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Radon Device Performance Check

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Notice

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TABLE OF CONTENTS

List of Tables iv
List of Figures iv
List of Abbreviations v
1. Policy Background and Research Question 1
2. Data Quality Objectives and Analysis Plan 2
2.1 The Precision Targets for the Study 3
2.2 Estimates of the Coefficient of Variation and Design Effect 4
2.3 Number of Tests Conducted and Sample Selected 4
3. Data Collection 5
3.1 EPA 5
3.2 Bowser-Morner, Inc 6
3.3 University of Colorado 8
3.4 Tests Conducted at Low Chamber Values 8
4. Results 9
4.1 Individual Relative Error 9
4.2 Average Relative Error 11
4.3 Passing Rates 13
5. Uncertainty 16
6. Alternative Analyses 17
7. Conclusions 19
Appendix 21
References 29

LIST OF TABLES

Table 1. Precision Targets: Size of the 95 Percent Confidence Intervals 3
Table 2. Inventory of Devices Tested and Sample Size Selected 6
Table 3. Number of Tests from BMI Included in the Sample 8
Table 4. Number of Tests from UCCS Included in the Sample 8
Table 5. Average Individual Relative Error of Tests Conducted by Private Laboratories, 2008–2013 (95 Percent Confidence Interval in Parentheses) 10
Table 6. Average Relative Error of Tests Conducted by Private Laboratories, 2008–2013 (95 Percent Confidence Interval in Parentheses) 12
Table 7. Passing Rate of Tests Conducted by EPA, 1991–1995 14
Table 8. Passing Rate of Tests Conducted by Private Laboratories, 2008–2013 and 95 Percent Confidence Interval 15
Table 9. Average Individual Relative Error, Average Relative Error, and Passing Rate of Tests Conducted by Private Laboratories, 2008–2013 (95 Percent Confidence Interval for Infinite Population in Parentheses) 17
Table 10. Regressions of Measured Radon Value Against Chamber Value 19
Table A1. Inventory of Tests and Sample Size, by Year, Device Type and Chamber Value Bowser-Morner, Inc 22
Table A2. Inventory of Tests and Sample Size, by Year, Device Type and Chamber Value University of Colorado, Colorado Springs 23
Table A3. Device Test Passing Rates and 95 Percent Confidence Intervals for Private Laboratories, Alpha Track 24
Table A4. Device Test Passing Rates and 95 Percent Confidence Intervals for Private Laboratories, Activated Charcoal 25
Table A5. Device Test Passing Rates and 95 Percent Confidence Intervals for Private Laboratories, Liquid Scintillation 26
Table A6. Device Test Passing Rates and 95 Percent Confidence Intervals for Private Laboratories, Short-Term Electret Ion 27

LIST OF FIGURES

Figure 1. Distribution of IRE by device type 11
Figure 2. Distribution of relative error (bias) by device type 13
Figure 3. Scatter plots of measured and chamber values 18

LIST OF ABBREVIATIONS

AARST-NRPP	American Association of Radon Scientists and Technologists–National Radon Proficiency Program
ARE	Average Relative Error
BMI	Bowser-Morner, Inc.
CV	Coefficient of Variation
DEFF	Design Effect
EPA	Environmental Protection Agency
IRE	Individual Relative Error
NRSB	National Radon Safety Board
pCi/L	picocuries per liter
RMP	Radon Measurement Proficiency
UCCS	University of Colorado, Colorado Springs

1. POLICY BACKGROUND AND RESEARCH QUESTION

The U.S. Environmental Protection Agency (EPA) established the Radon Measurement Proficiency (RMP) Program in February 1986 to help consumers identify organizations capable of providing reliable radon measurement analysis services (EPA 1986). The program was designed to improve the quality and reliability of radon measurement systems. EPA provided a list of program participants as a resource for the public to find analytical laboratories with demonstrated radon and/or radon progeny measurement capabilities. In 1998, EPA began transitioning the program for privatization. Since that transition, EPA has no longer collected or evaluated proficiency data. Two independent, private organizations now provide radon proficiency testing: the National Radon Safety Board (NRSB) and the American Association of Radon Scientists and Technologists–National Radon Proficiency Program (AARST-NRPP). State programs that require the use of state-certified devices use these two proficiency programs to validate their devices. This study reviews recent RMP data to determine the current proficiency of radon test devices that are available to the public, and it provides a response to the Office of the Inspector General's report regarding oversight of radon testing device accuracy and reliability (EPA 2009).

Performance tests are conducted on radon measurement devices periodically to ensure that manufacturers are designing and producing devices that take accurate measurements and that technicians can read the results accurately. Device batches are put into a chamber that has a known concentration of radon. The concentrations are varied between test batches, much like the questions and answers on a standardized test are changed frequently to avoid cheating. Once the devices have been in the chamber long enough to produce a reading, they are removed, and the measured value of the devices noted. The performance testing laboratories then send the devices back to the manufacturers so that their technicians can read and report the measured values. The value the technicians report is known as the "measured value" and the value the performance testing laboratories set the chambers at is called the "chamber value" or the "target value."

Prior to the transition, EPA provided regular reports of the proficiency of radon measurement devices. In the first six rounds of EPA's testing, proficiency was calculated by averaging the results of two to four radon devices in a lot and determining if the average was within ± 25 percent of the test chamber value. EPA changed the method of calculation for proficiency in 1991 and required that all devices—not just the average of the devices in each lot—submitted by a laboratory meet the criterion of ± 25 percent of the chamber value. The results were recorded monthly in public reports.

To evaluate test device performance, we used EPA's monthly proficiency data from 1991 through 1995, including the number of tests conducted, the number of devices that passed the initial test, the number of devices that did not pass the initial test and were retested and the number of devices that passed the second test. The study includes data for the following test devices that are generally available to the public:

- Alpha track
- Activated charcoal

- Liquid scintillation
- Short-term electret ion

We used this information for each device type and for each year to calculate the proficiency in terms of the percentage of devices submitted for proficiency testing that had measured results within ± 25 percent of the chamber value.

We also collected data from the two private laboratories that conduct national proficiency tests. Bowser-Morner, Inc. (BMI), provided data for tests conducted from 2008 through 2012. The University of Colorado, Colorado Springs (UCCS) provided data for 2011 through 2013. For each of the four device types, the laboratories provided the individual test results, including the device type, the test chamber target value and the reported results.

The performance assessment will use two measures of device accuracy for the private laboratories. The first measure is the average of the individual relative error (IRE) of each test:

$$IRE = \frac{|Measured - Target|}{Target} \quad (1)$$

"Measured" is the radon level measured by the laboratory after the devices have been exposed to a certain concentration in the laboratory's chamber. "Target" is the concentration to which the test chamber was set during the exposure. The second measure is the passing rate, which is the proportion of proficiency tests with an IRE of less than 0.25.

In addition to these two measures of device accuracy, the performance check also will measure the bias of the devices by looking at the average relative error (ARE):

$$ARE = \frac{\sum_{i=1}^{n} \frac{Measured - Target}{Target}}{n} \quad (2)$$

The variable "*n*" is the number of devices tested. The average IRE uses the absolute value of the relative error; the ARE, however, can be positive, negative, or zero. If the ARE is positive, it indicates that the devices tend to report higher radon levels than actually occur. If it is negative, it indicates that the devices tend to underreport radon levels. If the ARE is zero, it indicates that the device is not biased. The ARE is a measure of bias, not of accuracy. The IRE measures device accuracy. As such, the ARE is a supplement to the IRE, not an alternative.

2. DATA QUALITY OBJECTIVES AND ANALYSIS PLAN

We planned on collecting data on all of the tests conducted by the EPA laboratory prior to 1999 and a sample of tests conducted by the private laboratories from 1999 through 2013. Because very few tests were conducted by the private laboratories at chamber values of less than 8 picocuries per liter (pCi/L), we planned on collecting all of the results of these tests. The private laboratories conducted hundreds of performance tests at higher chamber values; rather than review every test, we planned on selecting a probability sample of tests conducted at chamber values greater than 8 pCi/L. We divided the sample of the private laboratories' tests

between the two laboratories in proportion to the number of tests conducted by each. The proportions were based on prior estimates of the number of tests conducted by each laboratory.

