ELEVATION INFLUENCE ON RADON MONITOR MEASUREMENTS

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ABSTRACT

In a previous study, E-PERM® electret ion chambers manufacturered by Rad Elec Inc. have been shown to record about 17% percent lower at 6000-foot elevation above sea level versus 1000-foot for the S-Chamber and 28% lower for the smaller L-Chamber. 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, 1554-m (5100-feet) and 2185-m (7170-feet) elevation above sea level. At each elevation the monitors were exposed for at least 14 hours to the same radium sources inside the same sealed steel containers. The ingrowth exposures at each location were averaged for each monitor type. The difference in measurement ingrowth from the third to the thirteenth hour at each location was used to determine the pulse ion detector monitors resulting variation at these elevations and a corresponding approximate correction factor.

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 predominately the release of an alpha particle, which is two positively charged protons and two non-charged 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 freed electrons create ion pairs before re-combining. 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. Gamma also produces some ionization but is considered an insignificant amount. This study measured the effect of air density on two types of CPID radon monitors.

The 1990 E-PERM study of elevation effect on ion chambers was made using three different sized E-PERM® chambers. Each of the different chambers were 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® electrect ion chamber performance variation with altitude

In the EPERM study they found that changes in measurement location elevation above sea level had an insignificant affect on the measurement performance up to varying elevations depending on their 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 chambers dimensions would be expected to have less influence from elevation change. In Table 1, the L Chamber, which is the smallest EPERM chamber, has an increasing requirement of a calibration factor as the elevation becomes higher to compensate for the reduction in ionization 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 increases to 2440 m (8000 ft).

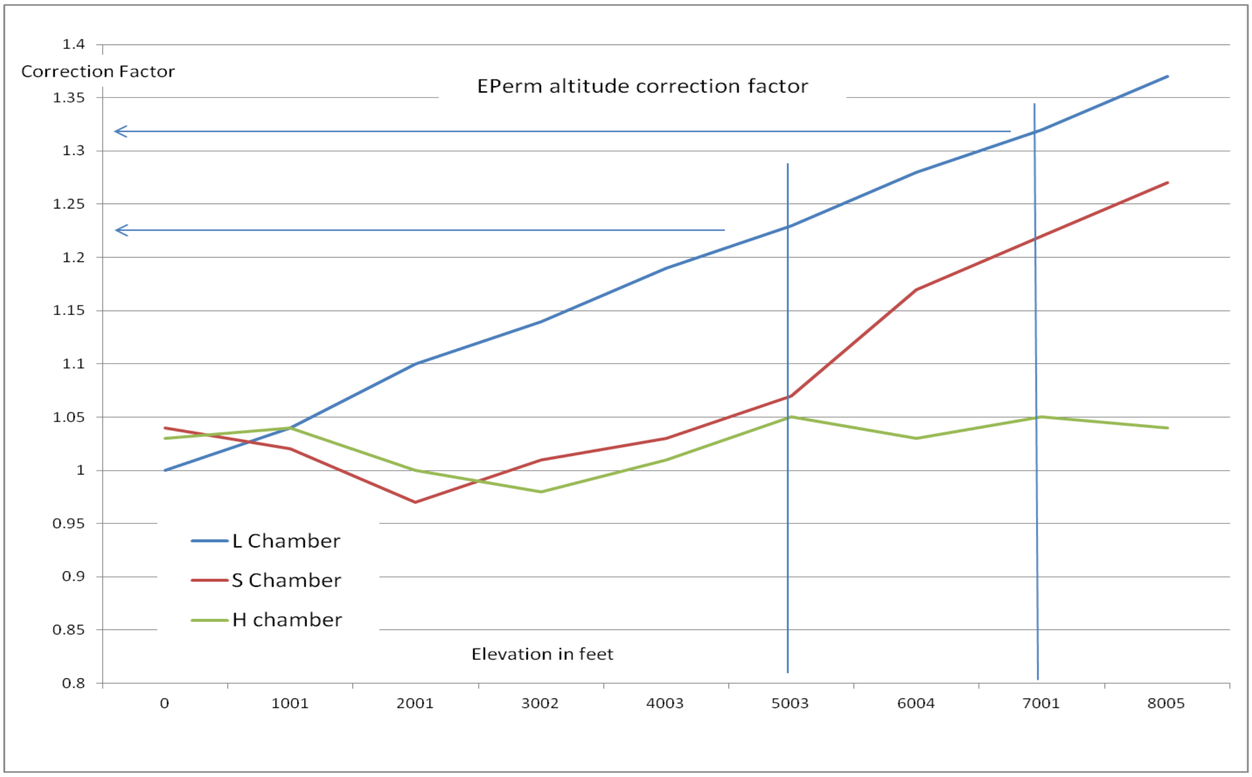

Figure (1): EPERM correction factor for three different chambers

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 1.0, at around 3000 to 4000 feet. After 6000 feet the L chamber and the S chamber appear to have similar and linear increase in CF.

