



Standard Test Method for Radon in Drinking Water¹

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1. Scope

1.1 This test method covers the measurement of radon in drinking water in concentrations above 2 Bq/L.

1.2 This test method may be used for absolute measurements by calibrating with a ^{226}Ra standard or for relative measurements by comparing the measurements made with each other.

1.3 This test method is used successfully with drinking water samples and Type III reagent water conforming to Specification D1193. It is the user's responsibility to ensure the validity of this test method for waters of untested matrices.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:²

D1129 Terminology Relating to Water

D1193 Specification for Reagent Water

D2777 Practice for Determination of Precision and Bias of Applicable Test Methods of Committee D19 on Water

D3370 Practices for Sampling Water from Closed Conduits

D7902 Terminology for Radiochemical Analyses

D5847 Practice for Writing Quality Control Specifications for Standard Test Methods for Water Analysis

2.2 Other Documents:

Multi-Agency Radiological Laboratory Analytical Protocols Manual EPA402-B-04-001A, NUREG1576, NTIS

¹ This test method is under the jurisdiction of ASTM Committee D19 on Water and is the direct responsibility of Subcommittee D19.04 on Methods of Radiochemical Analysis.

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

PB2004-105421, July 2004

3. Terminology

3.1 Definitions:

3.2 For definitions of terms used in this standard, refer first to Terminology D7902 and second to Terminology D1129. For terms not defined in this standard, or in Terminologies D7902 or D1129, reference may be made to other published glossaries.

4. Summary of Test Method

4.1 This test method is based on the scintillation counting of ^{222}Rn and its progeny.

4.2 In a glass liquid scintillation vial, an aliquot of unaerated water is drawn into a syringe then gently injected beneath 10 mL of a suitable liquid scintillation cocktail that does not contain an emulsifier. The vials are capped, shaken, and allowed to stand 3 hours prior to counting to permit dark adaptation and buildup of short-lived radon progeny. Radon-222 contained in the sample is selectively partitioned into the scintillation cocktail. The sample is counted using a liquid scintillation counting system optimized for detection of ^{222}Rn activity.

5. Significance and Use

5.1 The most prevalent of the radon isotopes in ground water is ^{222}Rn . This isotope presents the greatest health risk compared to the other naturally occurring radon isotopes if ingested via the water pathway.

6. Interferences

6.1 Other radionuclides soluble in the scintillation cocktail may interfere. High energy beta/gamma emitters, even though they are not soluble in the scintillation mix, may also interfere. These interferences will cause a high bias if present in a significant quantity. These interferences would be rare in drinking water samples but may be observed in some cases.

6.2 A reduced or increased counting efficiency may result if sample quenching is significantly different than that of the calibration standard.

6.3 Scintillation stock cocktails and sample cocktail mixes must be dark-adapted to prevent artificial excitation of fluorors

which may lead to falsely elevated count rates which could compromise data quality.

7. Apparatus

7.1 *Sampling Funnel.*

7.2 *Tube, with standard faucet fitting.*

7.3 *Disposable Syringe, 12 mL capacity, with 20 gauge, 38 mm hypodermic needle.*

7.4 *Glass Liquid Scintillation Vials, 20 mL capacity with polyethylene inner seal cap liners.*

7.5 *Liquid Scintillation Counter.*

8. Reagents and Materials

8.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.³ Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

8.2 *Purity of Water*—Unless otherwise indicated, references to water shall be understood to mean conforming to Specification **D1193**, Type III.⁴

8.3 *Radioactive Purity of Reagents*—Radioactive purity shall be such that the measured radioactivity of blank samples does not exceed the calculated probable error of measurements.

8.4 *Radium-226 Solution Standard*, traceable to a national standards laboratory such as the National Institute of Standards and Technology (NIST) or the National Physical Laboratory (NPL).

8.5 *Scintillation Cocktail Mix*, without emulsifier. Toluene based mix is acceptable.

