ONSITE RADON IN WATER MEASUREMENT METHOD

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Abstract

Elevated levels of radon in water exist throughout the New England states and other parts of the United States but often go undetected because of lack of easy radon in water testing. A simplified test method was developed using an available radon sniffer to be able to obtain radon in water measurement results, in about 15 minutes, on site. The results of this method are described and compared to radon in water measurements using traditional water samples measured with EPERM system or LS test kits sent to a laboratory.

1.0 Introduction

1.1 Radon in Water Contribution to Radon in the Air

Consumption of water that has elevated radon levels is considered a small risk of increasing the chance of internal cancers. Exposure to radon and radon decay products in the air has been correlated with increased risk of lung cancer. Radon in the water contributes to the radon in the air if the water is exposed to air, especially if the water is agitated. Appliances in the home that agitate water, such as a dishwasher, clothes washer or showering, transfers a large percentage of the radon in the water into the air. A typical bath, toilet usage or drinking water remove less of the radon that is in the water. The quantity of water used in a home is a relatively small amount in comparison to the overall volume of a home. The ventilation rate of the home, the amount and type of water usage and the size of the home make it difficult to predict how much the radon in the water will contribute to the average radon in air levels in the home. EPA review of the increased average radon in the home from radon in water considering typical usage and typical home size is in the range of 10,000 pCi/L in the water will increase the average radon levels in the house by 1 pCi/L. This 10,000 to 1 ratio is just an approximate indicator of waters contribution to radon in the air. In general, only well water that is transported within hours or days to a home is considered likely to have radon levels in the 10,000 pCi/L or higher level. Municipal water from lakes or even from wells that is stored for weeks at a time is considered to have insignificant radon levels.

1.2 EPA and State Guidance on Radon in Water

The EPA states in their Home Buyers and Sellers radon guide and Real Estate radon guide that if you have elevated radon in the air and your water comes from a well you should test the radon in water. The EPA however does not have any written recommendations of what level of radon in water is too high and should be reduced. Several Northeastern States have recommended radon in water levels above 4000 to 10,000 pCi/L level should be reduced. In states without recommendations for reduction of radon in water there is very little radon in water testing. A primary reason for this lack of testing is the cost of and inconvenience of testing radon in water. The testing requires obtaining a water sample that is fresh from the well and has no bubbles in the sample. The sample must be expedited shipped to a laboratory, where it is analyzed. Depending upon the shipping time and weekends, the results are available within a week of sampling.

2.0 Methodology

2.1 Onsite Radon in Air Testing Equipment

The radon industry has developed a number of grab sampling radon measuring instruments, typically referred to as radon sniffers that can obtain a relative radon in air measurement onsite in a period of time as short as 10 to 15 minutes. [ref:1] These quick radon measurements are considered diagnostic tests to either find a high radon source or determine if there is a potential elevated radon level in the building. This study uses the CT007-R radon sniffer manufactured by Environmental Instruments Canada Inc, which is referred to as the RS monitor(s) in this study. This radon sniffer includes an input as well as output port so that air can be circulated through the water sampling jar and the radon sniffer at the same time. There are other available radon sniffers but they are either prohibitively expensive or have no air pump or only have an input port. Any radon sniffer that has a pump to draw air in and a port that exhausts the sampled air would be able to be use the simplified method presented in this study if the conversion factor is determined for the sniffer measured radon level in comparison to the actual radon level of the water sample. This study is the determination of the conversion factor between the CT007-R radon sniffer sampling result and the radon in water measured level as determined by typical radon in water measurement method.

The RS radon chamber is approximately 270mL. The tubing and filter tube have an internal volume of about 50mL. The jar used to sample the radon in water has a volume of about 1250mL. This gives the total volume while the sniffer is sampling the air in the collection jar of about 1570mL.

2.2 CT007-R Instrument Calibration

The CT007-R is primarily used to locate radon entry points or quickly determine the approximate radon in the air. It's shortest counting interval is 15 seconds and uses a nominal efficiency of 340 Bq/m3 per count/15 seconds (9.2 pCi/L per count/15 seconds). This nominal efficiency was derived from theoretical considerations and side by side measurements with another instrument in a uranium mine. While the absolute efficiency of the CT007-R is not necessary for locating radon entry points, it is important when quantifying radon levels, as in this project. Additional Instrument calibration check was performed before the start of this project.

In June 2024, Environmental Instruments Canada Inc. exposed several RS monitors at the Radiation Safety Institute of Canada (RSIC) radon chamber, which is an AARST-NRPP accredited secondary reference chamber in Saskatoon. The chamber concentration was 1050 Bq/m3 (28.4 pCi/L). The results at 1050 Bq/m3 confirmed that the RS monitors are reading low. See Table 1. The devices used in this study, RS-24, RS-154, and RS-158

read 19.2%, 21.8%, and 14.9% low, respectively. To match the 1050 Bq/m3 chamber value, a correction factor of 1.23 was used. This 1.23 correction factor was used for all the RS measurements in this study.

Device	% Difference from Chamber	Correction Factor
CT007-RS-24	-19.2	1.24
CT007-RS-154	-21.8	1.28
CT007-RS-158	-14.9	1.17
	Average:	1.23

Table (1) CT007-R's variation from RSIC Chamber Readings and correction factor

2.3 Spiking Radon Monitors at KSU Radon Chamber

In order to verify that the CT007-R can provide representative measurements at higher concentrations than the RSIC chamber, each of the instruments sampled radon concentrations from the author's radon chamber at seven different concentrations. The radon chamber concentration in the chamber was determined by the average of two AB5 Pylons or by the average of four Ecosense RadonEye instruments. The RadonEye instruments and AB5 Pylons had their calibrations set by comparing them to four Ecosense EcoTrackers that were recently spiked at Kansas State University (KSU) radon chamber which had recently intercompared with EPA Montgomery radon chamber. The results of the spiking are shown in Figure 1. Three of the EcoTrackers calibration factors were adjusted to more closely match the measurements provided by KSU. These four EcoTrackers were then run in the author's radon chamber to then adjust the author's four RadonEye detectors, four other EcoTrackers and two AB5 Pylons. The Four RadonEye monitors and or two AB5 Pylons were then used to determine the radon levels in the chamber when the RS monitors drew radon samples from the grab ports of the chamber.
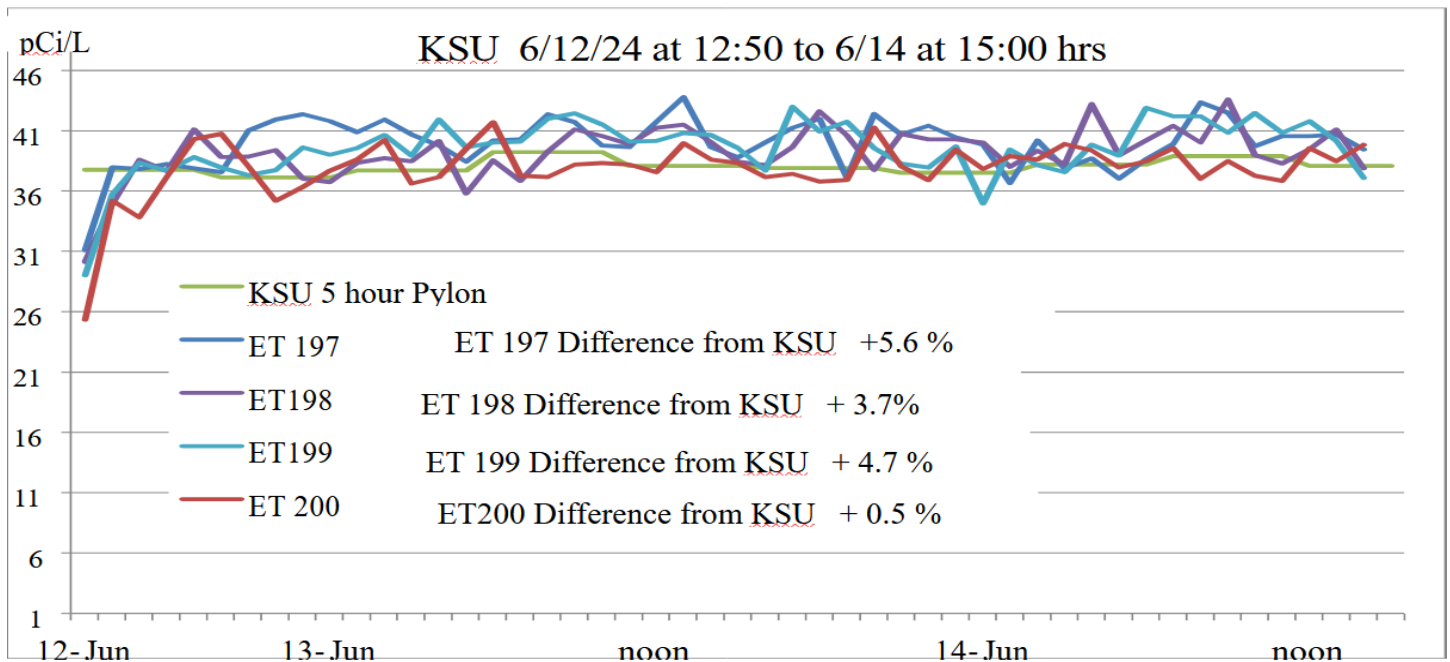

