measurement result.

3.2.8 Retrieval of Devices

Prior to pump shut-down, the flow rate should be measured with a calibrated flow meter (if possible) and the unit should be observed briefly to ensure that it is operating properly. The detector assembly or detector film should be removed for processing and the date, time, running-time meter reading, and flow rate should be recorded both on the envelope and in a log book. The filter should be checked for holes or dust loading and any other observed conditions that might affect the measurement. If TLDs or film discs are to be removed from the detector assembly, removal should be delayed for at least three hours after sampling is completed to allow for decay and registration of radon decay products on the filter.

3.2.9 Documentation

The reader should refer to Section 1.2.4 for the list of standard information that must be documented so that data interpretation and comparison can be made.

In addition, the serial numbers of the RPs, TLDs, film discs, or electrets must be recorded.

3.2.10 Analysis Requirements

Analysis of the film from the ATD-type RPs requires an analysis laboratory equipped to etch and count alpha track film.

Analysis of TLD-type RPs requires a TLD reader. The TLD reader is an instrument that heats the TLDs at a uniform and reproducible rate and measures simultaneously the light emitted by the thermoluminescent material. The readout process is controlled carefully, with the detector purged with nitrogen to prevent spurious emissions. Prior to analyzing the RPISU dosimeters, the TLD reader should be tested periodically using dosimeters exposed to a known level of alpha or gamma radiation. TLDs are prepared for reuse by cleaning and annealing at the prescribed temperature in an oven.

Analysis of the electret-type RPs requires a specially-built surface voltmeter for measuring electret voltages before and after exposure. For more information on analysis requirements, the reader should refer to Section 2.3.10 (Electret Ion Chamber Radon Detectors) of the Radon Measurement Device Protocols.

3.2.10.1 Sensitivity. The lower limit of detection (LLD [calculated using methods described by Altshuler and Pasternack 1963]) should be specified by individual suppliers for RP detectors exposed according to their directions. The LLD will depend upon the length of the exposure and the background of the detector for materials used. The LLD should be calculated using the results of the laboratory control devices.

3.2.10.2 Precision. Precision should be monitored and recorded using the results of the duplicate detector analyses described in Section 3.2.11.3. This method may achieve a coefficient of variation of 10 percent at radon decay product concentrations of 0.02 WL or greater. An alternate measure of precision is a relative percent difference, defined as the difference between two duplicate measurements divided by their mean; note that these two measures of precision are not identical quantities. It is important that precision be monitored continuously over a range of radon concentrations and that a systematic and documented method for evaluating changes in precision be part of the operating procedures.

3.2.11 Quality Assurance

The quality assurance program for an RP system includes five parts: (1) calibration, (2) known exposure detectors, (3) duplicate (collocated) detectors, (4) control detectors, and (5) routine instrument checks. The purpose of a quality assurance program is to identify the accuracy and precision of the measurements and to ensure that the measurements are not influenced by exposure from sources outside the environment to be measured. The quality assurance program should include the maintenance of control charts (Goldin 1984); general information is also available (Taylor 1987, U.S. EPA 1984).

Users of electret-type RPs should follow the quality assurance guidance given for electret ion chamber devices in Section 2.3 of this document.

3.2.11.1 Calibration. Every RP should be calibrated in a radon calibration chamber before being put into service, and after any repairs or modifications. Subsequent recalibrations should be done once every 12 months, with cross-checks to a recently calibrated instrument at least semiannually. Calibration of RPs requires exposure in a controlled radon-exposure chamber where the radon decay product concentration is known during the exposure period. The detector must be exposed in the chamber using the normal operating flow rate for the RP sampling pumps. Calibration should include exposure of a

minimum of four detectors exposed at different radon decay product concentrations representative of the range found in routine measurements. The relationship of TLD reader units or etched track reader units to working level (WL) for a given sample volume and the standard error associated with this measurement should be determined. Calibration of the RPs also includes testing to ensure accuracy of the flow rate measurement.

3.2.11.2 Known Exposure Devices. Anyone providing measurement services with RP devices should submit detectors with known decay product exposures (spiked samples) for analysis at a rate of three per 100 measurements, with a minimum of three per year and a maximum required of six per month. Known exposure detectors should be labeled in the same manner as the field detectors to assure blind processing. The results of the known exposure detector analysis should be monitored and recorded, and any significant deviation from the known concentration to which they were exposed should be investigated.

