# ELEVATION INFLUENCE ON RADON MONITOR MEASUREMENTS

Bill Brodhead
WPB Enterprises, Inc., 2844 Slifer Valley Rd., Riegelsville, PA 18017
wmbrodhead@gmail.com    www.wpb-radon.com

## ABSTRACT

In a previous study, Rad Elec E-PERM® electret ion S-Chamber recorded about a 17% percent lower result at a 6000-foot elevation above sea level versus 1000 feet, and the smaller L-Chamber recorded a result about 28% lower. Other types of active pulse ion chamber radon measurement monitors have not reported a need for a revised calibration factor if they are exposed at different altitudes or atmospheric pressures. This study repeated four measurements of two different pulse ion continuous radon monitors at about 97 m (320 feet) elevation, 640 m (2100 feet), 1554 m (5100 feet), and 2185 m (7170 feet) of elevation above sea level. At each elevation, the monitors were exposed for at least 14 hours to the same radium sources inside two similar sealed steel containers. The measured increased ingrowth between the third and the thirteenth hour was used to determine the average ingrowth per hour. The average of four runs at each higher elevation was compared to the average of the beginning and ending four runs at the 320-foot elevation. One monitor showed little elevation effect, while the other monitor had significant performance reduction at higher altitudes.

## 1.0 Introduction

### 1.1 Pulse Ion Chamber Size and performance variation with elevation change

One of the more popular radon measurement sensor methods is the continuous pulse ion detector, CPID. Each of the different CPID radon monitors has an ion chamber that includes an ionization sensor. The CPID senses and counts the formation of ion pairs that are produced from predominantly the release of alpha particles, which are two positively charged protons and two uncharged neutrons. The positively charged alpha particle travels about 4 cm (2 inches) and strips negatively charged electrons off primarily oxygen and nitrogen atoms in the air. The positive alpha particle and negatively charged free electrons create ion pairs before recombining. Once the alpha particle stops traveling or gives off its energy, it picks up two loose negative electrons, and the particle changes into a harmless helium atom. The CPID senses and counts this ionization. The amount of ionization that takes place in the radon monitor chamber from the alpha particle depends on the density of the air and the distance the alpha particle travels, which can be limited by the size of the chamber. In less dense air, the alpha particle can travel farther, causing similar ionization unless a smaller chamber restricts its travel length. Gamma also produces some ionization, but it is considered an insignificant amount. This study measured the effect of elevation on two types of CPID radon monitors.

The 1991 E-PERM study (Ref 1) of the elevation effect on ion chambers was made using three different-sized E-PERM® chambers. Each of the different chambers was exposed individually to a radium source inside a sealed vacuum chamber in which a negative pressure was induced to simulate an exposure at higher elevations. See the results in Table 1.

| Elev meters | Elev feet | L Chamber 50 mL | S Chamber 210 mL | H Chamber 960 mL |
|---|---|---|---|---|
| 000 | 000 | 1.00 | 1.04 | 1.03 |
| 305 | 1000 | 1.04 | 1.02 | 1.04 |
| 610 | 2000 | 1.10 | 0.97 | 1.00 |
| 915 | 3000 | 1.14 | 1.01 | 0.98 |
| 1220 | 4000 | 1.19 | 1.03 | 1.01 |
| 1525 | 5000 | 1.23 | 1.07 | 1.05 |
| 1830 | 6000 | 1.28 | 1.17 | 1.03 |
| 2134 | 7000 | 1.32 | 1.22 | 1.05 |
| 2440 | 8000 | 1.37 | 1.27 | 1.04 |

Table (1): E-PERM® electret ion chamber performance variation with altitude

In the EPERM study, they found that changes in elevation above sea level had an insignificant effect on the measurement performance up to varying elevation levels, depending on the chamber size and configuration. See Table (1). This was reported to be due to the travel length of the alpha particle compared to the chamber size and shape. Two of the alpha emissions happen from the short-lived radon decay products (RDPs) that are likely attached to the side wall of the chamber. At higher elevations, the alpha particles can travel further in the less dense air and still produce similar ionization as lower elevations if the chamber is large enough and the total alpha energy is expelled. Thus, larger chamber dimensions would be expected to have less influence from elevation change. In Table 1, the L Chamber, which is the smallest EPERM chamber, requires the most calibration factor increase as the elevation becomes higher to compensate for the reduction in ionization that the electret is experiencing. The S Chamber, which is sized between the L and the H chamber, has a significant calibration factor adjustment starting at 610 m (2000 ft). The large H chamber had almost no apparent change beyond the normal variation in measurements as the elevation increased to 2440 m (8000 ft).

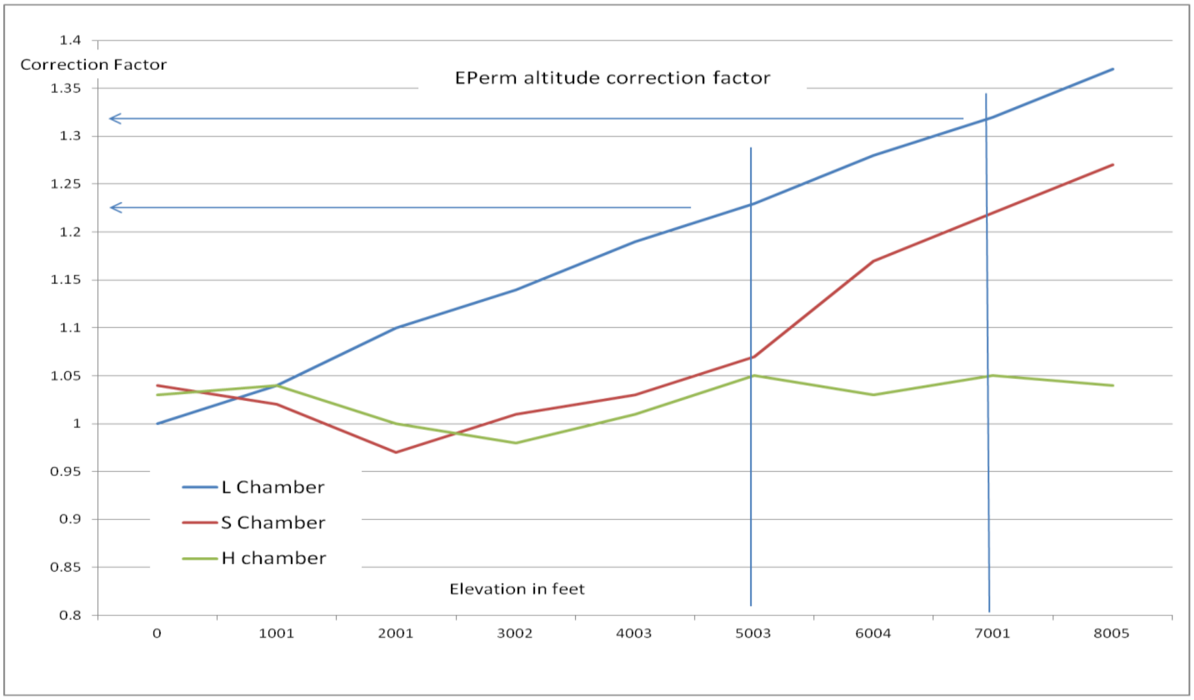

Figure (1): EPERM correction factor for three different chambers

Figure 1 graphs the correction factors (CF) determined for each of the EPERM chambers. Note that the S-Chamber begins to show a CF above 1.1 at around 5100 feet. After 6000 feet, the L chamber and the S chamber appear to have a linear increase in CF.

Figure 2 displays the average elevation of 26 US states. Six of the states average above 5000 feet elevation. Fourteen of the states average above 2000 feet.

