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Application Note – AN-0509-1

Radon Detection and Compensation Methods

Alpha Compensation for Radon Progeny Interference Using a Pseudo-Coincidence Method

Introduction

Radon and its progeny are a major interference in the effort to determine specific alpha radiation contamination particularly in applications such as air monitoring. Several techniques have been employed to identify and compensate for this interference. To achieve this goal these techniques take advantage of certain unique characteristics of radon and its daughters to estimate the interference. The two characteristics generally employed are the relatively short half-life of the isotopes and the relatively high energy of the interfering alphas.

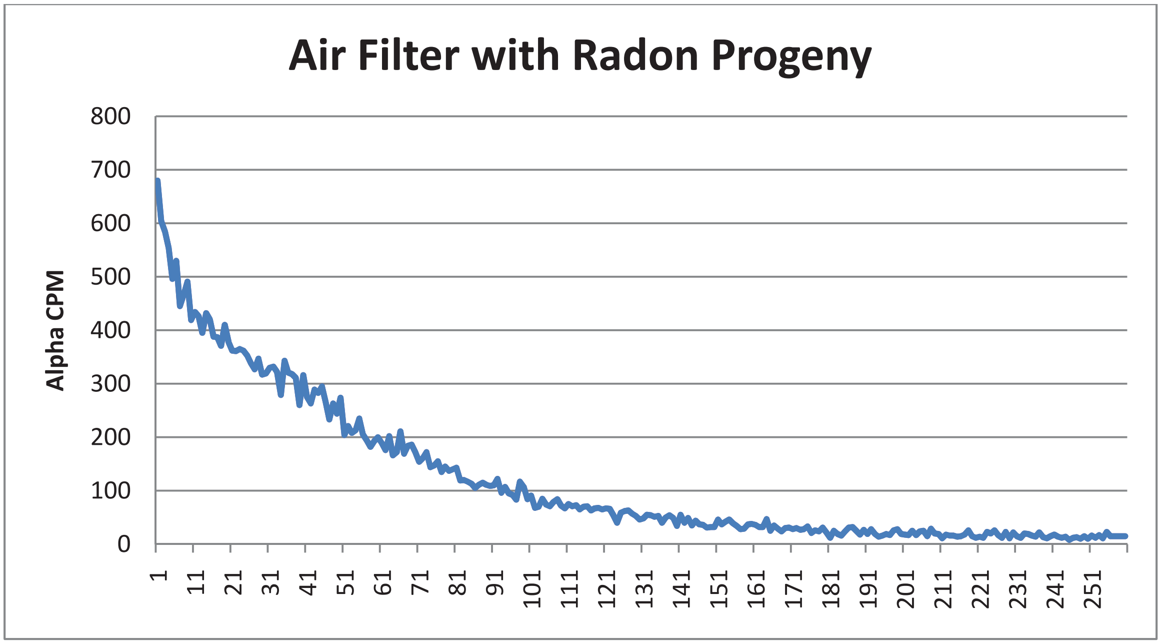

Figure 1

It is generally accepted that a delayed count provides the most interference free and therefore most accurate assessment of artificial airborne alpha emitting radioactivity on an air sample. The price paid is the wait.

Figure 1 shows the contribution and subsequent decay of Rn^{222} (radon) daughters as observed during the first 260 minutes after an air filter is removed from a sampler. This is an exaggerated case in an artificially produced environment. To eliminate the effects of radon and thoron it is customary to delay the count for about three days thus allowing the interfering isotopes to decay. But, the primary concern in the workplace is worker safety and a three day or even a four hour wait may not be acceptable. This is the driving force behind the need for an accurate and reliable method for radon compensation.

A Little Known Method

All of the compensation methods thus far employed have their pros and cons and can be compared on the basis of implementation cost, portability, reliability of the method, speed and accuracy of the results, and a number of other attributes. Protean has resurrected a lesser known method that is based upon a unique characteristic of the radon and thoron decay schemes. This method offers an almost unambiguous means of identification of a Rn^{222} decay. It is called the pseudo-coincidence method.

The pseudo-coincidence method was pioneered at the Hanford Laboratories in Washington State in the early 1960s. With the technology available at the time the implementation was cumbersome but now its time has come and Protean has implemented it in a number of its instruments. The implementation is available using conventional detectors including scintillation and gas-flow proportional detectors without sacrificing the numerous other benefits offered by these detectors (e.g., high counting efficiency, low backgrounds and economic costs).

For those unfamiliar with the theory behind the method the starting point is a definition of coincidence counting.

The Pseudo-Coincidence Method

Coincidence counting is a means of identifying a detected event using its proximity in time of occurrence to that of another detected event that occurs simultaneously. Pseudo-coincidence counting is a similar concept using serially occurring events that take place within a narrow time frame (i.e., almost simultaneously). The key premise is that the time frame is narrow enough that the probability of a chance occurrence is extremely low. The secondary premise is that no other decays in the isotopes of interest share these characteristics. Since the isotopes of interest are always long lived this is an assumption that is easily fulfilled.

