RESULTS FROM THE FIRST ANNUAL AARST RADON MEASUREMENT INTERCOMPARISON EXERCISE

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ABSTRACT

The First Annual AARST Radon Measurement Intercomparison Exercise was conducted at the radon calibration laboratory at Bowser-Morner, Inc. in November and December, 1997. There were thirty-two participants involved in the exercise, including Bowser-Morner. For grab radon measurements, the Environmental Measurements Laboratory (EML) sent samplers to be filled in the Bowser-Morner chamber simultaneously with the filling of scintillation cells from participants. For this measurement device type, therefore, the EML value was the reference for the exercise. Sets of three to four scintillation cells were filled simultaneously with EML's samplers for each of seven participants, including Bowser-Morner. The average relative differences from EML's value for these seven participants ranged from -12.4% to 7.3% and averaged -0.3%.

Bowser-Morner's chamber values were the references for all other device types. Eighteen sets of five charcoal devices were exposed in the chamber for periods of time ranging from two to seven days, during which the radon concentration was held relatively constant. The average relative differences from the chamber values for these eighteen sets ranged from -16.0% to 19.5% and averaged 0.6%. Seven sets of five short-term electret ion chamber devices were exposed for two days. The average relative differences from the chamber values for these seven sets ranged from -9.3% to 3.3% and averaged -1.0%. Eight continuous monitoring devices were exposed for periods ranging from two to nine days. The relative differences from the chamber values for these eight devices ranged from -16.7% to 2.3% and averaged -4.6%.

Three participants submitted sets of five alpha-track devices, and three participants submitted sets of five long-term electret ion chamber devices. Because of the small numbers of each of these two types of devices, they were combined into one category for reporting purposes. These six sets of devices were exposed simultaneously in the Bowser-Morner chamber for a period of 31 days, during which the radon concentration varied significantly. The average relative differences from the chamber value for these six sets of devices ranged from –31.5% to 27.3% and averaged –3.0%.

These results of measurements over a cross-section of the radon industry, using various types of devices, generally were in good agreement with each other and with the reference values. The average of the relative differences from the reference values for each device category was in the range of ±5%. However, some individual groups of devices were not in as close agreement with the reference value as would be desired, particularly in the long-term

measurement category. More participants with long-term devices are needed in future exercises so that alpha-track devices and long-term electret ion chamber devices can be categorized individually.

1 INTRODUCTION

1.1 Importance and History of Radon Intercomparison Exercises

An intercomparison exercise provides an opportunity for radon measurement service providers and manufacturers of radon measuring instruments and devices to perform exposures in a chamber at the same time and to compare their results not only to the chamber but also to the results of the other participants. Results of such an exercise can be used to document good performance, or to identify problems that need to be corrected. Further, the results of the exercise provide a measure of the current level of performance throughout the radon measurement community.

Several radon measurement intercomparison exercises have been conducted in the past, hosted by various U.S. government radon laboratories. Most notably, the Environmental Measurements Laboratory (EML), a US Department of Energy (DOE) facility in New York City, has for many years conducted radon intercomparison exercises. The last such intercomparison was conducted in April and May, 1996 (Scarpitta, et al., 1996). Programmatic changes within the DOE have caused EML to discontinue offering this valuable service.

1.2 AARST Intercomparison Exercise

The participants in radon measurement intercomparison exercises in the past have typically been national laboratories or agencies (international as well as domestic), state regulatory agencies, instrument or device manufacturers, and private calibration facilities, with only a few being representatives of the radon testing industry. The American Association of Radon Scientists and Technologists (AARST) recognized the value in continuing these intercomparison exercises. With the end of the program at EML, AARST promoted what we believe is the first radon intercomparison exercise to be held at a private-sector laboratory and encouraged participation from a cross-section of the radon industry.

The exercise was conducted at the radon laboratory at Bowser-Morner, Inc. in November and December, 1997. The calibration facility at Bowser-Morner includes a walk-in radon chamber with a volume of 1375 ft^3 (39 m^3), which is similar in size and layout to the chambers at the US Environmental Protection Agency (EPA) chambers in Montgomery, AL and Las Vegas, NV. This facility, which has been in operation since April, 1992, is independent in the sense that Bowser-Morner does not perform radon testing or mitigation services and does not sell radon measuring instruments or devices. The independence of the host of an intercomparison exercise is important, because the host should have no vested interest in the outcome of the exercise. Further, it is important in this type of exercise to maintain the anonymity of the results so that organizations can participate without worrying about potential embarrassment should their instruments or devices not perform well in comparison with the chamber or other participants. The repository of the results should be an organization that is independent.

The radon concentration in the chamber at Bowser-Morner is monitored continuously with a system of three detectors each consisting of a 1.4-L scintillation cell and a 5-inch (13-cm) diameter photomultiplier tube. This system of detectors is calibrated by periodic comparisons with measurements made in the chamber with 3-inch (7.6-cm) diameter scintillation cells. These cells are used in exercises to intercompare with the EML and EPA radon laboratories. In twelve such intercomparisons to date, the differences between the results from Bowser-Morner's cells and the reference values from either EML or EPA ranged from –4.4% to 4.0%, with an average of –0.4% and a standard deviation of 2.8%.

1.3 Assessment of Precision and Relative Bias

The assessment of precision of sets of measurement results from this study is based on guidance provided in two documents published by the US EPA: *Protocols for Radon and Radon Decay Product Measurements In Homes* (EPA, 1993) and *Guidance on Quality Assurance* (EPA, 1997). These documents indicate that the coefficient of variation (COV) of two or more measurements from collocated devices should be calculated and plotted on a precision control chart. The COV is equal to the standard deviation (s) of a set measurements divided by the average of the measurements (multiplied by 100 to convert from a fraction to a percent). Lines should be drawn on the control chart at an "In Control" value, which should be near the expected average of the COV's, and at a "Warning Level" value and a "Control Limit" value, which would be expected to be exceeded by 5% and 1%, respectively, of the COV's. These values ideally should be established based on the COV's of at least twenty sets of measurements that are considered to be "normal." In the absence of such data, assumed values for these parameters can be used initially until a base of data are available. Suggested initial values of COV for "In Control," "Warning Level," and "Control Limit" settings for sets of measurements that average 4 pCi/L or greater are 10%, 20% and 26%, respectively. Although these were intended to be initial values only, that should be adjusted as a base of data is established, they were used as "Precision Recommendations" in the protocol (EPA, 1993). Therefore, these values have been used in the radon measurement industry as a goal for performance, or an "acceptable level of performance," with respect to precision. For this reason, the COV's of sets of measurements from this study are compared with these values.

Similarly, for the assessment of relative bias for spiked samples, Relative Percent Errors (RPE's) of the measurements should be calculated and plotted on a relative bias control chart. The RPE is defined as follows:

$$RPE = 100\% \times (MV - RV) / RV$$

where RPE is the Relative Percent Error (%), MV is the Measured Value (pCi/L) and RV is the Reference Value (pCi/L).

Ideally, the values of RPE for "In Control," "Warning Level," and "Control Limit" settings should be established from a base of at least twenty samples that have been spiked in a radon chamber, where the Reference Value is provided by the chamber operator. In the absence of such data, suggested initial values for these settings are ±10%, ±20%, and ±30%, respectively.

Again, these values have been used in the radon measurements industry as a goal for performance, and for this reason they are used as the basis for the assessment of relative bias in this study.