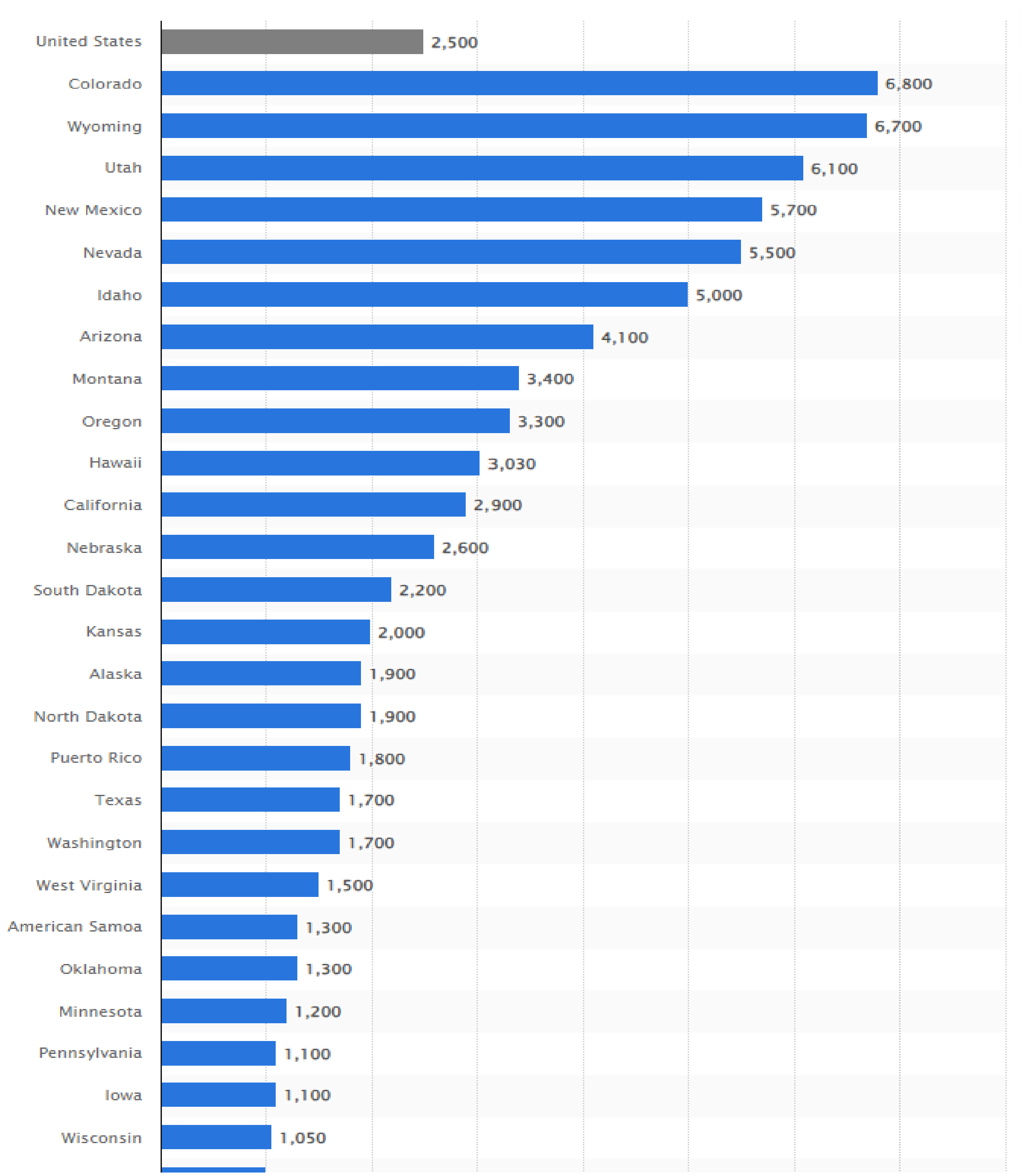

Figure (13): Average elevation of US states above 1000-foot elevation

Figure 13 displays the average elevation of 26 US states. Six of the states average above 5000 feet or higher elevation. Fourteen of the states average above 2000 feet or higher.

2.0 Methodology

2.1 Radon Monitors Tested in this Study

The two types 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 one of the RadonEye Pro's for the 5100-foot elevation tests.

2.2 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 atmospheric pressure induced by elevation change. The radon monitors were tested at three different elevations, 97 meters (320 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. 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 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 1930's and 1940's. 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-it notes and 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. The ingrowth of radon inside each of the containers was plotted each time and observed that the ingrowth was primarily linear for the first 15 hours. The rate of the ingrowth was calculated from the 3rd hour to the 13th hour for each of the measurements. After each chamber run the average of 3th hour was subtracted from the average at the 13th hour and the results were divided by 10 for each monitor type. The results for each of the four or five chamber runs at the different elevations were calculated and labeled as pCi/L/hr ingrowth. In the displayed results of each test of this study, the four EcoCube radon monitors or the four RadonEye monitors hourly data was averaged to determine the ingrowth of each monitor type for each individual run at each elevation that was tested. This allowed a direct comparison of the measured in growth at 100-m (328-ft), 1554-m (5100-ft) and 2185-m (7150-ft) of elevation. An average correction factor (CF) compared to the 300-foot elevation ingrowth was calculated for each of the individual CPID as well as the average of all the individual CPIDs.

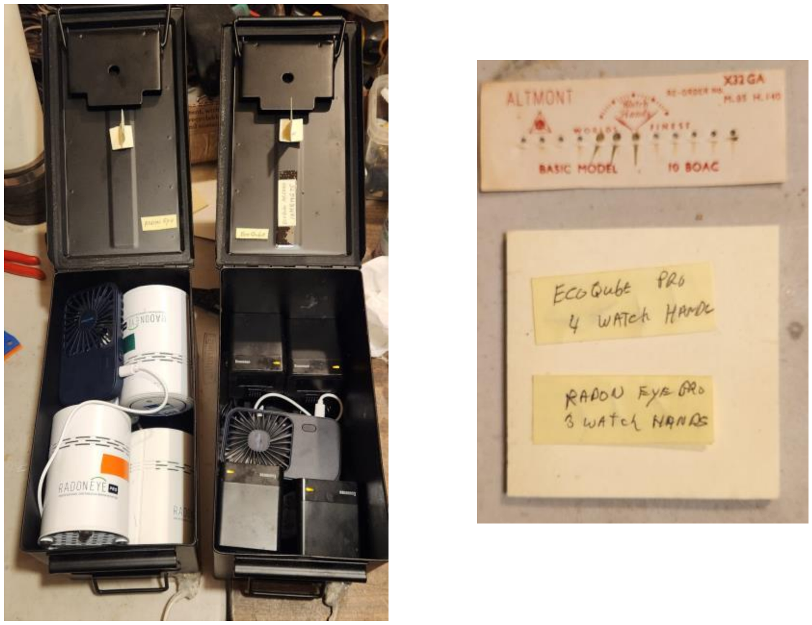

Figure (2): Gasket sealed metal containers, radon monitors and radon sources

2.2 Pretesting Calibration of Radon Monitors

In order to determine the ability of the radon monitors to track ingrowth of radon, the monitors were placed inside the authors 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). The Radoneye 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). Because the test was a comparison between results at different elevations, variation in comparison between two monitor types was not considered significant.