Pseudo-Coincidence and Radon Decay

The decay schemes of radon and thoron present opportunities to test the premise of the pseudo-coincidence method. *Figure 2* is a diagram of the Rn^{222} decay scheme. The relatively short daughter-to-parent half-life ratio between ^{214}Po and ^{214}Bi followed by the long half-life of ^{210}Pb makes this transition a good candidate for the pseudo-coincident method.

In this case the pseudo-coincidence method uses the beta detector to open the narrow time gate within which any detected alpha event is surmised to have originated from radon. Should this transpire, a pseudo-coincident event (*PCE*) is recorded identifying the radon transition. With a proper calibration of alphas and/or betas per *PCE*, the gross alpha counts and gross beta counts may be corrected to compensate for the elevating effects of the radon interference.

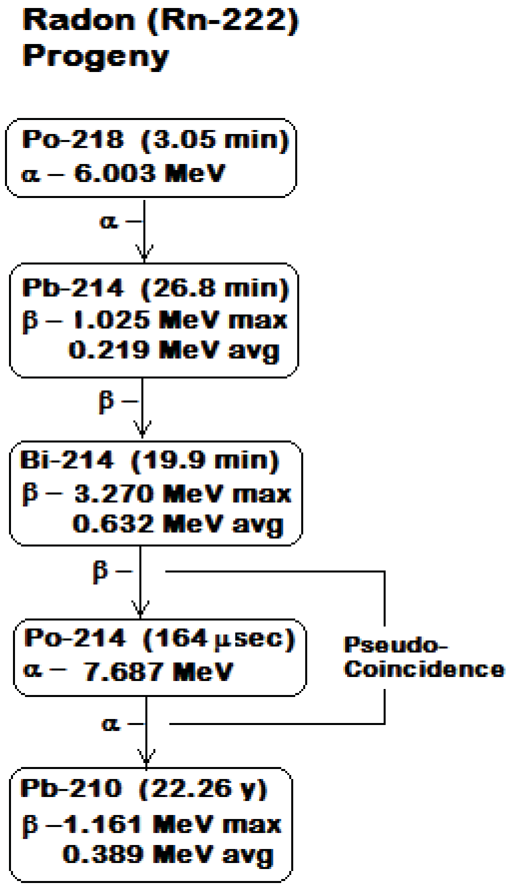

Figure 2

About the Data

The data graphically represented in this document was generated using a membrane type filter exposed to a concentrated radon/thoron atmosphere for at least 6 hours. This allowed the radon progeny to settle on the filter in secular equilibrium with the surrounding gas. Once removed from the artificial atmosphere the progeny begins to decay without regeneration thus simulating the removal of a filter from an air sampler.

The filter was immediately inserted into an instrument featuring a dual phosphor scintillation detector with pseudo-coincidence implementation. A series of one minute counts was promptly initiated that continued for approximately five hours. The results were transferred to a spread sheet for analysis. Filters were allowed to decay for a period of several days and were periodically recounted.

