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Using a Radon Pressure Chamber to Determine Cell Counting Efficiencies as a Function of Elevation.

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ABSTRACT

Building on previous research, which indicated that scintillation cells perform differently at different elevations (*Burkhart, 2005; Eberline, 1989; George, 1983)*, a pressure chamber has been designed which allows for the simulation of scintillation cell use at different "elevations." The pressure chamber has been constructed in such a way as to accommodate a large flexible bag that is filled with a known radon concentration. Radon is extracted from the bag into scintillation cells while the pressure chamber, and hence the flexible bag it contains, is maintained at various pressures. The most popular size scintillation cell is used for this study. The variation in counting efficiency caused by air density differences, and the resultant change in alpha particle travel distance, is similar to the 10 % error predicted in the previous theoretical study cited above (Burkhart, 2005).

INTRODUCTION

It has long been understood that alpha particles, a type of radiation emitted from ^{222}Rn and two of its decay products (^{218}Po and ^{214}Po), travel in air at sea level with a distance (R) that is related to the energy (E) of the alpha particle that is given by the following relationship:

$$R = 3.09\ E^{3/2},$$

where the units of the range are in centimeters and E is in MeV (*Lapp, 1963*). Further, this range can be increased or decreased in direct proportion to the deviation of air density from that at sea level where less dense air results in a greater range for any alpha particle for a given energy (*ibid, page 120*)

As an example, the three alpha particles that come from radon and two of its short-lived decay products, travel more than 20 % further in the rarified air of Colorado Springs (6000 feet elevation) than they do at sea level:

	^{222}Rn	^{218}Po	^{214}Po
Range at sea level:	4.12 cm	4.70 cm	6.70 cm
Range at 6000 feet:	4.99 cm	5.70 cm	8.13 cm

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What has not been fully appreciated is that the counting efficiency of radon measurement devices that rely upon sensing the impact of an alpha particle on a sensitive surface (such as a zinc sulfide coated scintillation cell) is affected by this path length. Quite obviously, any such device will be struck by more alpha particles, for a fixed radon and radon decay product concentration, at higher elevations, assuming that the air density within the device mirrors the air density in the external environment of the device. See figure 1 below.

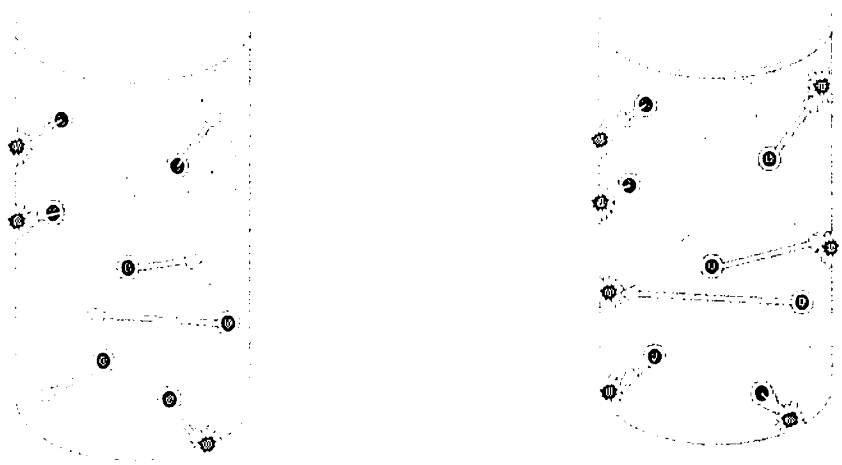

Figure 1: On the left, of the seven alpha particles being made during a one-second interval, only three can travel far enough to strike the sensitive surface of the interior of the cell. At 6000 feet, the cell on the right is filled with the same concentration of radon and radon decay products and the seven alpha particles being made during an equivalent one second interval all strike the sensitive surface of the interior of the cell and are counted.

Unfortunately, the difference in counting efficiency is not a simple multiplicative factor multiplied by the air density since the geometry of the sensitive surface affects the fraction of alpha particles being created within the interior volume of the device that can ultimately strike the sensitive surface. For example, a smaller right cylinder cell may already sense all of the alpha particles striking the zinc sulfide even at the relatively high air density of sea level because the longest dimension of the cell is already less than the path length of the lowest energy alpha particle. Therefore, this same cell, if filled at a higher elevation with lower air density, will not show any increase in counting efficiency. See figure 2. On the other extreme, a very large cell will likewise show no increase in counting efficiency at higher elevations because the increased path length of the alpha particles is insufficient to allow most alpha particles being generated within the device to strike the zinc sulfide surface. There seems to be a "middle-sized cell" that shows the greatest variation in counting efficiency at different elevations. We are investigating this cell in this paper.

