concentration at 4 pCi/L (148 Bq/m^3). Outdoor air concentrations vary, but in continental regions are typically between 0.3 and 0.9 pCi/L (10-30 Bq/m^3). However, concentrations up to 27,000 pCi/L (10^6 Bq/m^3) have been measured in unventilated mines, so there is a significant potential to increase indoor concentration if even a small amount of soil gas is allowed to flow into a house.

Two paths for radon to enter houses have seen significant attention: passive flow through cracks in the foundation, and entry with potable water. Another path is from the sewer or catch basin drain area or sump, up through the floor drain or sump cover, and into the breathing space (see Figure 1). Some homes use a one-way valve developed for this purpose to prevent flow upwards. Others rely on the trap being filled with water as a means of flow prevention.

One potential path that has not received significant attention is the path through sewer plumbing into the home. Recently a study by McHugh *et al*. (2017) found that there is a vapor transport pathway from the sewer to breathing space in a research house. The focus of their research was a pathway for carrying volatile organic compounds (VOCs) into the house. They cite several other studies that cite sewers as path for harmful vapor intrusion, such as chemicals from dry cleaning site and uncontrolled chemical releases. They use a tracer gas test to demonstrate and quantify intrusion from the city sewer line into the house. Roghani *et al*. (2018) confirmed the intrusion path as a means of VOC transport. They note that there is a great deal of temporal and special variability in concentrations, making measurements difficult, because they must be repeated frequently, or long term sampling methods, on scales up to several years, must be used. Guo *et al*. (2015) also found the sewer vapor pathway to be significant. Crockett *et al*. (2016) noted that seasonal variations in indoor radon concentration can be very significant.

Sewer lateral lines – the lines connecting a house sewer line to the city sewer line – are often cracked, or have their joints opened, by tree roots or shifts in the ground. This allows flow of soil gas into the sewer line. The sewer line is vented, so it may be at lower pressure than the surrounding soil, allowing flow into the line. A major barrier to study of this path is the difficulty of measuring radon concentrations in the sewer line. This difficulty, combines with the evidence described above that sewer vapor concentrations are highly variable, spatially and temporally, to create a challenging problem. There is a need to make low-cost and non-invasive measurements to sewer lines in houses, so that large numbers of houses can be measured over long periods of time, or measured multiple time.

This paper describes a method that has been developed to measure the radon concentration in residential sewer connections. This method will facilitate studies of typical concentrations in sewer lines, and facilitate studies to determine whether indoor concentrations are correlated with elevated sewer concentrations.

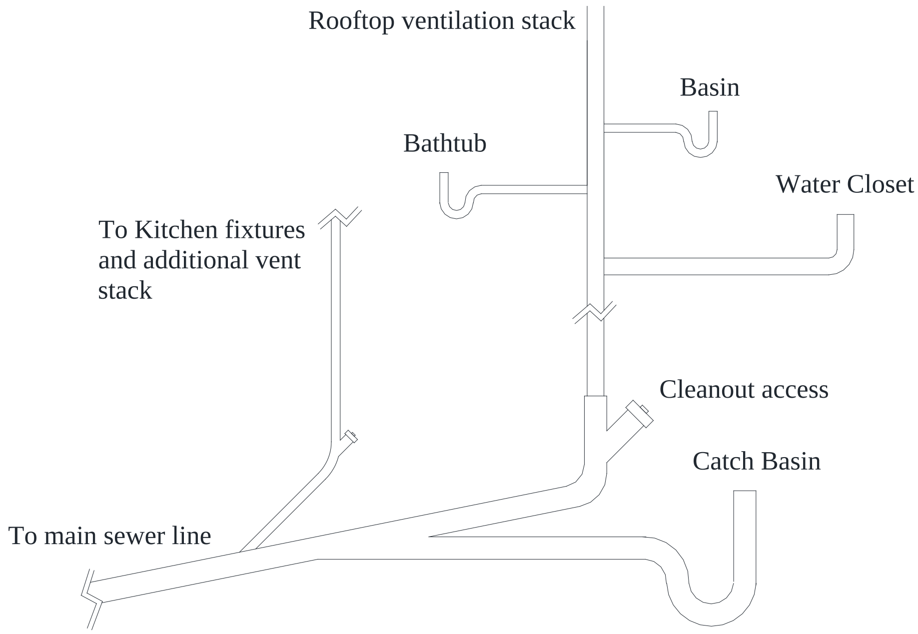

Figure 2: Typical layout of sewer system in a house with a basement

2. METHODOLOGY

2.1 Radon Concentration Measurement

To measure the sewer connection, a radon measurement device capable of measurement in a harsh condition must be deployed. In the proposed methodology, an electret ion chamber was selected as the measurement method (Kotrappa *et al.* 1990). The electret is a piece of dielectric material with a quasi-permanent electrical charge. The electret's charge is reduced by the presence of ionizing radiation, so that a correlation can be made between the cumulative exposure to radon and the reduction in surface voltage. The electret is enclosed in a passive chamber arrangement that has known diffusion characteristics and a filtered inlet (called a *diffuser bottle* hereafter). At the start and end of a radon measurement, the electret is removed from the diffuser bottle, and the surface potential of the electret is measured with the capacitive probe method (Gupta *et al*. 1985).