Figure (1): KSU 2024 radon chamber spiking of
four EcoTracker radon monitors before they were adjusted

2.4 Checking the CT007-R radon Measuring Capability

In order to determine how accurate the RS monitors was able to determine radon concentration in a short period of time, grab samples from the radon chamber were taken with each of the three radon monitors at different concentrations in the chamber. See Figure 2.

Figure (2): CT007 grab sampling

In each case the RS's sampled the radon in the chamber for about seven minutes. To test the ability to measure in a closed loop, the RS exhaust hose was disconnected from the chamber grab port first. The inlet hose sampling from the radon chamber was then disconnected from the valve and the RS exhaust tubing quickly connected to the RS inlet tubing. This allowed more sampling time. RS-024 saw a large decrease in radon levels when the tubes were hooked together after the chamber sampling was completed. This indicated there was a leak in the instrument and this instrument was excluded from the rest of the study.
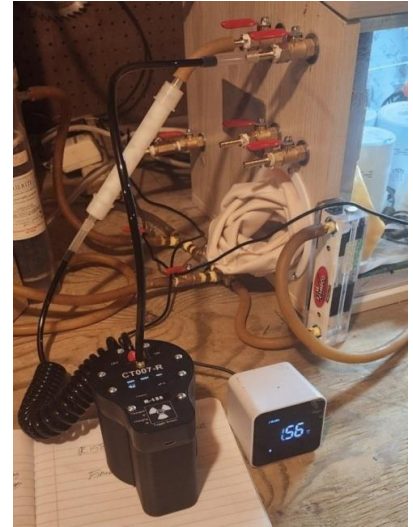
RS-154 and RS-158 tended to display a consistent radon concentration in the circular sampling period which indicated these two units were airtight. The average grab sample measurement of each test monitor was determined during the chamber exposures by using the graph function of the RS cell phone app. For water sampling both the graph function and five-minute average were used. The variation that occurs with any radon measurement can be smoothed out in the graph function by adjusting the sampling interval. In general, using an interval of 60 to 120 seconds in the graph mode seemed to provide the clearest display of the average measurement each RS was recording. In the Sniffer tab, the running 5-minute average provided a calculated average after 7 to 8 minutes of jar sampling. High radon in water concentrations such as were used in this study do cause background counts that can take several hours to decay away. The jar sampling time can be shortened by using the graph when high concentrations are measured and precise accuracy is not required.

Radon Chamber Level	RS-154	RS-158	Avg % Diff from Chamber
35 pCi/L	31	34	-7.14%
92 pCi/L	111	105	+17.39
108 pCi/L	108	111	+1.4%
124 pCi/L	115	124	-3.6%
219 pCi/L	209	221	-1.8%
245 pCi/L	266	272	+9.8%
384 pCi/L	400	406	5.0%

Table (2): RS Monitor Percent Variation from Radon Chamber after 1.23 Correction Factor

After applying the respective correction factors determined from the Canadian radon chamber, the radon concentrations measured by the RS monitors are in good agreement with the radon chamber values. See Table (2) and Figure (3). Interestingly, applying the average correction factor from Table 1 of 1.23 to all detectors,

instead of their individual correction factors, results in approximately the same level of agreement with the radon chamber values. See Figure (3).
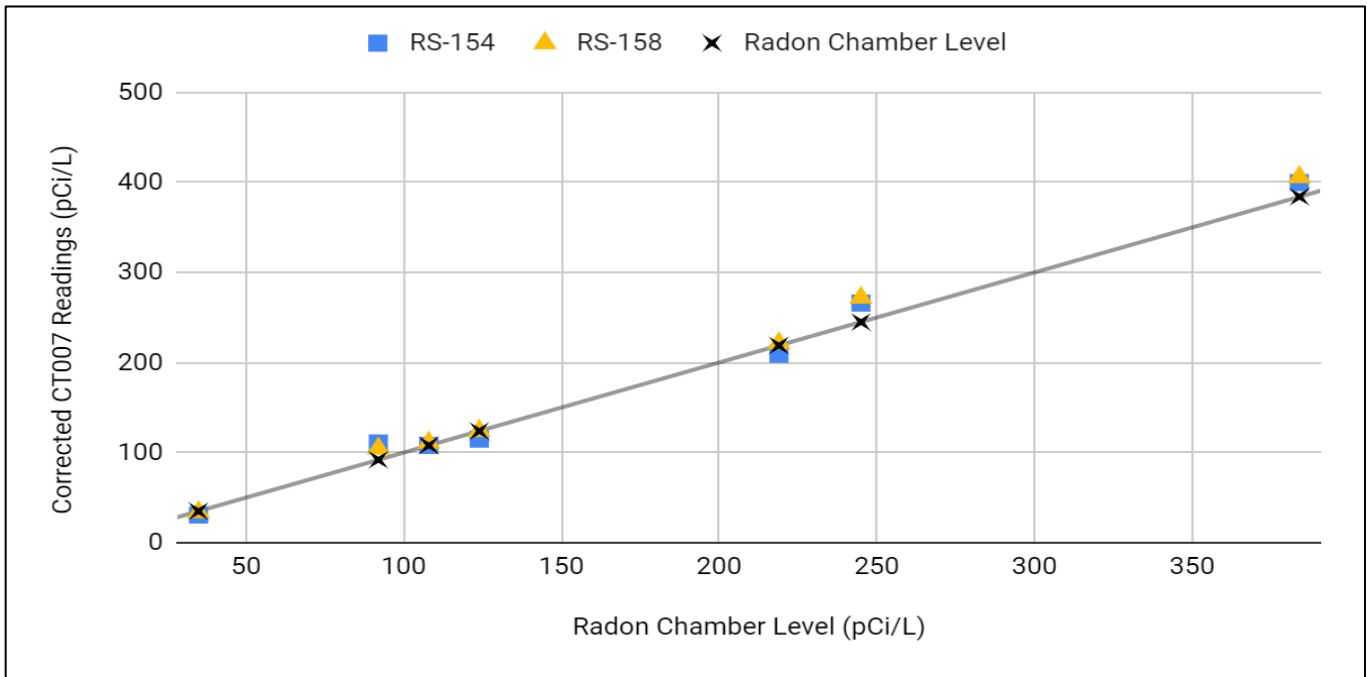

Figure (3) CT007's corrected measurement Vs Radon Chamber

After applying the respective correction factors determined from the Canadian radon chamber, the radon concentrations measured by the RS monitors are in good agreement with the radon chamber values. See Table (2) and Figure (3). Interestingly, applying the average correction factor from Table 1 of 1.23 to all detectors, instead of their individual correction factors, results in approximately the same level of agreement with the radon chamber values. See Figure (3).