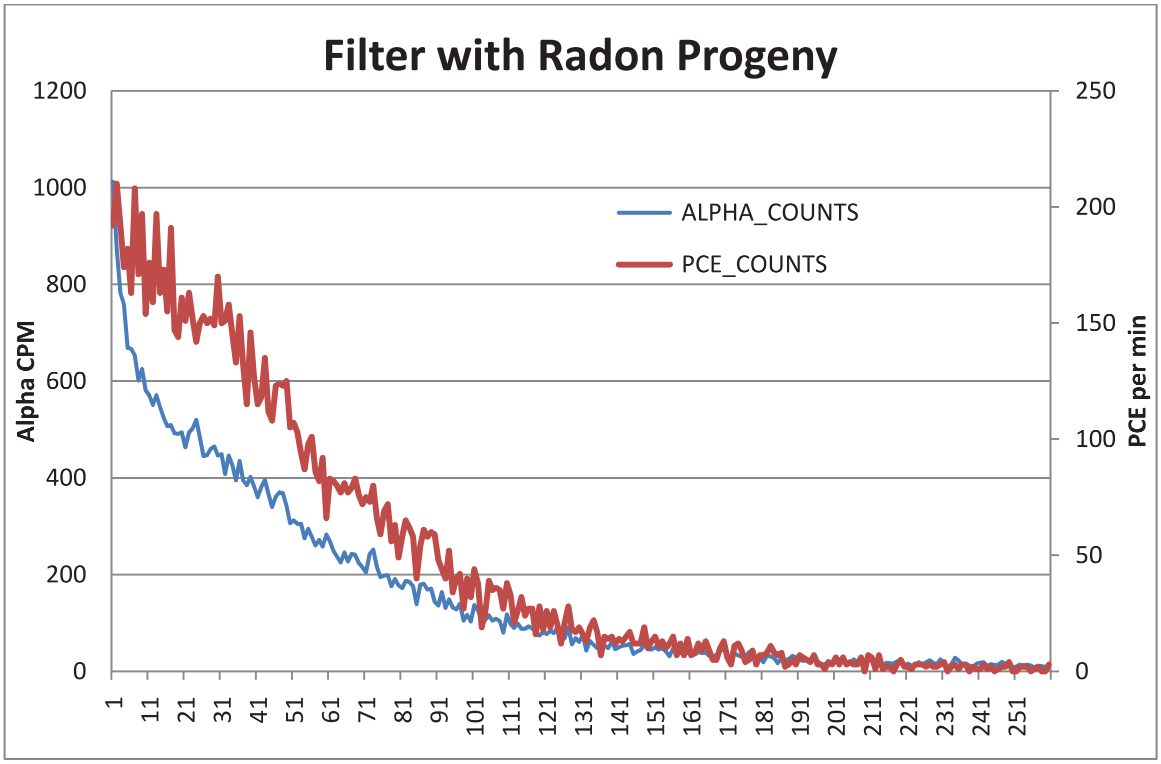

Figure 3

A *PCE* vs. Time Curve

Figure 3 shows the results obtained from a clean membrane filter that was exposed to the concentrated radon atmosphere for about 6 hours then removed and repeatedly counted. The curves of *Figure 3* show the relation between the alpha counts (lower curve) and the pseudo-coincident events (*PCE*). The shapes of both curves are affected by the convoluted relationship between parents and daughters as they transition from the equilibrium state to the simultaneous in-growth and decay mechanisms of the radon decay scheme.

The alpha curve initially reflects the rapid alpha decay of ^{218}Po (3 min half-life) of which <0.1% remains after 30 minutes. This is further illustrated with the *PCE* curve as the rate of growth of the progeny becomes dominated by ^{214}Bi and its pseudo-coincidence events.

Note that after approximately 220 minutes the radon progeny has almost entirely decayed leaving only the natural background of the filter, the inherent background of the instrument, thoron progeny, and any long lived alpha emitters present on the filter. A recount after 4 days will ensure that any thoron progeny has decayed and thus verify this conclusion. While thoron is also detectable using the pseudo-coincidence technique its low abundance renders it of less concern than the radon.

The Calibration

Calibration of an alpha/beta counting instrument involves the determination of efficiencies using traceable standards and backgrounds using suitable blanks. With radon compensation two more factors must be determined. These factors will be used to render the number of alpha and beta counts respectively that were recorded due to a radon decay.

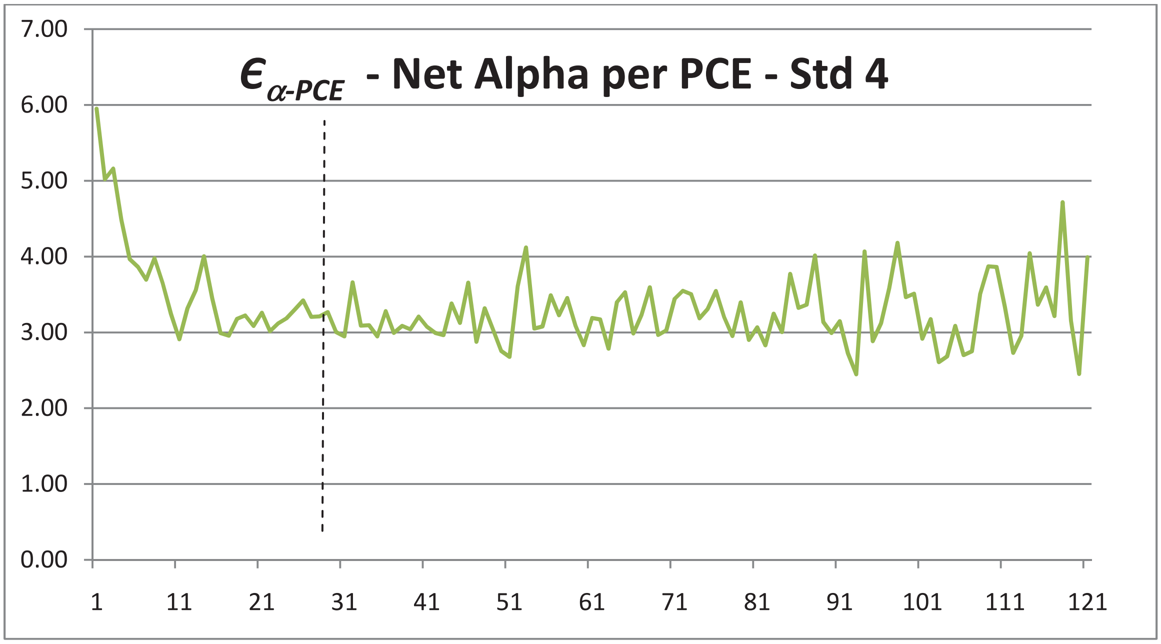

Figure 4

$\epsilon_{\alpha\text{-PCE}}$ - The Alpha Radon Compensation Factor

Figure 4 illustrates the number of alphas per *PCE* event as a function of time, where time zero is the end of exposure (i.e., simulating the cessation of flow in an air sampler). After the initial 30 minutes (to the right of the dashed line in *Figure 4*) the compensation factor is almost a constant. As the number of counts and events approach zero the poor statistics distort the results therefore only the first 120 minutes are used to determine the compensation factor.