3.2.11.3 Duplicate (Collocated) Detectors. Anyone providing measurement services with RP devices should place duplicate detectors in enough houses to test the precision of the measurement. The number of duplicate detectors deployed should be approximately 10 percent of the number of detectors deployed each month or 50, whichever is smaller. The duplicate detectors should be shipped, stored, exposed, and analyzed under the same conditions. The samples selected for duplication should be distributed systematically throughout the entire population of samples. Groups selling measurement services to homeowners can do this by making two side-by-side measurements in a random selection of homes. Data from duplicate detectors should be evaluated using the procedures described by Goldin (section 5.3 in Goldin 1984), by Taylor (Taylor 1987), or by the EPA (U.S. EPA 1984). Whatever procedures are used must be documented prior to beginning measurements. Consistent failure in duplicate agreement may indicate a problem in the measurement process and should be investigated.

3.2.11.4 Control Detectors. TLD-type RPs use a TLD that is shielded from the gamma radiation emitted by the material on the filter. This TLD is incorporated in the detector assembly to measure the environmental gamma exposure of the sampling detector. The two TLDs are processed identically and the environmental gamma exposure is subtracted from the sample reading. Electret-type RPs also require an environmental

gamma background correction.

3.2.11.4.1 Laboratory Control Detectors. The laboratory background level for each batch of assembled TLDs should be established by each supplier. Suppliers should measure the background of a statistically significant number of unexposed thermoluminescent assemblies that have been processed according to their standard operating procedures. To calculate the net readings used to calculate the reported sample radon concentrations, the analysis laboratory subtracts this laboratory blank value from the results obtained from the field detectors.

Similarly, the laboratory background level for each batch of ATD-type RPs should be established by each supplier of these detectors. Suppliers should measure the background of a statistically significant number of unexposed detector films that have been processed according to their standard operating procedures. The analysis laboratory will subtract this laboratory blank value from the results obtained from the field detectors before calculating the final result.

Users of electret-type RPs should follow similar control detector procedures discussed in section 2.3.11.1.

3.2.11.4.2 Field Control Detectors (Blanks). Field control detectors (field blanks) should consist of a minimum of five percent of the detectors deployed each month or 25, whichever is smaller. Users should set these aside from each shipment, keep them sealed, label them in the same manner as the field detectors, and, where applicable, send them back to the analysis laboratory as blind controls with one shipment each month. These field blank detectors measure the background exposure that may accumulate during shipment or storage. The results should be monitored and recorded. If one or a few of the field blanks have concentrations significantly greater than the LLD established by the supplier, it may indicate defective material or procedures. If the average value from the background control detectors (field blanks) is significantly greater than the LLD established by the supplier, this average value should be subtracted from the individual values reported for the other detectors in the exposure group. The cause for the elevated field blank readings should then be investigated.

3.2.11.5 Routine Instrument Checks. Proper operation of all analysis equipment requires that their response to a reference source be constant to within established limits. Therefore, analysis equipment should be subject to routine checks to ensure proper operation. This is achieved by counting an

instrument check source at least once per day during operation.

Pumps and flow meters should be checked routinely to ensure accuracy of volume measurements. This may be performed using a dry-gas meter or other flow measurement device of traceable accuracy.

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3.3 Protocol for Using Grab Sampling - Working Level (GW) to Measure Indoor Radon Decay Product Concentrations

3.3.1 Purpose

This protocol provides guidance for using the grab sampling-working level (GW) technique to provide accurate and reproducible measurements of indoor radon decay product concentrations. Adherence to this protocol will help ensure uniformity among measurement programs and allow valid intercomparison of results. Measurements made in accordance with this procedure will produce results representative of closed-building conditions. Measurements made under closed-building conditions have a smaller variability and are more reproducible than measurements made when the building conditions are not controlled.

The results of the GW method are influenced greatly by conditions that exist in the building during and for up to 12 hours prior to the measurement. It is therefore especially important when making grab measurements to conform to the closed-building conditions for 12 hours before the measurement. Grab sampling techniques are not recommended for measurements made to determine the need for remedial action. The investigator should also follow guidance provided by the EPA in "Protocols for Radon and Radon Decay Product Measurements in Homes" (U.S. EPA 1992c) or other appropriate EPA measurement guidance documents.

3.3.2 Scope

This procedure covers, in general terms, the equipment, procedures, and quality control objectives to be used in performing the measurements. It is not meant to replace an instrument manual but, rather, provides guidelines to be incorporated into standard operating procedures by anyone providing measurement services. Questions about these

guidelines should be directed to the U.S. Environmental Protection Agency.

3.3.3 Method

Grab sampling measurements of radon decay product concentrations in air are performed by collecting the decay products from a known volume of air on a filter and by counting the activity on the filter during or following collection. Several methods for performing such measurements have been developed and have been described previously (George 1980). Comparable results may be obtained using all these methods. This procedure, however, will describe two methods that have been used most widely with good results. These are the Kusnetz procedure and the modified Tsivoglou procedure.