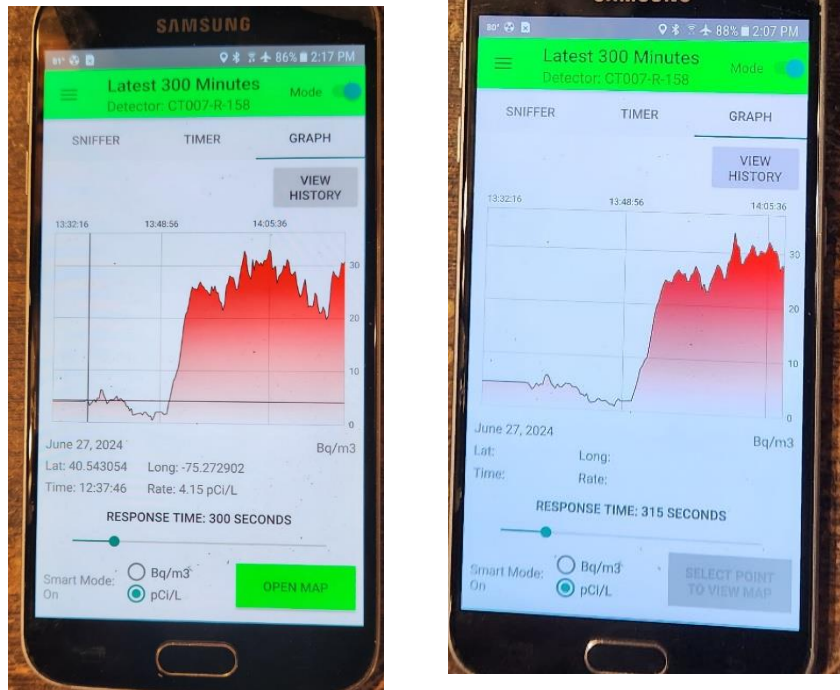

Figure (4) RS in re-circulation mode
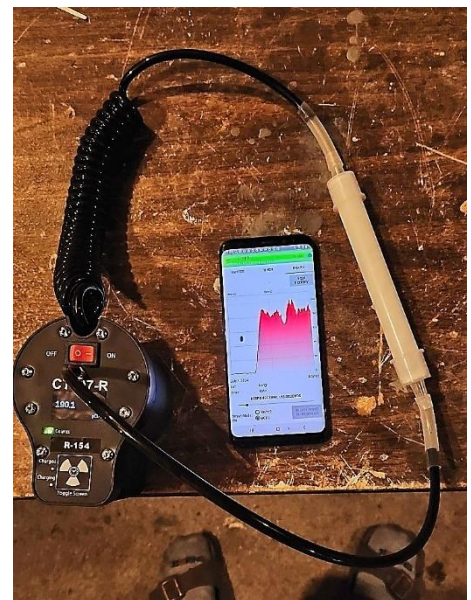
Figure (5) RS monitors graphs from sampling radon chamber at 35 pCi/L

Interpreting Figure 5, the RS-154, and RS-158 detectors read at approximately 25 pCi/L, and 27.5 pCi/L, respectively, all lower than the expected 35 pCi/L. After applying the individual correction factors from Table 1, these readings would be approximately 31 pCi/L, and 34 pCi/L.
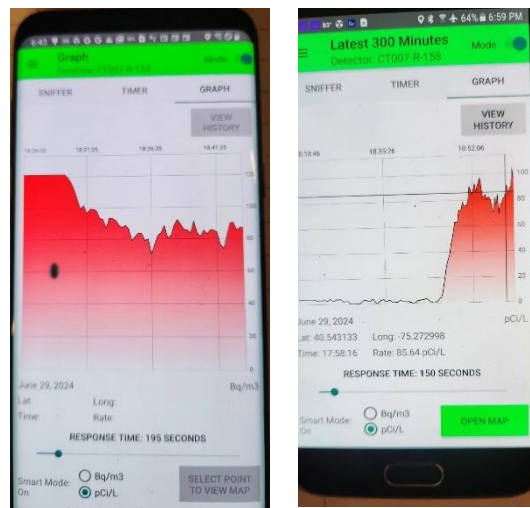

Figure (6): RS monitors graphs from sampling radon chamber at 92 pCi/L

Interpreting Figure 6, the RS-154, and RS-158 detectors read at approximately 90 pCi/L, and 85 pCi/L, all lower than the expected 92 pCi/L. After applying their respective correction factors from Table 1, the measurements are approximately 111 pCi/L, and 105 pCi/L.
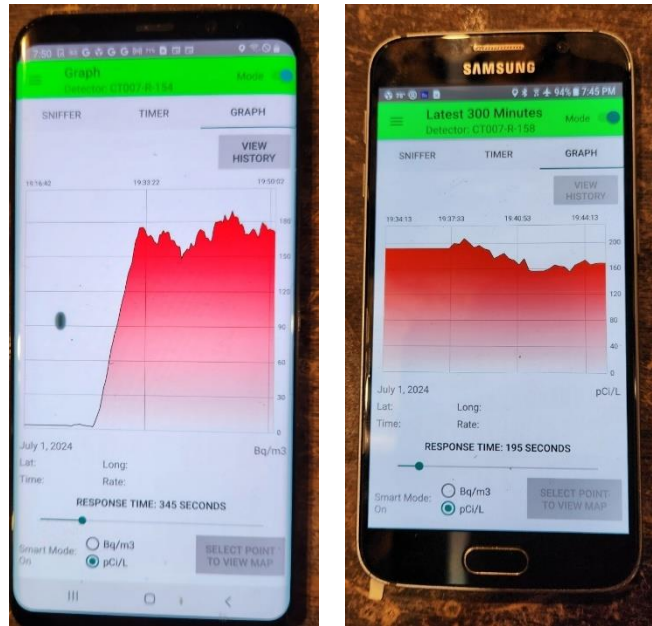

Figure (7): RS monitors graphs from sampling radon chamber at 219 pCi/L

Interpreting Figure 7, the RS-154, and RS-158 detectors read approximately 170 pCi/L, and 180 pCi/L, all lower than the expected 219 pCi/L. After applying their respective correction factors from Table 1, these measurements are approximately 209 pCi/L, and 221 pCi/L.
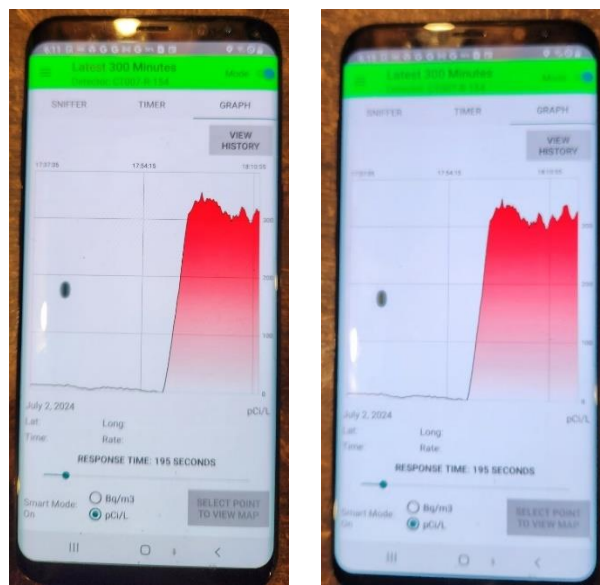

Figure (8): RS monitors graphs from sampling radon chamber at 384 pCi/L

Interpreting Figure 8, the RS-154, and RS-158 detectors read approximately 325 pCi/L, and 330 pCi/L, all lower than the expected 384 pCi/L. After applying the correction factors from Table 1, the measurements are approximately 400 pCi/L, and 406 pCi/L.