From *Figure 4* an immediate observation is the strong time dependence of the compensation factor in the first thirty minutes. This dependence is due to the influence of ^{218}Po and its 3 minute half-life. It is obvious why most all methods for radon compensation suggest or require at least a 30 minute delay before counting a sample.

The data between 30 minutes and 120 minutes post exposure is almost linear allowing an average to be used as a constant conversion factor. This range also represents the lowest uncertainty together with the lowest degree of time dependence.

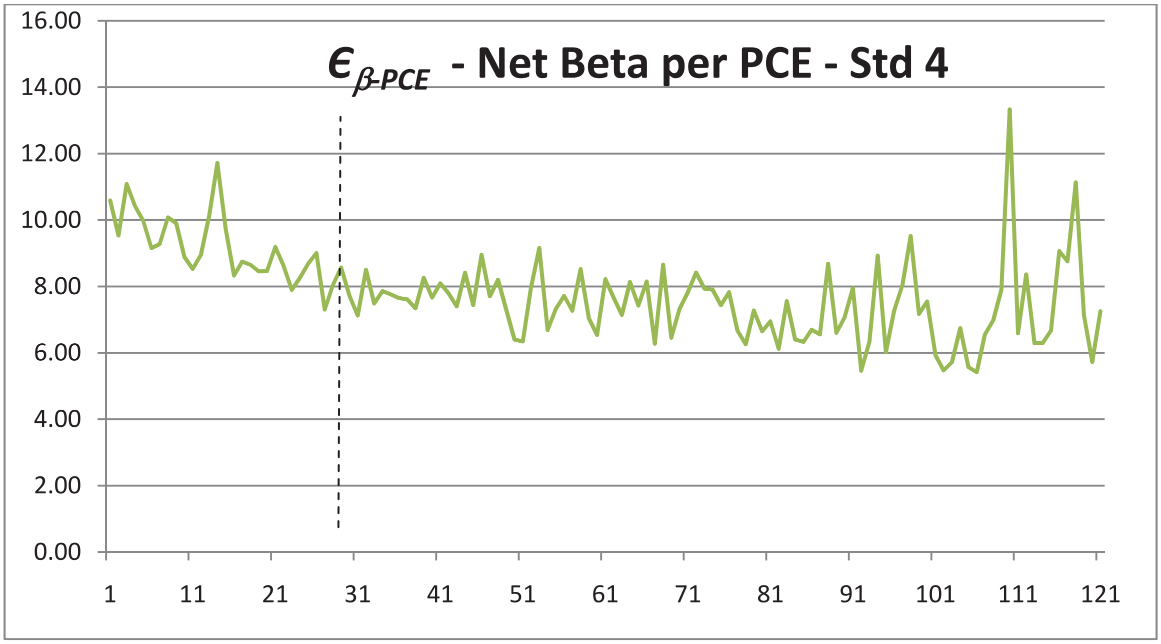

Figure 5

$\epsilon_{\beta\text{-}PCE}$ - The Beta Radon Compensation Factor

Figure 5 illustrates the number of betas per *PCE* event as a function of time with time zero indicating the end of exposure (i.e., post-flow cessation). Once again, as the numbers of PCE events approach zero the poor statistics are evident in the results. There are other dynamics at work with the beta compensation that are more obvious with a view of the beta-to-alpha ratio but for brevity are not discussed here.

Data Compensation Using Constant Factors

The test of the validity of the compensation method and of the use of constant factors is to apply the factors and compare the results with the results obtained after the radon/thoron has completely decayed. This is illustrated using blank filters in *Figures 6 & 7*.

The next test looks at a case where significant long lived radiation, in the form of a ^{210}Po alpha source, is present along with the radon exposed filter. Again the question is, does the compensation method render accurate reproducible results? This question is answered with *Figures 8-10*. While these figures offer only “arm waving” proof, the quantitative results are available and also back up the logical conclusions drawn from the graphs.