The Kusnetz procedure (ANSI 1973, Kusnetz 1956) may be used to obtain results in working levels (WL) when the concentration of individual decay products is unimportant. Decay products from up to 100 liters of air are collected on a filter in a five-minute sampling period. The total alpha activity on the filter is counted at any time between 40 and 90 minutes after the end of sampling. Counting can be done using a scintillation-type counter to obtain gross alpha counts for the selected period. Counts from the filter are converted to disintegrations using the appropriate counter efficiency. The disintegrations from the decay products collected from the known volume of air may be converted into WLs using the appropriate "Kusnetz factor" (see Section 3.3.11.3., Exhibit 3-1) for the counting time used.

The Tsivoglou procedure (Tsivoglou et al. 1953), as modified by Thomas (Thomas 1972), may be used to determine WL and the concentration of the individual radon decay products. Sampling is the same as that used for the Kusnetz procedure; however, the filter is counted three separate times following collection. The filter is counted between the interval of two to five minutes, six to 20 minutes, and 21 to 30 minutes, following completion of sampling. Count results are used in a series of equations to calculate concentrations of the three radon decay products and WL. These equations and an example calculation appear in Section 3.3.11.4.1.

3.3.4 Equipment

Equipment required for radon decay product concentration determination by GW consists of the following items:

An air sampling pump capable of maintaining a flow rate of two to 25 liters per minute through the selected filter. The flow rate should not vary significantly during the sampling period;

A filter holder (with adapters for attachment) to accept a 25- or 47-mm diameter, 0.8-micron membrane or glass fiber filter;

A calibrated air flow measurement device to determine the air flow through the filter during sampling;

A stopwatch or timer for accurate timing of sampling and counting;

A scintillation counter and a zinc sulfide scintillation disc;

A National Institute of Standards and Technology (NIST)-traceable alpha calibration source to determine counter efficiency; and

A data collection log.

3.3.5 Predeployment Considerations

The plans of the occupant during the proposed measurement period should be considered before deployment. The GW measurement should not be made if the occupant will be moving during the measurement period. Deployment should be delayed until the new occupant is settled in the house.

The GW device should not be deployed if the user's schedule prohibits terminating the measurement at the appropriate time.

3.3.5.1 Premeasurement Testing

Prior to collection of the sample, proper operation of the equipment must be verified, and the counter efficiency and background must be determined. This is especially critical for the Tsivoglou procedure, in which the sample counting must begin two minutes following the end of sampling.

The air pump, filter assembly, and flow meter must be tested to ensure that there are no leaks in the system. The scintillation counter must be operated with the scintillation tray (where applicable) and scintillation disc in place to determine

background for the counting system. Also, the counter must be operated with an NIST-traceable alpha calibration source in place of a filter in the counting location to determine system counting efficiency. Both the system background and system efficiency are used in the calculation of results from the actual sample.

3.3.6 Measurement Criteria

The reader should refer to Section 1.2.2 for the list of general conditions that must be met to ensure standardization of measurement conditions.

3.3.7 Deployment

3.3.7.1 Location in Room. The reader should refer to Section 1.2.3 for standard criteria that must be considered when choosing a measurement device location.

3.3.7.2 Sampling. A new filter should be placed in the filter holder prior to entering the building. Care should be taken to avoid puncturing the filter and to avoid leakage. The sampling is initiated by starting the pump and the clock simultaneously. The air flow rate should be noted and recorded in a log book. The time the sampling was begun should also be recorded. The sampling period should be five minutes, and the time from the beginning of sampling to the time of counting must be recorded precisely.

3.3.8 Documentation

The reader should refer to Section 1.2.4 for the list of standard information that must be documented so that data interpretation and comparison can be made.

3.3.9 Analysis Requirements

Analysis may be done using the Kusnetz procedure (ANSI 1973, Kusnetz 1956), the modified Tsivoglou procedure (Thomas 1972, Tsivoglou et al. 1953), or other procedures described elsewhere (George 1980). If the Tsivoglou procedure is used, the counting must be started two minutes following the end of sampling. Analysis using the Kusnetz procedure must be performed between 40 and 90 minutes following the end of sampling. A counting time of 10 minutes during this period is usually used. The reader should refer to Sections 3.3.3 and 3.3.11 for more information.

The filter from the holder must be removed using forceps, and placed carefully facing the scintillation phosphor. The side of the filter on which the decay products were collected must face the phosphor disc. The chamber containing the filter and disc should be closed and allowed to dark-adapt prior to starting counting. For the Tsivoglou method, this procedure of placing the filter in the counting position must be done quickly, since the first of the three counts must begin two minutes following the end of sampling. If the counter used has been shown to be slow to dark-adapt, the counting should be done in a darkened environment. Additional details on the procedure and calculations are available (Kusnetz 1956, Thomas 1972, Tsivoglou et al. 1953).