2.5 Sampling Jar and Sampling Hose Setup

The 1250 mL sampling glass food storage jar was purchased through Amazon for $22. The two valves which are 5/16" barbed feelers drip irrigation switch valves cost about $10 for two from Amazon. Each valve had one of the barbed ends smoothed with a bench grinder so that it could be installed into a hole, drilled in the wooden lid. This was repeated with the second valve. The valve was held in place using J-B Weld PlasticWeld epoxy two-part cement. A small camera bag was used to transport the jar safely. A pronged Tee nut was glued to the bottom inside of the jar. A half inch bolt was threaded into the nut to mark the 250 mL water level. To obtain the water samples, a brass swivel water hose connector with a 3/8" barb inlet and flexible rubber tubing was purchased.

Figure (9): Sample Jar and valve assembly parts
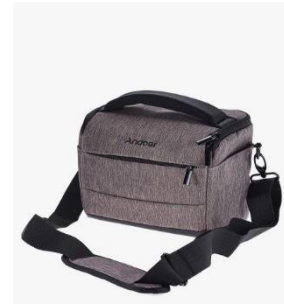

Figure (10): Water Sampling parts

Figure (11): Water level indicator & system carry case

2.6 Water Sampling Procedure

Before obtaining the water sample the two RS monitors were turned on and Radon Sniffer app on each of two smart phones was turned on. When the RS monitor number appeared in each Radon Sniffer app, it was double clicked to connect the cell phone Bluetooth connection to separate RS monitors.

It is important to have a fresh sample of water from the well. If the water has not been used the day of the sampling, the water needs to be run long enough to flush fresh well water through the system. At the sampling location water was run long enough to ensure there was fresh well water coming from this location. A spill bucket was necessary to minimize water flowing onto the floor or sampling table. The jar valves were closed and the lid removed from the jar. The jar was placed on a level work surface within reach of the sample fill tubing. It was necessary to have the jar and adequate lighting to see when the water had reached the top of the bolt inside the jar. The sampling hose was attached to a hose pip that had untreated house water. The water spigot was slowly turned on with the end of the hose placed in an extra bucket to get fresh water flowing from the well tank through the hose. The spigot was turned off and the hose was placed inside the jar with the tubing end resting in the jar bottom.   See Figure 12.
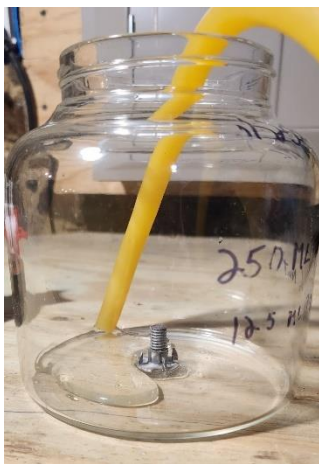

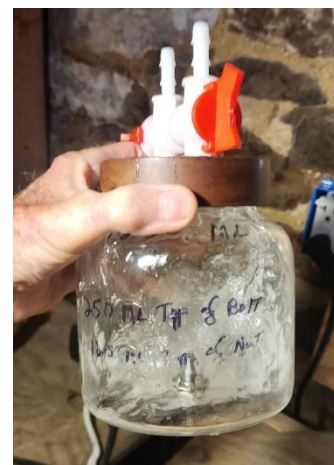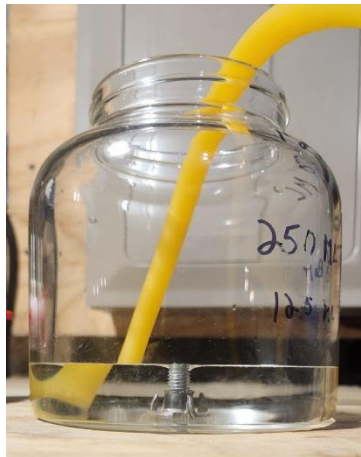
Figure (12): Obtaining water sample

Figure (13): Shaking Sample

The water was turned on to a very low flow so that minimal agitation happened as the water was added to the jar. The end of the hose was kept under the water in the jar until the water was turned off, when the water level had reached the top of the bolt that defines a 250 ml water sample. The hose was then removed and the lid to the jar screwed onto the top of the glass jar. The sampling jar was then moved to the location of the RS monitors. The second sampling jar was then filled in an identical process.

Before agitating the water for each sample jar, the lid was checked that the sampling jar was tight and both valves were closed. The jar is shaken for about 60 seconds so that the water inside the jar is thoroughly agitated. See Figure 13. After the water is fully agitated, the sampling jar is placed on the table adjacent to the RS monitor.

The RS monitor has a function to turn the monitor pump on or off. The pump was previously on while the water sample was being collected to allow the RS software to compensate for background counts. To begin the RS water measurement, the RS pump was turned off and the tubing from inlet and outlet of the RS monitor was connected to the sampling jar valves. Once the tubing was secured, both valves were opened and the RS monitor pump was turned on. After 60 seconds, the app display can be changed from count display to graph display. In the graph display, the averaging count interval can be adjusted by a slide function or by double tapping the interval display to set a specified time interval.

The RS monitor pump air flow is about 0.8 lpm. The volume of the RS monitor and tubing is about 320 ml. In two minutes, the RS monitor has about five air exchanges with the sampling jar. In general, 30 to 60 second averaging interval seemed to provide the best determination of the activity using the graph function. The RS also displays a rolling 15-second and 5-minute average. After about seven to eight minutes, the five-minute rolling average starts to plateau. The plateau five-minute average or a visual determination of the approximate radon concentration using the graph function can be made. The display interval can be extended to 120 seconds to better determine the graph average.

The determined average radon concentration is then multiplied by the calibration factor 1.23 to determine the correct measured radon level of the water sample. Both sample jar radon concentrations were measured at the same time using RS #154 and RS #158. This also allowed determination of the approximate precision of these two RS monitors.

3.0 Results and Discussions

3.1 Deriving Theoretical Calibration Factor

The calibration factor used to determine the concentration of radon in the water based on the concentration of radon in the air measured by the CT007-R Sniffer can be represented as:
$$CF = \frac{[w]_i}{[a]_f}$$
where $[w]_i$ is the radon concentration of the water sample before shaking, and $[a]_f$ is the radon concentration in the air after shaking. The units of concentration for radon in this experiment will be in pCi/L.

The Ostwald coefficient is used to describe the solubility of gases in liquids, and is expressed as the ratio of gas concentration in water to gas concentration in air within a mixture at equilibrium:

$$K = \frac{[w]}{[a]}$$

To determine a theoretically expected calibration factor for this experiment, based on the Ostwald coefficient and the volumes of the water sample, jar, and scintillation cell, the following assumptions were made. Assuming that all the initial radon is contained within the water sample, the total amount of radon in the experiment can be expressed as $[w]_i * V_w$, where V_w is the volume of the water sample used. Assuming that no radon escapes during the experiment, the leftover amount of radon in the water after shaking would be the initial amount of radon subtracted by the amount of radon found in the air. Therefore, the final concentration of radon in the water would be:

$$[w]_f = \frac{[w]_i V_w - [a]_f V_a}{V_w}, \qquad \text{and solving for } [w]_i \text{ gives} \qquad [w]_i = [w]_f + \frac{V_a}{V_w}[a]_f \,,$$

where V_a is the volume of air in the experiment. Assuming the radon concentrations in the water and air reach equilibrium after shaking the sample in the jar, the final radon in the concentration of the water would be:

$$[w]_f = K[a]_f$$

Substituting these expressions into the original calibration factor formula and simplifying results in the following:

$$CF = K + \frac{V_a}{V_w}$$

In this experiment, the total volume of air is the combined volume of the jar, the sniffer's scintillation cell, and any additional tubing, subtracted by the volume of the water sample used. The final expression for the calibration factor determined from this experiment is then:

$$CF = K + \frac{V_j + V_s}{V_w} - 1 \qquad\qquad (1)$$

where K is the Ostwald coefficient, V_j is the volume of the jar used, V_s is the volume of the CT007-R's scintillation cell and any additional tubing, and V_w is the volume of the water sample used.