The laboratories test devices in batches of five devices at a time. We used a two-staged stratified random sample design. In the first stage of the sample, we selected a stratified random sample of batches of test results. We stratified by device type, a range of chamber values, and the year of the test. In the second stage of the sample, we selected each device in the batch. This produced a clustered sample in which each device test result is not independent.

2.1 The Precision Targets for the Study

The precision targets for each chamber value range, device type, and year are shown in Table 1. We divided the tests into two periods, 1991–1998 and 1999–2012, and sampled with certainty from the first period. The sample of private laboratory results of tests was designed to estimate the mean IRE (a) without sampling error for tests conducted at chamber values less than 8 pCi/L and (b) with a margin of error of ± 20 percent—with 95 percent confidence—of the IRE for tests greater than 8 pCi/L for each device type, chamber value, and year. The precision target for the passing rate is ± 10 percentage points for devices tested by the private laboratories in chamber values greater than 8 pCi/L. For example, if 50 percent of the devices in the sample pass the test, we would be 95 percent confident that 40 percent to 60 percent of all the devices tested passed. The margins of error for the 1991–1998 tests and all of the tests with chamber values of less than 8 pCi/L are zero because we selected all of these tests. As explained in the next section, we expected that the sample designed to meet the mean IRE precision targets also would meet or exceed the precision targets for the estimated passing rate.

Table 1. Precision Targets: Size of the 95 Percent Confidence Intervals

Chamber Value	Device Type	Annual Precision Target for the Mean IRE (Percentage of the Mean IRE)		Annual Precision Target for the Passing Rate (Percentage Points)	
		1991–1998	1999–2012	1991–1998	1999–2012
< 8 pCi/L	Alpha Track	±0.0	±0.0	±0.0	±0.0
	Activated Charcoal	±0.0	±0.0	±0.0	±0.0
	Liquid Scintillation	±0.0	±0.0	±0.0	±0.0
	Short-Term Electret Ion	±0.0	±0.0	±0.0	±0.0
8–16 pCi/L	Alpha Track	±0.0	±20.0	±0.0	±10.0
	Activated Charcoal	±0.0	±20.0	±0.0	±10.0
	Liquid Scintillation	±0.0	±20.0	±0.0	±10.0
	Short-Term Electret Ion	±0.0	±20.0	±0.0	±10.0
> 16 pCi/L	Alpha Track	±0.0	±20.0	±0.0	±10.0
	Activated Charcoal	±0.0	±20.0	±0.0	±10.0
	Liquid Scintillation	±0.0	±20.0	±0.0	±10.0
	Short-Term Electret Ion	±0.0	±20.0	±0.0	±10.0

2.2 Estimates of the Coefficient of Variation and Design Effect

The sample size necessary for a given precision target increases as the range of possible test results increases. To estimate the sample sizes required, we estimated the variance of the test results using data from a small pilot study conducted by EPA. In fact, we needed two estimates of the variability of the test results.

1. To estimate the mean IRE with a margin of error of ± 20 percent, we needed the coefficient of variation (CV) of the IRE, which is the standard deviation divided by the mean.

2. To estimate the percentage of devices that pass the test, we needed to estimate the standard deviation of the proportion.

We used the preliminary pilot data to estimate the CV of the IRE. Although these data are only preliminary, they are the best information available about the variation in test results. The CV for these data, excluding some extreme values, is 0.85. We had suspected that the CV might decline as the chamber value increased, but this was not the case in the pilot data; therefore, we used a single, overall CV to estimate the sample size.

We also used the pilot data to estimate the design effect (DEFF) of clustering the data by batch. The DEFF is 1.45 in the pilot data. In other words, the clustering of the tests increases the variance by about 45 percent when compared to a simple random sample of the same size. To account for this design effect, we increased the required sample size accordingly.

Whether a device passes the test is a binomial outcome: The device either passes or fails. To estimate the confidence interval of the percentage of devices that pass the test, we used the normal approximation of the binomial distribution. The standard deviation of a proportion is $(P(1-P)/(n))^{0.5}$. To calculate the sample size required, we assumed that the standard deviation is 0.50, which is its largest possible value. This produces a conservative estimate of the required sample size.

The estimates of the CV of the IRE from the pilot study imply that the sample size required to estimate the mean IRE with a margin of error of ± 20 percent will be larger than the sample required to estimate the proportion of devices that pass with a margin of error of ± 10 percentage points. To ensure that the study meets both objectives, we designed the sample to meet the precision target for the mean IRE, as this sample would also meet the precision target for the percentage of devices that pass the test with a margin of error of ± 10 percentage points.

2.3 Number of Tests Conducted and Sample Selected

In the original study design, we had planned to collect all of the test result data from the EPA laboratory for the tests conducted from 1991 through 1998. EPA also conducted tests in 1989 and 1990. We excluded those early years because the methods used by the laboratories may have been in flux as the laboratories identified and eliminated potential problems. We had also

planned on collecting a sample of tests conducted by the two private laboratories from 1999 through 2012. During data collection, we discovered that not all these data were available.

- EPA conducted tests from 1991 through 1995, but we did not find any test results beyond 1995.

- EPA retained summary reports on the number of tests conducted and the number that met the performance criterion, not individual test results, at least not that we discovered. These data can be used to determine the passing rate, but cannot be used to calculate the IRE or ARE.

- BMI has records of the individual performance tests it conducted from 2001 through 2012. Data for tests conducted by BMI before 2001 were not available. Furthermore, only the tests conducted after 2007 were accessible. Therefore, we collected data for a sample of tests conducted during the years 2008–2012.

- Although UCCS conducted tests before 2011, only data from 2011–2013 were available. Because UCCS did not conduct many tests, we used all of that data.

We assembled the sample using the following steps:

1. Select all performance test results conducted from 1991 through 1995.

2. Select all performance tests conducted by BMI from 2008 through 2012 at chamber values of less than 8 pCi/L.

3. Select random samples from the remaining tests conducted by BMI from 2008 through 2012. Stratify each year's tests by the chamber value of the test (either 8–16 pCi/L or greater than 16 pCi/L), and by device type.

4. Select all of the tests conducted by UCCS in the years 2011–2013.

After we selected the sample of BMI test results, We found that data for tests conducted prior to 2011 by UCCS were not available. Therefore, we could not increase the sample of tests conducted by BMI. The inventory of tests conducted by EPA and the private laboratories, as well as the size of the sample selected, is shown in Table 2. The private laboratories' inventory and sample for each year are shown in the appendix.

3. DATA COLLECTION

3.1 EPA

EPA had 11 boxes of radon performance test project archives. Data collectors reviewed each file in each box and identified files related to the RMP program. The data collectors found the monthly cumulative reports from January 1991 through September 1995 (with June 1995 and

Table 2. Inventory of Devices Tested and Sample Size Selected

Device Type	Chamber Value	EPA		BMI		UCCS	
		Inventory	Sample	Inventory	Sample	Inventory	Sample
Alpha Track	< 8 pCi/L	N/A	N/A	0	0	0	0
	8–16 pCi/L	N/A	N/A	0	0	0	0
	> 16 pCi/L	N/A	N/A	135	130	5	5
	All	55	55	135	130	5	5
Activated Charcoal	< 8 pCi/L	N/A	N/A	30	30	5	5
	8–16 pCi/L	N/A	N/A	150	100	10	10
	> 16 pCi/L	N/A	N/A	380	215	35	35
	All	375	375	560	345	50	50
Liquid Scintillation	< 8 pCi/L	N/A	N/A	0	0	0	0
	8–16 pCi/L	N/A	N/A	80	70	0	0
	> 16 pCi/L	N/A	N/A	205	165	0	0
	All	74	74	285	235	0	0
Short-Term Electret Ion	< 8 pCi/L	N/A	N/A	30	30	30	30
	8–16 pCi/L	N/A	N/A	280	155	105	105
	> 16 pCi/L	N/A	N/A	1,090	330	140	140
	All	585	585	1,400	515	275	275

N/A = Not available. EPA reports did not show results by chamber value.