The electret method was selected because of its reported insensitivity to humidity change, which is a common problem with radon measurement (Sorimachi *et al*. 2009). It also meets the requirement of having flexibility to be able to measure a wide range of values with appropriate sensitivity, because different thicknesses of electret can be used, giving a range of initial voltages (Kotrappa *et al*. 1988). The radon concentrations in sewers have the potential to be near ambient (e.g. 0.5 pCi/L [18 Bq/m³]) if outdoor air is drawn down the sewer vents, or as high as pure soil gas (e.g. 27,000 pCi/L [10^6 Bq/m³]).

A system is commercially available to use the electret ion chamber approach. This system comes with electrets, passive chambers, and a shutter-type capacitive probe measurement device and signal processor. This system was used to develop the current method.

A second method, a track etch detector, was also tested and gave comparable results. Track etch detectors use a polyallyl digylcol carbonate foil in a diffusion chamber to measure cumulative radon exposure. The alpha particles etch the surface, and the quantity of etching indicates the radon concentration (Chen *et al*., 2010). The track etch detector's measured values were consistent with the electret system during the development of our method. However, the electret system is preferable for repeated measurements, because analysis can be conducted in the field, as opposed to returning the track etch detector to a laboratory.

A third radon measurement device was deployed in the development of the method. This method is a portable radiation monitor, which pumps filtered air through a scintillation counter chamber to give continuous real-time readings of radon.

2.2 Sewer Access Method

To access sewer gas without disruptive modifications to the system, a connection is made to the sewer cleanout, shown in Figure 1. These cleanouts need to be accessible for cleaning clogged sewer lines, and they commonly use a known thread and diameter for the threaded cap. A matching threaded plumbing fitting is connected to a one gallon (3.8 L) metal pail with an airtight, removable lid. The test chamber is shown in Figure 2.

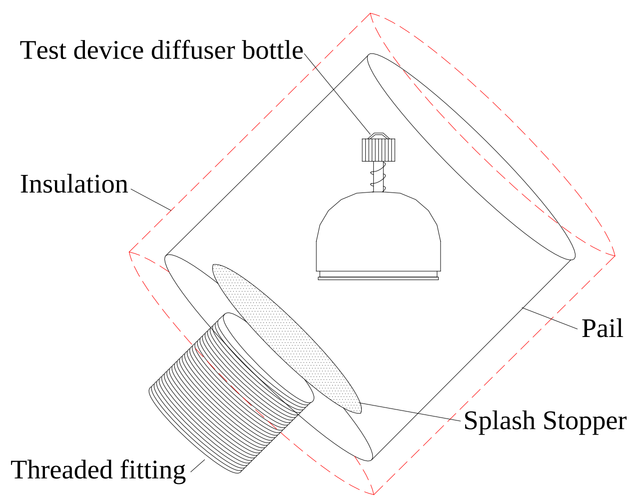

Figure 3: Test chamber design

The sewer cleanout cap is removed, and the chamber is screwed into its place. The removable lid allows the radon diffusion bottle to be placed in the chamber, where it is suspended. A splash guard is placed in the neck (threaded fitting) or in front of the opening, to prevent liquid splashing onto the diffusion bottle.

The principle behind this measurement approach is that the air in the vent stack is at the concentration of interest. There are several potential driving forces to mix air upward from the sewer line, or to draw outdoor air downward through the vent stack. To gain an increased understanding of the time-varying radon concentration, a 45 hour test with 10-minute samples was done with the portable radiation monitor on a randomly selected house, as part of a related study. The house was built in 1950 and located in Winnipeg, Canada. The residents were asked about their water usage activities. There were four activities that correlated very closely with raised radon levels:

1) On day one at 10:30 AM, a shower caused a clear spike in concentration
2) Several loads of laundry were done from 7:30 PM to 10 PM on day two, causing elevated concentrations

3) The entire household was asleep by 11 PM on day two. The concentration decayed at this point
4) On day 3 at 4:30 AM a long shower was taken, again causing an obvious spike

Toilet flushing, hand washing, and dish washing were not noted. However, the clear patterns from the four activities noted above show that water going down the drain causes an updraft of air from the sewer connection, elevating the concentration in the sewer and vent lines in the house. An apparent pattern also suggests that hot water draining has a more pronounced effect on radon concentration. The hot water going down the drain warms the air and increases its humidity, and each of these effects increase its buoyancy, so it is probable that an updraft draws air from lower regions of the sewer line.