9. Safety

9.1 Some scintillation cocktails can pose a significant health hazard if handled improperly. Refer to manufacturer instructions for the safe use of these materials.

³ *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, DC. For Suggestions on the testing of reagents not listed by the American Chemical Society, see *Annual Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

⁴ If this water is not aerated or degassed prior/subsequent to demineralization, radon background may be substantial. This can happen if the lab uses RO, EDI or only demineralization resins for purification of their water.

10. Sampling

NOTE 1—Refer to Practices **D3370** for applicable sampling instructions. Also see U.S. Environmental Protection Agency reports EPA 520⁵ and EPA 600.⁶

10.1 Attach the sampling funnel and tube to a faucet with the standard faucet fitting.

10.2 Slowly turn on the water and allow a steady stream to flow out of the funnel for approximately 2 min. This purges the tube and ensures a fresh sample.

10.3 Reduce the flow of water and invert the funnel. The flow should be adjusted to a level that does not cause turbulence in the pool of water contained in the funnel. Allow excess water to spill over one edge of the funnel.

10.4 Examine the hose connection and tubing for air bubbles or pockets. If these are visible, raise or lower the funnel until they are removed.

11. Calibration and Standardization

11.1 Add a known quantity of traceable ²²⁶Ra standard solution to a known volume of water.

11.2 Prepare three ²²²Rn calibration standards by combining a 10 mL aliquot of the ²²⁶Ra standard solution with 10 mL of scintillation cocktail in a 20 mL glass scintillation vial. Securely cap each vial and shake to mix the contents.

11.3 In liquid scintillation vials, prepare three background samples containing 10 mL of Type III reagent water and 10 mL of scintillation solution. Cap the vials and shake to mix the contents.

11.4 Allow approximately 30 days for buildup of radon (that is, secular equilibrium with ²²⁶Ra).

11.5 Shake vial to transfer nearly all the radon to the scintillation mix phase (radon is highly soluble in the scintillation mix). The ²²⁶Ra remains in the aqueous phase and, therefore, does not contribute significantly to the count rate.

11.6 Allow for the buildup of short-lived radon progeny and for dark-adapting by waiting 3 hours before counting.

11.7 Count the standard samples for a counting period sufficiently long to obtain a relative counting uncertainty of <1 % (10 000 net counts minimum). Count background samples at least as long as the test samples.

⁵ EPA 520/5–83–027 Methods and Results of EPA's Study of Radon in Drinking Water. Published December 1983. Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, <http://www.access.gpo.gov>.

⁶ EPA 600/2–87/082 Two Test Procedures for Radon in Drinking Water. Published March 1989. Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, <http://www.access.gpo.gov>.

11.8 Calculate the calibration factor (CF) as in accordance with 13.1.

12. Procedure

12.1 Clean scintillation vials with alcohol and add 10 mL of scintillation cocktail.

12.2 Collect unaerated sample in accordance with Section 10.

12.3 Place the tip of the hypodermic needle approximately 3 cm under the surface of the water in the funnel and withdraw a few millilitres of water and eject this water. Using this procedure, rinse the syringe and hypodermic needle two or three more times.

12.4 Again, place the tip of the needle approximately 3 cm below the surface of the water and withdraw approximately 12 mL.

NOTE 2—The water should be pulled into the syringe slowly to avoid extreme turbulence and collection of air bubbles. If large air bubbles are noticed in the syringe, the sample should be rejected and redrawn.

12.5 Invert the syringe and slowly eject any small air bubbles and extra water. Retain precisely 10 mL of water in the syringe.

12.6 Remove the cap from a vial and carefully place the tip of the needle into the bottom of the liquid scintillation solution. Slowly eject the water from the syringe into the vial.

NOTE 3—Water is injected under the liquid scintillation solution to prevent loss of radon from the sample. If the water is forced out of the syringe with much pressure, it will cause turbulence in the solution and could result in loss of radon.