August 1995 missing). The reports provide the number of devices tested, the number of devices that passed, and the number of tests canceled. If the IRE for a device was between 0.25 and 0.50, it was retested. The reports provide the number of devices retested and the number of devices that passed the retest, as well as the number of retests that were canceled. The results for the four device types in the study (alpha track, activated charcoal, liquid scintillation, or short-term electret ion) were double-key entered into an electronic dataset. (All discrepancies were noted and reviewed, then corrected by the original entrant.)

The EPA files included duplicate reports for 2 months, November 1993 and June 1994, with different counts of devices tested and passed. We calculated the passing rate using both sets of reports, and the differences are small. To calculate the passing rates, we randomly dropped one of each set of duplicated reports.

3.2 Bowser-Morner, Inc.

At BMI, the data for the years 2008–2009 were filed alphabetically by company name in filing cabinets. Most of the data for the years 2010–2012 were not filed, but were arranged in stacks around the laboratory, sorted approximately by year and month. Some 2010 and 2011 data were in the filing cabinets. Files from tests conducted before 2008 were stored in boxes in a separate room, along with hundreds of other test results. Beginning with the tests conducted in 2007, BMI

began color-coding the files according to the tests conducted; all performance tests were filed in blue folders or manila folders with blue labels. Some performance data from 2007 appeared in plain manila folders, indicating that the color-coding system was not fully implemented until 2008.

The data collectors inventoried the data from 2010 through 2012, by year and month, and put the files into storage boxes. They also inventoried the data from the years 2008–2009, which were already in file cabinets.

Two data collectors inventoried the data. The first person looked at each performance test (each test with a blue folder or a blue label) and determined if it involved one of the four device types of interest. If it did, that person announced the year, the device type (alpha track, activated charcoal, liquid scintillation, or short-term electret ion), and chamber value range (less than 8 pCi/L, 8–16 pCi/L, or greater than 16 pCi/L) to the second person, who prepared an adhesive label with those three pieces of information and placed it on the results page within the file. Any test that appeared to be missing key information was examined by the second person and if either the test type or test results could not be identified by either person, that test was not counted as part of the inventory. Files labeled as retests were inventoried separately; there were fewer than five of these.

The data collectors entered the counts of tests into a sampling tool spreadsheet, which later was used to calculate the number of tests that were to be sampled and to identify which tests to select. To enter the counts into the sampling tool spreadsheet, the first person tallied or read the labels aloud, and the second person keyed the count into the sampling tool spreadsheet.

The data collectors then selected the sample of tests identified by the sampling tool spreadsheet. For each test, the data collectors entered the chamber value, device type, test results and the date of the test into an electronic database using double-key entry. After each box of data or each filing cabinet drawer had been entered by both people, the second person compared the number of applicable performance tests in that section against the number of data entries made by each person. Where discrepancies in the number of entries were found, the box or drawer was reexamined to ensure no data were missing from the spreadsheet. At random intervals, the chamber values and test results were spot-checked, and where discrepancies were found, the data were examined and reentered. As a final check, the total number of tests under each device type was tallied, and both data sheets were found to contain the same counts of tests. The number of tests included in the study is shown in Table 3. Each test included five devices. In total, the study includes test results for 1,224 devices. (One result for a short-term electret ion device tested at 8–16 pCi/L was invalid.)

Table 3. Number of Tests from BMI Included in the Sample

Device Type	Chamber Value			
	< 8 pCi/L	8–16 pCi/L	> 16 pCi/L	All
Alpha Track	0	0	26	26
Activated Charcoal	6	20	43	69
Liquid Scintillation	0	14	33	47
Short-Term Electret Ion	6	31	66	103
Total	12	65	168	245

A subsequent comparison in Microsoft Excel identified 32 cells that contained discrepant information out of a total of 2,450 cells that were entered on each spreadsheet. These discrepancies arose mostly on the test results, in particular, the fifth test value. Eleven out of 32 errors appeared on the fifth value. Each discrepancy was examined and resolved.

In only one instance was there an entire row of discrepant results. Most likely, the folder contained two sets of distinct data (as some folders did) and one of the two entries was from the wrong results sheet in that folder. Only one of the records was used in the analysis.

3.3 University of Colorado

UCCS scanned the results of the device performance tests they conducted and provided the images to EPA. All of the data were entered into an electronic database using double-key entry. If any discrepancies were found, we reviewed the original scan and determined the correct value. The number of tests provided by UCCS is shown in Table 4. Each test includes five devices. Test results of two devices were blank; both were activated charcoal devices tested at chamber values of 8–16 pCi/L. The total number of devices with test results in the 66 tests is 328.

Table 4. Number of Tests from UCCS Included in the Sample

Device Type	Chamber Value			
	< 8 pCi/L	8–16 pCi/L	> 16 pCi/L	All
Alpha Track	0	0	1	1
Activated Charcoal	1	2	7	10
Liquid Scintillation	0	0	0	0
Short Term Electret Ion	6	21	28	55
Total	7	23	36	66

3.4 Tests Conducted at Low Chamber Values

Both BMI and UCCS conducted a limited number of tests at low chamber values. Tests conducted at low levels require a high level of effort to ensure minimal accuracy; therefore, the laboratories conduct very few tests at these low levels. BMI conducted one test (of a batch of five devices) of an activated charcoal device at chamber values of less than 3 pCi/L during the 2008–2013 period. UCCS conducted four tests at chamber values less than 3 pCi/l in the years 2012–2013: one of an activated charcoal device and three of short-term electret ion devices.

4. RESULTS

The sample of test results from the private laboratories was used to calculate the IRE, ARE and passing rate for each device type for tests conducted from 2008 through 2013. The summary data from EPA were used to calculate passing rates for the devices tested by EPA in the years 1991–1995. The average IRE, ARE and passing rate were calculated, along with 95 percent confidence intervals. The confidence intervals reflect the potential error introduced through sampling. When we used a census of devices, the interval width is zero. The confidence intervals do not incorporate other possible sources of error, such as measurement error. Other sources of uncertainty are discussed in Section 5.

4.1 Individual Relative Error

A summary of the IRE of the tests conducted by the private laboratories from 2008 through 2013 is shown in Table 5. The errors are quite small; the average IRE of each device is less than 0.15 in all years. The average IRE for activated charcoal and short-term ion electret is higher at chamber values less than 8 pCi/L than it is at higher chamber values. Table 5 also includes 95 percent confidence intervals; the intervals are design-based—that is, they reflect the stratification and clustering of the sample.