3.3.9.1 Sensitivity. For a five-minute sampling period (10 to 20 liters of air) on a 25-mm filter, the lower limit of detection (LLD [calculated using methods described by Altshuler and Pasternack 1963]) using the Kusnetz or modified Tsivoglou counting procedure can be approximately 0.0005 WL (George 1980).

3.3.9.2 Precision. Precision should be monitored using the results of duplicate measurements (refer to Section 3.4.10.2). Sources of error in the procedure may result from inaccuracies in measuring the volume of air sampled, characteristics of the filter used, and measurement of the amount of radioactivity on the filter. The method can produce duplicate measurements with a coefficient of variation of 10 percent or less at 0.02 WL or greater. An alternate measure of precision is a relative percent difference, defined as the difference between two duplicate measurements divided by their mean; note that these two measures of precision are not identical quantities. It is important that precision be monitored continuously over a range of radon concentrations and that a systematic and documented method for evaluating changes in precision be part of the operating procedures.

3.3.10 Quality Assurance

The quality assurance program for a GW system includes three parts: (1) calibration of the system, (2) duplicate measurements, and (3) routine instrument checks. The purpose of a quality assurance program is to identify the accuracy and precision of the measurements and to ensure that the measurements are not influenced by exposure from sources outside the environment to be measured. The quality assurance program should include the maintenance of control charts (Goldin 1984); general information is also available (Taylor 1987, U.S. EPA

1984).

3.3.10.1 Calibration. Pumps and flow meters used to sample air must be calibrated routinely to ensure accuracy of volume measurements. This may be performed using a dry-gas meter or other flow measurement device of traceable accuracy.

Every GW device should be calibrated in a radon (decay product) calibration chamber before being put into service, and after any repairs or modifications. Subsequent recalibrations should be done once every 12 months, with cross-checks to a recently calibrated instrument at least semiannually. Grab measurements should be made in a calibration chamber with known radon decay product concentrations to verify the calibration factor. These measurements should also be used to test the collection efficiency and self-absorption of the filter material being used for sampling. A change in the filter material being used requires that the new material be checked for collection efficiency in a calibration chamber.

3.3.10.2 Duplicate Measurements. Anyone providing measurement services with GW devices should place duplicate detectors in enough houses to test the precision of the measurement. The number of duplicate detectors deployed should be approximately 10 percent of the number of detectors deployed each month or 50, whichever is smaller. To the greatest extent possible, care should be taken to ensure that the samples are duplicates. The filter heads should be relatively close to each other and away from drafts. Care should also be taken to ensure that one filter is not in the discharge air stream of the other sampler. The measurements selected for duplication should be distributed systematically throughout the entire population of measurements. Data from duplicate samples should be evaluated using the procedures described by Goldin (section 5.3 of Goldin 1984), by Taylor (Taylor 1987), or by the EPA (U.S. EPA 1984). Whatever procedures are used must be documented prior to beginning measurements. Consistent failure in duplicate agreement may indicate a problem in the measurement process and should be investigated.

3.3.10.3 Routine Instrument Checks. Proper operation of all radiation counting instruments requires that their response to a reference source be constant to within established limits. Therefore, counting equipment should be subject to routine checks to ensure proper operation. This is achieved by counting an instrument check source at least once per day. The characteristics of the check source (i.e., geometry, type of

radiation emitted, etc.) should, if possible, be similar to the samples to be analyzed. The count rate of the check source should be high enough to yield good counting statistics in a short time (for example, 1,000 to 10,000 counts per minute).

The radiological counters should have calibration checks run daily to determine counter efficiency. This is particularly important for portable counters taken into the field that may be subject to rugged use and temperature extremes. These checks are made using an NIST-traceable alpha calibration source such as Am-241. In addition, the system background count rate should be assessed regularly.

Pumps and flow meters should be checked routinely to ensure accuracy of volume measurements. This may be performed using a dry-gas meter or other flow measurement device of traceable accuracy.

3.3.11 Supplementary Information for the Grab Sampling-Working Level (GW) Method

3.3.11.1 Sample Collection. Two commonly used methods are described below. There are several other methods reported in the literature. Sampling using these methods requires collection of radon decay products on a filter, and measuring the alpha activity of the sample with a calibrated detector at time intervals that are specific for each method.

The filter is installed in the filter holder assembly and attached to the pump. The pump is then operated for exactly five minutes, pulling air through the filter. Starting time and air flow rate should be recorded. The pump is stopped at the end of the five-minute sampling time. At this time, the stopwatch should be started or reset.

3.3.11.2 Sample Counting. Sample counting for two different techniques is described below.

3.3.11.2.1 Modified Tsivoglou Technique (Thomas 1972, Tsivoglou et al. 1953). The filter is transferred carefully from the filter holder assembly to the detector. The collection side of the filter is oriented toward the face of the detector.