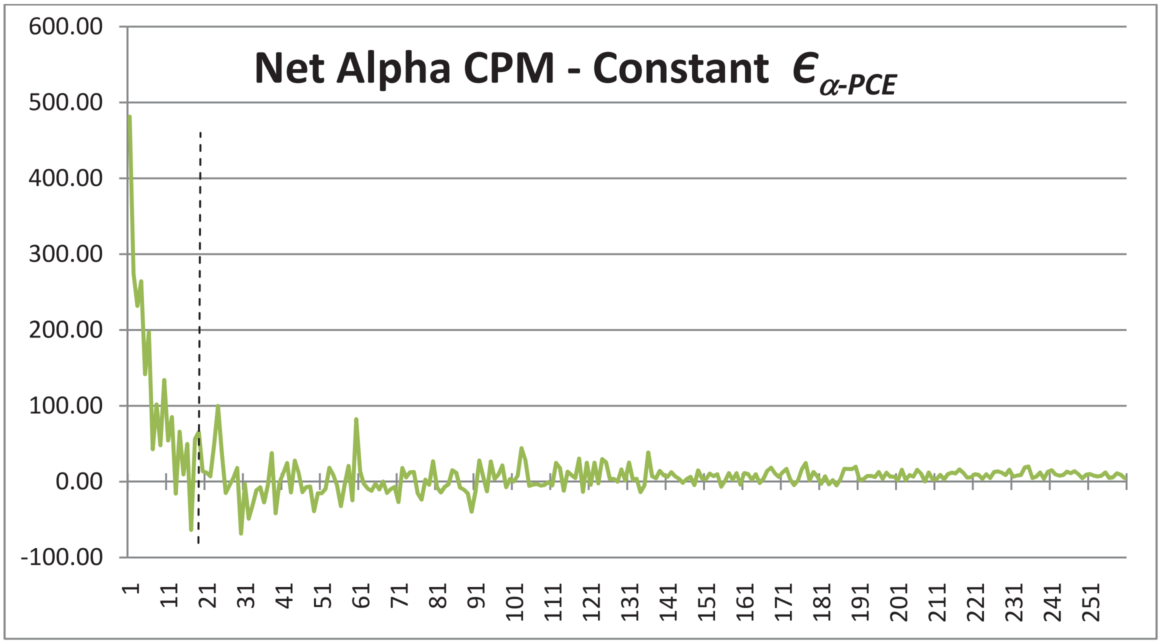

Figure 6

Net Alpha Determination on a Blank Filter

Using the constant factor $\epsilon_{\alpha\text{-}PCE}$, the net alpha results appear as illustrated in *Figure 6*. Not surprisingly the first 30 minutes show a positive bias - the influence of ^{218}Po and its 3 minute half-life.

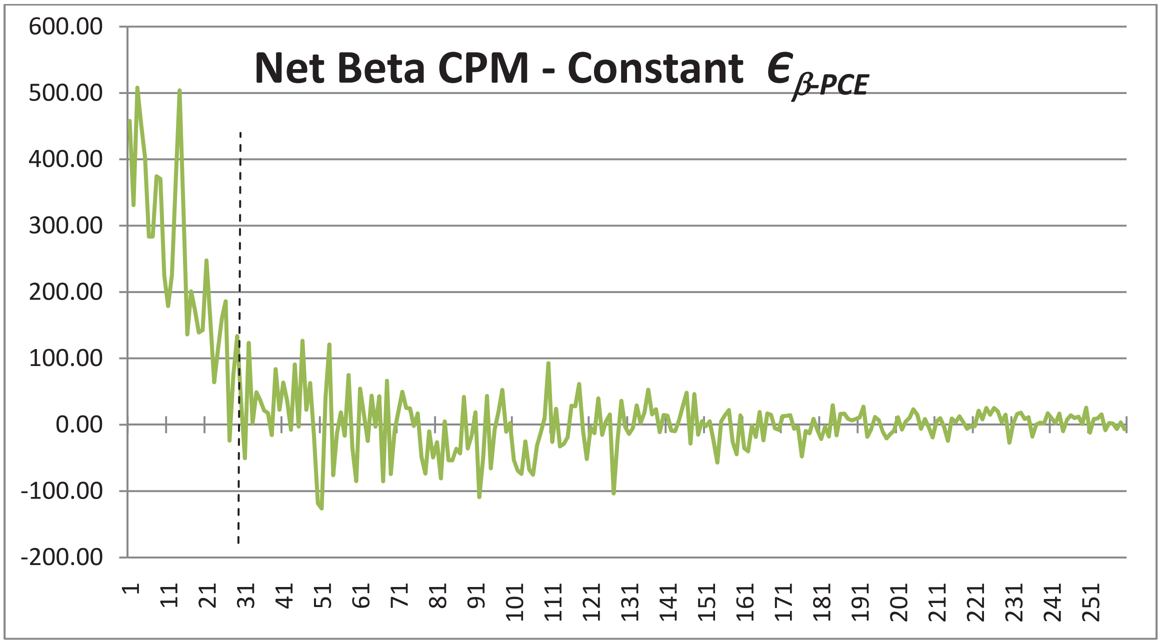

Figure 7

Net Beta Determination on a Blank Filter

For convenience sake we would like to treat the beta-to-*PCE* ratio as a constant, as we do the alpha-to-*PCE* ratio, even though *Figure 5* clearly indicates that it is not.

These results beg the question, how well does the compensation method work if real radiation is contained on the filter? To answer this question filters were exposed to radon and placed over a source with fixed radiation. The following figures illustrate the results.