It should be noted that whereas the COV can have only a positive value, the RPE can be either positive or negative. Therefore, on a relative bias control chart "In Control," "Warning Level," and "Control Limit" lines must be drawn at values of +10%, +20% and +30% and also at values of –10%, -20%, -30%. For a set of RPE values that have an average of zero and a standard deviation of 10%, the values should be within the range of ±20% about 95% of the time and within the range of ±30% about 99% of the time.

The RPE is similar to the Individual Relative Error (IRE) that has been used as an assessment of performance in EPA's Radon Proficiency Program (RPP). The IRE is equal to the absolute value of the RPE; i.e., if the value of RPE were negative, the IRE would have the same magnitude only it would be a positive value. The criterion for passing a performance test in the RPP is that the IRE for each device must not exceed 25%. This is equivalent to saying that the RPE for each device must be in the range of ±25%.

In this report, the RPE values for continuous measuring devices are plotted on a relative bias control chart. However, for other types of devices where more than one measurement was reported, Average Relative Percent Error (ARPE) values are plotted on bias control charts. The ARPE can be calculated by first determining the RPE for each device and then taking the average, but it can be calculated more simply by first taking the average of the reported measurements and then using the following equation:

$$\text{ARPE} = 100\% \times (\text{AMV} - \text{RV}) / \text{RV}$$

Where ARPE is the Average Relative Percent Error (%) and AMV is the Average of the Measured Values (pCi/L).

Whenever a value of ARPE is calculated, it is also possible to calculate an error bar associated with it based on the standard deviation (s) of the measurements. The basis for such an error bar should be consistent throughout this report. Any approach that is based on a constant multiple of s would not have a consistent basis. This is because the number of degrees of freedom associated with the values of s for different participants and/or device types is not constant (i.e., the number of devices in each set is not constant throughout the study). For a consistent basis, therefore, the 95% Confidence Interval (CI) is used in this report. The 95% CI can be thought of as a range about the average of the measurements that should contain 95% of all such measurements that could be taken. Perhaps the easiest way to express the value of the 95% CI is as follows:

$$95\%\ \text{CI} = 100\% \times t_{0.975\,(n-1)} \times s / \text{RV}$$

where s is the standard deviation of the measurements, and $t_{0.975\,(n-1)}$ is the two-tailed t-statistic with (n - 1) degrees of freedom (where n is the number of measurements), with an α value (Type

I error) of 0.025 associated with each tail. Confidence intervals and the t-statistic are discussed thoroughly in most statistics texts (one example is Ostle, 1963). The values of $t_{0.975}$ with four, three and two degrees of freedom are 2.776, 3.182 and 4.303, respectively. These values should be used for sets containing five, four or three devices, respectively.

Another way of calculating the 95% CI, which is more cumbersome, but perhaps easier to understand, is to determine the individual RPE value for each measurement, calculate the standard deviation of the RPE values and multiply by the t-statistic. This is mathematically equivalent to the expression shown above.

Results from intercomparisons are sometimes reported in terms of the Performance Ratio (PR), which is equal to the reported measurement, or average of a set of measurements, divided by the target value. The ARPE or RPE is related to the PR by the following equation:

$$\text{ARPE or RPE} = 100\% \times (\text{PR} - 1)$$

This relationship is included here in case the reader wishes to convert results expressed as ARPE's or RPE's to values expressed as PR's.

1.4 Participants

The names and locations of 32 organizations that participated in this intercomparison exercise are listed in Table 1. EML provided gas-sampling cylinders to be filled in the Bowser-Morner chamber, and subsequently analyzed at EML, so that EML rather than Bowser-Morner could provide the Reference Value for grab radon measurements. This made it possible for Bowser-Morner to participate with grab radon measurements, and therefore Bowser-Morner is listed in Figure 1 as a participant.

2 RESULTS

2.1 Grab Radon Measurements with Scintillation Cells

Scintillation cells were filled in the Bowser-Morner radon chamber on 11/11/97 for seven participants, including Bowser-Morner. Three cells were filled for one participant, and four cells were filled for each of the other participants. The types of scintillation cells used by the participants are listed in Table 2. The cells from all but one participant were of the flow-through type. Three gas-sampling cylinders from EML were also filled in the Bowser-Morner chamber.

All of the devices were evacuated before taking them into the radon chamber. The flow-through cells were connected with plastic tubing to form a single train, with the cylinders from EML interspersed among the cells. Filtered air was pumped through the train for approximately ten minutes. During this period, the cells with single ports were each evacuated and filled with filtered chamber air three times. The pumping was stopped, and all the cells and cylinders were closed at 13:00 EST.

The samples obtained with the metal cylinders were analyzed at EML by transferring the gas into EML's pulse ionization chambers. These chambers are calibrated against a radium solution traceable to the National Institute of Standards and Technology (Fisenne and Keller, 1985). The results of radon concentration measurements from the three samples reported by EML were 11.9 ± 0.2, 12.0 ± 0.2 and 12.1 ± 0.2 pCi/L. The error bars are single standard deviations based on Poisson counting statistics. The average of the three measurements, 12.0 pCi/L, was used as the reference value to which the results from the other participants were compared.

The results from the seven sets of scintillation cells are presented in Table 3. The participant code numbers, 1 through 7, were assigned at random to the participants. For the reasons stated in Section 1.2, participant code numbers are used to protect the anonymity of the results. The only participant whose anonymity should not be protected is Bowser-Morner; our participant number is "4."

In Table 3, the column titled "Range" contains the smallest and largest measurement value in pCi/L reported by each participant. In the next column the average and standard deviation (s) for the reported measurements for each participant is shown. In the next column, the coefficient of variation (COV) for each participant is shown. The next column contains the Reference Value (RV), which is 12.0 pCi/L in all cases. The last column in Table 3 contains for each participant the Average Relative Percent Error (ARPE) and the 95% Confidence Interval (CI). For an explanation of COV, ARPE, and CI, refer to Section 1.3.

The values of ARPE are plotted on a relative bias control chart in Figure 1 with the 95% confidence intervals shown as error bars. Applying the criteria discussed in Section 1.3, this set of results shows very good agreement with the Reference Value. All but one of the values of ARPE were within the range of ±10%. As a group, the ARPE values averaged –0.26%, with a standard deviation of 6.8%.

The COV's listed in the fourth column of Table 3 are plotted on a precision control chart in Figure 2. Applying the criteria discussed in Section 1.3, this set of results demonstrates good precision. The COV values were all less than 10%, and averaged 4.8%.

2.2 Radon Measurements with Activated Charcoal Devices

Eighteen sets of five charcoal devices were exposed in the Bowser-Morner radon chamber during the period of 11/08/97 to 11/17/97. Each set of five devices was assigned a unique participant number; although, in two cases two or more sets of different models of devices were sent from the same organization. The length of exposure ranged from two to seven days depending upon the device type and the request of the participant. The types of charcoal devices used by the participants are listed in Table 4.

The results from the eighteen sets of charcoal devices are presented in Table 5. The participant code numbers, 8 through 25, were assigned at random to the sets of devices. In the column titled "Range" the smallest and largest measurement value in pCi/L reported for each set of devices is shown. In the next column the average and standard deviation (s) for the reported measurements for each set of devices is shown. In the next column, the COV for each set of devices is shown. The next column contains the Reference Value (RV), which is the average of the hourly measurements from Bowser-Morner's continuous radon measuring system for the period of time in which the set of devices was in the chamber. The radon concentration in the chamber was held relatively constant; the standard deviation of the hourly measurements was in most cases 0.5 pCi/L, but in a few cases was smaller. The last column in Table 5 contains for each set of devices the ARPE and the 95% CI. For an explanation of COV, ARPE and CI, refer to Section 1.3.