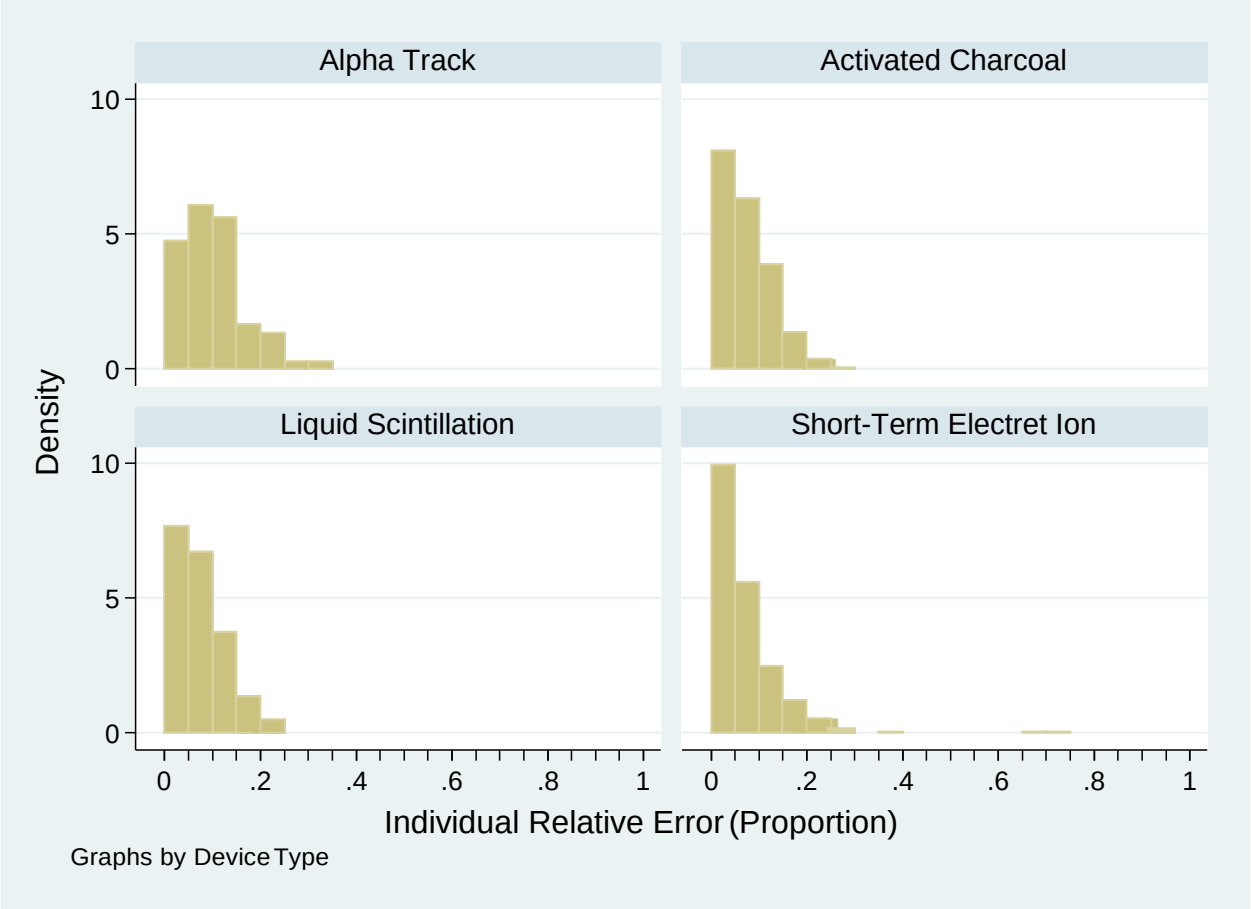
Table 5. Average Individual Relative Error of Tests Conducted by Private Laboratories, 2008–2013 (95 Percent Confidence Interval in Parentheses)

Device Type	Chamber Value	2008	2009	2010	2011	2012	2013	All
Alpha Track	< 8 pCi/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	8–16 pCi/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	> 16 pCi/L	0.123 (±0.013)	0.118 (±0.000)	0.054 (±0.000)	0.083 (±0.000)	0.119 (±0.000)	N/A	0.101 (±0.002)
	All	0.123 (±0.013)	0.118 (±0.000)	0.054 (±0.000)	0.083 (±0.000)	0.119 (±0.000)	N/A	0.101 (±0.002)
Activated Charcoal	< 8 pCi/L	0.087 (±0.000)	0.102 (±0.000)	N/A	0.093 (±0.000)	0.068 (±0.000)	N/A	0.092 (±0.000)
	8–16 pCi/L	0.037 (±0.000)	0.054 (±0.027)	0.072 (±0.031)	0.060 (±0.015)	0.059 (±0.011)	N/A	0.061 (±0.011)
	> 16 pCi/L	0.088 (±0.018)	0.098 (±0.011)	0.076 (±0.025)	0.051 (±0.015)	0.054 (±0.01)	0.06 (±0.000)	0.071 (±0.007)
	All	0.083 (±0.015)	0.086 (±0.01)	0.075 (±0.019)	0.055 (±0.011)	0.056 (±0.008)	0.06 (±0.000)	0.069 (±0.006)
Liquid Scintillation	< 8 pCi/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	8–16 pCi/L	0.147 (±0.000)	0.039 (±0.000)	0.027 (±0.006)	0.064 (±0.000)	0.078 (±0.000)	N/A	0.069 (±0.001)
	> 16 pCi/L	0.099 (±0.000)	0.076 (±0.013)	0.059 (±0.000)	0.074 (±0.000)	0.051 (±0.005)	N/A	0.071 (±0.004)
	All	0.115 (±0.000)	0.073 (±0.012)	0.048 (±0.002)	0.072 (±0.000)	0.066 (±0.002)	N/A	0.071 (±0.003)
Short-Term Electret Ion	< 8 pCi/L	0.13 (±0.000)	0.118 (±0.000)	N/A	0.125 (±0.000)	0.062 (±0.000)	N/A	0.109 (±0.000)
	8–16 pCi/L	0.077 (±0.000)	0.048 (±0.000)	0.086 (±0.021)	0.077 (±0.006)	0.062 (±0.01)	0.047 (±0.000)	0.069 (±0.005)
	> 16 pCi/L	0.053 (±0.011)	0.041 (±0.012)	0.036 (±0.007)	0.059 (±0.012)	0.057 (±0.007)	0.080 (±0.000)	0.051 (±0.005)
	All	0.057 (±0.01)	0.044 (±0.011)	0.049 (±0.007)	0.068 (±0.009)	0.059 (±0.006)	0.069 (±0.000)	0.057 (±0.004)

Note: Interval widths are zero when all devices were sampled.
N/A = No tests available.

Figure 1 contains histograms of IRE values, by type of device. The distributions are skewed to the left, and very few devices had IREs greater than 0.15. Two devices, both short-term electret ion devices tested at chamber values greater than 16 pCi/L, had IREs greater than 0.6. Three devices had IREs between 0.3 and 0.6, and another 10 devices had IREs between 0.25 and 0.3. Overall, the histograms are indications of the accuracy of the devices.

Figure 1**. Distribution of IRE by device type.**



4.2 Average Relative Error

The average relative error is a measure of the bias of a device. A positive ARE, for example, indicates that the device tends to overstate the true radon concentration. The ARE tends to be close to zero—across all years, device types and chamber values, ARE values range from −0.087 (activated charcoal, chamber value of less than 8 pCi/L) to 0.147 (liquid scintillation, chamber value of 8–16 pCi/L). The results are shown in Table 6 ,with design-based confidence intervals.

Table 6. Average Relative Error of Tests Conducted by Private Laboratories, 2008–2013 (95 Percent Confidence Interval in Parentheses)

Device Type	Chamber Value	2008	2009	2010	2011	2012	2013	All
Alpha Track	< 8 pCi/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	8–16 pCi/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	> 16 pCi/L	−0.037 (±0.081)	−0.026 (±0.000)	−0.048 (±0.000)	−0.070 (±0.000)	−0.078 (±0.000)	N/A	−0.055 (±0.012)
	All	−0.037 (±0.081)	−0.026 (±0.000)	−0.048 (±0.000)	−0.070 (±0.000)	−0.078 (±0.000)	N/A	−0.055 (±0.012)
Activated Charcoal	< 8 pCi/L	−0.087 (±0.000)	−0.043 (±0.000)	N/A	−0.061 (±0.000)	0.068 (±0.000)	N/A	−0.042 (±0.000)
	8–16 pCi/L	0.026 (±0.000)	0.008 (±0.06)	−0.062 (±0.039)	0.052 (±0.015)	−0.016 (±0.017)	N/A	−0.009 (±0.017)
	> 16 pCi/L	−0.012 (±0.051)	−0.025 (±0.028)	−0.040 (±0.036)	−0.045 (±0.017)	−0.007 (±0.021)	−0.045 (±0.000)	−0.026 (±0.014)
	All	−0.016 (±0.041)	−0.018 (±0.023)	−0.048 (±0.027)	−0.022 (±0.013)	−0.007 (±0.015)	−0.045 (±0.000)	−0.023 (±0.011)
Liquid Scintillation	< 8 pCi/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	8–16 pCi/L	0.147 (±0.000)	0.037 (±0.000)	−0.026 (±0.008)	0.004 (±0.000)	0.024 (±0.000)	N/A	0.024 (±0.002)
	> 16 pCi/L	0.037 (±0.000)	0.039 (±0.037)	0.015 (±0.000)	0.043 (±0.000)	0.017 (±0.038)	N/A	0.032 (±0.013)
	All	0.074 (±0.000)	0.039 (±0.035)	0.001 (±0.003)	0.035 (±0.000)	0.020 (±0.017)	N/A	0.030 (±0.009)
Short-Term Electret Ion	< 8 pCi/L	0.117 (±0.000)	0.088 (±0.000)	N/A	−0.024 (±0.000)	0.047 (±0.000)	N/A	0.024 (±0.000)
	8–16 pCi/L	0.041 (±0.000)	−0.007 (±0.000)	0.051 (±0.023)	−0.037 (±0.017)	0.024 (±0.028)	0.003 (±0.000)	0.012 (±0.011)
	> 16 pCi/L	0.012 (±0.022)	0.001 (±0.019)	−0.017 (±0.011)	−0.018 (±0.019)	0.015 (±0.017)	0.014 (±0.000)	−0.002 (±0.008)
	All	0.017 (±0.019)	0.003 (±0.017)	0.000 (±0.01)	−0.023 (±0.014)	0.020 (±0.014)	0.010 (±0.000)	0.002 (±0.006)

Note: Interval widths are zero when all devices were sampled.
N/A = No tests available.