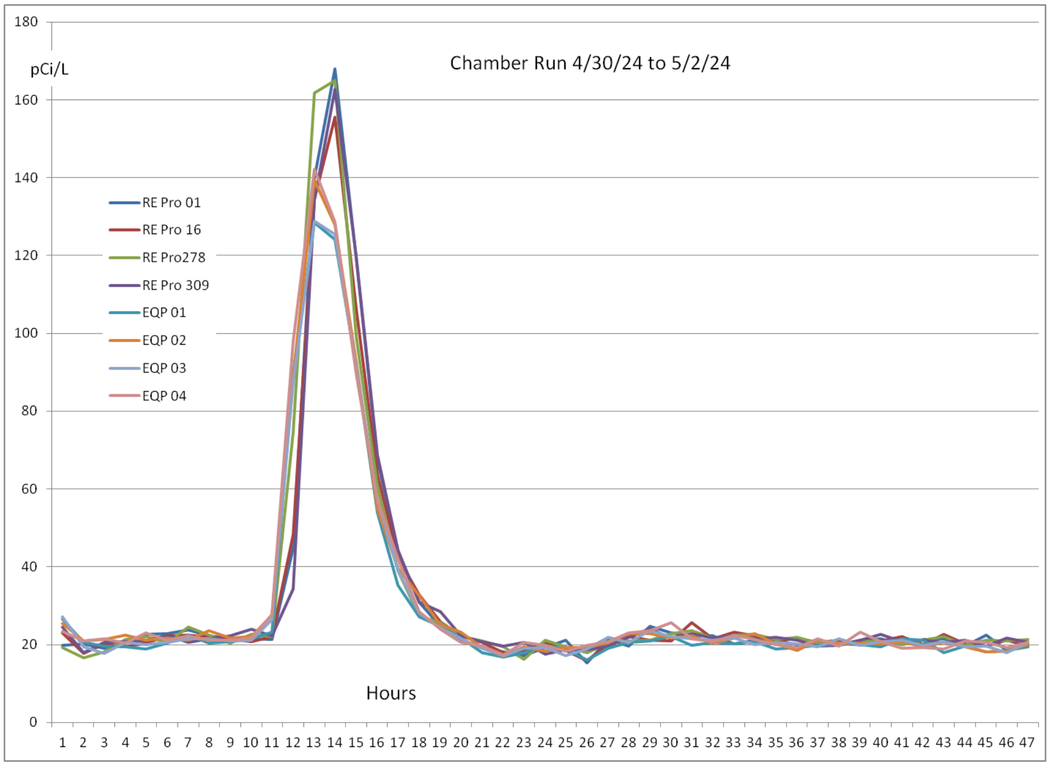

Figure (3): Exposure of test study radon monitors to a radon spike

2.3 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 EcoTracker radon monitors that have a similar design and sensor sensitivity were 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 (4). Three of the EcoTrackers calibration factors were adjusted to more closely match the measurements provided by KSU. The Radoneye instruments used in this study as well as two AB5 Pylons were then cross checked against these re-calibrated EcoTrackers and their calibrations adjusted to match the KSU exposed EcoTrackers average concentration. The radon monitors used in this study were then compared with each other in comparison to the two AB5 pylons in the author's radon chamber. See Figure (5).

