Designation: D4107 – 08 (Reapproved 2013)

Standard Test Method for Tritium in Drinking Water[1]

This standard is issued under the fixed designation D4107; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of tritium in drinking water by liquid scintillation counting of the tritium beta particle activity.

1.2 This test method is used successfully with drinking water. It is the user's responsibility to ensure the validity of this test method for untested water matrices.

1.3 The tritium concentrations, which can be measured by this test method utilizing currently available liquid scintillation instruments, range from less than 0.037 Bq/mL (1 pCi/mL) to 555 Bq/mL (15 000 pCi/mL) for a 10-mL sample aliquot. Higher tritium concentrations can be measured by diluting or using smaller sample aliquots, or both.

1.4 The maximum contaminant level for tritium in drinking water as given by the United States Environmental Protection Agency (U.S. EPA) National Interim Primary Drinking Water Regulations (NIPDWR) is 0.740 Bq/mL (20 pCi/mL). The NIPDWR lists a required detection limit for tritium in drinking water of 0.037 Bq/mL (1 pCi/mL), meaning that drinking water supplies, where required, should be monitored for tritium at a sensitivity of 0.037 Bq/mL (1 pCi/mL). In Appendix X1, Eq X1.3 is given for determining the necessary counting time to meet the required sensitivity for drinking water monitoring.

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

1.6 *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
D3648 Practices for the Measurement of Radioactivity

3. Terminology

3.1 *Definitions*—For definitions of terms used in this test method, refer to Terminology D1129. For terms not defined in this test method or in Terminology D1129, reference may be made to other published glossaries.[3]

4. Summary of Test Method

4.1 In this test method, a 100-mL drinking water sample aliquot is treated with a small amount of sodium hydroxide and potassium permanganate, distilled, and a specified fraction of the distillate is collected for tritium analysis. The alkaline treatment is to prevent other radionuclides, such as radioiodine and radiocarbon from distilling over with the tritium. Some drinking water supplies will contain trace quantities of organic compounds, especially surface water sources that contain fish and other life. The permanganate treatment is to oxidize trace organics in the sample aliquots which could distill over and cause quenching interferences. A middle fraction of the distillate is collected for tritium analysis because the early and late fractions are more apt to contain interfering materials for the liquid scintillation counting process.

4.2 As the sample distills, there is a gradient in the tritium concentration in the accumulating distillate due to isotope effects; therefore, it is important to collect the same fraction of the distillate for all samples and standards for tritium analysis.

[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.

[3] *American National Glossary of Terms in Nuclear Science and Technology*, available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, www.ansi.org.

4.3 The collected distillate fraction is thoroughly mixed and a portion (up to 10 mL) is mixed with liquid scintillator solution, and after dark adapting, is counted in the liquid scintillation counting system for tritium beta particle activity.

5. Significance and Use

5.1 This test method was developed for measuring tritium in water to determine if the concentration exceeds the regulatory statutes of drinking water. This test method also is applicable for the determination of tritium concentration in water as required by technical specifications governing the operations of nuclear power facilities. With suitable counting technique, sample size, and counting time a detection limit of less than 37 Bq/L (1000 pCi/L) is attainable by liquid scintillation.

6. Interferences

6.1 A reduced detection efficiency may result from quenching in the sample scintillator mixture. Quenching is caused by impurities in the sample, which can inhibit the transfer of energy, or by colored materials, which may absorb some of the emitted light. Corrections for quenching can be made by the use of internal standards[3] or by the ratio method.[4] The approach described in this test method, distillation after alkaline permanganate treatment, eliminates quenching substances, as well as radionuclides which might be present in a volatile chemical form such as radioiodine and radiocarbon. A boiling chip must be used with each distillation to avoid bumping, which can amount to a carry over excursion.

6.2 Scintillator stock solution or samples exposed to daylight must be dark-adapted. Also, toluene or xylene base scintillators exposed to fluorescent lighting should be dark-adapted for a minimum of 6 h and dioxane base scintillators exposed to fluorescent lighting for 24 h. All fluors should be checked for excitation under lighting conditions being used, and if possible, they should be exposed only to red light.

7. Apparatus

7.1 *Liquid Scintillation Spectrometer,* coincidence-type.

7.2 *Liquid Scintillation Vials,* of low-potassium glass are recommended. Polyethylene vials may be used when other than dioxane scintillator solution is used.

7.3 *Distillation Apparatus*—For aqueous distillation, 250-mL and 1000-mL round bottom borosilicate flasks, connecting side arm adapter,[5] condenser, graduated cylinder, boiling chips, and heating mantle.