Figure 2 contains the histograms of the relative errors by device type. The histograms show the distribution of the relative error of each device. The average of these values is the ARE. The relative errors are relatively tightly distributed around zero. The exceptions are the two short-term electret ion devices with IREs greater than 0.6.

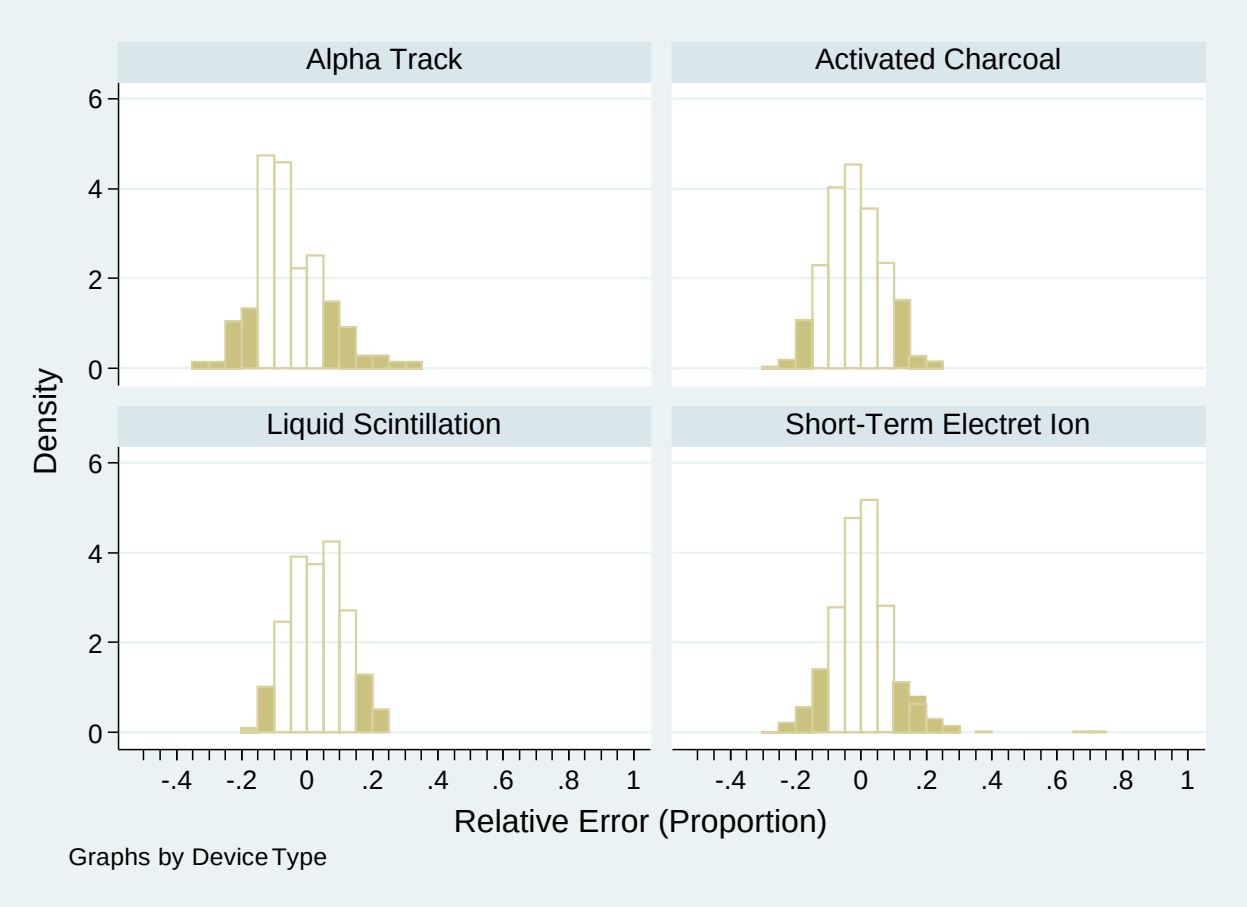


Figure 2. Distribution of relative error (bias) by device type.

4.3 Passing Rates

A device passes the tests if its IRE is less than 0.25. EPA tested more than 1,000 devices in the years 1991–1995. Overall, 69 percent of the devices passed the initial tests. The results are shown in Table 7. Overall, approximately three-quarters of the devices retested passed. EPA also conducted retests, which are not included in Table 7 to make comparing the private laboratory results easier. There also are some inconsistencies between the initial test and retest data. In some cases, the number of retests exceeded the number of initial tests.

Table 7. Passing Rate of Tests Conducted by EPA, 1991–1995

Device Type	Statistic	1991	1992	1993	1994	1995	All
Alpha Track	Devices Tested	22	7	5	10	8	52
	Devices Passed	5	3	2	7	4	21
	Passing Rate	0.227	0.429	0.400	0.700	0.500	0.404
Activated Charcoal	Devices Tested	171	37	45	107	15	375
	Devices Passed	99	20	32	84	4	239
	Passing Rate	0.579	0.541	0.711	0.785	0.267	0.637
Liquid Scintillation	Devices Tested	18	21	12	15	8	74
	Devices Passed	9	14	5	11	6	45
	Passing Rate	0.500	0.667	0.417	0.733	0.750	0.608
Short-Term Electret Ion	Devices Tested	164	117	86	184	34	585
	Devices Passed	123	83	71	144	20	441
	Passing Rate	0.750	0.709	0.826	0.783	0.588	0.754

Virtually all the devices tested by the private laboratories passed: The overall passing rate was 99 percent. Of the 1,552 tests reviewed, only 15 devices failed: 10 short-term electret ion devices, four alpha track devices, and one activated charcoal device. The overall passing rate for each device type is shown in Table 8. In addition to the passing rate, the table also includes the 95 percent confidence interval.[1] The interval includes a finite population correction, reflecting the relatively large sample selected. When the passing rate is 1.0, the interval is one-sided. No significant trends are apparent by chamber value. The passing rate by chamber value range is shown for each device type and year in the appendix.

The passing rate of the devices tested through proficiency programs from 2008 through 2013 is significantly higher than that achieved from 1991 through 1995. Although the study did not formally explore the reasons for the difference, several possible explanations exist. One reason may be differences in the chamber values of the tests. The reports summarized in Table 7 did not include the chamber values of the tests. But a separate report from 1995 indicates that approximately one-third of the tests conducted by EPA were conducted at chamber values less than 8 pCi/L (Price 1995). Because this memorandum did not provide detail by year, and because we could not document the quality assurance procedures used to produce its estimates, we did not include its results in this study. In contrast, approximately 6 percent of the tests conducted by private programs were at chamber values less than 8 pCi/L. The high proportion of tests conducted at chamber values less than 8 pCi/L may contribute to the lower passing rate for the tests conducted in the 1990s because it is harder to accurately test devices at lower chamber values. Although uncertainty is greater at lower chamber values, the private laboratories run their chamber monitoring systems down to 2 pCi/L. Running chambers at lower values requires greater time and effort, but can produce accurate results if the tests are carefully run. But the

[1] The intervals are binomial exact confidence intervals. This approach is used because the distribution of the number of devices that pass can be approximated using a binomial distribution. The high passing rate ($p > 0.9$) makes the binomial confidence interval more accurate than the normal approximation. (Cochran, 1977)

passing rates reported in the 1995 memorandum for tests conducted at chamber values greater than 8 pCi/L also were lower than those recorded by the two private laboratories in the years 2008–2013.