The values of ARPE are plotted on a relative bias control chart in Figure 3 with the 95% confidence intervals shown as error bars. Applying the criteria discussed in Section 1.3, this set of results shows very good agreement with the Reference Values. Fourteen of the eighteen values of ARPE were in the range of ±10%, and the remaining four values were within the range of ±20%. As a group, the ARPE values averaged 0.63% with a standard deviation of 9.0%.

The COV's listed in the fourth column of Table 5 are plotted on a precision control chart in Figure 4. Applying the criteria discussed in Section 1.3, this set of results demonstrates good precision. The COV values were all less than 10%, and averaged 3.2%.

2.3 Radon Measurements with Short-term Electret Ion Chamber Devices

Five short-term electret ion chamber devices were exposed in the Bowser-Morner radon chamber for each of seven participants either during the period of 11/08/97 to 11/10/97 or during the period of 11/15/97 to 11/17/97. The length of exposure in all cases was two days. Only one type of short-term electret ion chamber device was used, as indicated in Table 6.

The results from the seven sets of short-term electret ion chamber devices are presented in Table 7. The participant code numbers, 26 through 32, were assigned at random to the participants. In the column titled "Range" the smallest and largest measurement value in pCi/L reported for each set of devices is shown. In the next column the average and standard deviation (s) for the reported measurements for each set of devices is shown. In the next column, the COV for each set of devices is shown. The next column contains the Reference Value (RV), which is the average of the hourly measurements from Bowser-Morner's continuous radon measuring system for the period of time in which the set of devices was in the chamber. The radon concentration in the chamber was held relatively constant; the standard deviation of the hourly measurements was in most cases 0.5 pCi/L, but in one case was smaller. The last column in Table 7 contains for each set of devices the ARPE and the 95% CI. For an explanation of COV, ARPE and CI, refer to Section 1.3.

The values of ARPE are plotted on a relative bias control chart in Figure 5 with the 95% confidence intervals shown as error bars. Applying the criteria discussed in Section 1.3, this set of results shows very good agreement with the Reference Values. All seven of the values of ARPE were in the range of ±10%. As a group, the ARPE values averaged −1.0% with a standard deviation of 4.7%.

The COV's listed in the fourth column of Table 7 are plotted on a precision control chart in Figure 6. Applying the criteria discussed in Section 1.3, this set of results demonstrates good precision. Six of the seven COV values were less than 10%, and the remaining value was less than 20%. The average of the COV values was 7.1%.

2.4 Radon Measurements with Continuous Devices

Eight continuous radon-measuring devices were exposed in the Bowser-Morner radon chamber during the period of 11/08/97 to 11/17/97. Each device was assigned a unique participant number; although, in one case two devices were sent from the same organization. The length of exposure ranged from two to nine days depending upon the type of device and the request of the participant. The types of continuous devices used by the participants are listed in Table 8.

The results from the eight continuous devices are presented in Table 9. The participant code numbers, 33 through 40, were assigned at random to the devices. One measurement value was reported for each device; therefore, the range, standard deviation (s), and 95% CI are not reported for these devices. The Reference Value (RV) is the average of the hourly measurements from Bowser-Morner's continuous radon measuring system for the period of time in which each device was in the chamber. The radon concentration in the chamber was held relatively constant; the standard deviation of the hourly measurements was in most cases 0.5 pCi/L, but in two cases was smaller. The last column in Table 9 contains the RPE for each device. For an explanation of RPE, refer to Section 1.3.

The values of RPE are plotted on a relative bias control chart in Figure 7. Applying the criteria discussed in Section 1.3, this set of results shows very good agreement with the Reference Values. Six of the eight values of RPE were in the range of ±10%, and the remaining two values were in the range of ±20%. As a group, the RPE values averaged –4.6% with a standard deviation of 6.6%.

2.5 Radon Measurements with Long-term Devices

Three sets of five alpha-track devices and three sets of long-term electret ion chamber devices were submitted for participation in this study. It was felt that a group of only three sets of devices would not produce meaningful results, and further that the anonymity of the participants' results could be better protected with a larger group. Therefore, for these reasons and the fact that both types of devices are used for long-term measurements, these six sets of devices were combined into one group. These devices were exposed in the Bowser-Morner radon chamber during the 31-day period from 11/08/97 to 12/09/97. The types of devices used are listed in Table 10.

The results from the six sets of long-term devices are presented in Table 11. The participant code numbers, 41 through 46, were assigned at random to the sets of devices. In the column titled "Range" the smallest and largest measurement value in pCi/L reported for each set of devices is shown. In the next column the average and standard deviation for the reported measurements for each set of devices is shown. In the next column, the COV for each set of devices is shown. The next column contains the target value, which is the average of the hourly measurements from Bowser-Morner's continuous radon measuring system for the period of time in which the set of devices was in the chamber. The radon concentration in the chamber varied significantly during this period; the hourly average measurements ranged from 7.5 to 27.9 pCi/L, with a standard deviation of 7.1 pCi/L. The last column in Table 11 contains for each set of devices the ARPE and the 95% CI. For an explanation of COV, ARPE and CI, refer to Section 1.3.

The values of ARPE are plotted on a relative bias control chart in Figure 8 with the 95% confidence intervals shown as error bars. Applying the criteria discussed in Section 1.3, this set of results shows general agreement, but not good agreement, with the Reference Values. One of the six values of ARPE was in the range of ±10%, three values were in the range of ±20%, and two values were outside the range of ±20%. As a group, the ARPE values averaged –3.0% with a standard deviation of 20.6%.

The COV's listed in the fourth column of Table 10 are plotted on a precision control chart in Figure 9. Applying the criteria discussed in Section 1.3, this set of results demonstrates good precision. Five of the six COV values were less than 10%, and the remaining value was only slightly larger than 10%. The average of the COV values was 4.9%.

3 DISCUSSION AND CONCLUSIONS

The participants in the exercise represented a good cross-section of the radon community, including radon testers, manufacturers of radon measuring instruments and devices, charcoal analysis laboratories, universities, and state agencies. A variety of instruments and devices were included in the exercise.

Overall, the results from this exercise were very good and demonstrated that a variety of devices currently being used in the radon industry are capable of performing well, under laboratory conditions, in terms of relative bias and precision in relation to the criteria discussed in Section 1.3. The results from the seven sets of scintillation cells were very good with only one value of ARPE outside of the range of ±10%. From Figure 1 it can easily be seen that none of the sets of reported results were significantly different from the Reference Value at the 95% confidence level, since the 95% CI's include zero in every case. The precision of all seven sets was good, with all values of COV below 10%.

The results from short-term passive devices (charcoal and electret ion chamber devices) were very good. Only four values of ARPE out of eighteen sets of charcoal devices were outside the range of ±10%, but these were within the range of ±20%. An estimate of a 95% Confidence Interval about the Reference Value, i.e. the Bowser-Morner chamber value, that accounts for all sources of uncertainty is approximately ±10%. It can be easily seen from Figure 3 that the 95% CI's about all eighteen values of ARPE extend into the range of ±10%; therefore, none of these sets of data are significantly different from the Reference Value at the 95% confidence level. The precision of all eighteen sets of data from charcoal devices was good, with all values of COV below ±10%.