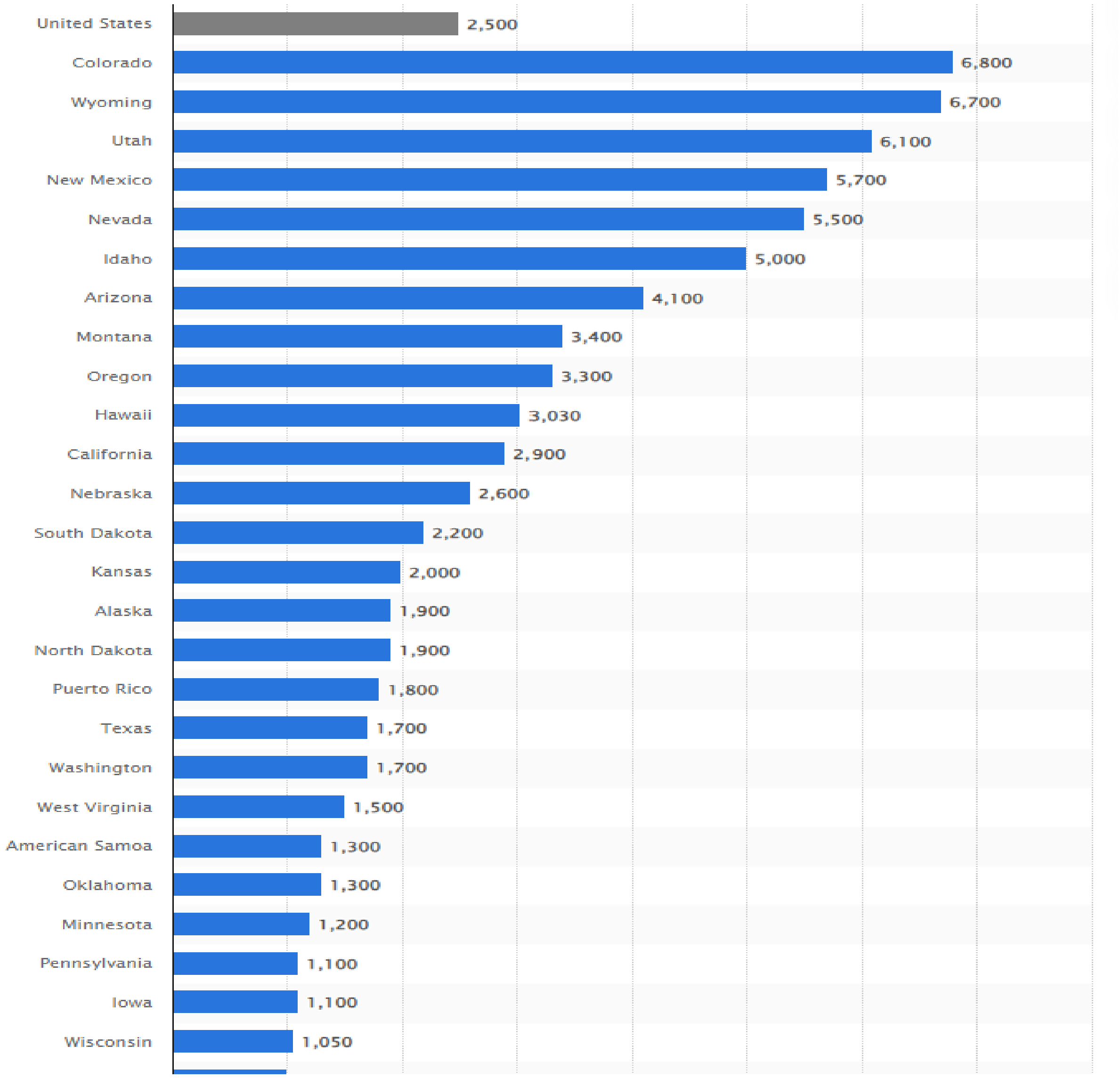

Figure (2): Average elevation of US states above 1000-foot elevation

## 2.0 Methodology

### 2.1 Radon Monitors Tested in this Study

The two types of radon monitors tested in this study were provided by Ecosense, the manufacturer and supplier of the devices in the United States. The RadonEye Pro and the EcoQube Pro® are certified as professional radon measurement devices by NEHA/NRPP. The RadonEye Pro and RadonEye 2+ are referred to as RadonEye in this document. The EcoCube

Pro is referred to as EcoQube. A single RadonEye 2+ was substituted for a RadonEye Pro for the 5100-foot elevation tests.

## 2.2 Spiking Radon Monitors at KSU Radon Chamber

In order to verify that the radon monitors in the study were measuring close to a certified radon chamber level, four WPB Ecosense EcoTracker radon monitors were spiked at the Kansas State University (KSU) radon chamber, which had recently been intercompared with the EPA Montgomery radon chamber. The results of the spiking are shown in Figure (3). Three of the EcoTrackers calibration factors were adjusted after this exposure to more closely match the measurements provided by KSU. The RadonEye monitors used in this study, as well as two AB5 Pylons, were then cross-checked against these recalibrated EcoTrackers and their calibrations adjusted to match the EcoTrackers' average concentration. The RadonEye and EcoQube monitors used in this study were then compared with two AB5 Pylons in the author's radon chamber. See Figure (4).