12.7 Carefully withdraw the hypodermic needle from the vial and replace the cap. The cap should be tightly secured to prevent leakage. Shake the vial to mix the contents.

12.8 Repeat the previous steps to obtain two separate aliquots from each sample.

12.9 Load the samples into the liquid-scintillation counting system and after waiting for 3 h, count at least 50 minutes.

12.10 After dark-adapting them, count a background sample, consisting of 10 mL of water and 10 mL of scintillation solution, and a standard radium-226 solution sample for 50 min at the beginning of counting and after every ten drinking water samples.

13. Calculation

13.1 *Calibration Factor, CF:*

$$CF = \frac{(C_{CS} - C_B)}{A_{CS}} \quad (1)$$

where:

C_{CS} = calibration standard count rate, counts per second (s^{-1}) (as prepared in 11.2),

C_B = average background sample count rate (s^{-1}) (as prepared in 11.3), and

A_{CS} = calibration standard ^{226}Ra activity, Bq.

13.2 *Sample Activity, AC*—Calculate the radon activity concentration in the sample as follows. First calculate the net count rate in counts per second:

$$R_n = R_a - R_b \quad (2)$$

Then calculate the activity concentration of radon in the sample, in becquerels per litre (Bq/L), using the following equation:

$$AC = \frac{R_n}{CF \times D \times V_a} \quad (3)$$

where:

AC = activity concentration of ^{222}Rn (Bq/L),

R_a = Sample count rate (s^{-1}),

R_b = background count rate (s^{-1}),

R_n = net count rate (s^{-1}),

CF = calibration factor calculated as in Eq 1,

D = decay correction factor $D = e^{-\ln(2) \times T/t_{1/2}}$,

V_a = volume of sample analyzed (0.010 L),

T = time in days from collection time to midpoint of counting time, and

$t_{1/2}$ = half-life of ^{222}Rn , 3.82 d.

13.3 Estimate the square of the standard uncertainty of R_n as follows:

$$u^2(R_n) = \begin{cases} \frac{J \times R_n + 2R_b}{t}, & \text{if } R_n > 0 \\ \frac{R_a + R_b}{t}, & \text{if } R_n \leq 0 \end{cases} \quad (4)$$

where:

t = counting time of the sample and background (s), and

J = index of dispersion for the net counts produced by ^{222}Rn and its progeny.⁷

If the counting time t is 3000 s, then J is approximately equal to 1.83 if the counter is configured to count alpha radiation only and J is approximately equal to 2.78 if it is configured to count both alpha and beta radiation. For longer count times estimate J as follows:

$$J = \frac{c_5 + \sum_{i=0}^3 c_i e^{-\lambda_i t}}{1 - e^{-\lambda_0 t}} \quad (5)$$

where the decay constants λ_0 through λ_3 are given by:

$\lambda_0 = 2.098 \times 10^{-6} \text{ s}^{-1}$,

$\lambda_1 = 0.003\,727 \text{ s}^{-1}$,

$\lambda_2 = 0.000\,431 \text{ s}^{-1}$, and

$\lambda_3 = 0.000\,581 \text{ s}^{-1}$.

and where the coefficients c_0 through c_5 are given either by:

$c_0 = -3.0060503$

$c_1 = 0.00038339968$

$c_2 = 0.026908241$

$c_3 = -0.015190995$

$c_4 = 0$

$c_5 = 2.9939497$

⁷ Lucas, H.F., Jr., and D.A. Woodward, *Journal of Applied Physics*, Vol. 35, pg. 452, 1964.