All seven values of ARPE for the sets of short-term electret ion chamber devices were within ±10%; therefore, none of these values is significantly different from the Reference Value at the 95% confidence level. The precision of all but one set of results was good, with COV's less than 10%. The COV for one set of data was 19.9%. More data are needed to draw any conclusions about the significance of this one high value of COV.

The results from continuous devices were very good. Two of eight values of RPE were outside the range of ±10%, but were in the range of ±20%. Five of the eight values of RPE were in the range of ±3%. Because only one radon concentration measurement value was reported from each participant, it was not possible to assess the precision of the continuous devices. It is theoretically possible to calculate an estimate of the precision of the measurements for most continuous radon monitors based on Poisson counting statistics; although, there are complicating factors, such as the effect of correlated counts. This was not possible to do for every device that was submitted for this exercise; therefore, no attempt was made to do an assessment of precision. In future intercomparison exercises, however, it may be advisable to limit the study only to devices for which the precision of the radon concentration measurement can be estimated.

The results from long-term devices were good, but not as good as with other types of devices. Only three sets of alpha-track devices and three sets of long-term electret ion chambers were included in the study, so it is difficult to draw significant conclusions from these results. Five of the six values of ARPE were outside the range of ±10%, and two of the six values were outside the range of ±20%. Assuming that the 95% Confidence Interval about the Reference Value is ±10%, it can be seen from Figure 8 that two of the six sets of devices were significantly different from the Reference Value at the 95% confidence level. It may be argued that, with an exposure to an average radon concentration of 17.8 pCi/L for 31 days (552 pCi-d/L), that these devices were exposed nearer their lower limits of detection than were the other types of devices. However, if this were a source of a problem it would seem that the precision of the reported measurements would be affected. Such was not the case, as five of six values of COV were less than 10%, with one value being 10.8%. In fact, four of the six values of COV were less than 3%.

The radon concentration in the Bowser-Morner chamber was held relatively constant during the period when the short-term devices were exposed. This was not the case during the exposure of the long-term devices. A plot of the hourly average measurements of radon concentration, temperature and relative humidity in the chamber during the 31-day exposure is presented in Figure 10. It can be seen from this figure that the concentration in the chamber was held relatively constant at about 13 pCi/L while the short-term devices were exposed. The concentration was raised to roughly 25 pCi/L for a few days, and then was lowered to roughly 9 pCi/L for a few days. It can also be seen that the temperature in the chamber was controlled to a value of about 70°F for the entire study, and the relative humidity was controlled to a value of approximately 50%, except for a few hours when it was lowered to roughly 24%. In theory, the long-term devices should not have been affected by the changes in radon concentration shown in Figure 10. However, this is a major difference between the manners in which the long-term and short-term devices were exposed in this study. Perhaps it would be advisable in future exercises to vary the radon concentration, in the fashion that the radon concentration might vary in a home, during the exposure of all types of devices.

4 REFERENCES

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5 ACKNOWLEDGMENTS

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Table 1-List of Participants

Participant	Location
Air Chek, Inc.	Fletcher, North Carolina
Airtech Radon	Coatesville, Pennsylvania
Alpha Energy Laboratories	Carrollton, Texas
Associated Radon Services	Stuart, Florida
Atomic Energy of Canada, Ltd.	Port Hope, Ontario
Bowser-Morner, Inc.	Dayton, Ohio
Environmental Science Lab., Inc.	Medway, Massachusetts
Environmental Solutions, Inc.	St. Louis, Missouri
femto-TECH, Inc.	Carlisle, Ohio
Gemmill Associates	Sterling, Pennsylvania
Key Technology, Inc.	Lebanon, Pennsylvania
Landauer, Inc.	Glenwood, Illinois
Microbac Laboratories, Inc.	Erie, Pennsylvania
Nemastil, Inc.	Cleveland Heights, Ohio
New York State Dept. of Env. Conservation	Albany, New York
New York University School of Medicine	New York, New York
PADEP/BRP – Radon Division	Harrisburg, Pennsylvania
Rad Elec, Inc.	Frederick, Maryland
Rad Elec, Inc.	Goldsboro, North Carolina
Radalink, Inc.	Atlanta, Georgia
Radon Environmental Monitoring, Inc.	Northbrook, Illinois
Radon Professional Services, Inc.	Jacksonville Beach, Florida
Radon Survey Systems, Inc.	Twinsburg, Ohio
Radon Testing Corporation of America	Elmsford, New York
Radonalysis	Rockford, Illinois
Ram/Gam Engineering Services, Inc.	Aurora, Colorado
Sun Nuclear Corporation	Melbourne, Florida
TCS Industries	Harrisburg, Pennsylvania
Tri-County Radon Testing Co.	Huntingdon Valley, Pennsylvania
UST Labs	Southampton, Pennsylvania
Wilkes University	Wilkes-Barre, Pennsylvania
Wisconsin Radiological Laboratories, Inc.	Madison, Wisconsin

Table 2-Types of Scintillation Cells

No. of Participants	Manufacturer and Model
5	Pylon Electronics, Inc., Model 300A
1	Rocky Mountain Scientific Glass Blowing Co., Model RA1000, (flow-through)
1	Rocky Mountain Scientific Glass Blowing Co., Model RA1000, (single port)

Table 3-Results from Scintillation Cells

Participant	Range	Avg. ± s	COV(%)	RV	ARPE (%) ± 95% C I
1	9.6 - 11.8	10.5 ± 0.9	9.0	12.0	-12.4 ± 25.1
2	11.5 - 12.9	12.4 ± 0.8	6.3	12.0	3.5 ± 28.1
3	10.9 - 11.6	11.3 ± 0.3	2.9	12.0	-6.0 ± 8.8
4	11.6 - 12.4	12.1 ± 0.3	2.8	12.0	0.6 ± 9.0
5	12.1 - 13.3	12.6 ± 0.5	4.0	12.0	5.0 ± 13.5
6	11.8 - 12.4	12.0 ± 0.3	2.2	12.0	0.2 ± 7.0
7	12.2 - 14.0	12.9 ± 0.8	6.3	12.0	7.3 ± 21.4