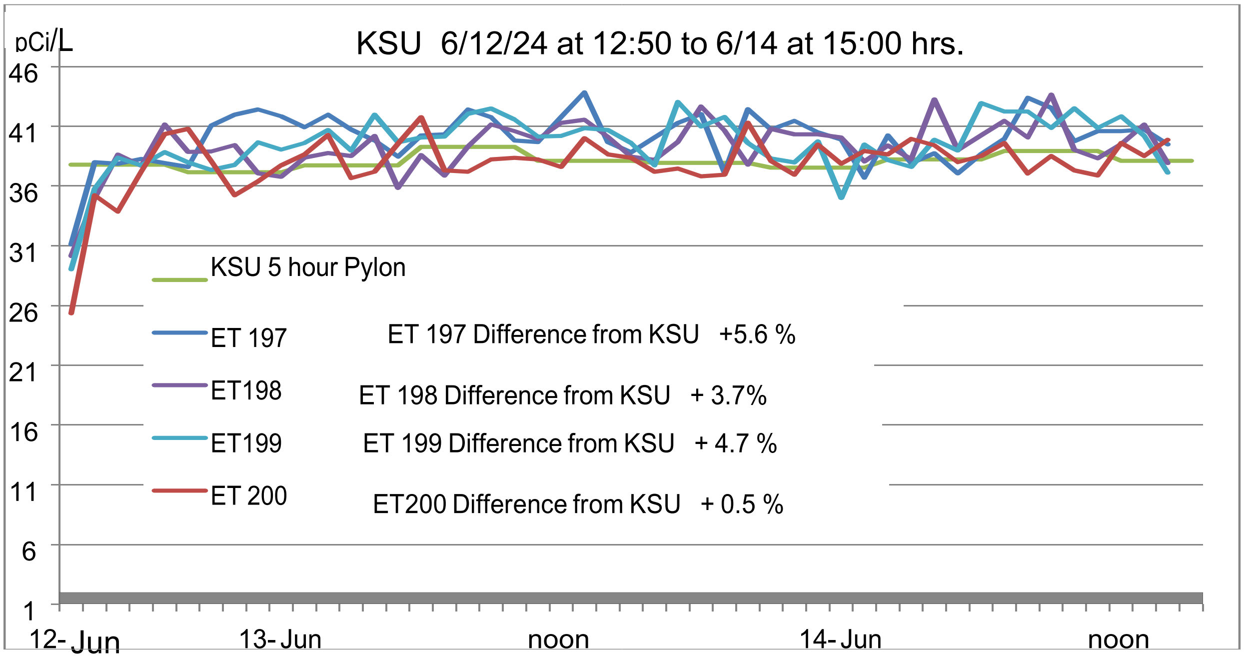

Figure (3): KSU Radon Chamber run to compared to WPB radon monitors

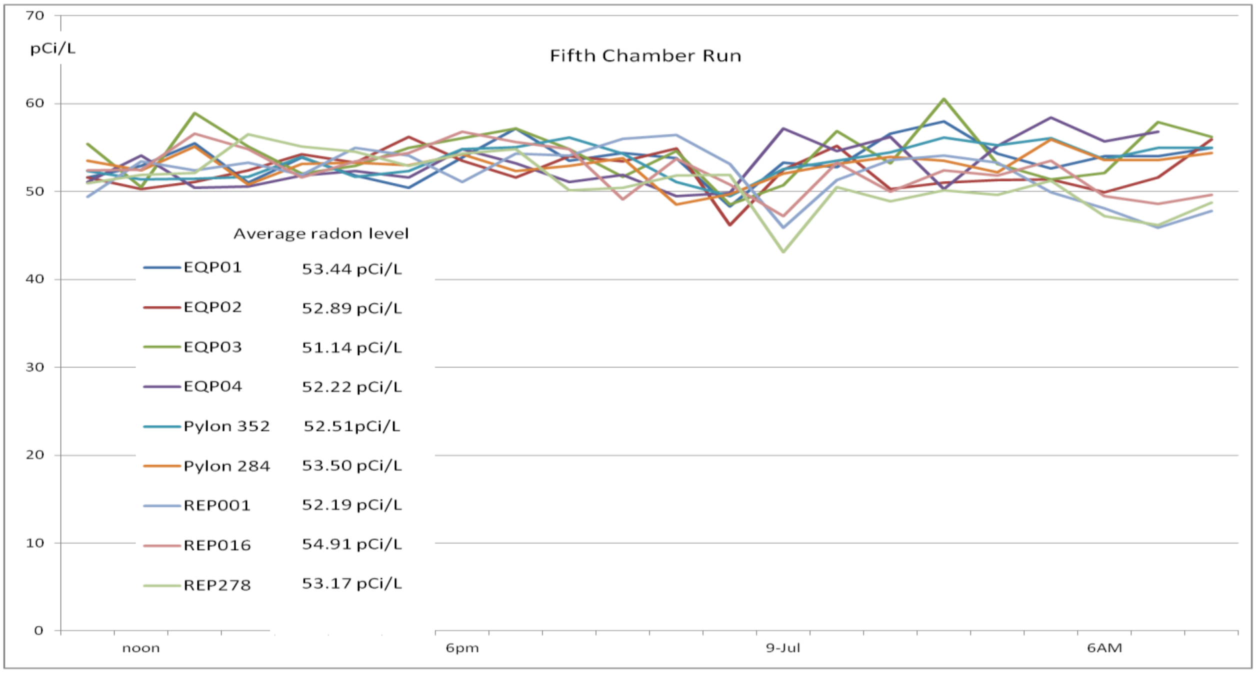

Figure (4): Chamber run to compare monitor performance

## 2.3 Pretesting Calibration of Radon Monitors

To determine the ability of the radon monitors to track ingrowth of radon, the monitors were placed inside the author's radon chamber, and the radon levels were spiked up and down from about 20 pCi/L (740 Bq/m3) to about 160 pCi/L (6000 Bq/m3). See Figure (5). The RadonEye Pro monitors measured a peak concentration of about 160 pCi/L (6000 Bq/m3) compared to the EcoQube Pro peak of about 135 pCi/L (5000 Bq/m3). This may be due to the easier path of radon into the open bottom of the RadonEye versus the EcoQube. Because the study was a comparison between results at different elevations, variation in performance between the two monitor types was not considered significant.

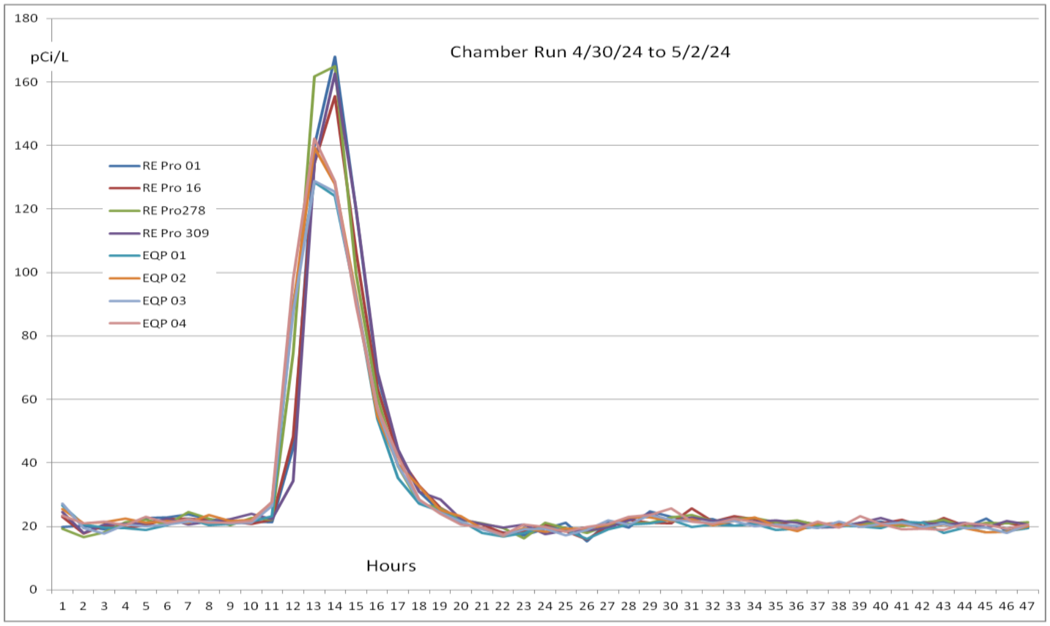

Figure (5): Exposure of test study radon monitors to a radon spike

## 2.4 Radon Chambers Used in this Study

In order to test the influence of elevation change on measurement performance, the exposure of the radon monitors needed to be identical for all conditions except the change in air density induced by elevation change. The radon monitors were tested at three different approximate elevations, 97 meters (320 ft), 640 meters (2100 ft), 1554 meters (5100 ft), and 2185 meters (7170 ft). In each case, two metal airtight containers were used as the radon chambers. The metal containers were specifically made to store ammunition in a watertight condition. An electrical cord was routed into each container, and each penetration was carefully sealed on the inside and outside of the container with silicone caulking. The containers had snap-down lids that included rubber gaskets. The airtight condition of the containers was not tested as the primary requirement of the study was not to determine the strength of the radon source inside the container, but rather that the test was identical at the different elevation locations. The source of the radon was small radium-painted replacement watch second or hour hands that were manufactured in the 1930s and 1940s. See Figure (6). Three radium watch hands were used in one container, and four radium watch hands were used in the other container. The watch hands were suspended from the inside surface of the container lids using Post-its notes and

Figure (6): Gasket sealed metal containers, radon monitors and radon sources double-stick Velcro strips to hold them in place. A small battery-powered fan was included in each case to provide uniform circulation of the radon produced by the sources. The sources induced a radon level ingrowth up to about 3700 Bq/m3 (100 pCi/L) in about 18 hours.

## 2.5 Radon Ingrowth in the Chamber

The EcoQube monitors were always exposed in Chamber 1. The RadonEye monitors were always exposed in Chamber 2. Figure (7) displays the calculated ingrowth as a dashed line. The measured fall-off from the calculated ingrowth was assumed to be caused by radon leakage out of the chamber at higher concentrations. Test 75 switched both monitor types to the other chamber to determine if one chamber leaks radon more than the other. The actual measured fall off from the mathematical dashed line happens at about the same hour of exposure for each monitor type exposed in different chambers, indicating the chambers have the same radon tightness. For a reason not known, the EcoQube tended to fall off the mathematical ingrowth at about the 13th hour, while the RadonEye fell off around the 20th hour. In this study, the ingrowth was always determined between the 3rd and 13th hour.