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.[6] 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 reagent water conforming to Specification D1193, Type III.

8.3 *Reagents of Distillation Treatment:*

8.3.1 *Sodium Hydroxide Pellets.*

8.3.2 *Potassium Permanganate.*

8.4 *Background Water,* with tritium activity below the minimum detectable activity (most deep well waters are low in tritium content).

8.5 *Scintillator Solutions:*

8.5.1 *Dioxane Liquid Scintillator Solution*—Dissolve 4 g of scintillation-grade PPO (2,5-diphenyloxazole), 0.05 g of scintillation-grade POPOP [1,4-bis (5-phenyloxazolyl-2-yl)-benzene], and 120 g of naphthalene in 1 L of spectroquality, 1,4-dioxane. Store the solution in a dark (amber) bottle. This solution can be used with glass or polyethylene vials.

8.5.2 *Solution G Scintillator Solution*—Dissolve 18 g of scintillation-grade PPO (2,5-diphenyloxazole) and 3.6 g of scintillation-grade BIS-MSB [p-bis (o-methylstyryl) benzene] in 2 L of spectroquality *p*-xylene. Add 1 L of Triton N-101[7] detergent to the *p*-xylene scintillator solution. Dissolve 50 g of SXS (sodium xylene sulfonate) in 100 mL of water and add this solution to the *p*-xylene scintillator-Triton solution. Mix thoroughly. Store the solution in a dark (amber) bottle. This solution should be used with glass vials since the *p*-xylene solvent evaporates slowly through the wall of the polyethylene vials.

8.5.3 Other commercially available scintillators can be used, such as the environmentally safe di-isopropyl napthalene based scintillators. It is the responsibility of the user to verify the acceptability of a substitute scintillator.

8.6 Tritium standard solution as tritiated water traceable to a National Standards Laboratory such as NIST or NPL, approximately 17 kBq/mL.

9. Sampling

9.1 Collect the sample in accordance with Practices D3370.

9.2 Since tritium in drinking water is likely to be in the form of T_2O or HTO, there is no need for special handling or preservation.

[4] Bush, E. T., "General Applicability of the Channels Radio Method of Measuring Liquid Scintillation Counting Efficiencies," *Analytical Chemistry*, Vol 35, No. 1024, 1963.

[5] Corning Part No. 9060 has been found satisfactory for this purpose.

[6] *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.

[7] The sole source of supply of the apparatus known to the committee at this time is Rohm and Haas Company, Independence Mall West, Philadelphia, PA 19105. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

10. Calibration

10.1 *Determination of Recovery and Detection Efficiency Factors:*

10.1.1 Prepare in a 1-L volumetric flask, a tritium standard solution containing approximately 17 Bq/mL using low level tritium background raw water, RWS (undistilled), and standard tritium activity. Label this solution as *raw water tritium standard solution, RWTS*.

10.1.1.1 Distill approximately 600 mL of water obtained from the same raw water source (RWS) as above (without tritium activity added). Use this distillate for background tritium determinations. Using the distillate and standard tritium activity, prepare a tritium standard solution in a 500-mL volumetric flask to contain the same specific activity as the raw water tritium standard solution. Label this solution as *distilled water tritium standard solution, DWTS*.

10.1.2 *Aqueous Alkaline Permanganate Distillation*—Place a 100-mL aliquot of the RWTS solution in a 250-mL distillation flask. Add 0.5 g of sodium hydroxide, 0.1 g of potassium permanganate, and a boiling chip. Proceed with the distillate according to the procedure described in 11.1, discard 10 mL, and collect 50 mL of distillate for analysis. Mix the 50-mL distillate fraction. Repeat the distillation with two more 100-mL aliquots for triplicate analyses. This is the distilled raw water tritium standard (DRWTS).

10.1.3 Prepare for counting three aliquots of the DRWTS distillate tritium standard solution (from 10.1.2), three aliquots of the DWTS, and three aliquots of the distilled raw water (for background). Mix 4 mL of water with 16 mL of the dioxane scintillator solution, or 10 mL of water with 12 mL of Solution G scintillator solution in a liquid scintillator vial (glass vials should be used for detergent-type scintillator solutions). Shake well, dark-adapt the vials overnight, and count in a liquid scintillation counter. Count each vial long enough to meet the required detection (0.037 Bq/mL) or longer (see Appendix X1 for calculating required counting time).