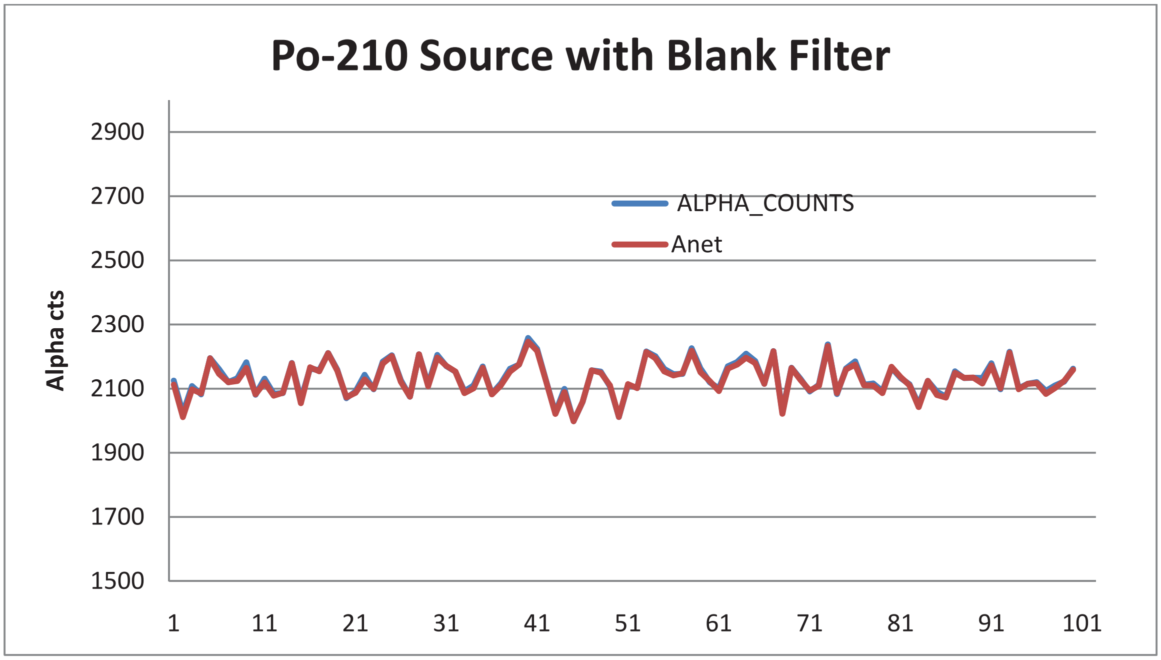

Figure 8

Using a ^{210}Po Alpha Source

Figure 8 shows the alpha count results from a ^{210}Po source covered by a blank filter for a series of 100 counts. The filter was then exposed in the radon atmosphere for eight hours after which it was placed back above the source and another series of 300 one-minute counts were performed.

Figure 9 shows both the raw alpha counts and the compensated alpha counts using the pseudo-coincident technique. *Figure 10* shows the beta results from the same series. The graphs furnish instant feedback as to the effectiveness of the compensations.