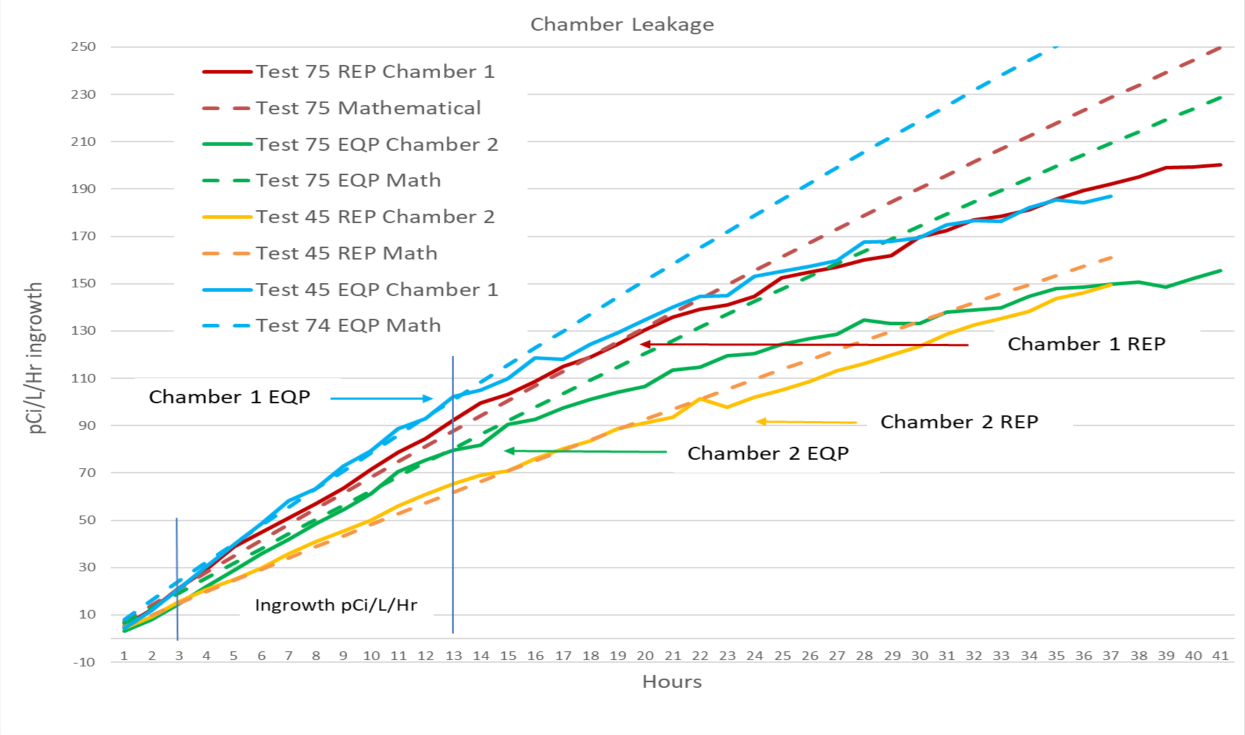

Figure (7): Chamber Leakage Test

For each run, the average of the hourly measurements of all four monitors of each type was used to determine the average pCi/L/hr ingrowth for that monitor type. The average of the four monitors' 3rd hour was subtracted from the average at the 13th hour, and the result was divided by 10. Averaging of four or five runs for each monitor type was used to determine the average in growth at 100 m (328 ft), 640 m (2100 ft), 1554 m (5100 ft), and 2185 m (7170 ft) of elevation. An average correction factor (CF) for each elevation was determined by comparison to the total average of the initial 320-foot elevation ingrowth and the final 320-foot elevation ingrowth.

### 2.6 Elevation Test Procedures

Each round of measuring ingrowth in the two chambers was performed in the same procedure. A cell phone Bluetooth app was used to start, end, and transfer the data for the Ecosense Pro and the RadonEye Pro. The RadonEye Pros and RadonEye 2+ only needed to set each monitor to continuous mode and delete the previous data in order to begin the test. After the connection was made to each EcoQube, an individual file and test version name were input. The EcoQube Pro monitor name was always given as “test# eqp# date” to keep track of the four different device results for each round of testing. The same naming approach was done for the RadonEyes, which required the file name to be given at the end of the testing rather than the beginning. The ability of the CPIDs to connect to WIFI was not used. After the monitors were all started, the small fan in each case was turned on at a low speed. The fan had three speeds. The case was then locked closed and left sealed for a minimum of 14 hours. The start date, time, and current barometric pressure were recorded on a tabulated sheet attached to the lid.

At the end of the exposure, the case was opened, and the app for each monitor type was used to capture all the data. The RadonEye data was then uploaded to a Google Drive account, where it could be downloaded onto a desktop computer. The EcoQube files were uploaded to an Ecosense Dashboard cloud storage system. The EcoQube files were accessed from this Dashboard and downloaded as Excel files. All the EcoQube and RadonEye data from each run were tabulated in a master spreadsheet for the elevation location. The average ingrowth results of all four monitors from each test and each location were transferred to another spreadsheet for comparisons.

## 3.0 Results and Discussions

### 3.1 Ingrowth Testing at 320-feet at the beginning and end of the study

Identical ingrowth tests were performed at the start and end of the study to determine if any significant change in performance occurred using the same test procedures. Table 2 depicts the small difference in the RadonEye monitors, which were the monitors that showed a significant elevation difference. The EcoQubes showed a larger difference between the first and second 320-foot elevation test, and little change at the two higher elevations.

All the individual monitor results of each test were plotted on a spreadsheet graph to determine if there were any visual outliers that needed investigation. Figures 8 and 9 are examples of the ingrowth individual tests at the start and end of the study. Each graph included the average ingrowth result of that test, plus the average results of previous tests, to be able to compare the differences.

| Category | RadonEye Pro | EcoQube Pro |
|---|---|---|
| Pre study avg ingrowth | 6.053 | 7.487 |
| Post study avg ingrowth | 5.969 | 7.855 |
| Average pCi/L/Hr | 6.011 | 7.671 |
| Difference | 1.4% | 4.8% |