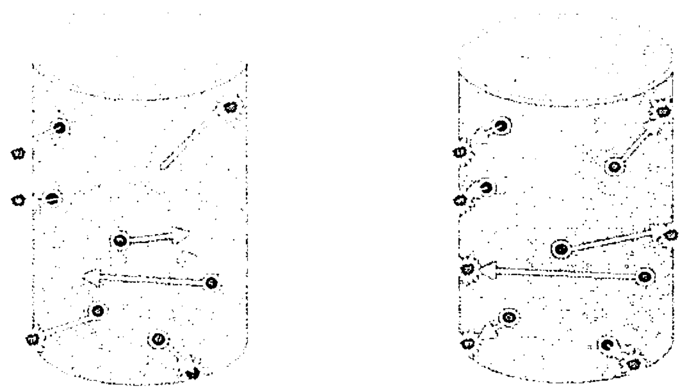

Figure 2: For the same radon concentration, the cell on the left, still at sea level, now has five alpha particles striking the zinc sulfide surface. The only difference between this example and the example in figure 1 is that both cells are now smaller. This allows more alpha particles to strike the left hand cell at any air density (elevation).

USEFUL DEFINITIONS

For the purposes of this paper, the following definitions are used. The authors understand them to be more or less standard, but they are reiterated here to remove any ambiguity that may arise in the reading.

Decays per minute (dpm): The true number of alpha particles being produced each minute within a certain sized cell.
Counts per minute (cpm): The number of alpha particles which make it to the cell wall and cause a flash which can be counted.
Cell counting efficiency: cpm/dpm, or the fraction of alpha particles being produced that create flashes.

It is important to emphasize that the counting efficiency of the whole counting system, including the electronics, is not an issue here and does not enter into this discussion. In addition, differences in volume of air sampled at different elevations have been accounted for throughout this paper. In other words, it is not necessary to further correct the results presented here by factoring in the different volume of radon sampled (at different elevations) because of the different air pressures.

We contend that, once the volume of radon has been corrected for, the true radon concentration, in picocuries per liter, will be miscalculated when the same radon concentration is measured at two different elevations with the same sized scintillation cell. This error, or percent difference, can be calculated in two equivalent ways:

$$\text{Percent difference} = \frac{N_h - N_l}{N_l} \times 100\ ,$$

where N_h is the number of flashes per unit time at high elevation and N_l is the number of flashes per unit time at low elevation when the radon concentration is held constant. Or,

$$\text{Percent difference} = \frac{C_h - C_l}{C_l} \times 100,$$

where C_h is the radon concentration measured at high elevations and C_l is the radon concentration measured at low elevations when the cell calibration coefficient is held constant.

THEORETICAL PREDICTION FROM EARLIER WORK

By using computer modeling, Robert E. Camley, a co-author on the earlier work (*Burkhart, 2005*) showed that the "error", as calculated using either of the two formulae above, was highly dependent upon the size of the scintillation cell. The error was predicted to be the largest, at 9.8% (indicated by the black arrow) for a Rocky Mountain cell[3] (a right cylinder cell, 7 cm in diameter and 9.7 cm long, .36 L) used at sea level and again at 6000 feet. The error decreased for larger cells (up to ten times larger) and for smaller cells (down to one-half the size of the Rocky Mountain cell). See figure 3.

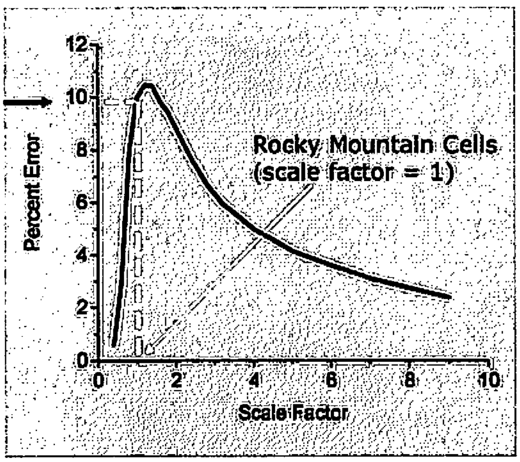

Figure 3: A theoretical model which predicts the error resulting from using a given cell at sea level and again at 6000 feet. The largest theoretical error occurs for the Rocky Mountain cell, the most common cell used in the radon industry and the standard cell used in intercomparisons.