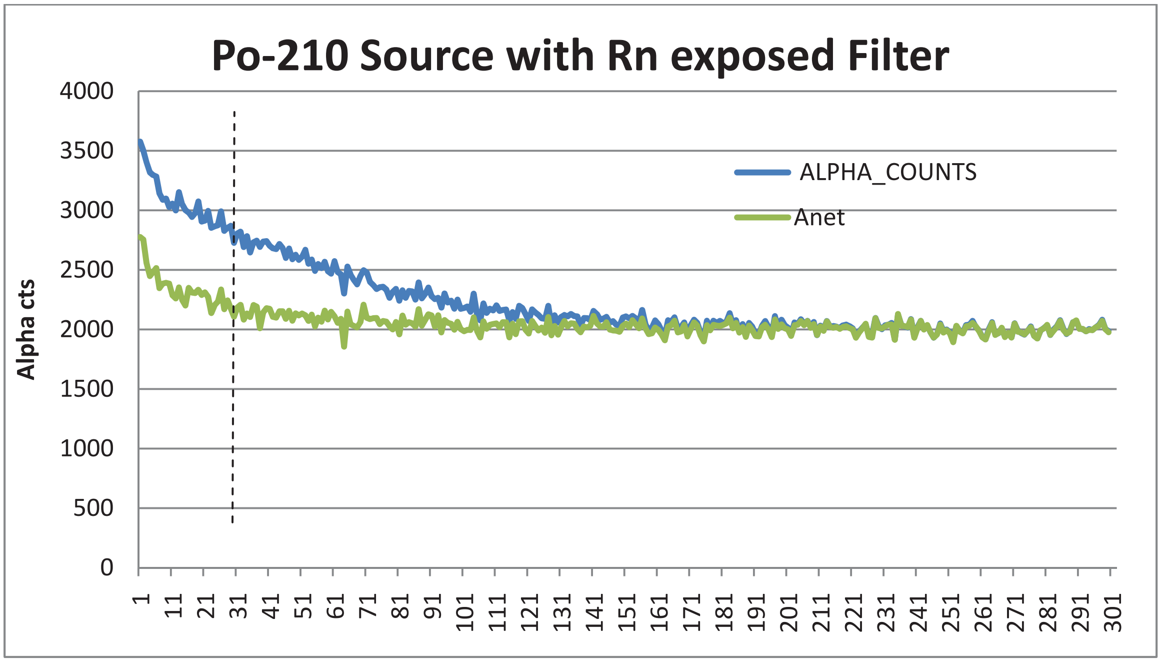

Figure 9

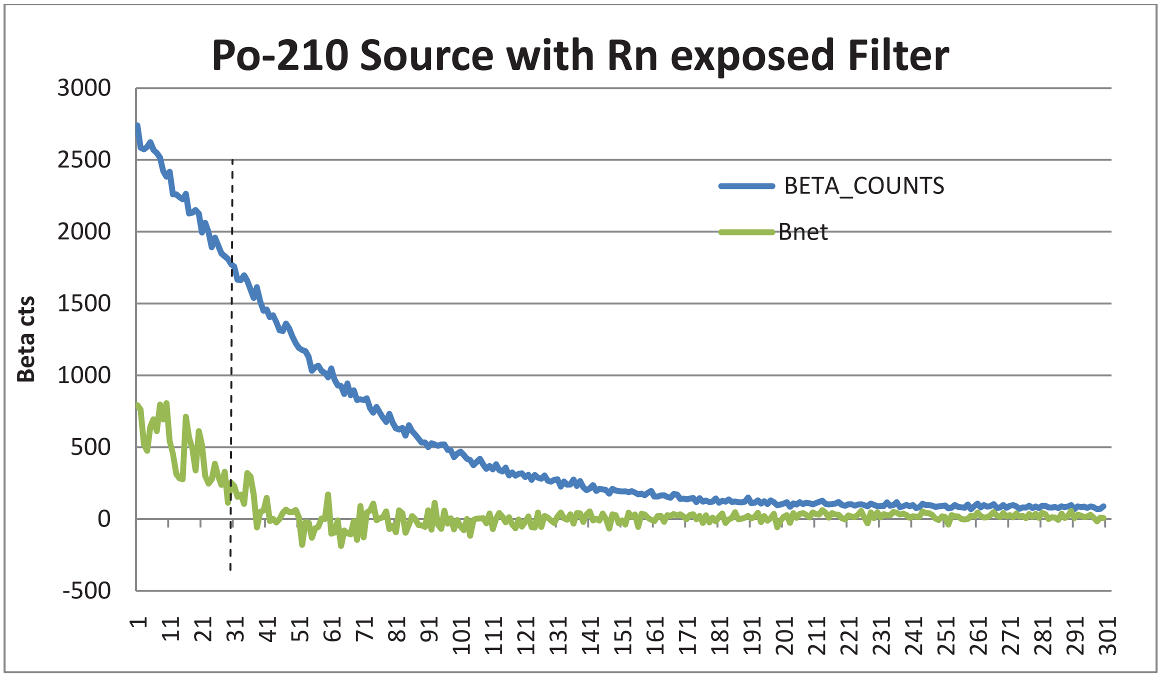

Figure 10

Time Dependent Compensation

If an immediate assessment, within the recommended 30 minute delay, is essential it is possible to incorporate time dependent compensation functions as shown for the alpha counts in *Figure 11* and *Figure 12.* In this case a second-order hyperbolic function was used instead of the constant factor of the previous discussions. Other functions may represent a better fit to the empirical data, especially for the beta compensation factor.

The major limitation of such a process is the burden of very accurate time keeping. Using a time dependent function places such a great importance on the accuracy of the time as to restrict its practicality unless it is recorded automatically using electronic methods such as is possible with Protean's TRAC air sample tracking systems.