3.2 Determining Well Water Radon Concentration with EPERM

In order to determine the actual radon in water levels both EPERM and laboratory determined liquid scintillation (LS) water samples were used. In each round of testing two to four 68 ml EPERM sampling jars were carefully filled, so that no bubble appeared when a sample bottle was inverted. The EPERM water samples were placed inside a 3.7-liter Rad Elec radon in water measurement jar that included lids that hold the S-Chamber suspended above the water sample and leak proof rubber tightening collars. The water sample bottles inside the larger jar are given twisting motion to aerate the water at the start of the test. See Figure 14. The electret voltage of the EPERM was read before and after the 15-to-26-hour EPERM exposure in the sealed jar. All of the collected data for the EPERM radon in water measurements were recorded in a spreadsheet created by Rad Elec Inc. to calculate the results. See Figure 15 illustration of the Rad Elec spreadsheet. The spreadsheet allows using a 1.15 correction factor but in general all the EPERM results were greater than the LS results using the standard CF. There was a variation between EPERM results with older electrets of about 6% to 22%. The newer electrets the variation between duplicates was 5 to 8%.

Figure (14): EPERM radon in water measurement system

7/9/2024		1st 250 ml test		US/SI Units		US		Use 115% CF?	No										1st 250 ml test		
Electret Serial	Sample Collection Date/Time	Start Date/Time	End Date/Time	Total Days Delay	Exposure	Initial Voltage	Final Voltage	EIC CF	EIC Config	Elevation Feet	CF	γ µR/h	Sample Volume	Air	Volume (L) Water	Misc.	Corrected Air Volume	Temperature °F	°C	Radon in Water pCi/L	± pCi/L	% Error
5581-83	2024-07-09 16:30	2024-07-09 16:40	2024-07-10 08:50	0.01	0.67	459	346	1.877586	SST	300	1.00	10.0	Small	4.044	0.066	0.033	3.7213	65	18.3	5353.9	275.9	5.15%
5576-91	2024-07-09 16:30	2024-07-09 16:40	2024-07-10 08:50	0.01	0.67	446	340	1.871361	SST	300	1.00	10.0	Small	4.044	0.066	0.033	3.7213	65	18.3	5035.7	260.5	5.17%
																				5194.8		

Figure (15): Spreadsheet to calculate radon in water measurements provided by Rad Elec Inc.

3.3 Determining Water Radon Concentration with Liquid Scintillation (LS)

At the same time as the RS sample jars and EPERM sample jars were filled with water, sample bottles for Accustar were filled for Test Run 1, 4, 5, 6 and 7. There was a variation between the four duplicate Accustar water samples of 0.2% to 7.5%. The last Accustar measurement was a single water sample. The first Accustar samples were mailed by USPS and the samples were analyzed 6 days after being sampled. The lab reported a bubble in the sample. The second set for Test 4 were shipped by UPS and were analyzed 4 days after sampling. The final 3 separate samples were also shipped using UPS and were analyzed two days after sampling.

The sixth and seventh test run included single water samples sent via UPS to the Pennsylvania DEP office to be analyzed by their lab. Thes two samples were collected and shipped in identical method as the Accustar water test samples.

3.4 Results of RS Monitors Radon in Water Measurements

The measurements included measuring the radon in water with at least two EPERM jars and one or two vial liquid scintillation test kits. Two RS monitors were used to measure two 1250 ml jars that were each filled to the 250 mL level with well water, agitated and sampled for about 10 minutes. Figure 16 is a photo of the final process of the water testing with two EPERM radon in water measurement setups.

Figure (16): Two water sampling jars being sampled by two RS monitors

3.4.1 RS water test 1

In Figure 17 the cell phone Radon Sniffer app is displaying about 10 minutes of measuring the 250 mL water sample in the jars with graph interval averaging every 120 seconds. The RS-154 monitor on the left is reading about 850 pCi/L. The RS-158 monitor on the right is reading about 825 pCi/L, which is only a 3% difference between the two RS monitor readings. Table 3 displays all the results of Test 1.

Figure (17): Test 1 - 250mL water sampled 7/9/24 for 10 minutes.

Older EPERM pCi/L	Older EPERM pCi/L	LS # 1282104	LS # 1282105	CT007 RS-#	CT007 pCi/L	RS 1.23 CF	EPERM CF	Accu LS CF
5354	5036	4400	4410	RS-154	850	1045	4.97	4.21
5354	5036	4400	4410	RS-158	825	1015	5.11	4.34
EPERM Avg 5195 Variation 6.3%		LS Avg 4405 Variation 0.2%		CT007 variation 3%		**Test 1 7/9/24 250 mL sample**	EPERM Avg CF 5.04	LS Avg CF 4.27

Table (3) Test 1 results of 250 mL radon in water measurements.

The first Accustar sampling, the lab reported there was an air bubble in the sample jars mailed to the lab. The lab did not report the size of the bubble but in general they will report any bubble pea size or larger. The lab did not specify how much reduction in measurement value the bubble had caused. The samples were mailed by USPS and took six days to get to the lab even though they were mailed the same day as sampling. The next

sample was mailed by UPS and took four days to get to the lab. The final three samples made it to the lab in two days, using UPS. It was decided to not use the results from the Test 1 because of the Accustar reported bubble.

3.4.2 RS water test 2

Figure (18) Test 2 - 250mL water sampled 7/11/24 for 10 minutes.

The second test round the two RS monitors average around 1300 to 1350 pCi/L. See Figure 18.

Older EPERM pCi/L	Older EPERM pCi/L			CT007 RS-#	CT007 pCi/L	RS 1.23 CF	EPERM CF	
9017	7791			RS-154	1350	1661	5.05	
9017	7791			RS-158	1300	1599	5.25	
EPERM Avg 8404 Variation 15.7%				CT007 variation 3.8%		**Test 2 7/11/24 250 mL sample**	EPERM Avg CF 5.15	

Figure (18): Test 2 results 250 mL radon in water measurements

Table 4 displays the results from the Test 2. No LS test kits were mailed to the lab because the results from the Test 1 had not been received due to the delay in shipping. The EPERM average results in comparison to the RS monitor results for Test 2 were very similar to the results of the Test 1.

3.4.3 RS water test 3

Figure (19) Test 3 results 250mL water sample 7/13/24 sampled for 10 minutes.

RS monitor results for Test 3 averaged about 850 and 900 pCi/L. See Figure 19.

Older EPERM pCi/L	Older EPERM pCi/L			CT007 RS-#	CT007 pCi/L	RS 1.23 CF	EPERM CF	
7534	6982			RS-154	900	1107	6.55	
7534	6982			RS-158	850	1045	6.94	
EPERM Avg 7258 Variation 7.9%				CT007 variation 5.9%		**Test 3 7/13/24 250 mL sample**	EPERM Avg CF 6.745	

Figure (20): Test 3 results 250 mL radon in water measurements

In Test 3 the water sample in RS158 was shook for 30 seconds and the water sample in RS154 was shook for 90 seconds. The 90 second shake versus the 30 second shake was 5.9% greater however this test was not repeated and was within the normal variation between these two RS monitors. Neither of the RS monitors was consistently higher or lower than the other RS monitor during all of the duplicate measurements.

3.3.4 RS water test 4

Figure (20): Test 4 with 250mL of water 7/15/24 sampled for 10 minutes.

In Figure 20, the Sniffer tab of the RS app is displayed. In the Sniffer tab the "Radon 5min Avg" can be used to determine the sample measured concentration after about 7 minutes of sampling the jar and the concentration appears to have reach a plateau. The RS monitors were recording about 1328 pCi/L and 1412 pCi/L at this point.