Table (2): Variation in pCi/L/Hr average ingrowth beginning vs End of study

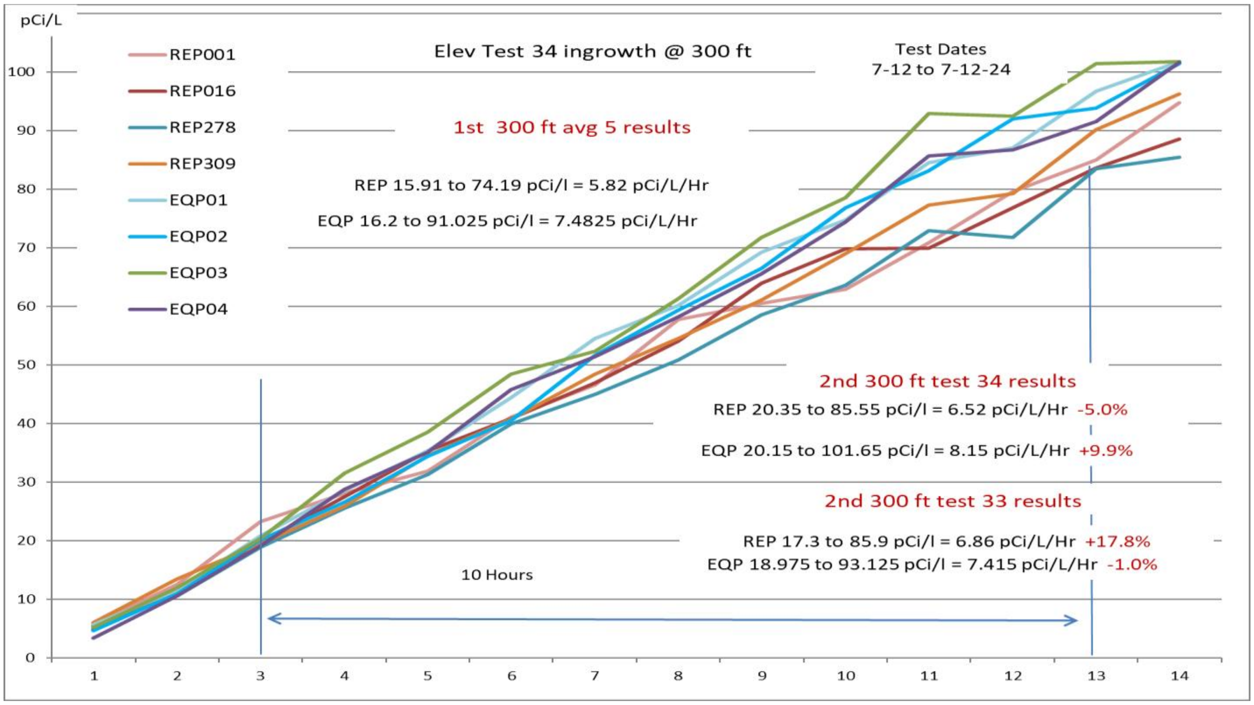

Figure (8): Ingrowth at Initial 320-foot elevation test

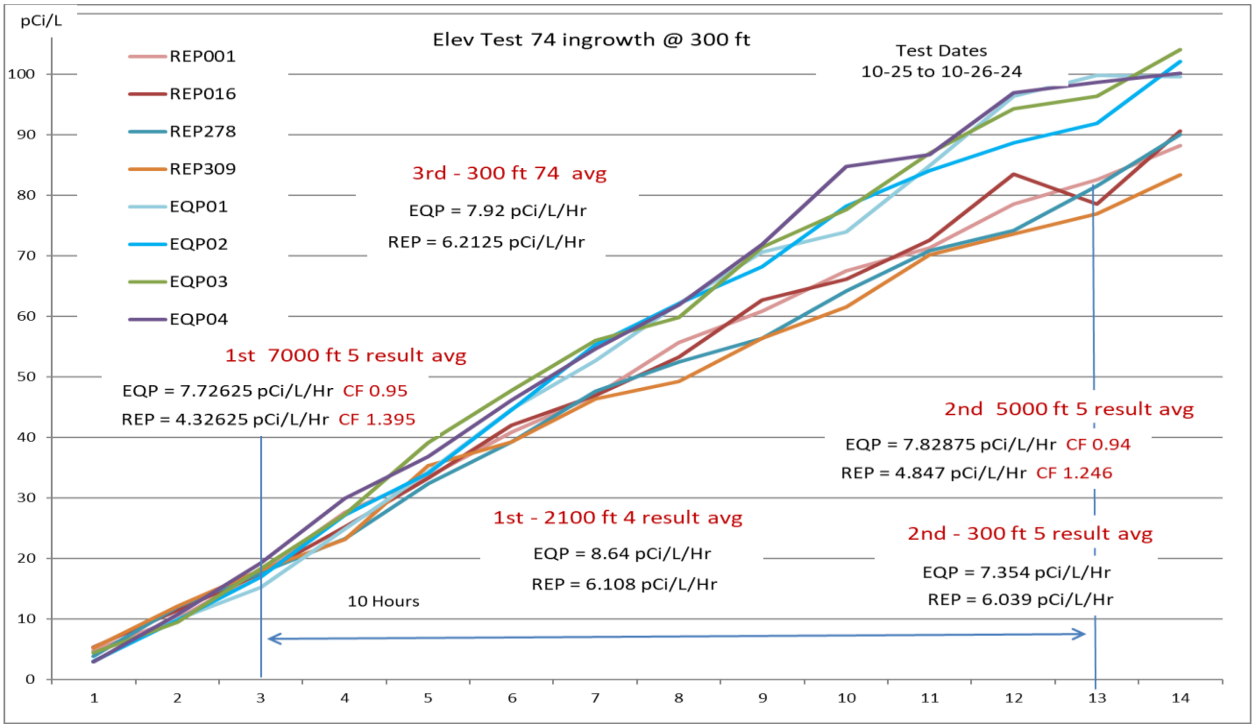

Figure (9): Ingrowth at Final 320-foot elevation test

## 3.2 Ingrowth Testing at 2100 feet, 5100 feet, and 7170 feet

The degree of tight pattern between the same monitor type depicted the precision of the monitors during each test. In general, the RadonEye monitors displayed greater variation than the EcoQube monitors. See an example of the precision variation in Figure (11).