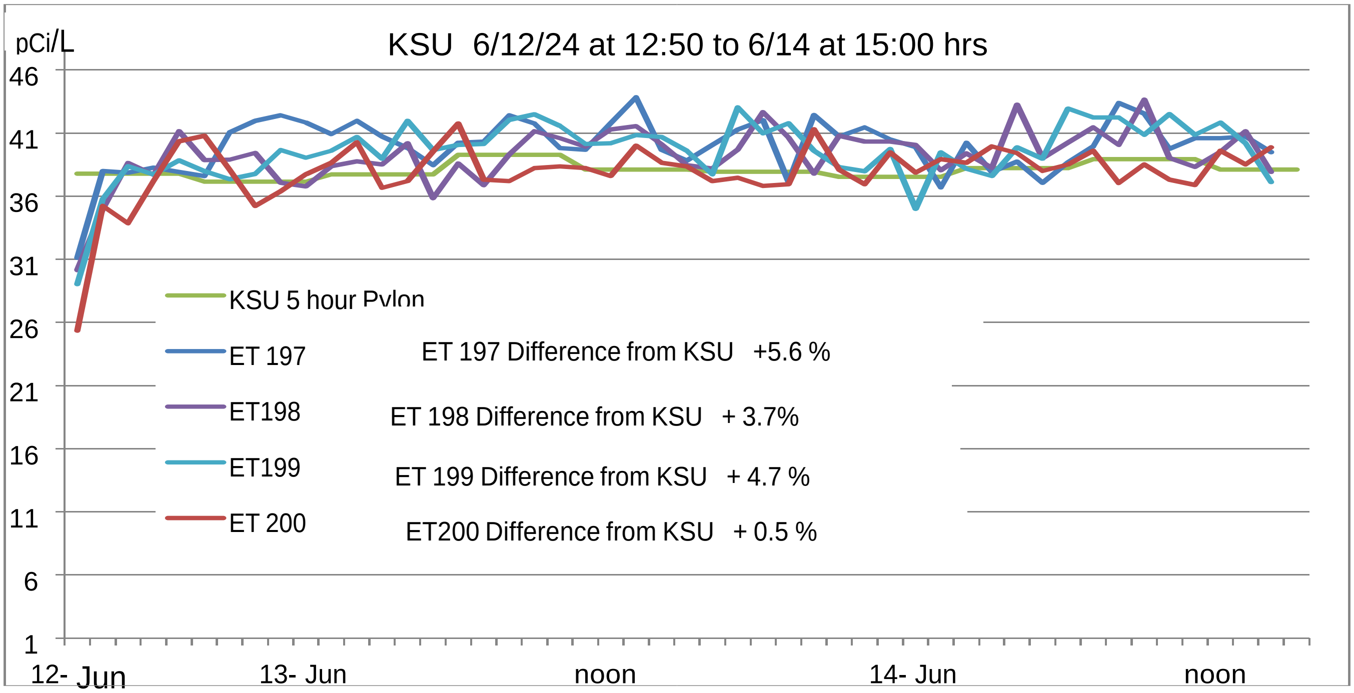

Figure (4): Spiking results of EcoTrackers at KSU radon chamber

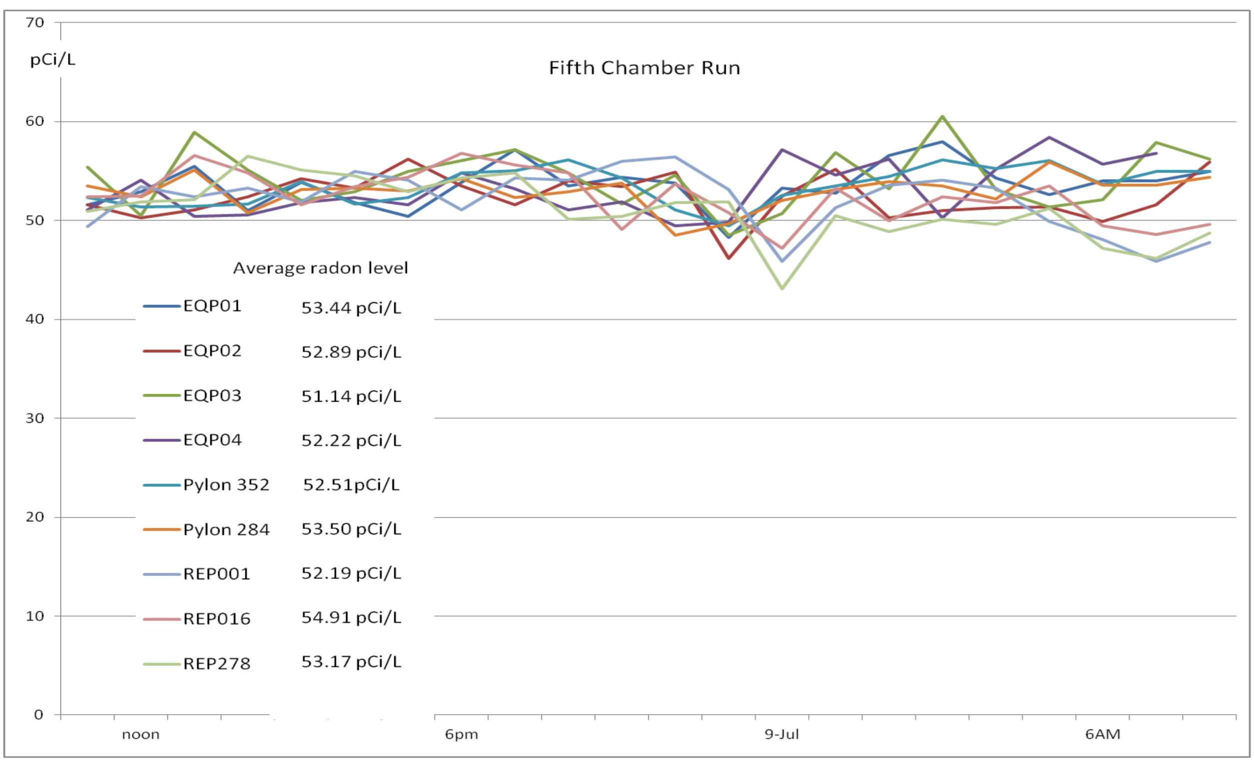

Figure (5): Checking study radon monitor performance comparison to Pylons

2.4 Elevation Test Procedures

Each round of measuring ingrowth in the two chambers was performed in the same procedure. A smart cell phone was used to run the Ecosense app for each detector type. A blue tooth connection was made through each app to the individual CPIDs to start the test, download the data and clear the data for the next test. The RadonEye Pro's and RadonEye 2+ only needed to set the monitors to continuous mode and delete the previous data in order to begin the test. The EcoQube Pro's after the previous data was deleted required each monitor to be given a file name and then skipping the next prompts before setting the time delay of measurement to none. The EcoQube was then started and the process was repeated with the other EcoQube Pro monitors. 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 RadonEye's 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 to 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, and time as well as 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 was accessed from this Dashboard and downloaded as excel files. All the EcoQube and RadonEye data from each run was tabulated in a master spreadsheet for the elevation location. The average ingrowth results from each test and each location was transferred to another spreadsheet for comparisons.

3.0 Results and Discussions

3.1 Results from Ingrowth Testing at 320 Feet

All the monitor results of each test were plotted on a spreadsheet graph to determine if there are any visual outliers that need investigation. Figure (6) displays how each test run was graphed to determine if there were any outlier measurements. The average ingrowth for each of the two monitor types was determined by first averaging all the hourly data for each monitor type. In each case the average of the 3^{rd} hour was subtracted from the average of the 13^{th} hour. The result was then divided by 10 to determine the average pCi/L ingrowth per hour for the test run. This was repeated for each elevation ingrowth run. A minimum of four ingrowth test runs were repeated at each elevation. Figure (6) includes the average ingrowth result at 320-foot elevation as well as the ingrowth average for previous test done at the same elevation to provide a comparison.