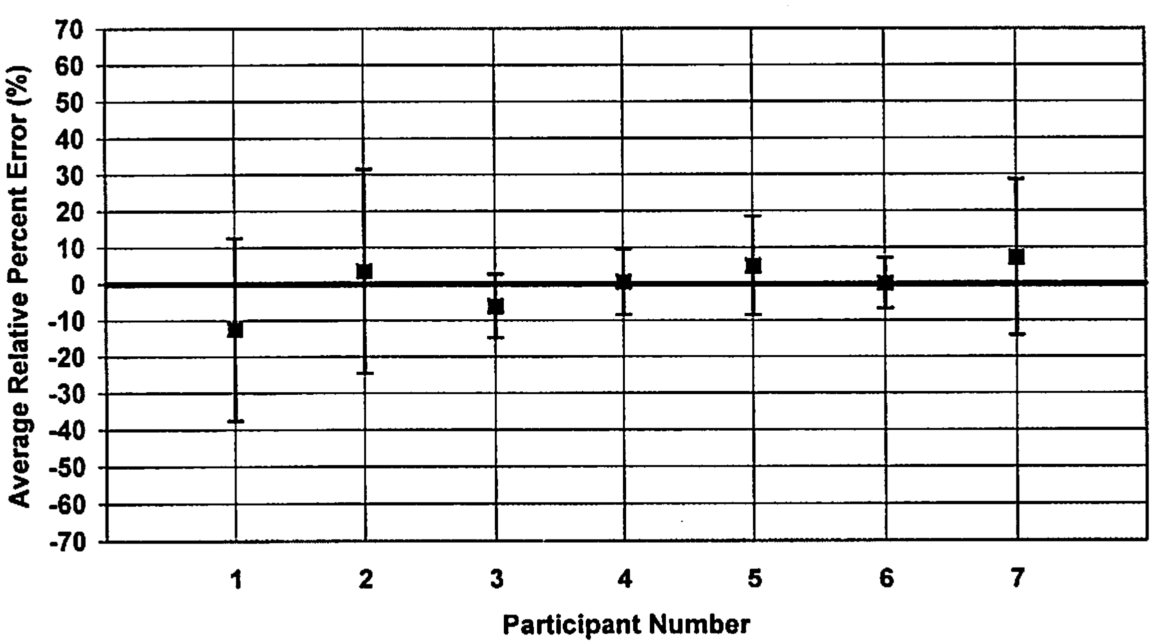

Figure 1-Relative Bias Control Chart for Results from Scintillation Cells

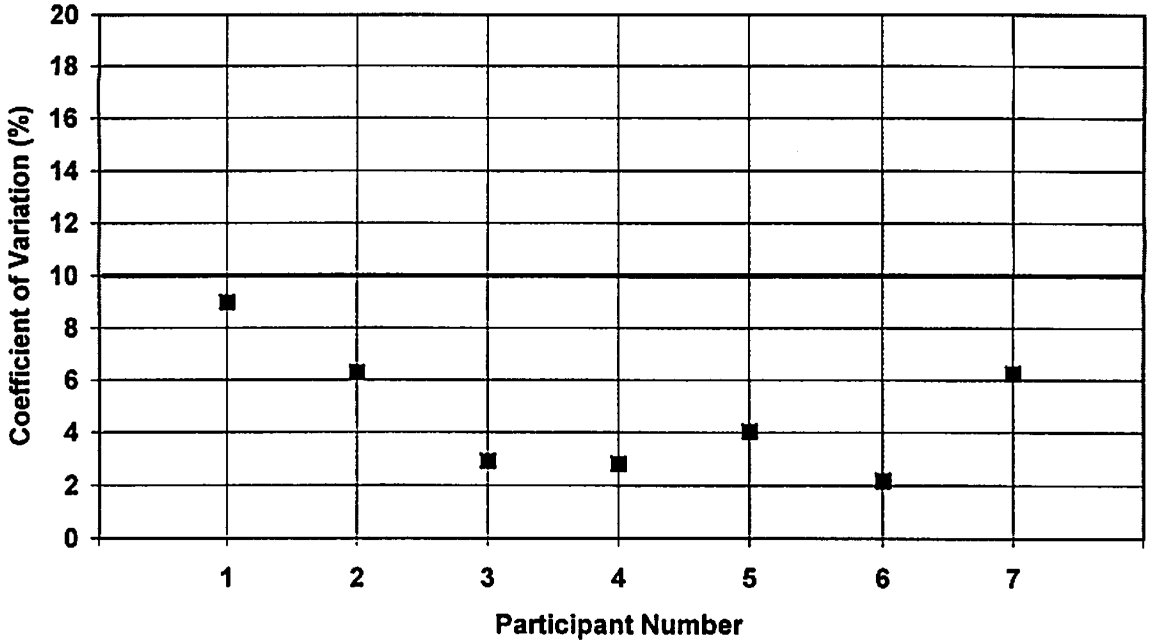

Figure 2-Precision Control Chart for Results from Scintillation Cells

Table 4-Types of Charcoal Devices

No. of Participants	Manufacturer, Model or Description, & Length of Exposure
1	Air Chek, Inc., Model Radon Test Kit, 4 days
1	Alpha Energy Laboratories, TRAY RD1, 2 days
1	F & J Specialty Products, Model R40VDB, 7 days
6	F & J Specialty Products, Model RA40V, 2 days
1	F & J Specialty Products, Model RA40V, 4 days
1	Key Technology, Inc., Model 002V, 3 days
1	Radon Environmental Monitoring, Inc., Model ST-100B, 2 days
1	Radon Testing Corporation of America, Liquid Scintillation, 4 days
1	Radon Testing Corporation of America, Model 3-PAS-DIF, 4 days
2	Radon Testing Corporation of America, Model 4-PAS-DIF, 4 days
1	TCS Industries, Model G, 3 days
1	TCS Industries, Model SG, 2 days

Table 5-Results from Charcoal Devices

Participant	Range	Avg. ± s	COV(%)	RV	ARPE (%) ± 95% C I
8	11.2 – 13.7	12.8 ± 1.1	8.9	12.9	-1.1 ± 24.5
9	11.2 – 11.9	11.7 ± 0.3	2.6	13.3	-11.9 ± 6.3
10	13.7 – 14.7	14.2 ± 0.4	2.9	13.0	9.1 ± 8.9
11	10.6 – 11.7	11.2 ± 0.4	4.0	13.1	-14.7 ± 9.4
12	13.1 – 14.1	13.7 ± 0.4	2.9	13.1	4.9 ± 8.6
13	12.8 – 14.7	13.9 ± 0.9	6.6	12.9	7.6 ± 19.6
14	13.8 – 14.4	14.1 ± 0.3	2.0	12.9	9.3 ± 6.1
15	13.2 – 13.8	13.5 ± 0.2	1.7	13.3	1.5 ± 4.7
16	13.0 – 13.3	13.1 ± 0.1	1.0	12.9	1.9 ± 2.9
17	13.3 – 13.5	13.4 ± 0.1	0.6	12.9	4.0 ± 1.8
18	12.9 – 14.0	13.5 ± 0.4	3.0	13.0	3.8 ± 8.5
19	14.5 – 16.4	15.4 ± 0.9	5.6	12.9	19.5 ± 18.5
20	12.6 – 13.1	12.8 ± 0.2	1.9	12.9	-0.8 ± 5.3
21	10.3 – 11.5	10.8 ± 0.4	4.0	12.9	-16.0 ± 9.3
22	11.7 – 12.7	12.2 ± 0.4	3.1	13.3	-8.3 ± 7.9
23	12.4 – 13.4	12.9 ± 0.4	3.1	13.3	-3.0 ± 8.3
24	13.0 – 13.2	13.1 ± 0.1	0.7	13.0	1.1 ± 1.9
25	13.2 – 14.0	13.6 ± 0.4	3.0	13.0	4.3 ± 8.8