Table 8. Passing Rate of Tests Conducted by Private Laboratories, 2008–2013 and 95 Percent Confidence Interval

Device Type	Statistic	2008	2009	2010	2011	2012	2013	All
Alpha Track	Devices Tested	15	30	20	35	35	0	135
	Devices Passed	14	28	20	35	34	0	131
	Passing Rate	0.933	0.933	1.000	1.000	0.971	N/A	0.970
	95% CI	0.804 to 0.967	0.933 to 0.933	1.000 to 1.000	1.000 to 1.000	0.971 to 0.971	N/A	0.962 to 0.974
Activated Charcoal	Devices Tested	60	80	65	80	93	15	393
	Devices Passed	60	80	64	80	93	15	392
	Passing Rate	1.000	1.000	0.985	1.000	1.000	1.000	0.997
	95% CI	0.968 to 1.000	0.982 to 1.000	0.939 to 0.995	0.978 to 1.000	0.982 to 1.000	1.000 to 1.000	0.991 to 0.999
Liquid Scintillation	Devices Tested	30	40	50	70	45	0	235
	Devices Passed	30	40	50	70	45	0	235
	Passing Rate	1.000	1.000	1.000	1.000	1.000	N/A	1.000
	95% CI	1.000 to 1.000	0.952 to 1.000	0.976 to 1.000	1.000 to 1.000	0.972 to 1.000	N/A	0.995 to 1.000
Short-Term Electret Ion	Devices Tested	110	85	130	210	164	90	789
	Devices Passed	110	85	128	205	161	90	779
	Passing Rate	1.000	1.000	0.985	0.976	0.982	1.000	0.987
	95% CI	0.980 to 1.000	0.971 to 1.000	0.955 to 0.995	0.954 to 0.987	0.958 to 0.992	1.000 to 1.000	0.980 to 0.992

CI = Binomial exact confidence Interval. All of the tests were sampled in cases where the upper bound of the confidence is the same as the lower bound.
N/A = No tests available.

Other factors may influence the results as well. Further research should explore whether and how low chamber values affect device proficiency.

Changes in the standard operating procedures may also contribute to the improvement in the passing rates. When EPA ran the program in the 1990s, individual devices in a batch were sometimes exposed in two or more chambers (U.S. EPA, 1996, p. 54). The two private laboratories now test each device in a batch in a single chamber. In theory, the current practice could contribute to a higher passing rate. Lacking the individual test results from the 1990s, we

cannot test if this is, in fact, the reason the passing rates have increased noticeably over the last two decades.

The improvement in the passing rates over time also may reflect other changes in test procedures. The test procedures may not have been standardized by the early 1990s, but they were well established by 2008 when both laboratories performing tests for the proficiency program had been conducting radon performance testing for the past two decades. Proficiency testing currently represents about 25 percent of the work of the laboratories currently certified for those tests, and they now conduct hundreds of performance tests for short-term testing devices every year.

The improvement also could reflect improvements in the devices themselves. Additional research on the devices and test procedures is needed to continue investigating the change in passing rates.

5. UNCERTAINTY

The confidence intervals presented in the tables provide an indication of the uncertainty introduced by sampling. For example, we are 95 percent certain that the true IRE for all alpha track devices tested by BMI with a chamber value greater than 16 pCi/L from 1998 through 2012 is included in the range 0.099 to 0.103 (0.101, ± 0.002; see Table 5). But sampling error is only one of several potential sources of uncertainty in the estimates.

If we were to predict the IRE of future tests conducted by the laboratories, the current intervals would not reflect the uncertainty of this forecast for two reasons. First, the finite population-correction factor we applied would not be appropriate because the future inventory of tests may be larger. Second, future conditions may change, which could affect the test results. Given this uncertainty, the confidence interval for a forecast of future tests likely would be larger.

The confidence interval we estimated reflects the inventory of tests we could access. Although we sampled from all available tests, other tests were conducted that we could not access. We do not have tests from UCCS for the years 2008–2010 or from BMI for 2013. If the inventory were expanded to include these other tests, the selected samples would be relatively smaller and the intervals larger.

One way to evaluate both the problem of possibly incomplete inventories and forecasting future tests is to think of the sample of test results we observed as being drawn from an infinite population of possible test results. In this scenario, we would *not* use a finite population correction when we estimate the 95 percent confidence interval. Table 9 shows the estimated mean IRE, the ARE, the passing rate, and the infinite-population 95 percent confidence interval for each device type for both laboratories, for all chamber values for 2008 through 2013. The intervals are larger, but the range still is relatively small. For example, the 95 percent confidence interval for the IRE for alpha track devices is 0.083 to 0.119 in this scenario. Again, other factors would affect the accuracy of a forecast of future tests, but this approach captures an additional source of uncertainty.

Table 9. Average Individual Relative Error, Average Relative Error, and Passing Rate of Tests Conducted by Private Laboratories, 2008–2013 (95 Percent Confidence Interval for Infinite Population in Parentheses)

Device Type	IRE	ARE	Passing Rate
Alpha Track	0.101 (±0.018)	−0.055 (±0.039)	0.970 (0.926–0.992)
Activated Charcoal	0.069 (±0.009)	−0.023 (±0.017)	0.997 (0.986–1.000)
Liquid Scintillation	0.071 (±0.010)	0.030 (±0.021)	1.000 (0.987–1.000)*
Short-Term Electret Ion	0.057 (±0.005)	0.002 (±0.009)	0.987 (0.977–0.994)

* One-sided 95 percent confidence interval.

Decreased access to some of the test results could introduce an additional source bias. It appears that our access to some of the laboratories' test results and not others was random, simply an artifact of the state of the filing systems in the laboratories—in other words, we do not have evidence that some tests were withheld because of their results. If, in fact, the laboratories had conducted additional tests whose results differed systematically from the tests we could access, the estimates would be biased.

An important source of uncertainty is a possible difference between device performance in laboratory settings and in homes, especially with radon levels less than 8 pCi/L. Potential sources of bias include operator mistakes (homeowners may not place the devices correctly, for example) and differences between device performance in laboratories and in the field, especially when radon levels are less than 8 pCi/L. The estimates of device accuracy produced in this study are potentially upwardly biased vis-à-vis home settings. Further research into the variability of device performance in home settings is necessary to estimate the potential bias.

6. ALTERNATIVE ANALYSES

The IRE and passing rates are our primary measure of the accuracy of the devices, and the ARE provides a measure of the devices' bias. Another way to assess the accuracy of the devices is to plot the relationship between the measured radon levels—i.e., the individual test results—and the target value, the chamber value of the test. If the results of the tests are accurate, we would expect that a scatter plot of the measured values against the targeted values would closely fit a 45-degree line. If the results are unbiased (that is, if the errors in the tests are random), we would expect that the line approximated by the scatter plot would have a slope of 1 and an intercept of 0. An example of this analysis is shown in Figure 3. The black dots are the scatter plot of the measured radon levels against the chamber value. The blue line is a 45-degree line—if the measured value was exactly the chamber value, it would fall on this line. The red lines are the interval of ± 25 percent of the target value. The points are scattered about the 45-degree line, and most fall within the 25 percent interval.