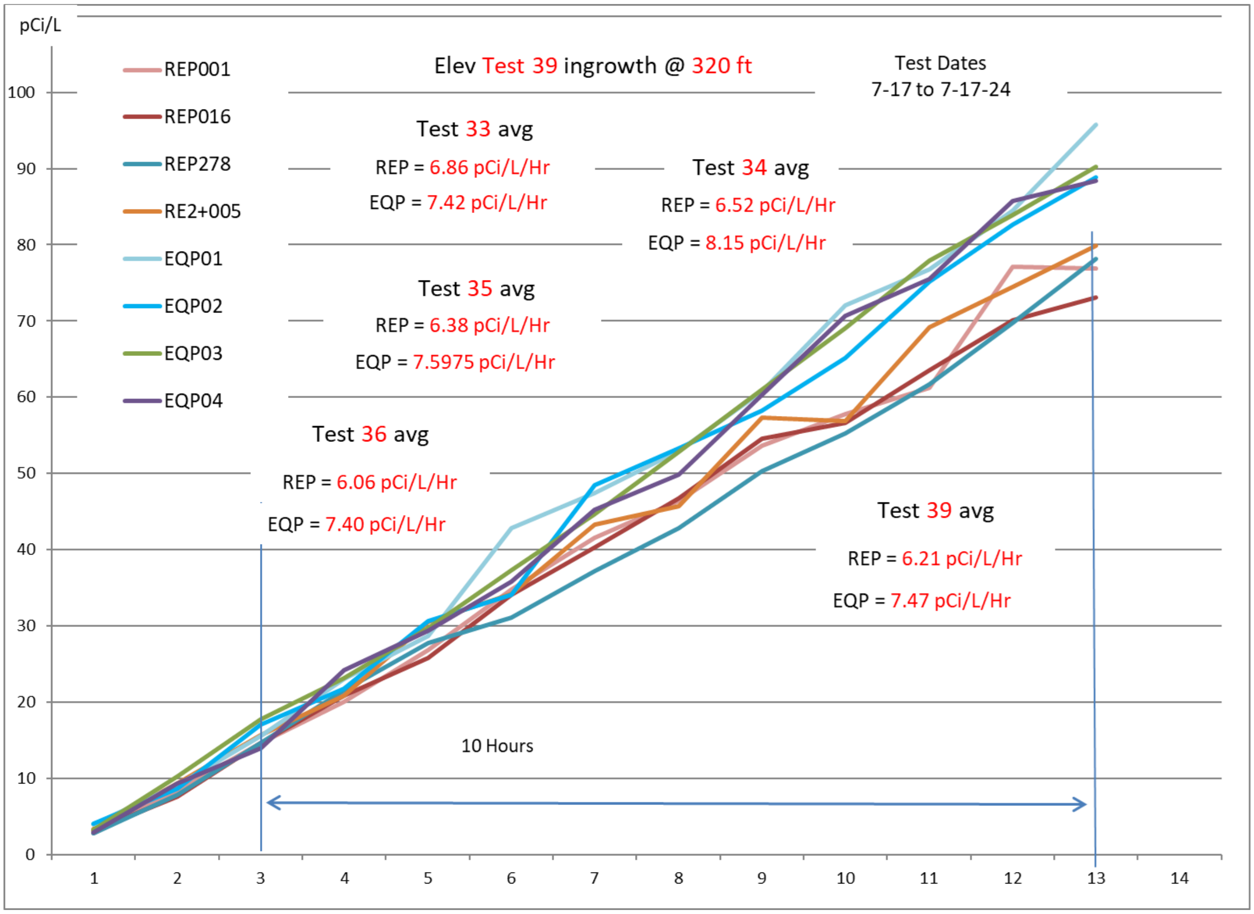

Figure (6): Ingrowth Test 39 at 300 feet of elevation

At the 320-foot elevation Test 39, the grouping of the EcoQubes appears tighter than the grouping of the RadonEyes. The maximum variation in the EcoQube ingrowth between test runs was about 10% while the maximum variation in the RadonEye ingrowth results between test runs was about 13%.

3.2 Results from Ingrowth Testing at 5100 Feet

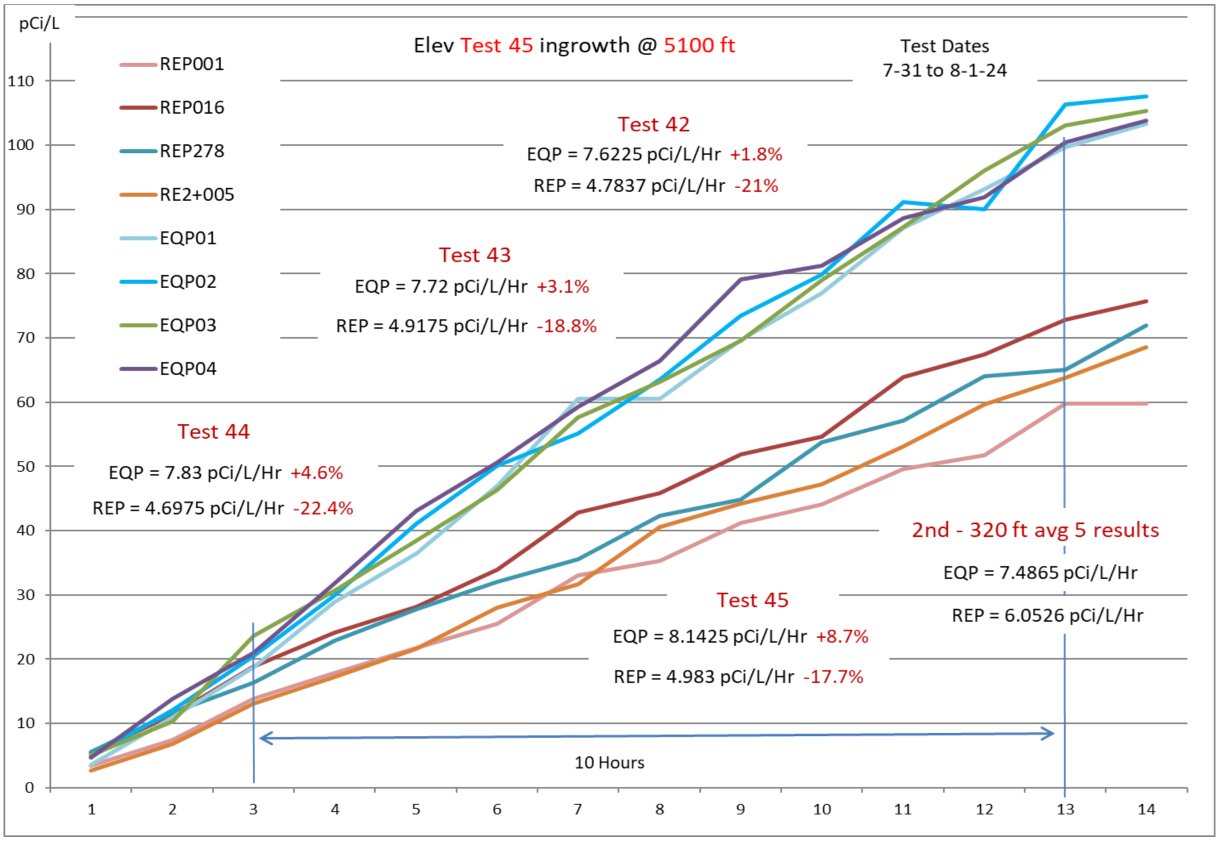

Figure (7): Ingrowth Test 45 at 5100 feet of elevation

At the 5100-foot elevation Test 45, the grouping of the EcoQubes still appears tight while the grouping of the RadonEyes is more divergent. This tends to indicate that the individual RadonEye monitors are responding to the higher elevation at varying amounts. The maximum variation in the EcoQube ingrowth between test runs displayed was about 6.8% as compared to the previous variation at 320-foot test of 10%. The maximum variation in the RadonEye average test run ingrowth at 5100-foot was about 6.1% as compared to the 320-foot maximum variation of about 13%.