Older EPERM pCi/L	Older EPERM pCi/L	LS # 1282118	LS # 1282119	CT007 RS-#	CT007 pCi/L	RS 1.23 CF	EPERM CF	Accu LS CF
8425	9586	6700	6860	RS-154	1328	1633	5.65	4.15
9249	9668	6700	6860	RS-158	1412	1736	5.32	3.91
EPERM avg 9232 Variation 14.7% EPERM +36% vs LS		LS Avg 6780 Variation 2.3%		CT007 variation 6.3%		**Test 4 7/15/24 250 mL sample**	EPERM Avg CF 5.49	LS Avg CF 4.03

Table (6) 4th Test results with 250 mL radon in water measurements

The results of this Test 4 had the greatest difference between the EPERM results and the LS results. The LS determined CF is well below the calculated CF of 5.53 at K value of 0.25 as detailed in section 4.1. There is no explanation of the reason for this low LS value. The water sample did take four days to arrive at the Accustar lab. The final three Accustar test results arrived at the lab in two days.
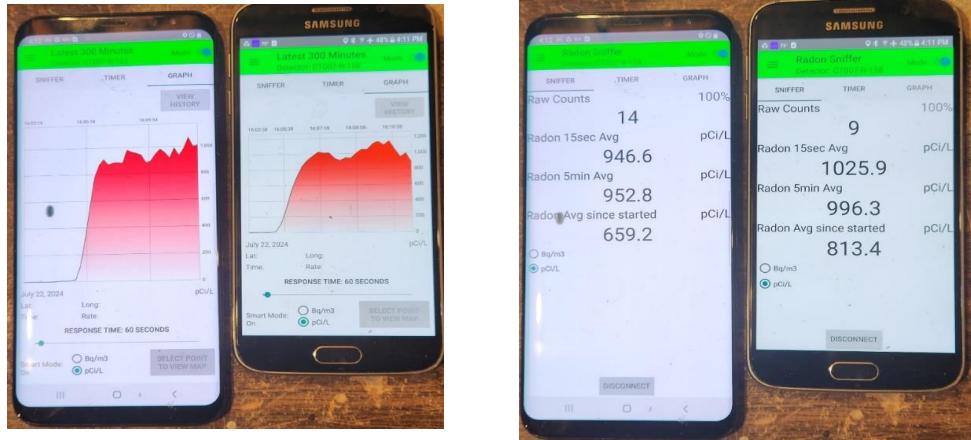
3.3.5 RS water test 5

Figure (21) Test 5 with 250mL of water 8/12/24 sampled for 8 minutes

The results of the RS sampling for the Test 5 display the choices of viewing the measurement using the graph function or the averaging function. If the radon in water are high levels as was measured in this project, the graph function can be used to more quickly determine the approximate measured radon level to avoid saturating the scintillation cell with background counts. To obtain a more accurate averaging the Sniffer tab "Radon 5min Avg" result provides a more precise measurement.

Older EPERM pCi/L	Newer EPERM pCi/L	LS # 1292116	LS # 1292117	CT007 RS-#	CT007 pCi/L	RS 1.23 CF		Accu LS CF
		7290	7840	RS-154	952	1171		6.46
				RS-158	996	1225		6.17
		LS Avg 7560 Variation 7.5 %		CT007 variation 3.0%		**5th Test 7/22/24 250 mL sample**		LS Avg CF 6.31

Table (7) Test 5 results with 250 mL radon in water measurements

The EPERM chambers were unfortunately not opened during their exposure and no results were obtained from them to compare to the LS results. The RS calibration factor in Test 5 using the LS results are 1.57 times higher the LS factors in Test 4. The LS results are 1.15 times higher than the EPERM CF from Test 4.
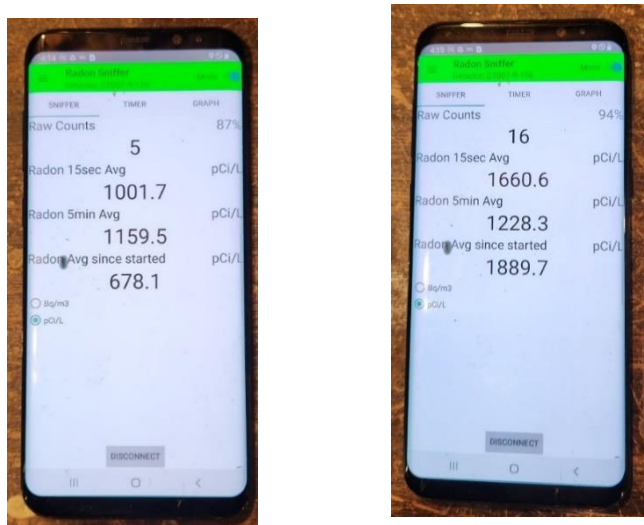
3.3.6 RS water test 6

Figure (22) Test 6 with 250mL of water 8/6/24 sampled for 8 minutes

These are the 5-minute average results for Test 5 of 1160 pCi/L and 1228 pCi/L. One of the cell phone RS app stopped running during the sampling and needing to be re-started. This is why the "Radon Avg since started " is so more than double for RS158 displayed on the right in Figure 22. This happened on several occasions for no known reason.

Older EPERM pCi/L	Newer EPERM pCi/L	Accu LS # 1292104 1292105	PA DEP LS # 5920831	CT007 RS-#	CT007 pCi/L	RS 1.23 CF	EPERM CF	Accu LS CF	PA DEP LS CF
8402	8269	8830	8078	RS-154	1160	1426	6.04	6.23	5.66
10129	8974	8960		RS-158	1228	1510	6.70	5.89	5.35
Old EP avg 9266 New +4.2% vs LS New EP avg 8622 New -3.1% vs LS		Accu LS Avg 8895 Variation 1.5 % PA DEP - 9.5%		CT007 variation 5.8%		Test 6 8/6/24 250 mL sample	New EPERM Avg CF 6.37	Accu avg LS CF 6.06	DEP avg LS CF 5.50

Table (8) 6th Test results with 250 mL radon in water measurements

New EPERM electrets were obtained for Test 6 and Test 7 to measure a comparison to older electrets. The average results between the LS and the EPERMs were within 5% for the Test 6.
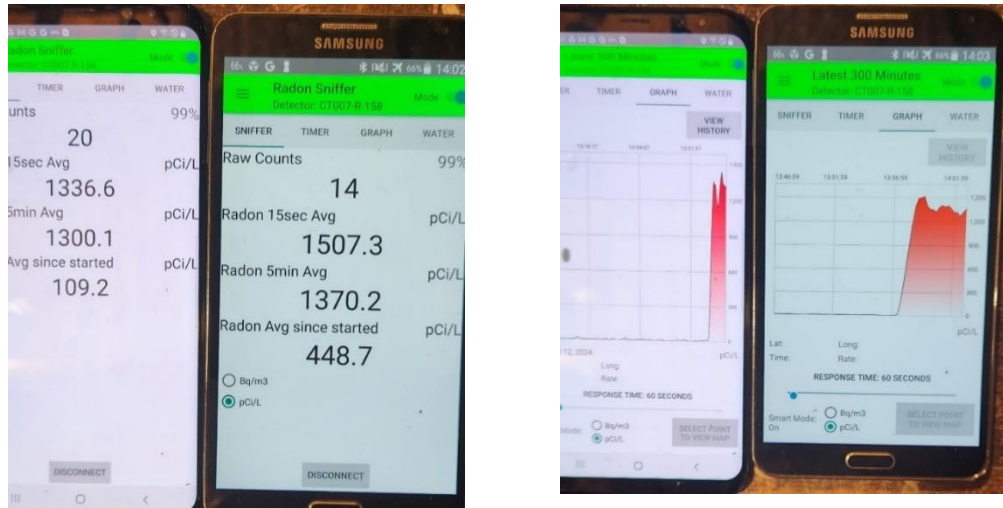
3.3.7 RS water test 7

Figure (23) Test 7 with 250mL of water 8/12/24 sampled for 10 minutes

The results of the RS Test 7 are displayed as a graph and as the Sniffer tab "Radon 5min Avg". The app for RS154 turned off initially and had to be restarted. The approximate RS measurement value can be obtained by the graph but the more precise result is the Sniffer tab Radon 5min Avg after the value reaches a plateau.