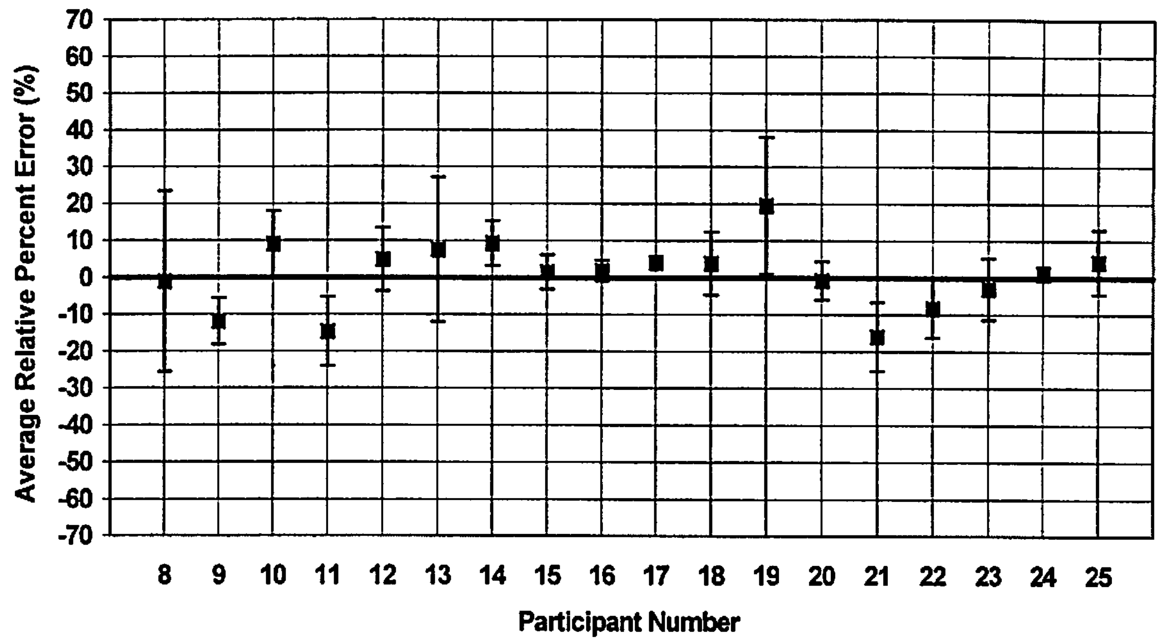

Figure 3 -Relative Bias Control Chart for Results from Charcoal Devices

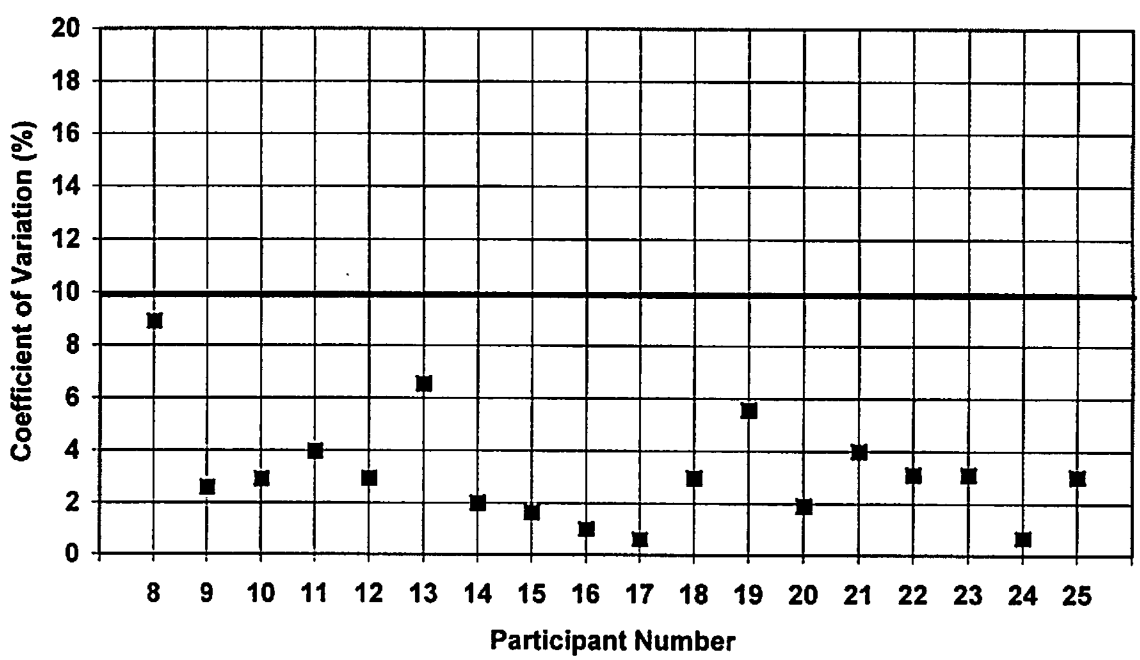

Figure 4 -Precision Control Chart for Results from Charcoal Devices

Table 6 -Types of Short-term Electret Ion Chamber Devices

No. of Participants	Manufacturer, Model or Description
7	Rad Elec, Inc., Model E-Perm, "S" Electrets, "S" Chambers

Table 7-Results from Short-term Electret Ion Chamber Devices

Participant	Range	Avg. ± s	COV(%)	RV	ARPE (%) ± 95% C I
26	11.8 – 13.5	12.6 ± 0.8	6.2	12.9	-2.2 ± 17.0
27	11.7 – 13.2	12.3 ± 0.6	4.6	12.9	-4.8 ± 12.1
28	11.8 – 14.8	13.0 ± 1.1	8.6	12.9	0.6 ± 24.1
29	11.6 – 18.0	13.3 ± 2.6	19.9	12.9	3.3 ± 56.9
30	12.9 – 13.8	13.2 ± 0.4	2.7	12.9	2.2 ± 7.7
31	10.5 – 12.5	11.7 ± 0.8	6.6	12.9	-9.3 ± 16.7
32	13.1 – 13.4	13.3 ± 0.1	1.0	12.9	2.9 ± 2.8

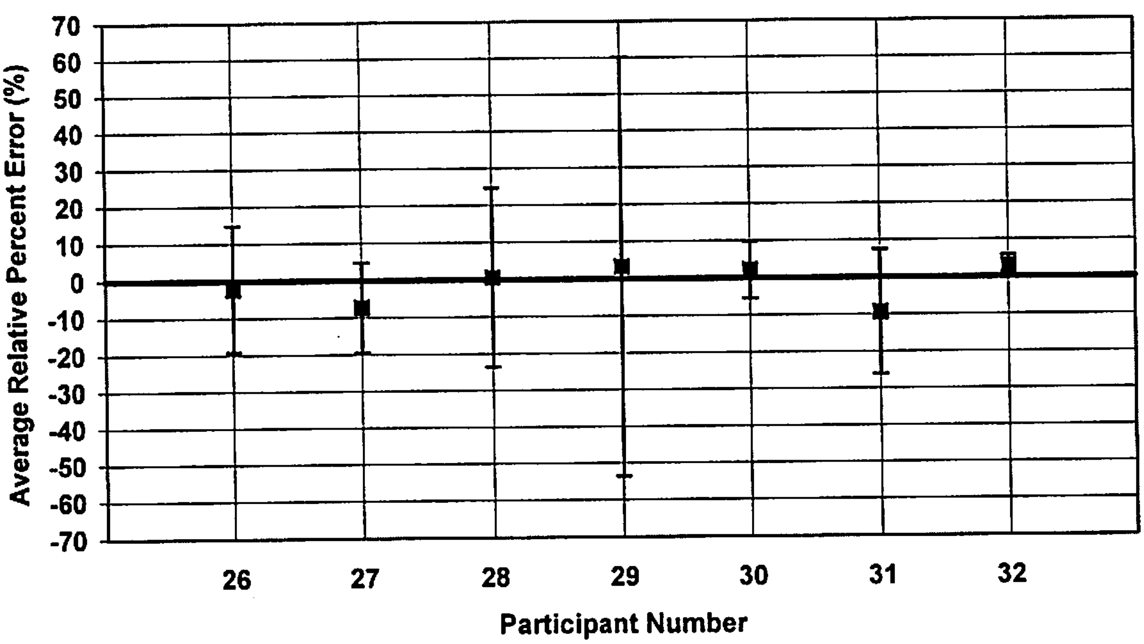

Figure 5-Relative Bias Control Chart for Results from Short-term Electret Ion Chamber Devices