3.3 Results from Ingrowth Testing at 7170 Feet

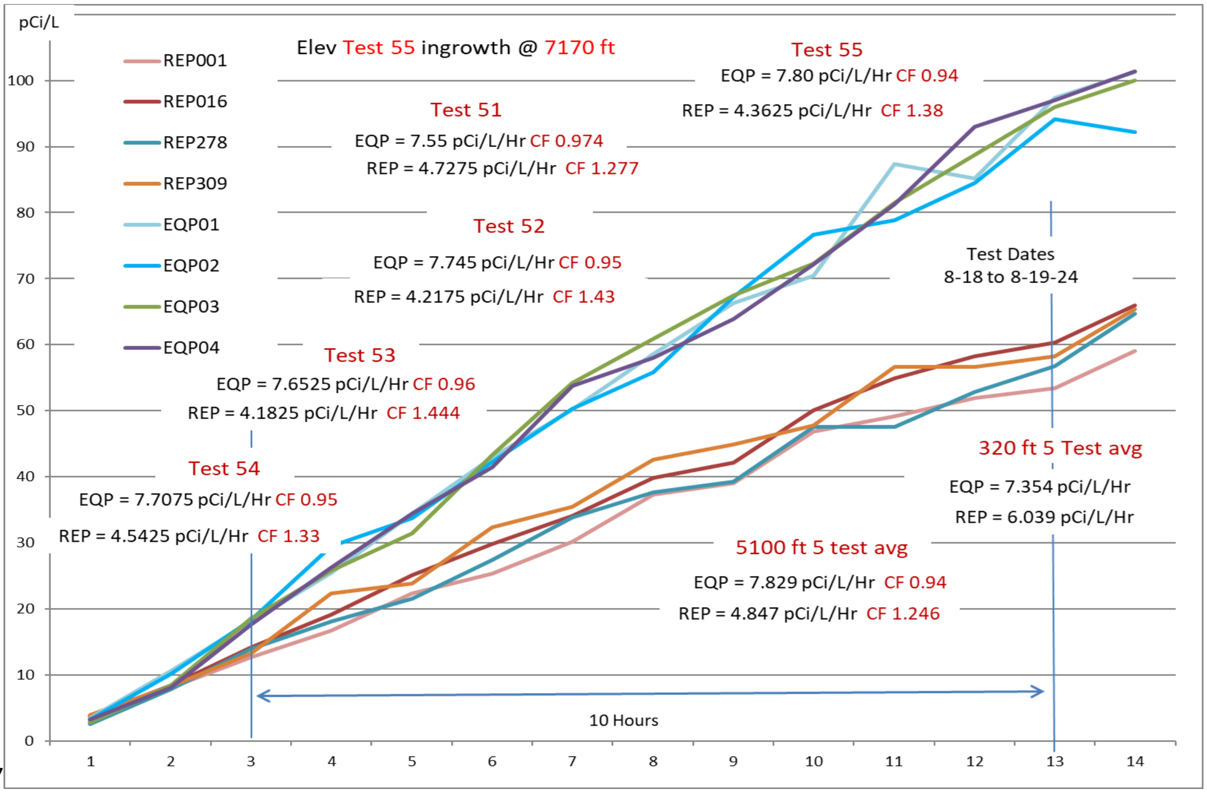

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Figure (8): Ingrowth Test 55 at 7170 feet of elevation

At the 7170-foot elevation Test 55, the grouping of the EcoQubes still appears very tight while the grouping of the RadonEyes is more divergent but tighter than Test 45 at 5100 feet. The REP001 that was reporting a lower ingrowth result than the other RadonEye Pro monitors in Test 45 at 5100-feet was still displaying a slightly lower bias in Test 55 at 7170-foot elevation. The maximum variation in the EcoQube ingrowth between test runs displayed in Figure 7 was about 3.3% as compared to the previous variation at 320-foot test runs of 10% and 5100-foot runs of 6.8%. The maximum variation in the RadonEye ingrowth results was about 12.1% as compared to the 320-foot maximum variation between runs of about 13% and 5100-foot test run maximum variation of 6.1%.

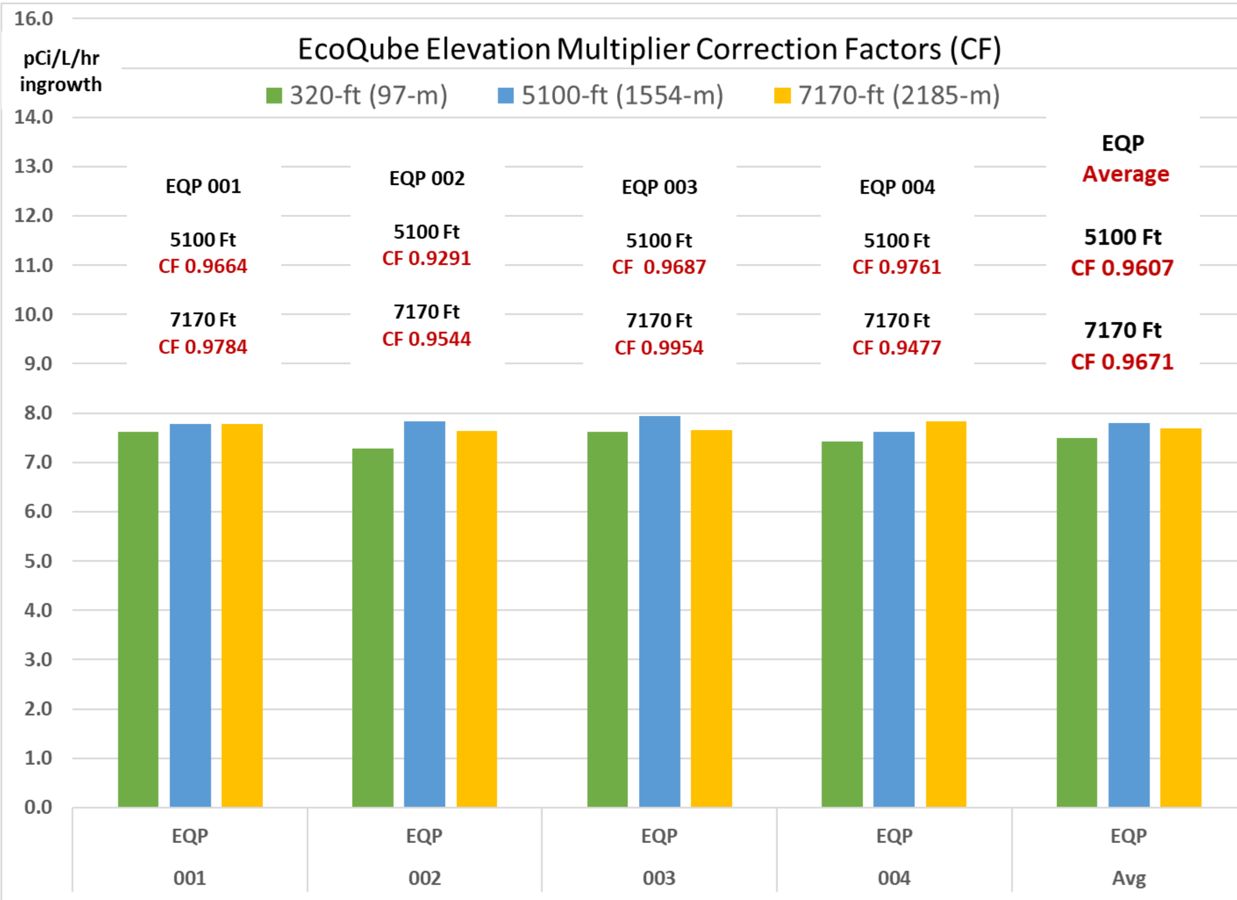

Figure (9): Individual EcoQube average performance at varying elevations

Figure 9 displays the individual ingrowth performance of all four of the EcoQubes monitors. Above the stacked graph the average Correction Factor (CF) is displayed that 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. This comparison to the 320-feet original exposure requires a final repeat exposure of all the monitors to four test runs at the 320-foot elevation to confirm the reference ingrowth is less at the reference elevation.