Old electret EPERM pCi/L	New electret EPERM pCi/L	PA DEP LS # 5920832	LS # 1252371	CT007 RS-#	CT007 pCi/L	RS 1.23 CF	New EPERM CF	Accu LS CF	PA DEP LS CF
10,362	9,534	8,833	10,400	RS-154	1300	1599	6.11	6.50	5.52
11,438	10,011			RS-158	1370	1685	5.80	6.17	5.24
Old EP avg 10900 Old + 4.8 % vs LS New EP avg 9772 New - 6.1 % vs LS		Accustar LS +17.7% PA DEP -15.1%		CT007 variation 5.4%		**Test 7 8/12/24 250 mL sample**	New EPERM Avg CF 5.95	Accu LS CF 6.34	DEP LS CF 5.38

Table (9) Test 7 results with 250 mL radon in water measurements

New EPERM electrets averaged about 11% less than the older electrets in Test 7. The new electrets were used to determine the calibration factor for Test 7.

3.4 Measuring Ostwald Coefficient Through Double Sampling

To determine the theoretical calibration factor expected for this study from Equation (1), the Ostwald coefficient must be known. The Ostwald coefficient at 20 degrees Celsius (68 F) is approximately between 0.23-0.25. However, this value corresponds to the water and gas mixture being at equilibrium, which may not occur after shaking for 30-60 seconds. Two tests, referred to as double sampling, were run to estimate the amount of radon remaining in the water after shaking, based on air measurements. Firstly, a single sample jar was filled with 250 ml water sample, as was done in Test 1 through Test 7. The water sample was shaken for 60 seconds. One of the RS sniffers was used to sample the radon that accumulated in the initial jar shaking, using the same method as the previous tests. After the RS sampling was complete, the jar valves were closed and the RS sniffer disconnected from the jar valves. The sample jar with the valves closed was then placed on a table and the sample jar lid was opened and set to the side. A small ventilation fan was turned on low speed and aimed into the sample jar for about 30 seconds. See Figure 24. The jar lid was then replaced and the water inside was shaken a second time for about 60 seconds. A second RS sniffer was then set up as per the previous testing procedure and after the jar valves were open, the RS sniffer pump was turned on. The radon inside the jar was measured for the 2nd time using the graph and or Sniffer tab "Radon 5min Avg". The results are displayed in Figure 25 and Figure 26 for the first double sampling.

Figure (24): Airing out the jar after 1st shaking
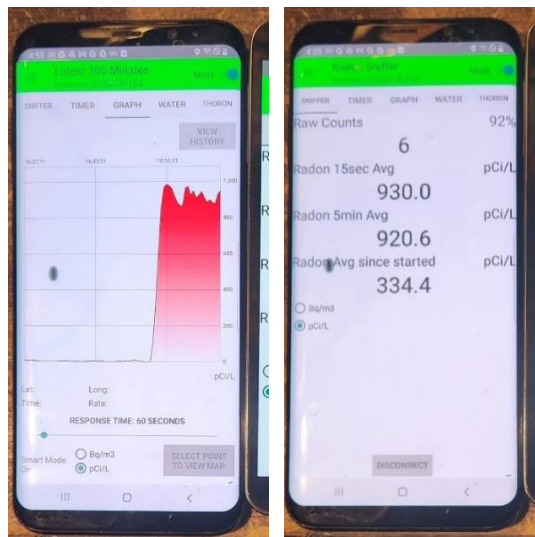
3.4.1 First try double measuring a water sample

Figure (25): First double sampling with initial radon measured before making 2nd shaking measurement
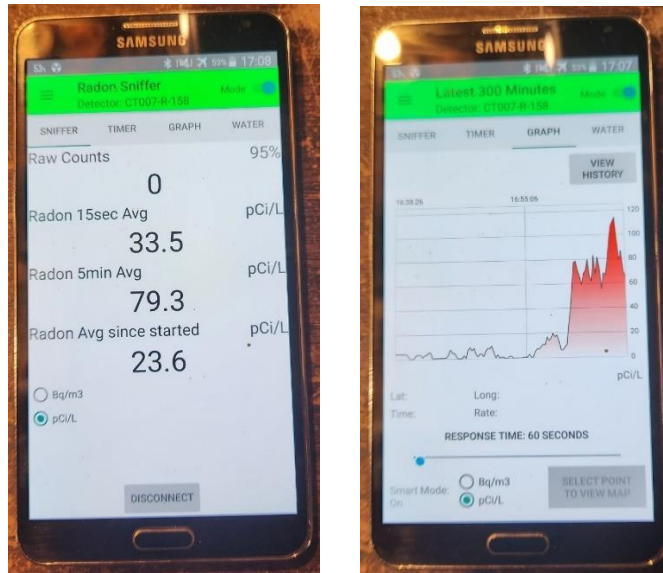
Figure (26): First double sampling with radon
measurement results after ventilation and 2nd shaking

3.4.2 Second try double measuring a water sample

Figure (27): Second double sampling with initial radon
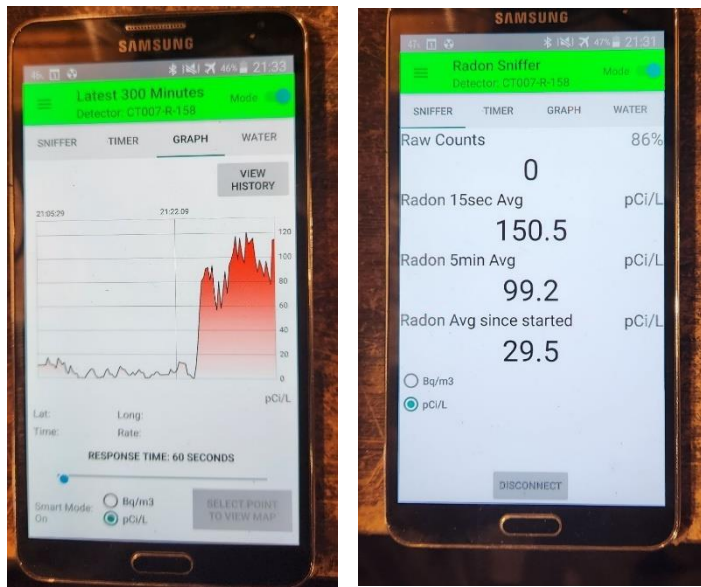measured before making 2nd shaking measurement

Figure (28): Second double sampling with radon
measurement results after ventilation and 2nd shaking

3.5 Determining Ostwald Coefficient from Measured Results

The ratio of the measurements gathered after the 1st and 2nd shakes can be used to estimate the Ostwald Coefficient (K). Assuming that the ratio of radon in the water to radon in the air is the same after both shakes, the Ostwald Coefficient (K) can be represented as the following:

$$K = \frac{[w]_1}{[a]_1} = \frac{[w]_2}{[a]_2}$$

Where $[w]_1$ and $[w]_2$ are the concentrations of radon in the water after the 1st and 2nd shake, and $[a]_1$ and $[a]_2$ are the concentrations of radon in the air after the 1st and 2nd shake, which are measured by the Radon Sniffers. Assuming that no residual radon in the water from the 1st shake escapes during the fanning process, and that all the radon in the air above the water from the 1st shake is removed during the fanning process, the Radon concentration in the water after the 2nd shake would be:

$$[w]_2 = \frac{[w]_1 V_w - [a]_2 V_a}{V_w} = [w]_1 - \frac{V_a}{V_w}[a]_2$$

Where V_a and V_w are the volumes of air and water in this experiment, respectively.
Replacing $[w]_1$ with $K[a]_1$, subbing $[w]_2$ into the Ostwald coefficient formula, and solving for K gives the following expression for this test:

$$K = \frac{V_a}{V_w\left(\frac{[a]_1}{[a]_2}-1\right)} \tag{2}$$

The CT007-R has a scintillation cell volume of 270 mL, and the desiccant tube and additional tubing used in the experiment is an estimated 50 mL. Using a 1250 mL jar and a 250 mL water sample, the following Ostwald Coefficients were calculated from the 2 measurements using equation (2).

1st Shake Measurement (pCi/L)	2nd Shake Measurement (pCi/L)	Ostwald Coefficient (K)
921	79	0.50
1327	99	0.43
	Average	0.47

Table (10): Double Measurement Results and Calculated Ostwald Coefficients

The average determined K value is greater than the expected 0.23-0.25 value at equilibrium. This indicates that the radon in the mixture is not quite at equilibrium after shaking, and there is more Radon remaining in the water than expected.