The counter is operated for the following time intervals (after sampling has stopped): two to five minutes, six to 20 minutes, and 21 to 30 minutes. The total counts for each time period are then

recorded.

3.3.11.2.2 Kusnetz Technique (Kusnetz 1956). The filter is transferred carefully from the filter holder assembly to the detector. The collection side of the filter is oriented toward the face of the detector.

The counter is operated over any 10-minute time interval between 40 minutes and 90 minutes after sampling starts. The total counts for the sample and the time (in minutes after sampling) at the midpoint of the 10-minute time interval are then recorded.

3.3.11.3 Data Analysis. Data analysis for the two different techniques is described below.

3.3.11.3.1 Modified Tsivoglou Technique. The concentration, in picoCuries per liter (pCi/L), of each of the radon decay products (Po-218, Pb-214, and Po-214) can be determined by using the following calculations:

C2 = 1/FE (0.16921 G1- 0.08213 G2 + 0.07765 G3 - 0.5608 R)

C3 = 1/FE (0.001108 G1 - 0.02052 G2 + 0.04904 G3 - 0.1577 R)

C4 = 1/FE (-0.02236 G1 + 0.03310 G2 - 0.03765 G3 - 0.05720 R)

It is important to note that the constants in these equations are based on a 3.04-minute half-life of Po-218. The working level (WL) associated with these concentrations can then be calculated using the following relationship:

Where:

C_2 = concentration of Po-218 (RaA) in pCi/L;

C_3 = concentration of Pb-214 (RaB) in pCi/L;

C_4 = concentration of Po-214 (RaC') in pCi/L;

F = sampling flow rate in liters per minute (Lpm);

E = counter efficiency in counts per

minute/disintegrations per minute (cpm/dpm);

G_1 = gross alpha counts for the time interval of two to five minutes;

G_2 = gross alpha counts for the time interval of six to 20 minutes;

G_3 = gross alpha counts for the time interval of 21 to 30 minutes; and

R = background counting rate in cpm.

Reference: (Thomas 1972).

3.3.11.3.2 Kusnetz Technique. WL is calculated as follows:

$$WL = C/Kt\ VE$$

Where:

C = sample cpm - background cpm;

K_t = factor determined from Exhibit 3-1 (PHS 1957) for time from end of collection to midpoint of counting;

V = total sample air volume in liters [calculated as flow rate (L/m) x sample time (m)]; and

E = counter efficiency in cpm/dpm.

Exhibit 3-1

Kusnetz Factors (Public Health Service, 1957)			
Time	Kt	Time	Kt
40	150	66	98
42	146	68	94
44	142	70	90
46	138	72	87
48	134	74	84
50	130	76	82
52	126	78	78

54	122	80	75
56	118	82	73
58	114	84	69
60	110	86	66
62	106	88	63
64	102	90	60

3.3.11.4 Sample Problems

3.3.11.4.1 Sample Problem for the Modified Tsivoglou Technique

Given:

F = sampling flow rate = 3.5 Lpm

E = counting efficiency = 0.47 cpm/dpm

$G_1 = 880$

$G_2 = 2660$

$G_3 = 1460$

R = 0.5

Calculate:

C2 = 1/3.5 x 0.47 (0.16921 x 880 - 0.08213 x 2660 + 0.07765 x 1460 - 0.05608 x 0.5)

C2 = 26.8 pCi/L

C3 = 1/3.5 x 0.47 (0.001108 x 880 - 0.02052 x 2660 + 0.04904 x 1460 - 0.1577 x 0.5)

C3 = 10.9 pCi/L

C4 = 1/3.5 x 0.47 (-0.02236 x 880 + 0.03310 x 2660 - 0.03766 x 1460 - 0.05720 x 0.5)

C4 = 8.1 pCi/L

WL = (1.028×10^{-3} x 26.8 + 5.07×10^{-3} x 10.9 + 3.728×10^{-3} x 8.1)

WL = 0.11

3.3.11.4.2 Sample Problem for the Kusnetz Technique

Background count = 3 counts in 5 minutes, or 0.6 cpm

Standard count = 5,985 counts in 5 minutes, or 1,197 cpm

Efficiency = 1197 cpm - 0.6 cpm/2430 dpm = 0.49
(known source of 2439 dpm)

Sample volume = 4.4 liter/minute x 5 minutes = 22 liters

Sample count at 45 minutes (time from end of sampling period to start of counting period) = 560 counts in 10 minutes, or 56 cpm

K_t at 50 minutes (from Exhibit 3-1) = 130

WL = 56 cpm - 0.6 cpm/130 x 22 L x 0.49

WL = 0.04

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"Indoor Radon and Radon Decay Product Measurement Device Protocols"

Glossary

Accuracy: The degree of agreement of a measurement (X) with an accepted reference or true value (T); usually expressed as the difference between the two values (X – T), or the difference as a percentage of the reference or true value (100[X – T]/T), and sometimes expressed as a ratio (X/T).