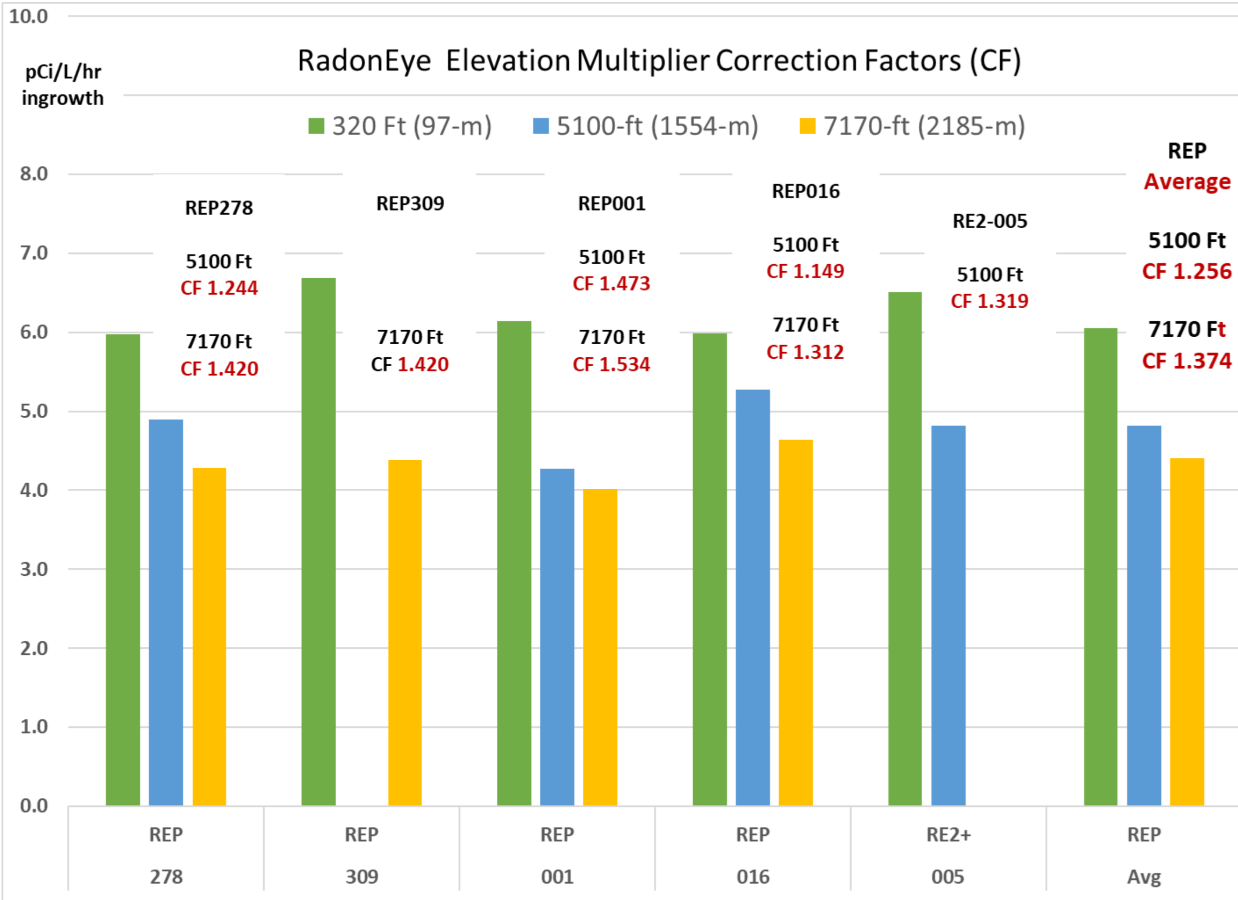

Figure (10): Individual RadonEye average performance at varying elevations

Figure 10 displays the average elevation individual ingrowth performance of all five of the RadonEye monitors. Above the stacked graph the average Correction Factor (CF) is displayed that would be used to adjust each monitor's results to match the ingrowth results at 320-feet. In each case the RadonEyes had a significant lower ingrowth result at both the 5100-foot and 7170-foot elevation than at 320-feet. 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 1.256 at 5100-feet and 1.374 at 7170-feet to match the ingrowth at 320-feet of elevation.

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.