J vs. Count Time (t) in Minutes

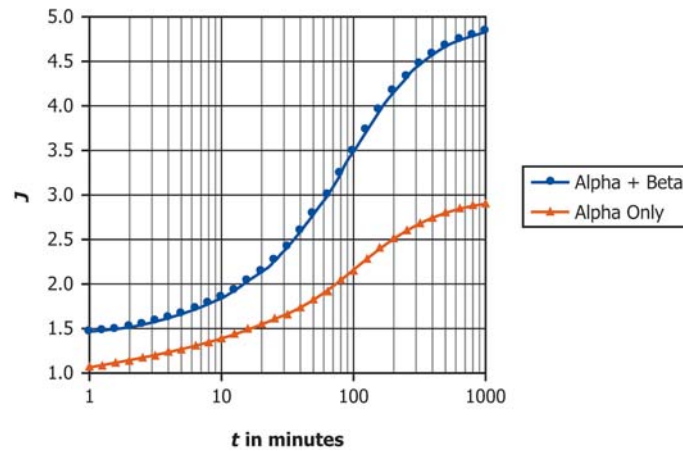


FIG. 1 Plot of J Verses Count Time (minutes) from Eq 5

if the counter is configured to count alpha radiation only, or by:

- $c_0 = -5.0106487$
- $c_1 = 0.00020574781$
- $c_2 = 0.036387727$
- $c_3 = -0.015296013$
- $c_4 = 0$
- $c_5 = 4.9893513$

if the counter is configured to count both alpha and beta radiation.

13.4 The combined standard uncertainty of the radon activity concentration can be estimated as follows:

$$u_c(AC) = \frac{\sqrt{u^2(R_n) + R_n^2 \times (u_r^2(CF) + u_r^2(V_a) + u_r^2(D))}}{CF \times D \times V_a} \quad (6)$$

where:

- $u_c(AC)$ = combined standard uncertainty of the radon activity concentration (Bq/L),
- $u_r(CF)$ = relative standard uncertainty of the calibration factor CF,⁸
- V_a = volume of sample analyzed (0.010 L),
- $u_r(V_a)$ = relative standard uncertainty of the volume (0.010 L) of sample analyzed, and
- $u_r(D)$ = relative standard uncertainty of the decay correction D.

13.5 The *a priori* minimum detectable radon activity concentration (MDC) can be estimated by the following equation:

$$MDC = \frac{\frac{2.71 \times J}{t} + 4.65 \sqrt{\frac{R_b}{t}}}{CF \times D \times V_a} \quad (7)$$

where:

- MDC = minimum detectable radon activity concentration (Bq/L).

13.6 The critical level L_c for radon activity concentration can be calculated by the following equation:

$$L_c = \frac{2.33 \sqrt{\frac{R_b}{t}}}{CF \times D \times V_a} \quad (8)$$

where:

- L_c = critical level radon activity concentration (Bq/L).

14. Precision and Bias⁹

14.1 The collaborative test conducted on this test method included 15 laboratories each with one operator. Three activity levels between 60 Bq/L and 2454 Bq/L were tested with three replicates per level. The determination of the precision and bias statements were made in accordance with Practice D2777.

14.2 These collaborative test data were obtained using reagent grade water. For other matrices, these data may not apply.

14.3 The overall and single operator precision have been found to vary with level in a manner according to Table 1.

14.4 The bias of this test method, based upon the collaborative test data, was found to vary with level according to Table 2.

15. Quality Control

15.1 In order to provide reasonable assurance that the analytical results obtained using this method are valid and accurate within the confidence limits of the method, Quality Control (QC) samples are analyzed with each batch of samples undergoing analysis. Each batch should include not more than 20 samples excluding those used for QC purposes. Laboratory or project quality assurance plans may contain more restrictive process QC requirements. The following minimum QC procedures must be followed when running the test method:

15.2 Initial Demonstration of Laboratory/Instrument/Analyst Capability:

⁸ Guidance on calculating standard uncertainties can be found in Multi-Agency Radiological Laboratory Analytical Protocols Manual, chapter 19.

⁹ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D19-1142. Contact ASTM Customer Service at service@astm.org.