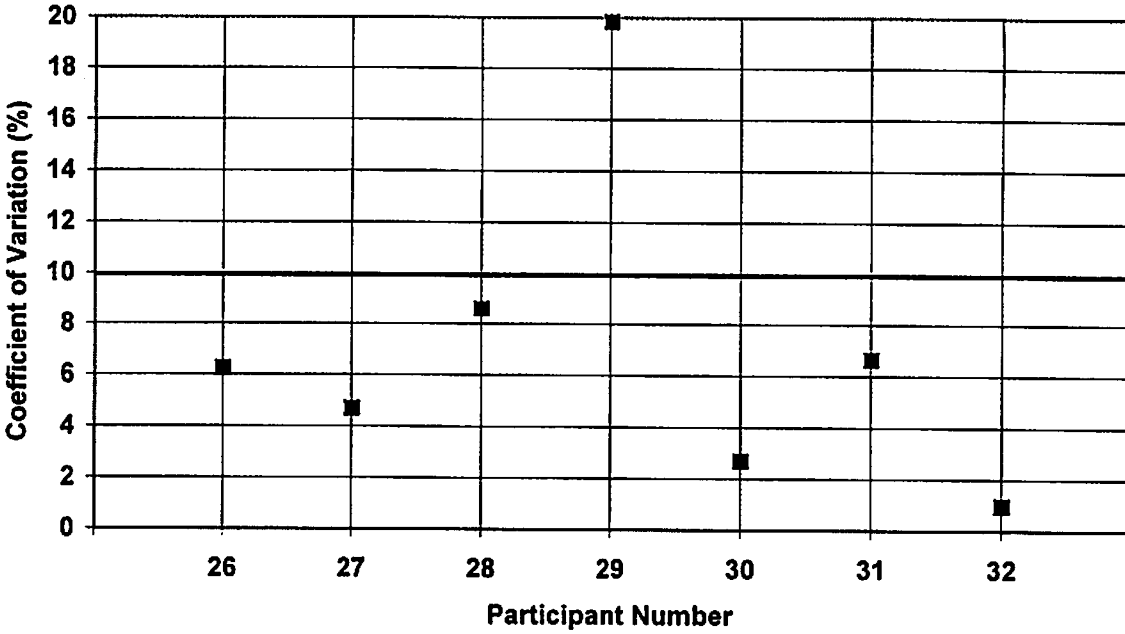

Figure 6 -Precision Control Chart for Results from Short-term Electret Ion Chamber Devices

Table 8-Types of Continuous Devices

No. of Participants	Manufacturer, Model or Description, & Length of Exposure
1	Family Safety Products, Model Safety Siren, 9 days
1	femto-TECH, Inc., Model CRM510F, 2 days
1	femto-TECH, Inc., Model R210F, 2 days
1	Genitron Instruments, Model Alpha Guard, 3 days
1	Honeywell, Model A9000, 2 days
1	Niton Corporation, Model RAD 7, 2 days
1	Radalink, Inc., Model 6000, 2 days
1	Sun Nuclear Corporation, Model 1027, 2 days

Table 9-Results from Continuous Devices

Participant	Measurement	RV	RPE (%)
33	13.2	12.9	2.3
34	12.8	13.1	-2.3
35	11.4	12.9	-11.6
36	12.6	13.5	-6.7
37	12.9	12.9	0.0
38	12.6	12.9	-2.3
39	13.0	12.9	0.8
40	11.0	13.2	-16.7

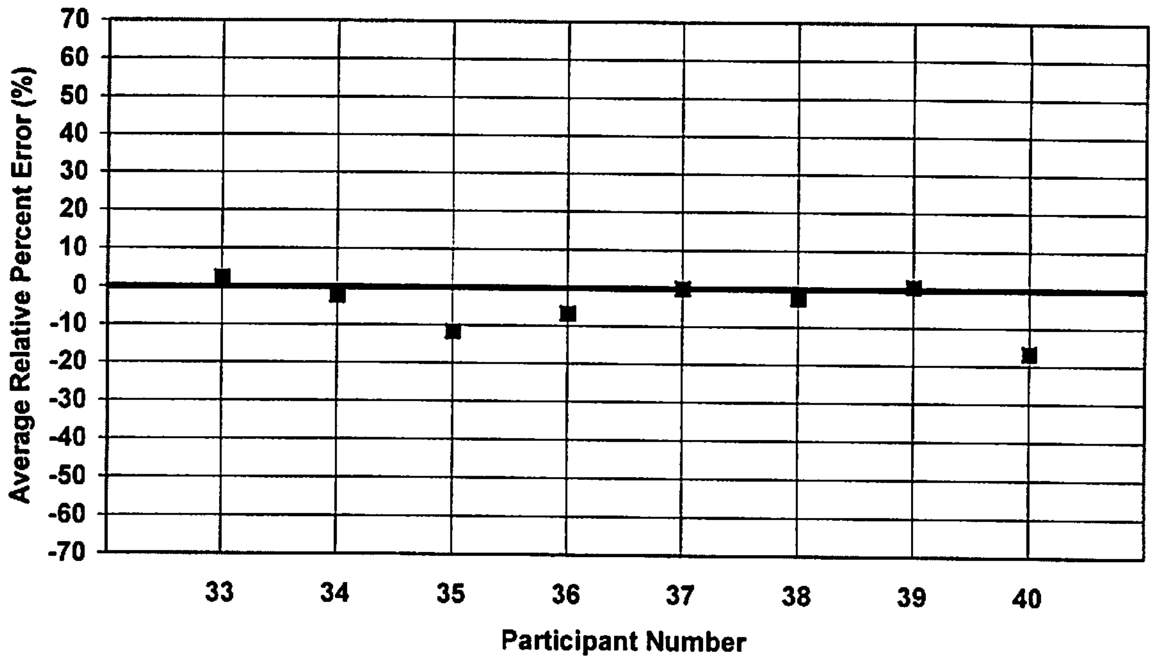

Figure 7-Relative Bias Control Chart for Results from Continuous Devices

Table 10-Types of Long-term Devices

No. of Participants	Manufacturer, Model or Description
1	Landauer, Inc., Model Radtrak
1	NYU School of Medicine, Alpha-Track Detector
3	Rad Elec, Inc., E-Perm, L Electrets, L Chambers
1	Radon Environmental Monitoring, Inc., Alpha-Track Detector

Table 11-Results from Long-term Devices

Participant	Range	Avg. ± s	COV(%)	RV	ARPE (%) ± 95% C I
41	22.0 – 23.4	22.7 ± 0.6	2.7	17.8	27.3 ± 9.6
42	15.1 – 15.9	15.5 ± 0.3	2.2	17.8	-13.0 ± 5.2
43	11.0 – 13.8	12.2 ± 1.1	9.3	17.8	-31.5 ± 17.7
44	17.2 – 22.2	19.7 ± 2.1	10.8	17.8	10.6 ± 33.1
45	15.2 – 16.0	15.6 ± 0.3	2.0	17.8	-12.6 ± 4.8
46	17.3 – 18.4	18.0 ± 0.5	2.5	17.8	1.1 ± 7.1