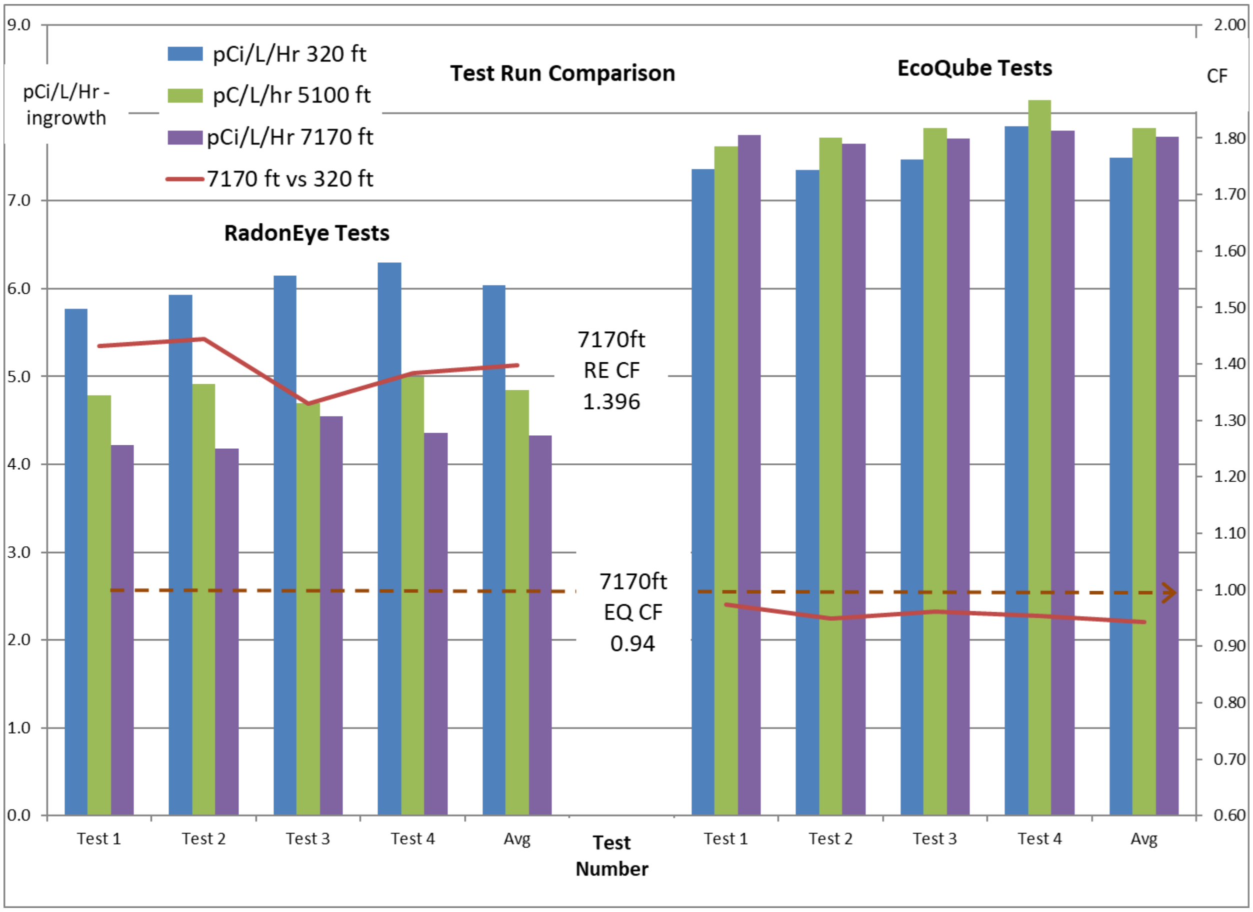

Figure (11): Individual Test Average Ingrowth Results

Figure 11 displays a comparison of the average results of first to fourth tests that were used to determine the Correction Factor for each elevation. The solid red line represents the correction factor for each test run at 7170-foot elevation compared to the same test number in the 320-foot elevation test runs.

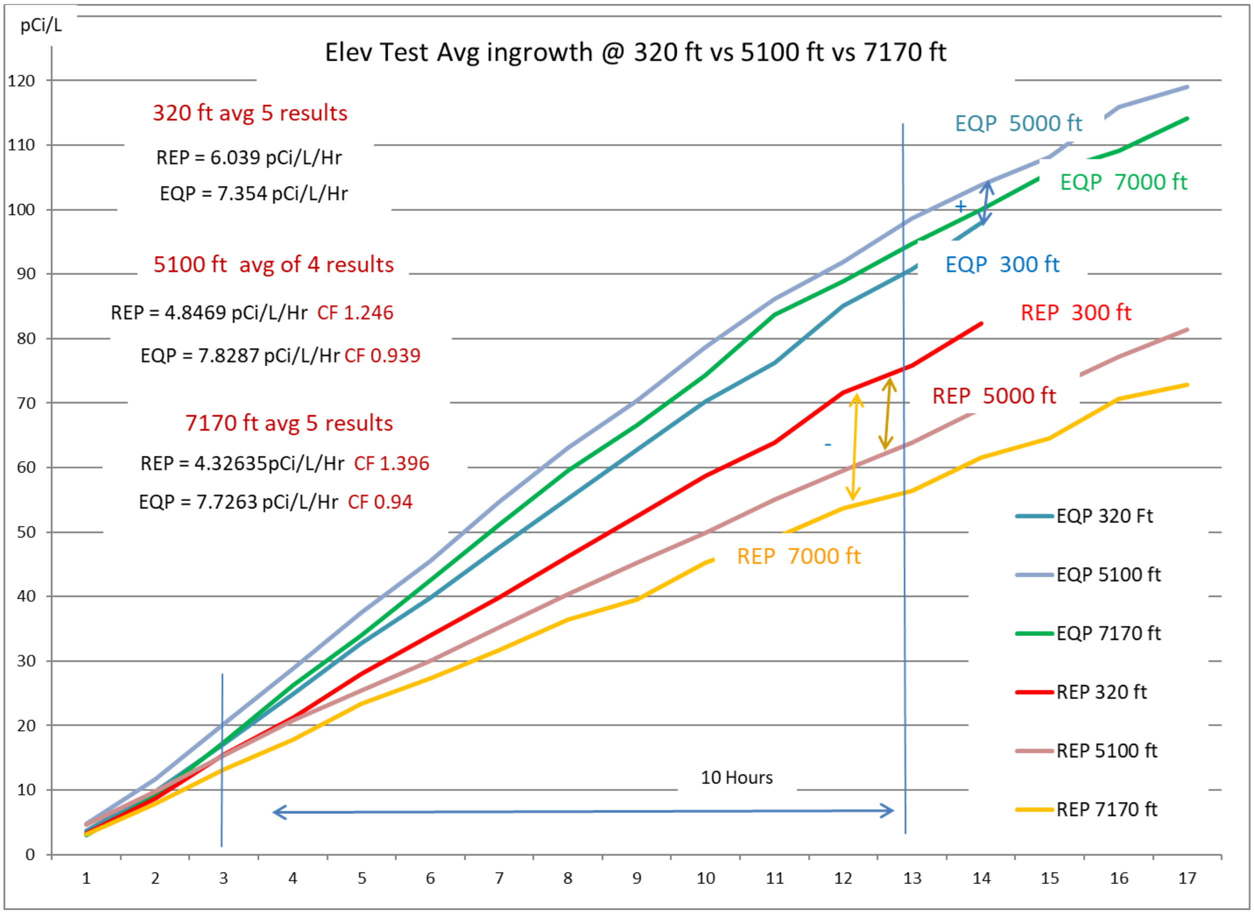

Figure (12): Average Ingrowth of RadonEye and EcoQube at three Elevations

Figure 12 displays the average results of each CPID monitor type tested in this study. The EcoQube showed a slight change of around 6 % higher ingrowth measurement at both the 5100-foot and 7170-foot elevation level 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.

3.0 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, especial when the elevations are over 1000 meters or 4000 feet. This study was limited to testing only three elevations, 320-ft (97-m), 5100-ft (1554-m) and 7170-ft (2185-m). The elevation affect at 5100-feet and 7170-feet was marginal for the EcoQube Pro CPID and substantial for the Radoneye monitors used in this study. The average correction factor (CF) for the Radon 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 correction factor varied from 1.32 to 1.53 with an average CF of 1.374. This research shows the necessity of measuring radon CPID performances at air densities that the monitor will be exposed at in order to determine how significant elevation change affects the monitor performance and what correction factors can be applied to increase the accuracy of the measurements.

4.0 References

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