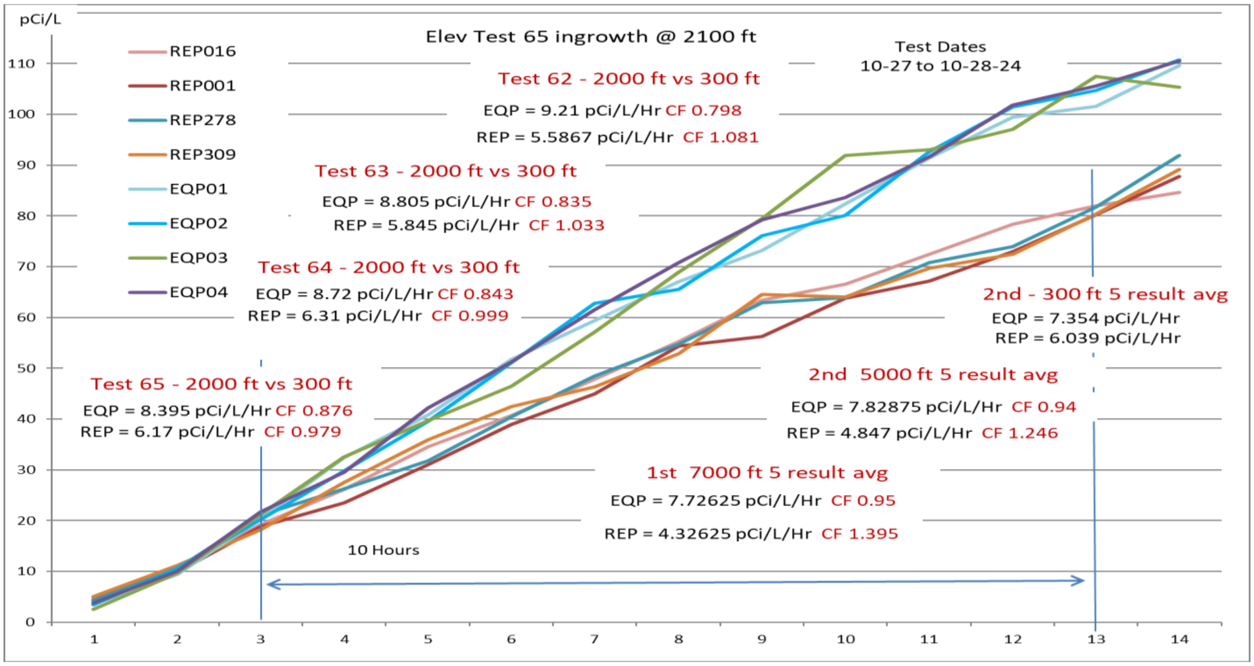

Figure (10): Test five ingrowth at 2100-foot elevation test

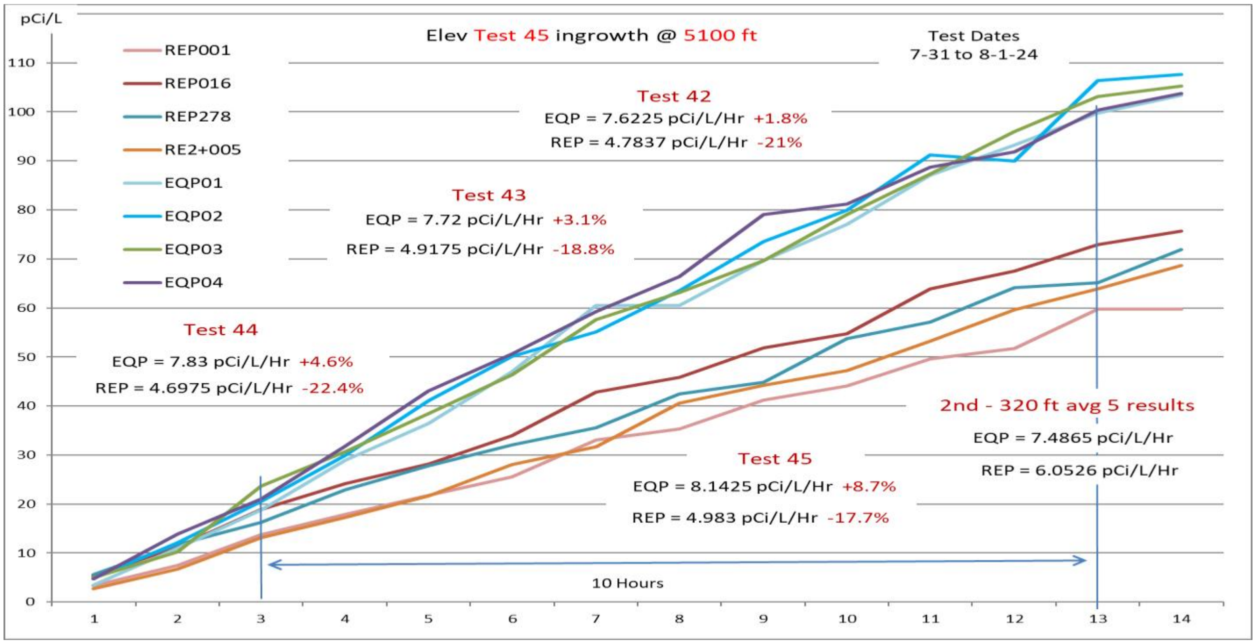

Figure (11): Test five ingrowth at 5100-foot elevation test

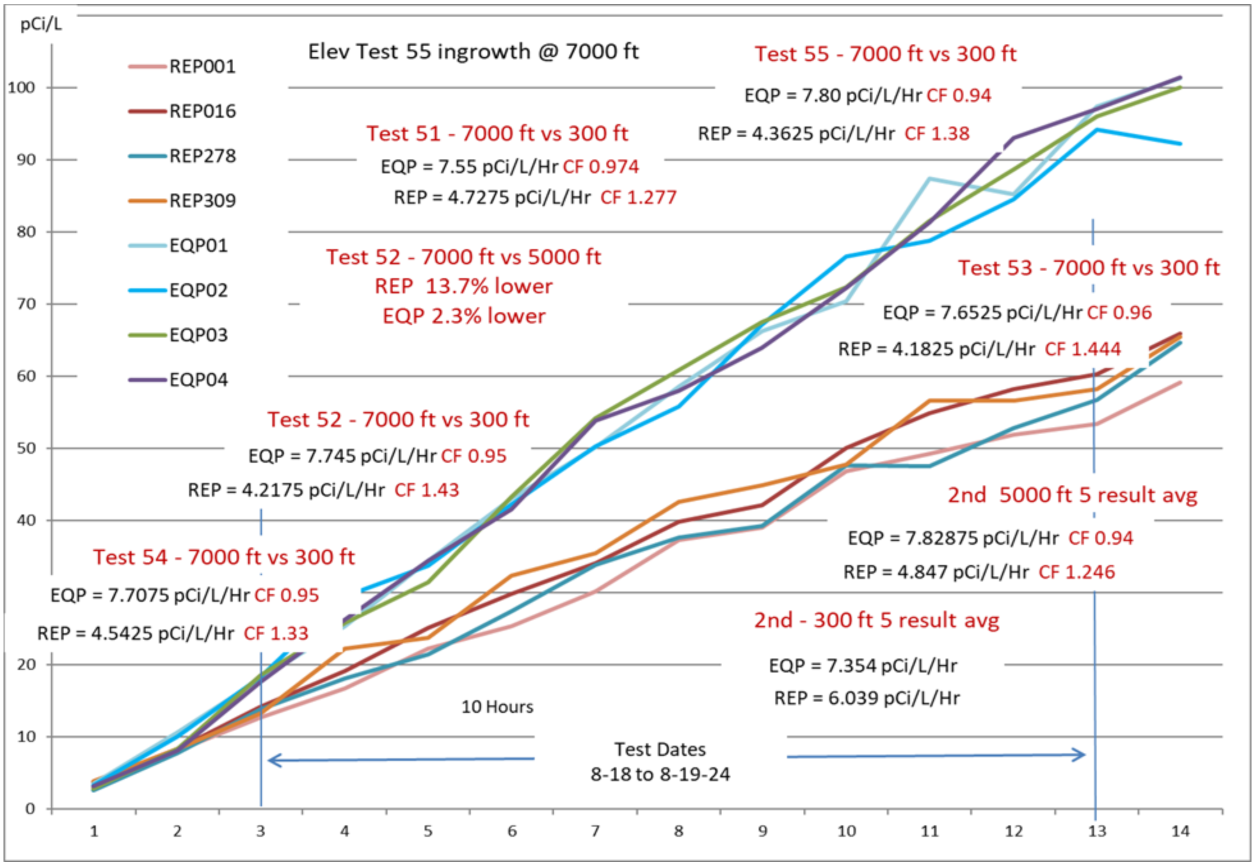

Figure (12): Test five ingrowth at 7170-foot elevation test

The variation of each test run from the total average of all the monitors for that elevation run is displayed in Table 3. In general, the EcoQube ingrowth between test runs was a tighter grouping than the RadonEye results.

| | RadonEye Pro | | | | | | EcoQube Pro | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 |
| Pre 320 | 0.12% | -4.67% | -2.08% | 2.65% | 3.98% | | -1.12% | -1.69% | -1.82% | -0.25% | 4.89% |
| Post 320 | 7.98% | -2.82% | -9.25% | 4.09% | | | 5.98% | -1.27% | -5.54% | 0.83% | |
| 2100 Ft | -6.54% | | -2.22% | 5.56% | 3.21% | | -9.51% | 7.36% | 2.64% | 1.65% | -2.14% |
| 5100 Ft | -0.72% | 2.06% | -2.51% | 3.55% | -2.39% | | -2.19% | -0.94% | 0.47% | 4.48% | -1.83% |
| 7170 Ft | 7.28% | -4.29% | -5.08% | 3.09% | -1.00% | | -1.83% | 0.70% | -0.50% | 0.21% | 1.42% |

Table (3): Individual test % difference from overall elevation average

## 3.3 Determining an Elevation Correction Factor (CF)

The average ingrowth of both the initial 320-foot elevation test results and the final 320-foot elevation test was used as the baseline to monitor performance. The results of the higher elevation tests were then compared to the 320-foot average results for both individual radon monitors and for the average of all of the monitors for each type. The average correction factor (CF) that would be needed to have the monitors equal the 320-foot elevation ingrowth results is included.

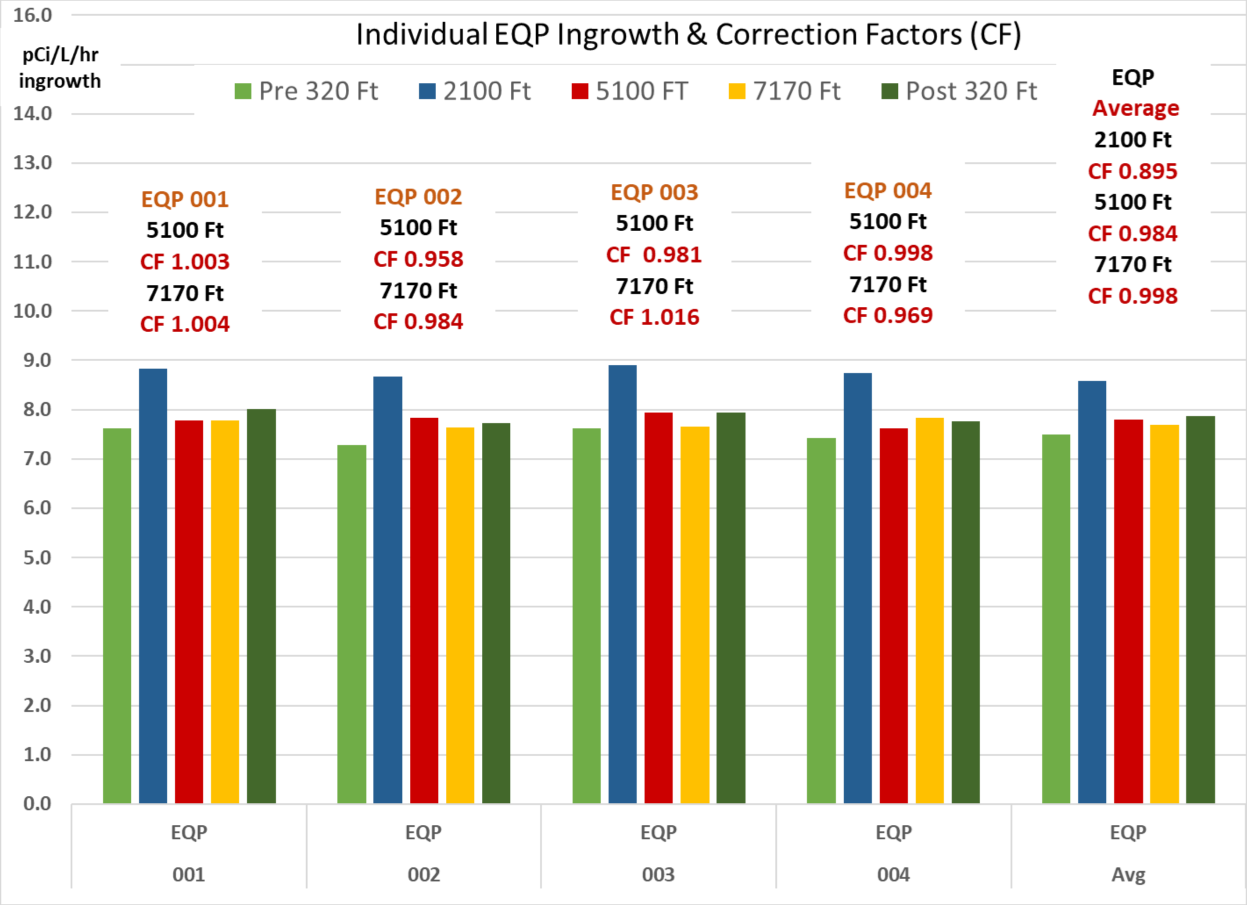

Figure (13): Individual EcoQube average performance at varying elevations

Figure 13 displays the individual ingrowth performance of all four of the EcoQubes monitors. The average Correction Factor (CF) is displayed, which would be used to adjust each monitor's results to match the ingrowth results at 320 feet. In each case, the EcoQubes had a 3% to 5% higher performance at 5100-feet and 7170-feet than at 320-feet. These results indicate there is little, if any, correction factor necessary for the EcoQube monitors. For an unknown reason, the

EcoQubes during the 2,100-foot elevation test had an ingrowth about 12% higher than the 320-foot average.