Active radon/radon decay product measurement device: A radon or radon decay product measurement system which uses a sampling device, detector, and measurement system integrated as a complete unit or as separate, but portable, components. Active devices include continuous radon monitors, continuous working level monitors, and grab radon gas and grab working level measurement systems, but does not include devices such as electret ion chamber devices, activated carbon or other adsorbent systems, or alpha track devices.

Alpha particle: Two neutrons and two protons bound as a single particle that is emitted from the nucleus of certain radioactive isotopes in the process of decay.

Background count rate: The counting rate obtained on a given instrument with a background counting sample. Typical reference background counting samples are:

- Empty planchet: for G-M detectors, internal proportional counters, low background beta counters, alpha spectrometers.
- Scintillation vial containing scintillant and sample

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known to contain no radioactivity: for liquid scintillation counters.
- Container filled with distilled water: for gamma spectrometers.

Background measurements: Measurements made with either active instruments exposed to a radon-free gas, such as aged air or nitrogen, or for passive detectors by analyzing unexposed detectors. Results are subtracted from the actual field measurements before calculating the reported concentration. Background levels may be due to electronic noise of the analysis system, leakage of radon into the detector, detector response to gamma radiation, or other causes.

Background radiation: Radiation arising from radioactive material other than that under consideration. Background radiation due to cosmic rays and natural radioactivity is always present; background radiation may also be due to the presence of radioactive substances in building materials.

Bias: A systematic (consistent) error in test results. Bias can exist between test results and the true value (absolute bias, or lack of accuracy), or between results from different sources (relative bias). For example, if different laboratories analyze a homogeneous and stable blind sample, the relative biases among the laboratories would be measured by the differences existing among the results from the different laboratories. However, if the true value of the blind sample were known, the absolute bias or lack of accuracy from the true value would be known for each laboratory. See **Systematic error**.

Blank sample: A control sample in which the detector is unexposed and submitted for analysis. Often used to determine detector background values.

Blind spikes: Detectors exposed to known radon or decay product concentrations and submitted for analysis without being labeled as such. Used to evaluate the accuracy of the measurement.

Calibrate: To determine the response or reading of an instrument relative to a series of known values over the range of the instrument; results are used to develop correction or calibration factors.

Check source: A radioactive source, not necessarily calibrated, which is used to confirm the continuing satisfactory operation of an instrument.

Coefficient of variation (COV), relative standard deviation (RSD): A measure of precision, calculated as the standard deviation (s or s) of a set of values divided by the average (X_{ave} or μ), and usually multiplied by 100 to be expressed as a percentage.

COV = RSD = / x 100 for a sample,

COV' = RSD' = / x 100 for a population

See **Relative percent difference**.

Curie (Ci): A standard measurement for radioactivity, specifically the rate of decay for a gram of radium – 37 billion decays per second. A unit of radioactivity equal to 3.7×10^{10} disintegrations per second.

Duplicate measurements: Two measurements made concurrently and in the same location, or side-by-side. Used to evaluate the precision of the measurement method.

Electron: An elementary constituent of an atom that orbits the nucleus and has a negative charge. Beta decay is radioactive decay in which an electron is emitted from a nucleus.

Electron volt (eV): One eV is equivalent to the energy gained by an electron in passing through a potential difference of one volt. One unit of energy = 1.6×10^{-12} ergs = 1.6×10^{-19} joules; 1 MeV = 10^6 eV.

Equilibrium, radioactive: A state in which the formation of atoms by decay of a parent radioactive isotope is equal to its rate of disintegration by radioactive decay.

Equilibrium ratio, radioactive: The total concentration of radon decay products (RDPs) present divided by the concentration that would exist if the RDPs were in radioactive equilibrium with the radon gas concentration which is present. At equilibrium (i.e., at an equilibrium ratio of 1.0), 1 WL of RDPs would be present when the radon concentration was 100 pCi/L. The ratio is never 1.0 in a house. Due to ventilation and plate-out, the RDPs never reach equilibrium in a house environment. A commonly assumed equilibrium ratio is 0.5 (i.e., the progeny are halfway toward equilibrium), in which case 1 WL corresponds to 200 pCi/L. However, equilibrium ratios vary with time and location, and ratios of 0.3 to 0.7 are commonly observed. Large buildings, including schools, often contain equilibrium ratios less than 0.5.

Exposure time: The length of time a specific mail-in device must be in contact with radon or radon decay products to get an accurate radon measurement. Also called exposure period, exposure parameters, or

duration of exposure.