TABLE 1 Radon Precision Data

Bq/L	s(o)	s(t)
60	3	5
604	20	61
2454	67	288

TABLE 2 Radon Bias Data

Amount Added Bq/L	Amount found Bq/L	% Bias
60	58	-2.6
604	576	-4.7
2454	2308	-6.0

15.2.1 If a laboratory or analyst has not performed this test before or there has been a major change in the measurement system, for example, significant instrument change, new instrument, etc., a precision and bias study must be performed to demonstrate laboratory, analyst, or instrument capability. A significant change is defined as any change, repair, or alteration of any component in the system, which may be expected to affect the response of the measurement system.

15.2.2 Analyze seven replicates of a standard solution prepared from an independent reference material (IRM) containing accurately known concentrations of ^{226}Ra at concentrations sufficient to minimize the counting uncertainty to 2 % or less at one sigma. Each replicate should be prepared in accordance with Section 11. The matrix and chemistry of the solution should be equivalent to that of the samples.

15.2.3 Calculate the mean and standard deviation of the replicate values and compare to the acceptable ranges of precision and mean bias of 10 % and ± 10 % respectively, based on a review of the collaborative study data. Practice D5847 should be consulted on the manner by which precision and mean bias are determined from the initial demonstration study.

15.2.4 Analyze three replicates of a blank solution matrix. The matrix used for the demonstration should represent a water sample typical for which the method will be used.

15.2.5 Calculate the radon activity for each of these three blank solutions. The result of each of the three blank solutions should be below the critical level.

15.3 Calibration Verification Standard:

15.3.1 To ensure that the test method is within control limits, analyze a Calibration Verification Standard with each batch of no more than 20 samples.

15.3.2 Add a known quantity of traceable ^{226}Ra standard solution to a known volume of water. The standard solution should be prepared from an independent reference material (IRM) than the calibration solution of Section 11.

15.3.3 Combine a 10 mL aliquot of the ^{226}Ra standard solution with 10 mL of scintillation mix in a 20 mL glass scintillation vial. The activity added should be appropriate for

the type of samples analyzed and allow sufficient precision to ensure a meaningful assessment of accuracy. Securely cap the vial and shake to mix the contents.

15.3.4 Allow approximately 30 days for buildup of radon (that is, secular equilibrium with ^{226}Ra).

15.3.5 Shake the vial to transfer radon to the scintillation mix phase.

15.3.6 Allow for the buildup of short-lived radon progeny and for dark-adapting by waiting 3 hours before counting.

15.3.7 The result obtained for the Calibration Verification Standard should fall within the limit of ± 15 % of the expected value.

15.3.8 If the result is not within the limit, analyses should be stopped and the reason for the failure should be identified and resolved.

15.4 Method Blank:

15.4.1 Analyze a reagent water test blank with each batch of no more than 20 samples. The concentration of radon found in the blank should be less than the critical level. If the radon activity is found above this level, provide an explanation in a case narrative.

15.5 Duplicate:

15.5.1 To check the precision of sample analyses, analyze a sample in duplicate with each batch of no more than 20 samples. Calculate the statistical agreement duplicate error ratio (DER) between the two results. This calculation is performed using the combined standard uncertainty of each result as shown below.

$$DER = \frac{|AC_S - AC_D|}{\sqrt{u^2(AC_S) + u^2(AC_D)}} \quad (9)$$

where:


- AC_S = original sample activity concentration,
- AC_D = duplicate sample activity concentration,
- $u(AC_S)$ = combined standard uncertainty of the original sample, and
- $u(AC_D)$ = combined standard uncertainty of the duplicate sample.

15.5.2 In those cases where there is insufficient sample volume to allow performance of a duplicate sample analysis, a duplicate Calibration Verification Standard should be performed and analyzed using the same DER criteria.

15.5.3 The value of DER should be less than or equal to 3.0. If the sample duplicate or Control Standard duplicate result is not within these limits all samples in the batch must be reanalyzed, or an explanation must be provided in a case narrative.

16. Keywords

16.1 ^{222}Rn ; ^{226}Ra ; Ra-226; radium; radium-226; radon; radon-222; Rn-222; water-drinking

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