Using a 1250 mL jar, 250 mL water sample, and a CT007-R sniffer, the following calibration factors would be expected from this experiment from equation (1).

Ostwald Coefficient	K = 0.25	K = 0.47
Expected CF	5.53	5.75

Table (11): Theoretical Calibration Factors

To account for the radon in the jar not reaching equilibrium after shaking during the experiment, the theoretical calibration factor used for analysis will be 5.75.

4.0 Conclusion

This study demonstrates that Radon Sniffers can be used to detect radon in water quickly and onsite, with a simple testing procedure and applying a calibration factor. When calibrated correctly, these devices can use air measurements to determine radon in water levels that are comparable to traditional methods such as using EPERM devices and liquid scintillation tests.

To ensure the CT007-R reads radon levels accurately, a predetermined correction factor of 1.23 was applied to each measurement, and the devices were checked using grab samples from radon chambers. When comparing the RS devices to the radon chambers, they read -7.1% to 17.4 % off the radon chamber level, with an average absolute percent difference of 6.6%. With the applied correction factors, the radon sniffers agreed with the radon chamber levels, confirming the sniffers can detect radon levels within reasonable error.

A theoretical calibration factor was calculated based on the ratio of water and air in the experiment and an Ostwald coefficient. To determine the ratio of radon in the water and air after shaking, the Ostwald coefficient was estimated from the ratio of radon measured by a CT007-R sniffer after an initial shake to the radon measured after ventilating the jar and shaking again. The estimated ratio of radon left in the water to radon in the air after shaking the jar was determined to be K = 0.47, and the corresponding theoretical calibration factor was calculated to be 5.75.

An experiment was designed to determine the radon in water concentration from radon sniffer air measurements. A water sample is added to a jar, then shaken to agitate the radon in the water into the air. A CT007-R sniffer is then connected to the jar to determine the concentration of radon in the air. A calibration

factor is then applied to determine the initial radon concentration in the water based on the concentration measured in the air after agitation. Each water sample was also tested with EPERM and liquid scintillation lab tests.
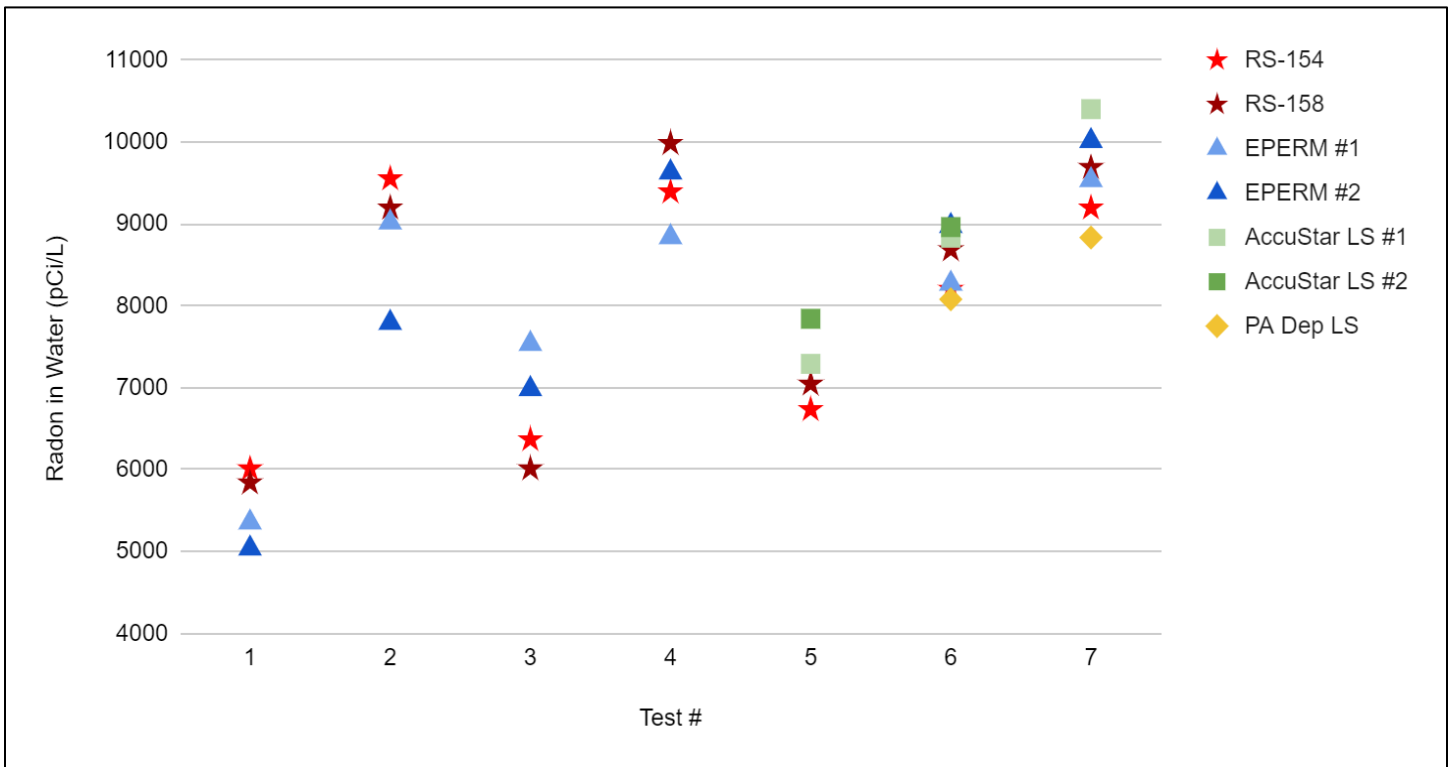

Figure (29): Spread of Measurements using RS 5.75 CF

Figure 29 showcases the spread of radon measurements for each water sample. The RS monitor radon in water readings were determined by applying the theoretical calibration factor of 5.75 from Table 11 to the 1.23 corrected measurements.

Test #	EPERM CF	AccuStar LS CF	PA Dep LS CF
1	5.04	Excluded	-
2	5.15	-	-
3	6.75	-	-
4	5.49	Excluded	-
5	-	6.31	-
6	6.37	6.06	5.50
7	5.95	6.34	5.38
Average	5.79	6.24	5.44

Table (12): Experimental Calibration Factors

Table 12 shows the average calibration factors determined from each test based on the respective EPERM and liquid scintillation water measurements compared to the RS monitor readings. For each method of measuring radon in water, the average calibration factor differs considerably. This indicates that the calibration factor used for the CT007-R sniffer depends on the intended radon in water measurement method to replicate.

The average calibration factor determined from the EPERM measurements differs from the theoretically determined calibration factor of 5.75 by less than 0.7%, indicating that applying the theoretical calibration factor to corrected RS measurements can provide radon in water measurements that compare to measurements from an EPERM device. The average calibration factor from the AccuStar liquid scintillation results is greater than the theoretical 5.75 calibration factor. For the CT007-R sniffer to read the same radon concentration as AccuStar liquid scintillation tests, a larger calibration factor of 6.23 should be applied to corrected sniffer measurements. The average calibration factor for the PA Department liquid scintillation results was lower than the theoretical 5.75 calibration factor, indicating that a lower calibration factor of 5.44 would be needed for the CT007-R sniffers to read the same as the PA Department's liquid scintillation tests.

Overall, CT007-R sniffers can replicate EPERM and liquid scintillation radon measurements with the use of a specific calibration factor. EPERM measurements take 1-2 days to produce a result, and liquid scintillation results can take days to weeks, whereas the CT007-R measurement can be completed within 15 minutes. Using the test procedure from this report, a CT007-R sniffer can be used to obtain Radon in water measurements faster than alternative detection measurements and produce results that compare to EPERM and liquid scintillation results.

5.0 Reference Papers

1) Brodhead B., Use of Sniffers in Radon Mitigation
   Proceedings of AARST International Radon Conference; 2021