Gamma radiation: Short-wavelength electromagnetic radiation of nuclear origin, with energies between 10 keV to 9 MeV.

Integrating device: A device that measures a single average concentration value over a period of time. Also called a time integrating device.

Ion: An electrically charged atom in which the number of electrons does not equal the number of protons.

Ionization: The process whereby a neutral atom or molecule becomes negatively or positively charged by acquiring or losing an electron.

Ionizing radiation: Any type of radiation capable of producing ionization in materials it contacts; includes high-energy charged particles such as alpha and beta rays, and nonparticulate radiation such as gamma rays and X-rays. In contrast to wave radiation (e.g., visible light and radio waves) in which waves do not ionize adjacent atoms as they move.

Lower limit of detection (LLD): The smallest amount of sample activity which will yield a net count for which there is confidence at a predetermined level that activity is present. For a five percent probability of concluding falsely that activity is present, the LLD is approximately equal to 4.65 times the standard deviation of the background counts (assuming large numbers of counts where Gaussian statistics can be used [ANSI 1989, Pasternack and Harley 1971, U.S. DOE 1990]).

Passive radon/radon decay product measurement device: A radon or radon decay product measurement system in which the sampling device, detector, and measurement system do not function as a complete, integrated unit. Passive devices include electret ion chamber devices, activated carbon or other adsorbent systems, or alpha track devices, but does not include continuous radon/radon decay product monitors, or grab radon/radon decay product measurement systems.

PicoCurie (pCi): One pCi is one trillionth of a Curie, 0.037 disintegrations per second, or 2.22 disintegrations per minute.

PicoCurie per liter (pCi/L): A unit of radioactivity corresponding to one decay every 27 seconds in a volume of one liter, or 0.037 decays per second in every liter of air.

Pooled estimate of variance: An estimate of precision derived from different sets of duplicates, calculated as follows:

$$S2dp = s2d1 (n1 - 1) + S2ds (n2 - 1)/(n1 - 1) + (n2 - 1)$$

where:

S^2dp = pooled variance;

S^2d1 = variance observed with the first group of detectors or equipment;

S^2d2 = variance observed with the second group of detectors or equipment;

n_1 = sample size of the first group of detectors or equipment; and

n_2 = sample size of the second group of detectors or equipment.

Precision: A measure of mutual agreement among individual measurements of the same property, usually under prescribed and similar conditions. Most desirably expressed in terms of the standard deviation, but can be expressed in terms of the variance, pooled estimate of variance, range, relative percent difference, or other statistic.

Quality assurance: A complete program designed to produce results which are valid, scientifically defensible, and of known precision, bias, and accuracy. Includes planning, documentation, and quality control activities.

Quality control: The system of activities to ensure a quality product, including measurements made to ensure and monitor data quality. Includes calibrations, duplicate, blank, and spiked measurements, interlaboratory comparisons, and audits.

Radon (Rn): A colorless, odorless, naturally occurring, radioactive, inert, gaseous element formed by radioactive decay of radium (Ra) atoms. The atomic number is 86. Although other isotopes of radon occur in nature, radon in indoor air is almost exclusively Rn-222.

Radon chamber: An airtight enclosure in which operators can induce and control different levels of radon gas and radon decay products. Volume is such that samples can be taken without affecting the levels of either radon or its decay products within the chamber.

Random error: Variations of repeated measurements that are random in nature and not predictable individually. The causes of random error are assumed to be indeterminate or non-assignable. The distribution of random errors is assumed generally to be normal (Gaussian).

Range: The difference between the maximum and minimum values of a set of values. When the number of values is small (i.e., eight or less), the range is a relatively sensitive (efficient) measure of variability. As the number of values increases above eight, the efficiency of the range (as an estimator of the variability) decreases rapidly. The range, or difference between two paired values, is of particular importance in air pollution measurement, since in many situations duplicate measurements are performed as part of the quality assurance program.

Relative percent difference (RPD): A measure of precision, calculated by:

$$Rd\% = [X1 - X2\}/Xave \times 100$$

where:

X_1 = concentration observed with the first detector or equipment;

X_2 = concentration observed with the second detector, equipment, or absolute value; and

X_{ave} = average concentration = ((X1 + X2) / 2)

The relative percent difference (RPD) and coefficient of variation (COV) provide a measure of precision, but they are not equal. Below are example duplicate radon results and the corresponding values of relative percent difference and coefficient of variation:

Rn1 (pCi/L)	Rn2 (pCi/L)	RPD (%)	COV (%)
8	9	12	8
13	15	14	10
17	20	16	11
26	30	14	10
7.5	10	29	20

See **Coefficient of variation** (COV).

Relative standard deviation: See **Coefficient of variation**.