Another interesting finding from the portable radiation monitor study is that it took 10 hours for the radon concentration in the sample chamber to reach equilibrium. This may be partly caused by the splash guard, which inhibits diffusion and buoyancy driven flow into the chamber. It also may be caused by slower flow into the test diffuser bottle, because it is enclosed within the relatively small test chamber. This means that long sample times are necessary for accurate measurements of average radon concentrations, to reduce the effect of the period before equilibrium.

Once equilibrium was reached, the average radon concentration in the sewer was 133.3 pCi/L (4930 Bq/m^3). Unfortunately, the data from the portable radiation monitor were lost, so they cannot be displayed here. Nevertheless, they served the purpose of showing the close correlation between increased concentration and drain activity.

3. RESULTING FIELD TEST PROCEDURE

3.1 Field test and revision of measurement method

The measurement method was tested in a randomly selected house in Winnipeg, Canada. A small amount of water was poured down each of the drains in the house, to ensure that none of the p-traps were dry. A first test, over a 24 hour period completely depleted the electret. A higher initial voltage electret was used and the test repeated, but again the voltage was entirely depleted. We formed a theory that although the electret may not be significantly affected by humidity, if water droplets condensed on the surface of the electret, these could deplete the voltage.

To prevent condensation, a modification was made to the test chamber. The interior of the chamber was wrapped in heating tape that maintains 50°C temperature. This keeps the radon diffusion bottle at a temperature in excess of any likely dewpoint temperature of the air in the sewer line. The exterior of the chamber was also insulated with 3/4” (1.9 cm) foam insulation.

After modifying the test chamber, the house was successfully retested for a six-hour period. This test showed the average radon concentration to be 636 pCi/L (23,500 Bq/m^3). As previously noted, the system may take approximately 10 hours to reach equilibrium, so the measured value is likely lower than the true concentration.

3.2 Field test procedure

The final field test procedure requires a high voltage electret as part of electret ion chamber measurement system, so that long-term measurements can be made. The length of measurement should be sufficiently long so that a ten-hour pre-equilibrium period does not unduly affect the results. The test chamber must be heated to 50°C to prevent condensation on the electret, and a splash guard placed in the test chamber to prevent splashing onto the ion chamber diffusion bottle. Insulation is recommended on the exterior of the test chamber. A threaded ABS plumbing fitting should match the local standard for sewer cleanouts. In the Omaha region, a nominal 3” (7.6 cm) cap is common. In some regions there may be multiple common sizes. Grease should be applied to the threads to promote an airtight seal, and facilitate removal of the chamber and of the cleanout cap for subsequent measurements. A penetrating oil and special set of wrenches will commonly be needed for initial removal of the cleanout cap.

A lower voltage electret should be used with a second test diffusion bottle deployed in the breathing space of the house simultaneously with the sewer measurement, so that the concentrations can be compared to see whether there are correlations, as suggested by researchers discussed above.

4. CONCLUSIONS

This paper has described the need for a simple field test procedure for measurement of radon concentrations in sewer systems of houses. Although radon has been measured extensively in varied locations throughout the earth, the typical concentrations in sewers connected to houses are still unknown. Since the sewers are so close to occupied breathing space, there is the potential for transient flow into the breathing space.

A field test method is proposed, and the results of deploying and refining this method are presented. One measurement made during the development of the field test method showed a concentration of 636 pCi/L (23,500 Bq/m³), which could pose a significant health risk to occupants if it were to leak into the breathing space. A second, short term measurement at a different house showed a 133.3 pCi/L (4930 Bq/m³) concentration, which also could elevate the indoor concentration to unsafe levels. The field test method found that a heated chamber is necessary, to avoid condensation on the electret.

Future work will involve a larger sample of measurements of sewers and the adjacent breathing spaces to determine (a) typical sewer concentrations; (b) whether there is any correlation between sewer and house concentration; (c) to gain a better understanding of the transient concentrations.

NOMENCLATURE

Bq	Bequerel
d	Day
EPA	Environmental Protection Agency
m	Minute
pCi/L	picocurie per litre
s	Second
y	Year

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ACKNOWLEDGEMENT

The author is grateful for support from the Natural Sciences and Engineering Research Council of Canada to conduct this research project.