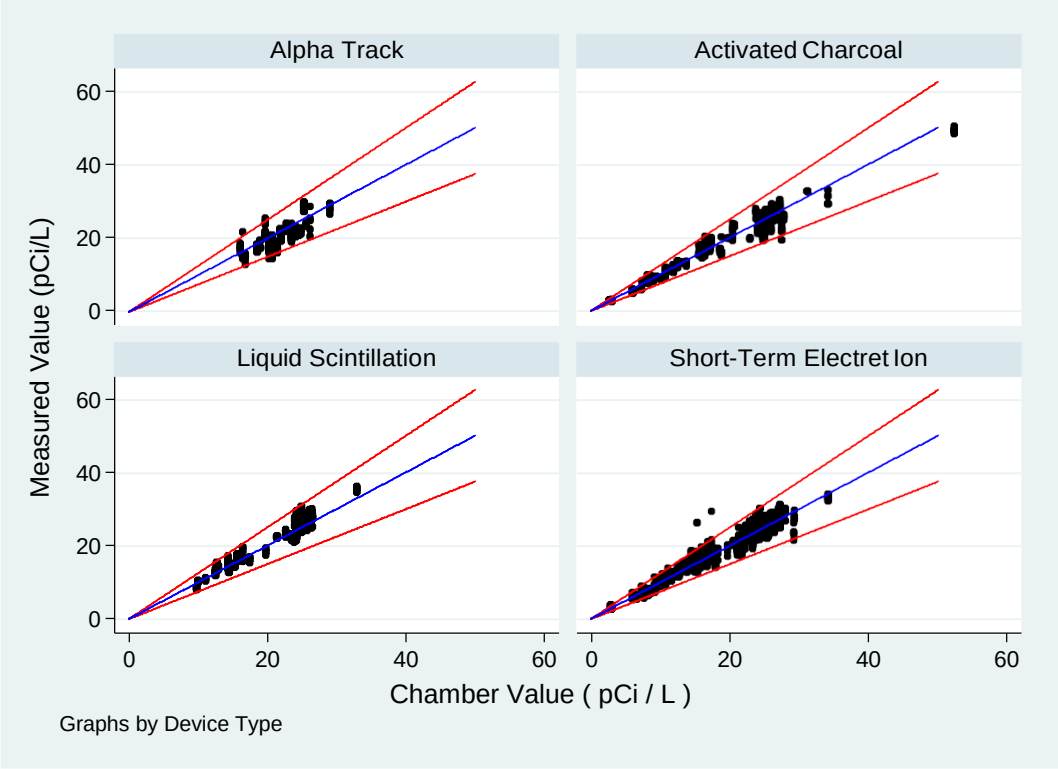


Figure 3. Scatter plots of measured and chamber values.

We can use regression analysis to find the line that best fits these data points. The results of the regression models are in Table 10, which shows the slope, intercept, and their standard errors, as well as the number of observations used in the regression and the R^2 (a measure of goodness of fit). Except for alpha track devices, the slope in each model is statistically significantly different from 1, but the difference is small. Although the alpha track slope is farther from 1 than the other device types, the standard error is large. The slope is indistinguishable from 1. The intercepts for activated charcoal and short-term electret ion are statistically significantly different from 0, but the practical differences are small. (With chamber values ranging from 2.7 to 52.4 pCi/L, the intercepts are between 0 and 1 in both cases.) The intercepts for the other device types are statistically indistinguishable from 0.

Based on the R^2, the regression fits the data very well, except for alpha track devices. The relatively poor fit for the alpha track devices may be because of the relatively narrow range in chamber values for tested alpha track devices; no tests were conducted at chamber values less than 16 pCi/L. The tests generally fall along a line with an intercept of 0 and a slope of 1, and they are randomly scattered around the line. Although further analysis is needed to explain the variability in the models, the regressions are further evidence that the devices are accurate in a laboratory setting.

Table 10. Regressions of Measured Radon Value Against Chamber Value

Variable	Alpha Track	Activated Charcoal	Liquid Scintillation	Short-Term Electret Ion
Slope	0.887* (0.0637)	0.944* (0.0104)	1.064* (0.0201)	0.975* (0.00809)
Intercept	1.231 (1.408)	0.589* (0.216)	-0.614 (0.437)	0.461* (0.158)
Observations	135	393	235	789
R-squared	0.593	0.955	0.923	0.949

Standard errors in parentheses.
* $p < 0.01$

7. CONCLUSIONS

This study describes collected and evaluated recent radon proficiency program data from the two private laboratories conducting proficiency tests during the years 2008–2013. It compared the passing rates of the laboratories to those achieved by EPA prior to privatization in the years 1991–1995 to determine the current performance of radon test devices that are available to the public.

The study relied on data that were readily available. Only summary reports on tests conducted by EPA from 1991 through 1995 were available. Individual test results from 1991 through 1995 were not available. Results of tests conducted by the private laboratories before 2008 were not accessible for this study. Furthermore, relatively few of the tests were conducted at chamber values less than 8 pCi/L. Finally, the results are subject to several sources of uncertainty, including differences between device performance in laboratory settings and in the field. This study evaluates only the uncertainty introduced by sampling and not the other sources of potential uncertainty.

The analysis shows that radon testing devices perform consistently in a laboratory setting. In tests conducted in a laboratory chamber from 2008 through 2013, radon testing devices measured the concentration of radon in the chamber to within 25 percent of the target value 99 percent of the time.

APPENDIX

The following tables provide additional details on the number of tests conducted, the size of the sample, and the test results for the tests conducted by the private laboratories.

Table A1. Inventory of Tests and Sample Size, by Year, Device Type and Chamber Value
Bowser-Morner, Inc.

Device Type	Chamber Value	Statistic	2008	2009	2010	2011	2012	2013	All
Alpha Track	< 8 pCi/L	Inventory	0	0	0	0	0	0	0
		Sample	0	0	0	0	0	0	0
	8–16 pCi/L	Inventory	0	0	0	0	0	0	0
		Sample	0	0	0	0	0	0	0
	> 16 pCi/L	Inventory	20	30	20	35	30	0	135
		Sample	15	30	20	35	30	0	130
	All	Inventory	20	30	20	35	30	0	135
		Sample	15	30	20	35	30	0	130
Activated Charcoal	< 8 pCi/L	Inventory	10	15	0	0	5	0	30
		Sample	10	15	0	0	5	0	30
	8–16 pCi/L	Inventory	10	30	45	25	40	0	150
		Sample	10	15	20	20	35	0	100
	> 16 pCi/L	Inventory	85	60	75	75	85	0	380
		Sample	40	50	45	35	45	0	215
	All	Inventory	105	105	120	100	130	0	560
		Sample	60	80	65	55	85	0	345
Liquid Scintillation	< 8 pCi/L	Inventory	0	0	0	0	0	0	0
		Sample	0	0	0	0	0	0	0
	8–16 pCi/L	Inventory	10	5	20	15	30	0	80
		Sample	10	5	10	15	30	0	70
	> 16 pCi/L	Inventory	20	65	40	55	25	0	205
		Sample	20	35	40	55	15	0	165
	All	Inventory	30	70	60	70	55	0	285
		Sample	30	40	50	70	45	0	235
Short-Term Electret Ion	< 8 pCi/L	Inventory	5	10	0	0	15	0	30
		Sample	5	10	0	0	15	0	30
	8–16 pCi/L	Inventory	30	25	75	55	95	0	280
		Sample	30	25	45	25	30	0	155
	> 16 pCi/L	Inventory	225	250	230	235	150	0	1,090
		Sample	75	50	85	60	60	0	330
	All	Inventory	260	285	305	290	260	0	1,400
		Sample	110	85	130	85	105	0	515

Table A2. Inventory of Tests and Sample Size, by Year, Device Type and Chamber Value
University of Colorado, Colorado Springs

Device Type	Chamber Value	Statistic	2008	2009	2010	2011	2012	2013	All
Alpha Track	< 8 pCi/L	Inventory	0	0	0	0	0	0	0
		Sample	0	0	0	0	0	0	0
	8–16 pCi/L	Inventory	0	0	0	0	0	0	0
		Sample	0	0	0	0	0	0	0
	> 16 pCi/L	Inventory	0	0	0	0	5	0	5
		Sample	0	0	0	0	5	0	5
	All	Inventory	0	0	0	0	5	0	5
		Sample	0	0	0	0	5	0	5
Activated Charcoal	< 8 pCi/L	Inventory	0	0	0	5	0	0	5
		Sample	0	0	0	5	0	0	5
	8–16 pCi/L	Inventory	0	0	0	5	5	0	10
		Sample	0	0	0	5	5	0	10
	> 16 pCi/L	Inventory	0	0	0	15	5	15	35
		Sample	0	0	0	15	5	15	35
	All	Inventory	0	0	0	25	10	15	50
		Sample	0	0	0	25	10	15	50
Liquid Scintillation	< 8 pCi/L	Inventory	0	0	0	0	0	0	0
		Sample	0	0	0	0	0	0	0
	8–16 pCi/L	Inventory	0	0	0	0	0	0	0
		Sample	0	0	0	0	0	0	0
	> 16 pCi/L	Inventory	0	0	0	0	0	0	0
		Sample	0	0	0	0	0	0	0
	All	Inventory	0	0	0	0	0	0	0
		Sample	0	0	0	0	0	0	0
Short Term Electret Ion	< 8 pCi/L	Inventory	0	0	0	30	0	0	30
		Sample	0	0	0	30	0	0	30
	8–16 pCi/L	Inventory	0	0	0	40	35	30	105
		Sample	0	0	0	40	35	30	105
	> 16 pCi/L	Inventory	0	0	0	55	25	60	140
		Sample	0	0	0	55	25	60	140
	All	Inventory	0	0	0	125	60	90	275
		Sample	0	0	0	125	60	90	275