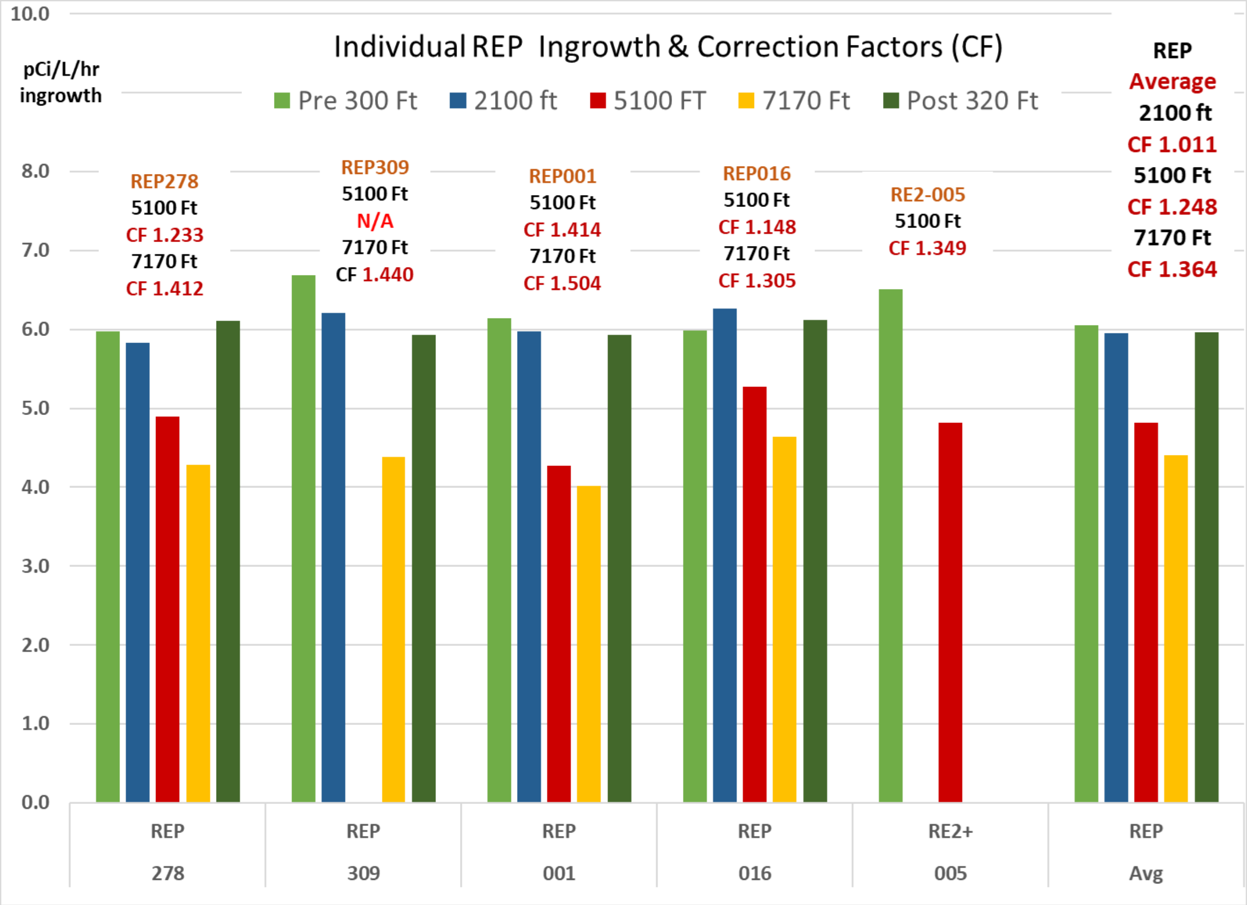

Figure (14): Individual RadonEye average performance at varying elevations

Figure 14 displays the average individual elevation ingrowth performance of all five of the RadonEye monitors. RadonEye RE2-005 was used for the 5100-foot elevation runs because REP309 was giving erratic results. Above the stacked graph, the average Correction Factor (CF) is displayed, which would be used to adjust each monitor's results to match the average ingrowth results at 320 feet. In each case, the RadonEyes had a significantly lower ingrowth result at both the 5100-foot and 7170-foot elevations than at the 320-foot elevation. The maximum ingrowth variation between individual RadonEye monitors was 28.2% at 5100-feet and 16.9% at 7170-feet. Overall average correction factor for the RadonEye monitors was 1.248 at 5100-feet and 1.364 at 7170-feet to match the ingrowth average of both 320-feet elevation tests.

If the correction factors were used at 5100 feet of elevation, a RadonEye 48-hour test result of 3.3 pCi/L would need to be corrected to 4.1 pCi/L. At 7100 feet of elevation, a RadonEye 48-hour test result of 3.0 pCi/L would need to be corrected to 4.1 pCi/L.

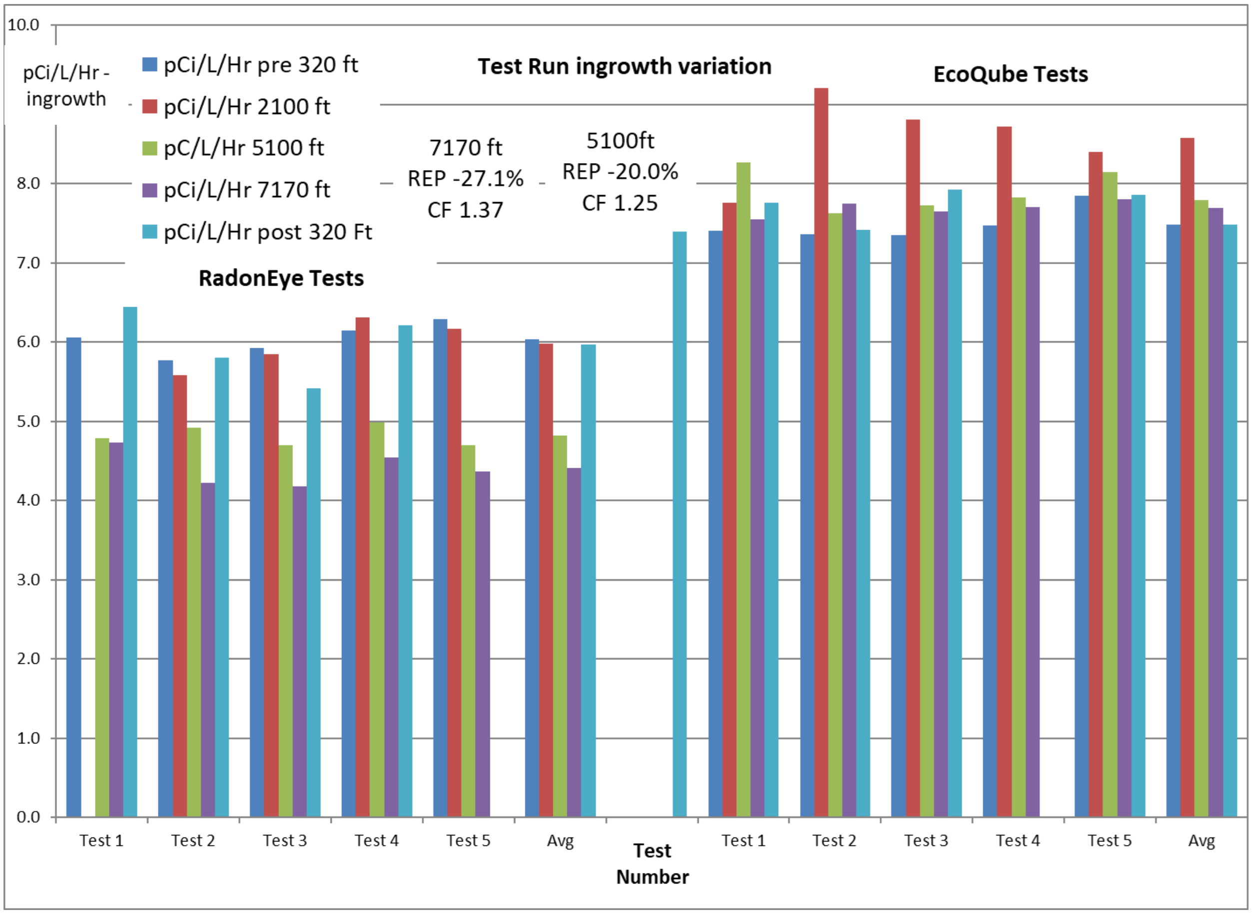

Figure (15): Individual Test Average Ingrowth Results

Figure 15 displays a comparison of the average results of the first to fifth tests that were used to determine the Correction Factor for each elevation. The beginning and ending 320-foot average ingrowth results for the RadonEye were about 1% different, while the EcoQube average results were about 2.5% different.