Spiked measurements, or known exposure measurements: Quality control measurements in which the detector or instrument is exposed to a known concentration and submitted for analysis. Used to evaluate

accuracy.

Standard deviation (s): A measure of the scatter of several sample values around their average. For a sample, the standard deviation (s) is the positive square root of the sample variance:

$$s = \frac{\sqrt{\sum_{i=1}^{n} (X_i - X_{ave})^2}}{\sqrt{n - 1}}$$

For a finite population, the standard deviation (s) is:

$$\sigma = \frac{\sqrt{\sum_{i=1}^{N} (X_i - \mu)^2}}{\sqrt{N}}$$

where μ is the true arithmetic mean of the population and N is the number of values in the population. The property of the standard deviation that makes it most practically meaningful is that it is in the same units as the observed variable X. For example, the upper 95% probability limit on differences between two values is 2.77 times the sample standard deviation.

Standard operating procedure: A written document which details an operation, analysis, or action whose mechanisms are prescribed thoroughly and which is commonly accepted as the method for performing certain routine or repetitive tasks.

Statistical control chart, Shewhart control chart: A graphical chart with statistical control limits and plotted values (for some applications in chronological order) of some measured parameter for a series of samples. Use of the charts provides a visual display of the pattern of the data, enabling the early detection of time trends and shifts in level. For maximum usefulness in control, such charts should be plotted in a timely manner (i.e., as soon as the data are available).

Statistical control chart limits: The limits on control charts that have been derived by statistical analysis and are used as criteria for action, or for judging whether a set of data does or does not indicate lack of control. On a means control chart, the warning level may be two standard deviations above and below the mean, and the control limit may be three standard deviations above and below the mean.

Systematic error: The condition of a consistent deviation of the results of

a measurement process from the reference or known level. The cause for the deviation, or bias, may be known or unknown, but is considered "assignable" (i.e., if the cause is unknown, it should be possible to determine the cause). See **Bias**.

Time integrated sampling: Sampling conducted over a specific time period (e.g., from two days to a year or more) producing results representative of the average value for that period.

Uncertainty: The estimated bounds of the deviation from the mean value, expressed generally as a percentage of the mean value. Taken ordinarily as the sum of (1) the random errors (errors of precision) at the 95% confidence level, and (2) the estimated upper bound of the systematic error (errors of accuracy).

Variance: Mathematically, the sample variance is the sum of squares of the differences between the individual values of a set and the arithmetic average of the set, divided by one less than the number of values:

$$s^2 = \frac{\sum_{i=1}^{n} (X_i - X_{ave})^2}{n - 1}$$

For a finite population, the variance s^2 is the sum of squares of deviations from the arithmetic mean, divided by the number of values in the population:

$$\sigma^2 = \frac{\sum_{i=1}^{N} (X_i - \mu)^2}{N}$$

where μ is the true arithmetic mean of the population.

Working level (WL): Any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy. This number was chosen because it is approximately the alpha energy released from the decay products in equilibrium with 100 pCi of Ra-222. Exposures are measured in working level months (WLM).

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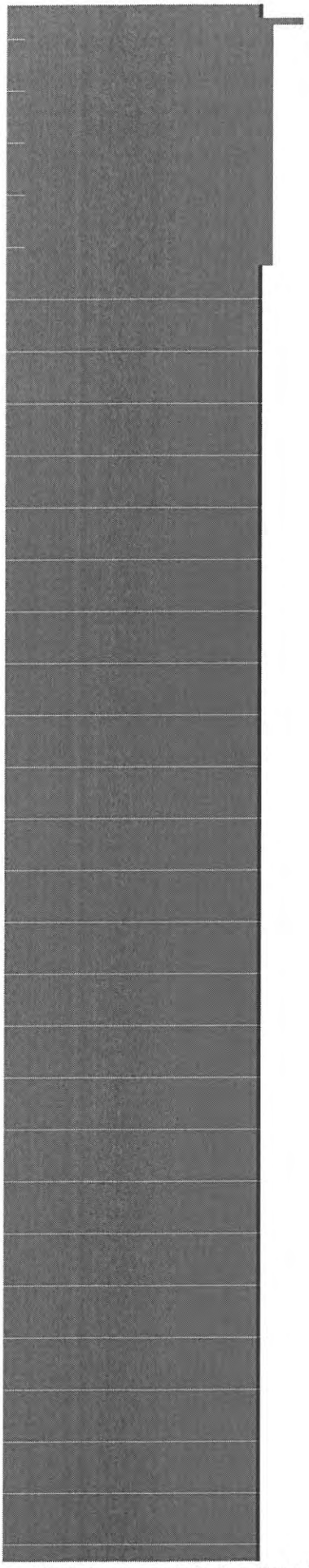

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