What is the practical affect of this error? Assume both cells, the one at sea level and the one at 6000 feet, were calibrated by the same radon source (say, the U.S. EPA chamber in Las Vegas, NV). That is, a cpm/dpm was determined for each cell. Then, in any

(3) The Rocky Mountain cell was manufactured by Rocky Mountain Scientific Glass Blowing Co., 4990 Asbury Ave., Denver, Colorado, 80222.

subsequent intercomparisons with Las Vegas or with any other facility also calibrated with Las Vegas), the two cells with always give identical results, as long as the same air/radon mixture (and pressure) is maintained during the interchange of the cells between measuring facilities; i.e., the cell is not opened during the intercomparisons. However, when the cell is used at one of the facilities by being filled at the atmospheric pressure of that facility, the cell will then over respond or under respond if the facility continues to use the same calibration as initially determined in its intercomparison with Las Vegas. Specifically, a cell initially calibrated by an intercomparison with Las Vegas (2205 feet in elevation) will over-report the true radon by about 6 % if the sampling is at Colorado Springs (6000 feet in elevation) because more alpha particles will be counted for a given radon concentration than is accounted for by the original calibration. Similarly, a cell initially calibrated by an intercomparison with Las Vegas will under-report the true radon by about 3 % in Dayton, OH, because fewer alpha particles will be counted for a given radon concentration than is accounted for by the original calibration with Las Vegas.

EXPERIMENTAL DESIGN

A 25-liter flexible bag that is typically used for transporting radon was used. The bag was filled over a 5-minute interval from a commercial radon source manufactured by Pylon™ with the final concentration of radon in the bag being approximately 100 pCi/L. The bag was placed inside a large metal cylinder (40 cm in diameter and 150 cm in length) which was then sealed for a pressure tight fit. See figure 4.

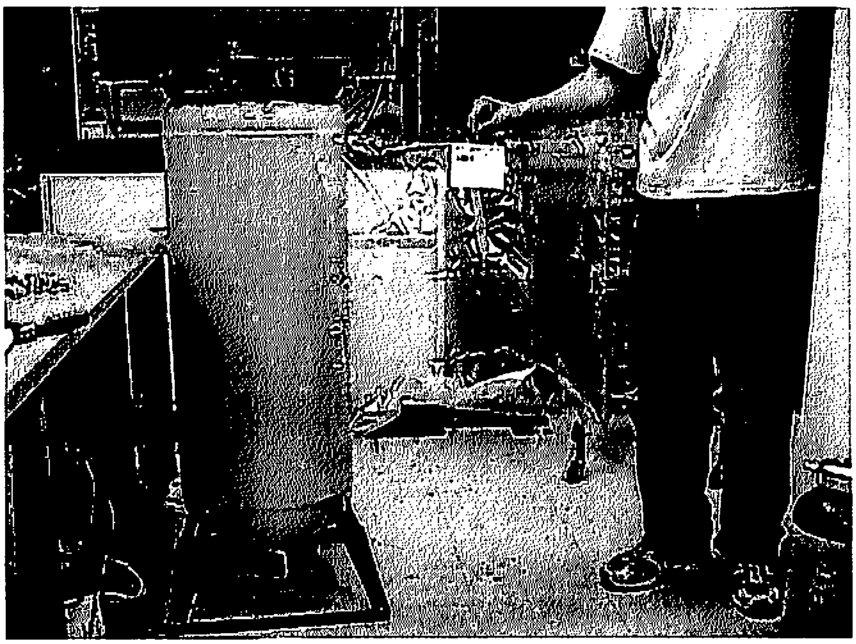

Figure 4: The pressure chamber and the large flexible bag. The bag will be filled with radon and inserted into the chamber, which is then sealed.

The chamber, and the flexible bag, was then pumped to the desired pressure. The pressure was read by a gauge and maintained to within 0.01 pound per square inch with a regulator. While being held at the desired pressure, radon was extracted from the bag at a rate of 0.5 L/min and passed through a cell (after the decay products were filtered out) for 5 minutes. The outlet of the cell was then closed and the cell allowed to equilibrate with the pressure in the bag for one minute. See figure 5.