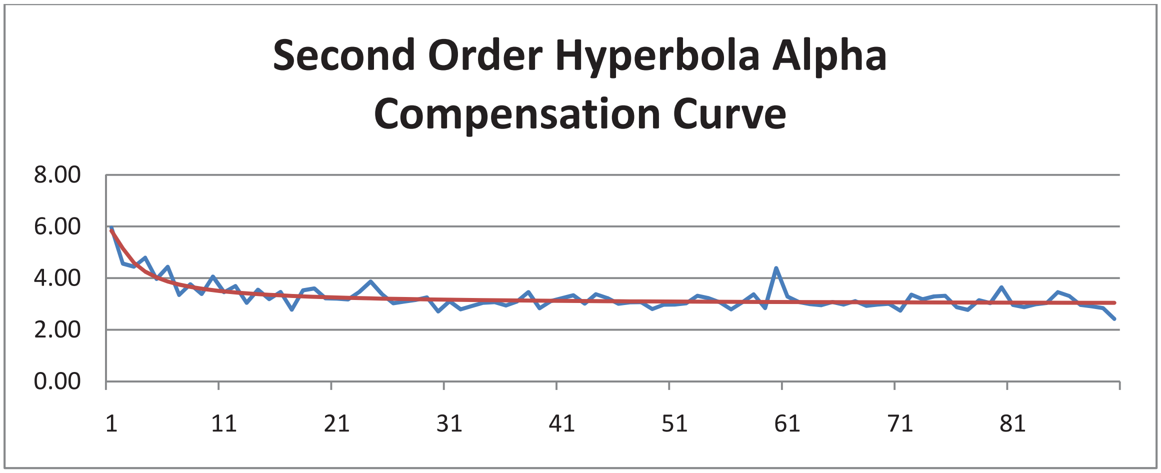

Figure 11

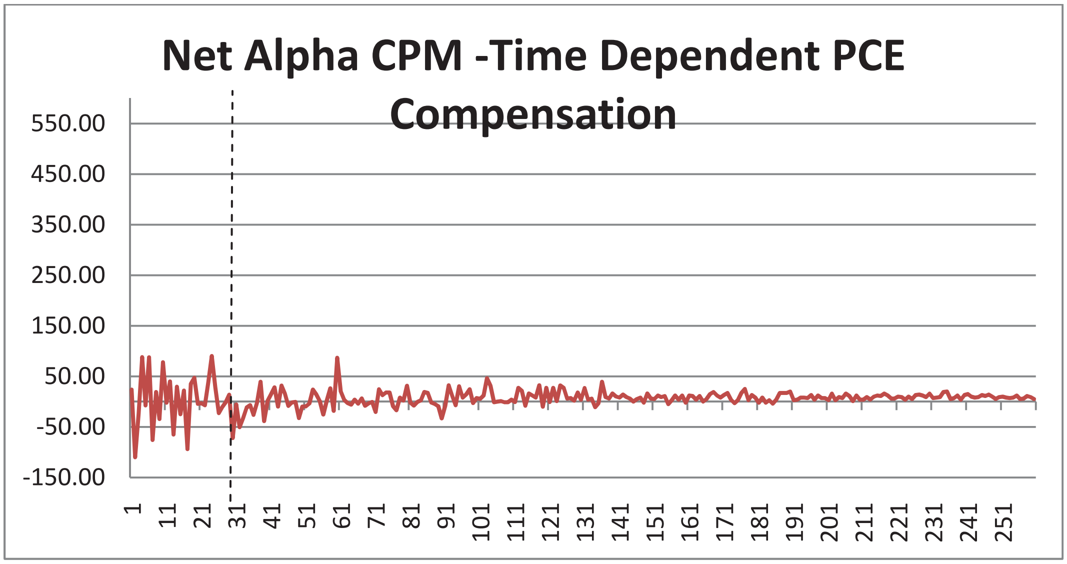

Figure 12

Figure 12 demonstrates a typical result once the timekeeping hurdles are overcome. It also demonstrates how accuracy falls prey to statistical uncertainty – the rapidly changing count rate due to the 3 minute half-life of ^{218}Po introduces significant measurement errors.

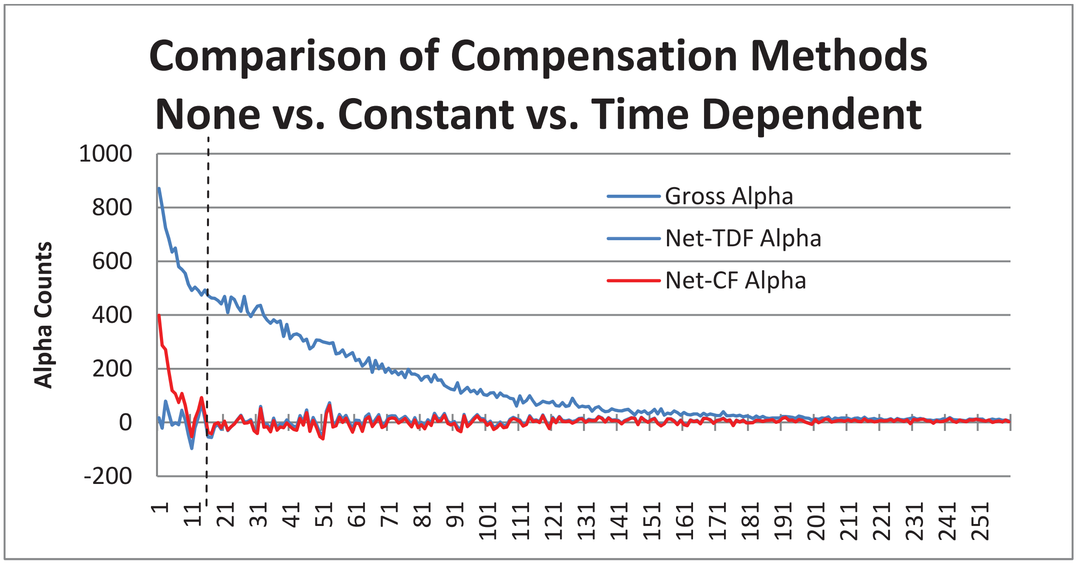

Figure 13

Finally, *Figure 13* shows a comparison of the raw data overlaid with the constant factor and the time dependent compensated data.

Conclusions

The pseudo-coincidence method of radon compensation proves itself to be an accurate, useful technique. It is easier to use than other methods and is less affected by energy dispersion due to absorption issues. As with any counting system, calibrations should be performed in conditions that match that of routine sampling. The same is true of counting geometries, sample media, and filter types.

The method is readily implemented in alpha/beta counters utilizing gas-flow proportional detectors where it combines with cosmic guard detectors to provide very low beta background in addition to radon identification. It equally adapts to PMT/scintillator alpha/beta detectors for a portable, gas-less solution.