All of the test runs for the RadonEyes show a marginal change at 2100-feet and significant reduction at 5100-feet and 7170-feet. The EcoQubes showed slightly higher ingrowth at elevations above 320 feet. For an unexplained reason, the EcoQubes had about a 12% higher ingrowth at 2,100 feet versus 320 feet.

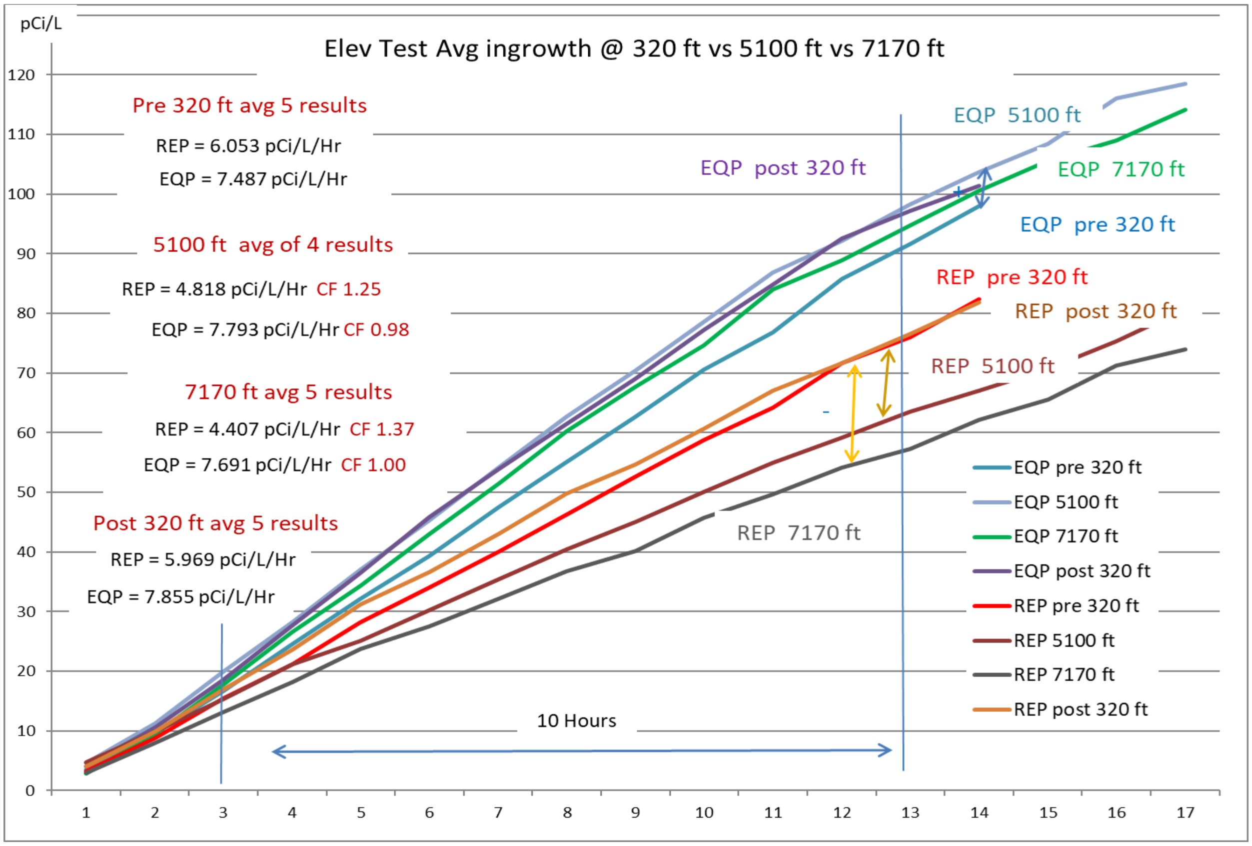

Figure (16): Average Ingrowth of RadonEye and EcoQube at three Elevations

Figure 16 displays the average ingrowth of each CPID monitor type tested for three different elevations. The EcoQube showed a slight change of around 6 % higher ingrowth measurement at both the 5100-foot and 7170-foot elevation levels as compared to the same monitors being exposed at 320 feet. The RadonEye monitors had decreasing ingrowth results of about 19.8% at 5100-feet and 28.4% at 7170-feet of elevation as compared to the ingrowth at 320-feet of elevation.

## 3.4 Adjusting for Barometric Pressure

The density of air is directly related to the barometric pressure, air temperature, and humidity. Because there was no pre-established calibration factor for changes in air density, this study did not make on-site measurements of these parameters, which would be appropriate for further testing. A range of barometric pressures was recorded using local weather apps and historical weather data from a nearby airport. Table 4 has the approximate range of barometric pressures that were recorded and the calculated range of equivalent feet in elevation above sea level. A correlation between changes in barometric pressure and changes in radon ingrowth was not made part of this study.

| Listed Elevation | Barometric Pressure Range | Equivalent Elevation Range |
|---|---|---|
| First 320 feet | 29.44 to 29.79 | 230 ft to 556 ft |
| 2100 feet | 28.0 to 28.09 | 1856 ft to 1944 ft |
| 5100 feet | 24.6 to 24.9 | 5100 ft to 5432 ft |
| 7170 feet | 23.24 to 23.39 | 6768 ft to 69.39 |
| Last 320 feet | 29.67 to 29.77 | 51 ft to 328 ft |

Table (4): Elevation based on Barometric Pressure.

## 3.0 Conclusion

This study has demonstrated that consideration of the altitude for some pulse ion radon monitors needs to be taken into consideration when they are used at higher elevations, especially when the elevations are over 1000 meters or 4000 feet. This study was limited to testing only four elevations: 320-ft (97-m), 2100-ft (-m), 5100-ft (1554-m), and 7170-ft (2185-m). The elevation effect at 2100-feet, 5100-feet, and 7170-feet was marginal for the EcoQube Pro. The elevation effect for the RadonEye monitors was not significant at 2100-feet but was significant at 5100-feet and 7170-feet of elevation. The average correction factor (CF) for the RadonEye monitors at 5100 feet varied from 1.15 to 1.47, with an average CF of 1.256. At 7170 feet of elevation, the RadonEye monitors correction factor varied from 1.32 to 1.53 with an average CF of 1.374. This research shows the necessity of measuring radon continuous pulse ion detector performances at elevations above 2000 feet to determine how significant elevation change affects the monitor performance and what elevation correction factors can be applied to increase the accuracy of the measurements.

## 4.0 References

1) Kotrappa P., Stieff L., Elevation Correction Factors for E-PERM® Radon Monitors Proceedings of AARST International Radon Symposium; 1991

2) Note: QuillBot free AI was used to correct grammar, spelling, and tense.

## Study Assistants

The following individuals graciously contributed their time, energy and advice to this study.

Henri Boyea, Radoncontrol@cs.com, webpage: https://www.radoncontrolproducts.com/
Dr. Leo Moorman LMoorman1@aol.com webpage: https://www.radon-mitigation.org/
Brad Turk TurkEBSI@aol.com webpage: http://www.environmentalbuildingsciences.com/