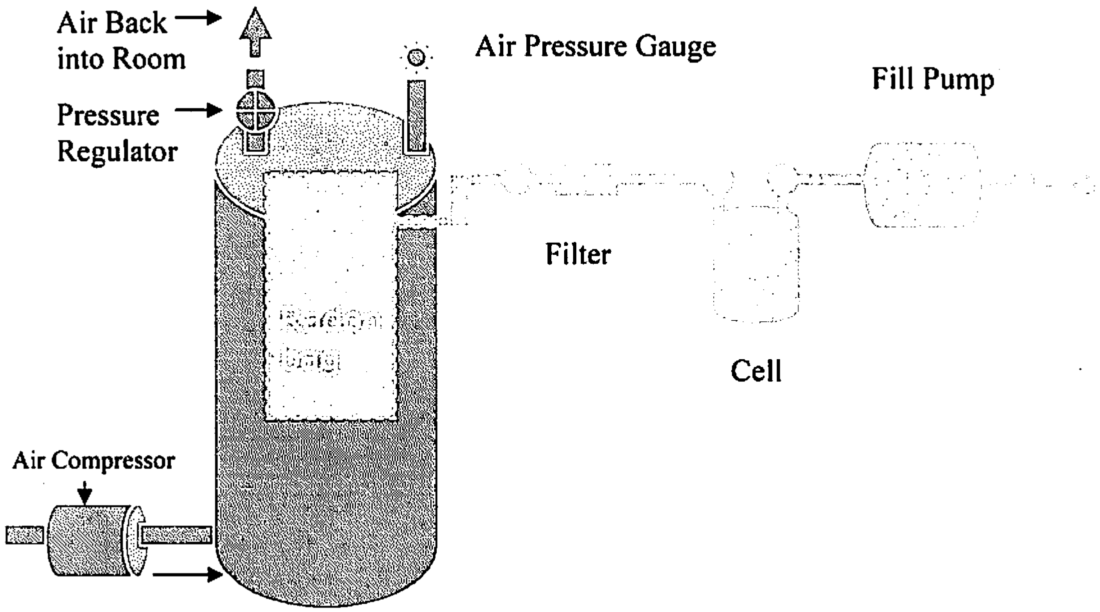

Figure 5: An air compressor brings the chamber to a desired pressure. The pressure is maintained to within 0.01 pound per square inch with a gauge and a regulator. Using a second, independent pump, the radon is extracted from the bag (under pressure), filtered and flowed through the Rocky Mountain cell.

The same cell was filled at ambient pressure (0 pounds per square inch over-pressure, or 819 mbar), an over-pressure of 1 pound per square inch (equivalent to 4000 feet elevation or 888 mbar), an over-pressure of 2 pounds per square inch (equivalent to 2000 feet elevation, or 957 mbar) and an over-pressure of 3 pounds per square inch (equivalent to sea level, or 1026 mbar). The cell was flushed between samples and the background for the cell re-established for each sample. Of course, the time delay for radon half-life was utilized. Also, when sampling at higher pressures, the increased volume of air/radon that was being captured within the fixed volume cell (because the air/radon was being compressed) was accounted for by multiplying by the ratio of the ambient pressure divided by the new pressure.

EXPERIMENTAL RESULTS

Five runs were completed, each at a different radon concentration and each run consisting of four different pressures, as outlined above. Because of difficulties in consistently filling the cell at different pressures, a few of the measurements were invalid and had to be discarded. These instances are shown with small "x's" on the chart on table 1, below.

Run Number	Error at Sea Level	Error at 2000'	Error at 4000'	Error at 6000'
1	0.92	x	x	1
2	x	0.92	0.95	1
3	0.92	0.97	0.97	1
4	x	0.94	0.98	1
5	0.91	x	x	1

Table 1: the error in cell counting efficiency and the resultant radon concentration for four different elevations. Six data points had to be expunged because of difficulty in maintaining consistent flow rates when filling the cell under pressure.

Because there were two discarded measurements at sea level, the error was calculated by dividing by the number of counts at the higher elevation instead of, as shown earlier, the number of counts at sea level. In other words, the equation used here to calculate the error was:

$$\text{Percent difference} = \frac{N_h - N_l}{N_h} \times 100$$

Notice that we are dividing by N_h instead of N_l. The practical difference is that the error shown (on this table) is less by about 1 % than that which would have been calculated if dividing by N_l (a smaller number than N_h). Thus, in comparing this result with the theoretical result predicted earlier, this result should be less than the theoretical result by a 1 % difference in predicted error. This is seen to be the case. The theoretical predicted error between 6000 feet and sea level, found by dividing by N_l, was 9.8 %, as discussed earlier. From table 1 above, that same error, found by dividing by N_h, is 8.3 % (1 minus the average of the three errors shown on the left-most column).