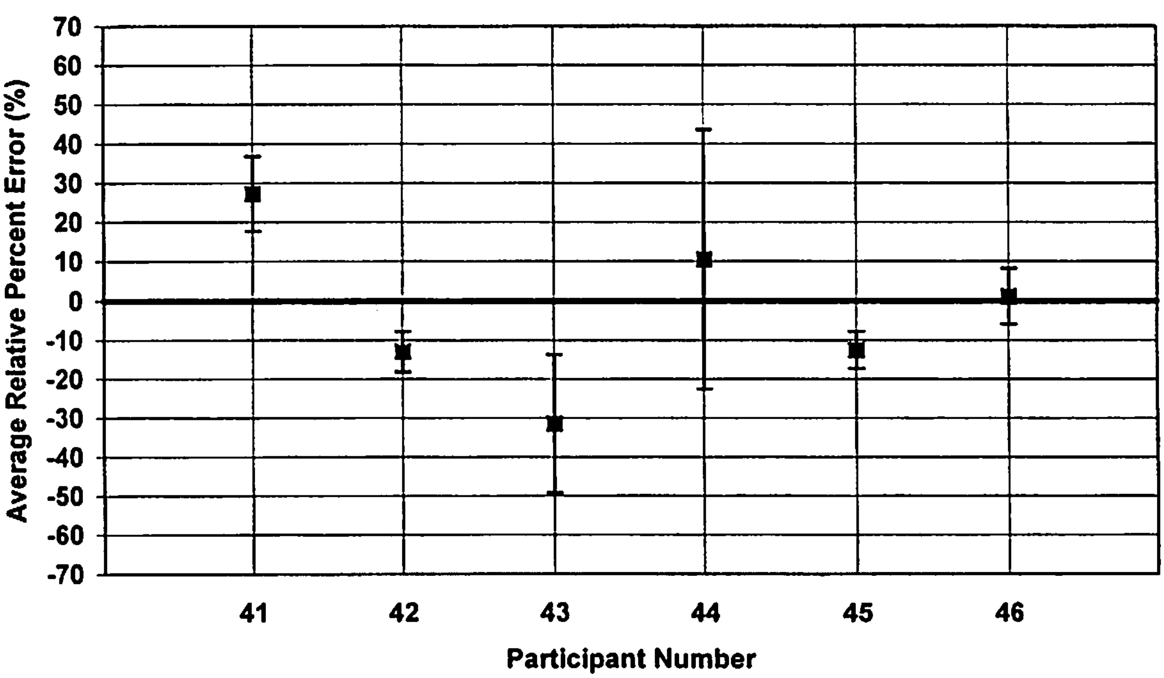

Figure 8-Relative Bias Control Chart for Results from Long-term Devices

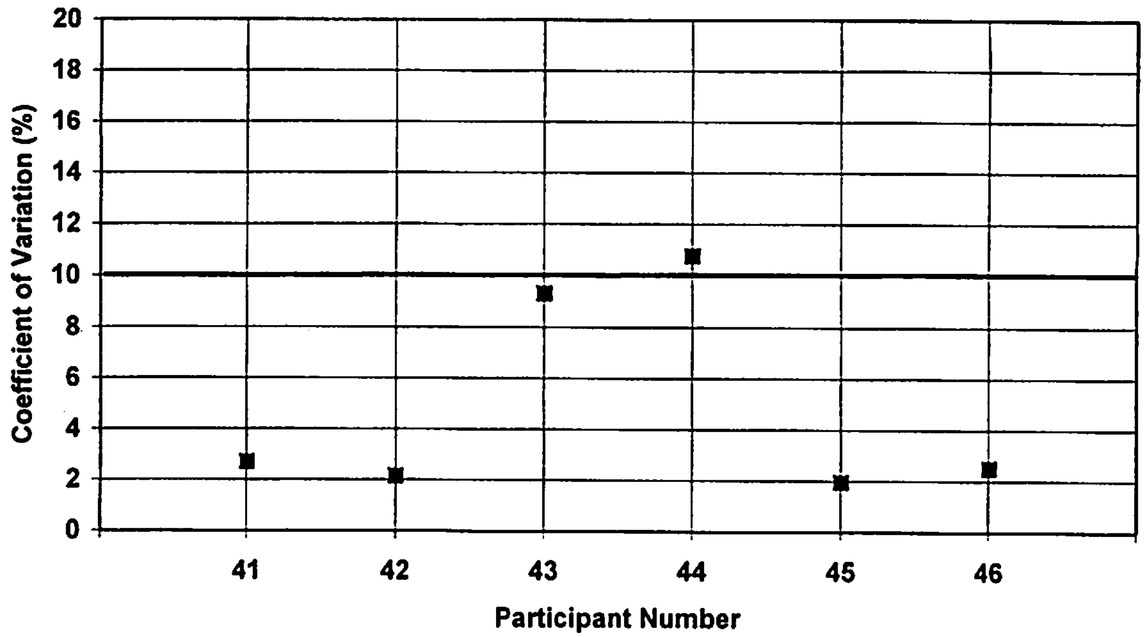

Figure 9-Precision Control Chart for Results from Long-term Devices

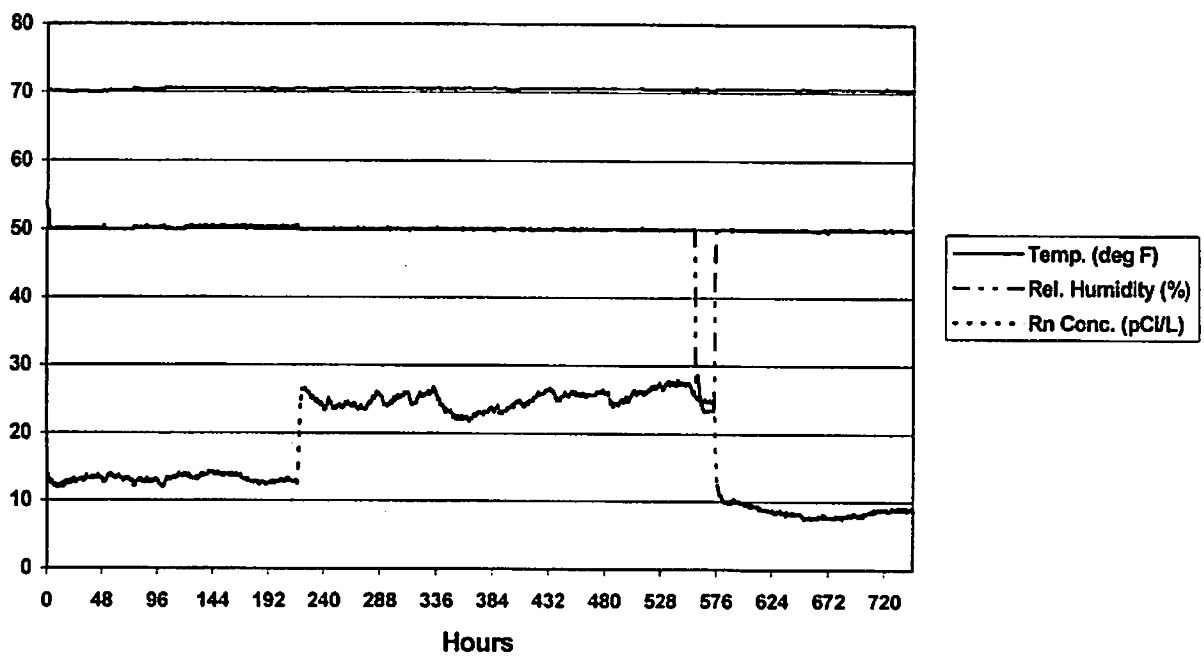

Figure 10-Conditions in Bowser-Morner Chamber During Intercomparion Exercise