Table A3. Device Test Passing Rates and 95 Percent Confidence Intervals for Private Laboratories, Alpha Track

Chamber Value	Statistic	2008	2009	2010	2011	2012	2013	All
< 8 pCi/L	Devices Tested	0	0	0	0	0	0	0
	Devices Passed	0	0	0	0	0	0	0
	Passing Rate	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	95% CI	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8–16 pCi/L	Devices Tested	0	0	0	0	0	0	0
	Devices Passed	0	0	0	0	0	0	0
	Passing Rate	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	95% CI	N/A	N/A	N/A	N/A	N/A	N/A	N/A
> 16 pCi/L	Devices Tested	15	30	20	35	35	0	135
	Devices Passed	14	28	20	35	34	0	131
	Passing Rate	0.933	0.933	1.000	1.000	0.971	N/A	0.970
	95% CI	0.804 to 0.967	0.933 to 0.933	1.000 to 1.000	1.000 to 1.000	0.971 to 0.971	N/A	0.962 to 0.974
All	Devices Tested	15	30	20	35	35	0	135
	Devices Passed	14	28	20	35	34	0	131
	Passing Rate	0.933	0.933	1.000	1.000	0.971	N/A	0.970
	95% CI	0.804 to 0.967	0.933 to 0.933	1.000 to 1.000	1.000 to 1.000	0.971 to 0.971	N/A	0.962 to 0.974

All of the tests were sampled in cases where the upper bound of the confidence is the same as the lower bound.
CI = Binomial Exact Confidence Interval.
N/A = No tests available.

Table A4. Device Test Passing Rates and 95 Percent Confidence Intervals for Private Laboratories, Activated Charcoal

Chamber Value	Statistic	2008	2009	2010	2011	2012	2013	All
< 8 pCi/L	Devices Tested	10	15	0	5	5	0	35
	Devices Passed	10	15	0	5	5	0	35
	Passing Rate	1.000	1.000	N/A	1.000	1.000	N/A	1.000
	95% CI	1.000 to 1.000	1.000 to 1.000	N/A to N/A	1.000 to 1.000	1.000 to 1.000	N/A	1.000 to 1.000
8–16 pCi/L	Devices Tested	10	15	20	25	38	0	108
	Devices Passed	10	15	20	25	38	0	108
	Passing Rate	1.000	1.000	1.000	1.000	1.000	N/A	1.000
	95% CI	1.000 to 1.000	0.870 to 1.000	0.895 to 1.000	0.953 to 1.000	0.970 to 1.000	N/A	0.984 to 1.000
> 16 pCi/L	Devices Tested	40	50	45	50	50	15	250
	Devices Passed	40	50	44	50	50	15	249
	Passing Rate	1.000	1.000	0.978	1.000	1.000	1.000	0.996
	95% CI	0.947 to 1.000	0.976 to 1.000	0.917 to 0.992	0.961 to 1.000	0.961 to 1.000	1.000 to 1.000	0.985 to 0.998
All	Devices Tested	60	80	65	80	93	15	393
	Devices Passed	60	80	64	80	93	15	392
	Passing Rate	1.000	1.000	0.985	1.000	1.000	1.000	0.997
	95% CI	0.968 to 1.000	0.982 to 1.000	0.939 to 0.995	0.978 to 1.000	0.982 to 1.000	1.000 to 1.000	0.991 to 0.999

All of the tests were sampled in cases where the upper bound of the confidence is the same as the lower bound.
CI = Binomial Exact Confidence Interval.
N/A = No tests available.

Table A5. Device Test Passing Rates and 95 Percent Confidence Intervals for Private Laboratories, Liquid Scintillation

Chamber Value	Statistic	2008	2009	2010	2011	2012	2013	All
< 8 pCi/L	Devices Tested	0	0	0	0	0	0	0
	Devices Passed	0	0	0	0	0	0	0
	Passing Rate	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	95% CI	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8–16 pCi/L	Devices Tested	10	5	10	15	30	0	70
	Devices Passed	10	5	10	15	30	0	70
	Passing Rate	1.000	1.000	1.000	1.000	1.000	N/A	1.000
	95% CI	1.000 to 1.000	1.000 to 1.000	0.812 to 1.000	1.000 to 1.000	1.000 to 1.000	N/A	0.985 to 1.000
> 16 pCi/L	Devices Tested	20	35	40	55	15	0	165
	Devices Passed	20	35	40	55	15	0	165
	Passing Rate	1.000	1.000	1.000	1.000	1.000	N/A	1.000
	95% CI	1.000 to 1.000	0.944 to 1.000	1.000 to 1.000	1.000 to 1.000	0.883 to 1.000	N/A	0.992 to 1.000
All	Devices Tested	30	40	50	70	45	0	235
	Devices Passed	30	40	50	70	45	0	235
	Passing Rate	1.000	1.000	1.000	1.000	1.000	N/A	1.000
	95% CI	1.000 to 1.000	0.952 to 1.000	0.976 to 1.000	1.000 to 1.000	0.972 to 1.000	N/A	0.995 to 1.000

All of the tests were sampled in cases where the upper bound of the confidence is the same as the lower bound.
CI = Binomial Exact Confidence Interval.
N/A = No tests available.

Table A6. Device Test Passing Rates and 95 Percent Confidence Intervals for Private Laboratories, Short-Term Electret Ion

Chamber Value	Statistic	2008	2009	2010	2011	2012	2013	All
< 8 pCi/L	Devices Tested	5	10	0	30	15	0	60
	Devices Passed	5	10	0	27	15	0	57
	Passing Rate	1.000	1.000	N/A	0.900	1.000	N/A	0.950
	95% CI	1.000 to 1.000	1.000 to 1.000	N/A	0.900 to 0.900	1.000 to 1.000	N/A	0.950 to 0.950
8–16 pCi/L	Devices Tested	30	25	45	65	64	30	259
	Devices Passed	30	25	43	64	62	30	254
	Passing Rate	1.000	1.000	0.956	0.985	0.969	1.000	0.981
	95% CI	1.000 to 1.000	1.000 to 1.000	0.887 to 0.980	0.947 to 0.993	0.914 to 0.988	1.000 to 1.000	0.966 to 0.988
> 16 pCi/L	Devices Tested	75	50	85	115	85	60	470
	Devices Passed	75	50	85	114	84	60	468
	Passing Rate	1.000	1.000	1.000	0.991	0.988	1.000	0.996
	95% CI	0.968 to 1.000	0.948 to 1.000	0.972 to 1.000	0.961 to 0.998	0.951 to 0.996	1.000 to 1.000	0.987 to 0.999
All	Devices Tested	110	85	130	210	164	90	789
	Devices Passed	110	85	128	205	161	90	779
	Passing Rate	1.000	1.000	0.985	0.976	0.982	1.000	0.987
	95% CI	0.980 to 1.000	0.971 to 1.000	0.955 to 0.995	0.954 to 0.987	0.958 to 0.992	1.000 to 1.000	0.980 to 0.992

All of the tests were sampled in cases where the upper bound of the confidence is the same as the lower bound.
CI = Binomial Exact Confidence Interval.
N/A = No tests available.

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