SUMMARY OF RESULTS

We have demonstrated that there is a significant (almost 10 %) error when using scintillation cells when comparing measurements done at sea level and at 6000 feet. In intermediate elevations, the error is somewhat less. It is recommended that practitioners who are concerned about the most accurate measurements use the chart shown in table 2 below to correct for these differences. At this time, the chart has been formulated for one cell geometry only, that of the Rocky Mountain 0.36 L cell. To use this chart, multiply the calculated radon result by the ratio of the error for the elevation at which the cell was calibrated divided by the error for the elevation at which the cell was subsequently filled for the measurement. For example, if a cell was calibrated by an intercomparison with Las Vegas (2000 feet, with an error of 0.94) and the cell is filled for a measurement at 6000 feet (with an error of 0), then the final radon result should be multiplied by .94/1. This would decrease the calculated radon value by about 6 %. On the other hand, if a cell was initially calibrated at Las Vegas (an error of 0.94) and is subsequently read at sea level (an error of 0.91), one would multiply the calculated radon result by (.94/.91 = 1.032) thereby increasing the calculated radon by about 3 %.

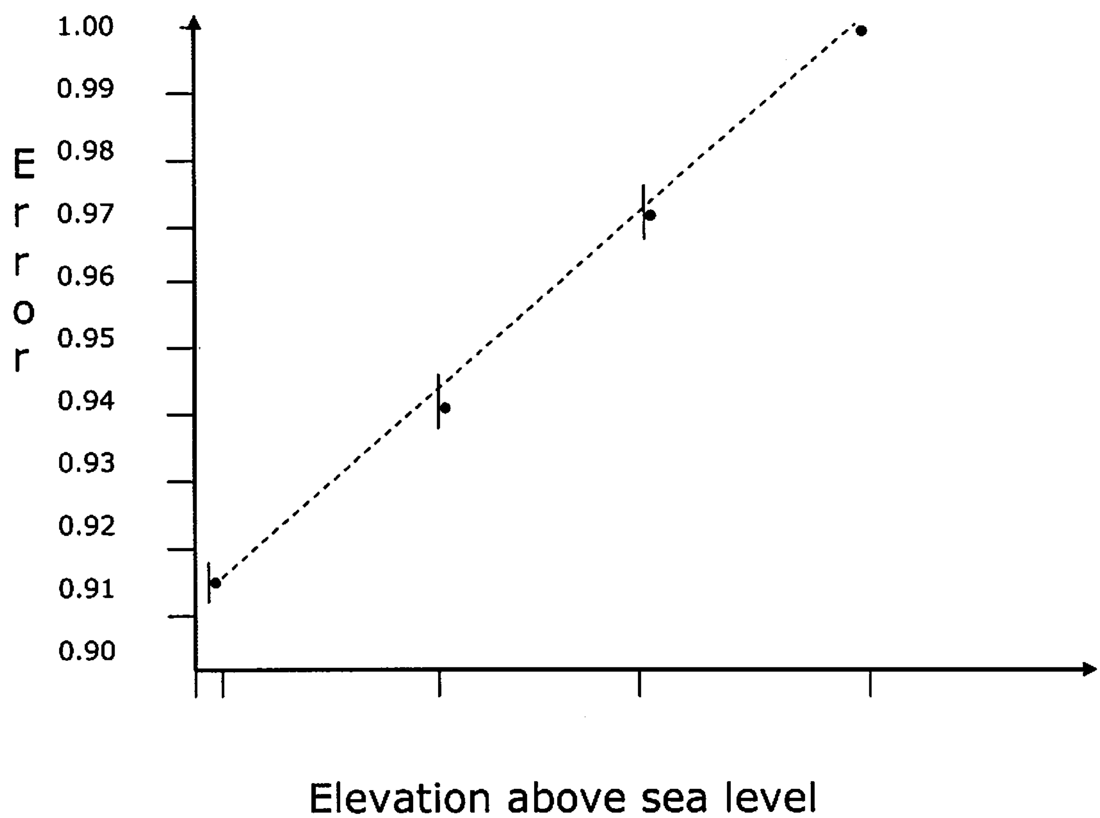

Table 2: This graph shows the corrections that are to be made to the calculated radon when using a Rocky Mountain cell that has been calibrated at one elevation and has been used to sample for radon at a different elevation. Directions for using this graph are in the paragraph above.

References

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