11. Procedure

11.1 Add 0.5 g of sodium hydroxide and 0.1 g of potassium permanganate to a 100-mL aliquot of the sample in a 250-mL distillation flask. Add a boiling chip to the flask. Connect a side-arm adapter and a condenser to the outlet of the flask. Place a graduated cylinder at the outlet of the condenser. Heat the sample to boiling to distill, collect the first 10 mL of distillate as a separate fraction and discard it.

11.2 Collect the next 50 mL of distillate for tritium analysis. Thoroughly mix the 50-mL distillate fraction.

NOTE 1—It is important that only the first 10-mL fraction be discarded or the same fraction for samples and standards alike since there is a gradient in the tritium concentration of the distillate.

11.3 Thoroughly mix 4 mL of the distillate with 16 mL of the dioxane scintillator or 10 mL of distillate with 12 mL of Solution G scintillator in a liquid scintillation vial. Three aliquots of each sample distillate should be analyzed for tritium.

11.4 Prepare background standard tritium-water solutions for counting, using the same amount of water and the same scintillator as used in the preparation of samples. Use low tritium background distilled water for these preparations (distillate of most deep well water sources is acceptable, but each source should be checked for tritium activity before using).

11.5 Dark-adapt all samples, backgrounds, and standards. Count the samples, backgrounds, and standards at least long enough to meet the required detection limit (0.037 Bq/mL) for the sample (see Appendix X1 for calculating counting time for required detection limit). The DRWS distillate should be counted for sufficient time to accumulate at least 50 000 net counts.

12. Calculation

12.1 *Detection Efficiency, ε:*

$$\epsilon = \frac{R_{DWTS} - R_b}{A_{DWTS}} \tag{1}$$

$$u(\epsilon) = \sqrt{\frac{\frac{R_{DWTS}}{t_{DWTS}} + \frac{R_b}{t_b}}{A_{DWTS}^2} + \epsilon^2 \left(\frac{u(A_{DWTS})}{A_{DWTS}} \right)^2}$$

where:

A_{DWTS} = activity of distilled water tritium standard, in becquerels (Bq),
R_b = background aliquot count rate, in counts per second (s^{-1}),
R_{DWTS} = distilled water tritium standard count rate (s^{-1}),
$u(A_{DWTS})$ = standard uncertainty of the activity ADWTS (Bq),
t_{DWTS} = count time for the distilled water tritium standard (seconds), and
t_b = count time for the background sample (seconds).

12.2 *Recovery Correction Factor, F:*

$$F = \frac{R_{DWTS} - R_b}{\epsilon \times A_{RWTS}} \tag{2}$$

where:

R_{DRWTS} = count rate of distilled raw water standard (s^{-1}), and
A_{RWTS} = activity of (undistilled) raw water tritium standard Bq.

12.3 *Sample Tritium Activity, AC, for each aliquot:*

$$AC = \frac{R_a - R_b}{\epsilon \times F \times V \times e^{-\lambda t}} \tag{3}$$

where:

R_a = sample aliquot gross count rate (s^{-1}),
R_b = background aliquot count rate (s^{-1}),
ε = detection efficiency, as determined in Eq 1,
V = volume of the sample aliquot (mL),
F = recovery factor, as determined in Eq 2,
λ = decay constant for tritium, (ln 2) / $t_{1/2}$,
$t_{1/2}$ = half-life of tritium, 4500 d, and
t = elapsed time between sampling and counting, in days.

12.4 The result of the measurement has an uncertainty due to counting statistics (counting uncertainty). The component of

the combined standard uncertainty of the tritium concentration in the sample due to counting statistics, $u_{cC}(AC)$, is given by:

$$u_{cC}(AC) = \frac{\sqrt{\frac{R_a}{t_a} + \frac{R_b}{t_b}}}{\epsilon \times F \times V \times e^{-\lambda t}} \quad (4)$$

where:

t_b = count time of the background sample, in seconds.

12.5 The combined standard uncertainty, $u_c(AC)$, of the measured concentration can be calculated as follows:

$$u_c(AC) = \sqrt{u_{cC}^2(AC) + AC^2\left[\left(\frac{u(F)}{F}\right)^2 + \left(\frac{u(V)}{V}\right)^2 + \left(\frac{u(\epsilon)}{\epsilon}\right)^2\right]} \quad (5)$$

where:

AC = measured tritium concentration (Bq/mL), from Eq 3,
$u_{cC}(AC)$ = standard counting uncertainty of AC , from Eq 4,
$u(V)$ = standard uncertainty of the volume, V,
$u(\varepsilon)$ = standard uncertainty of the detection efficiency, ε, and
$u(F)$ = standard uncertainty of the recovery factor. The standard uncertainty of F could be determined by repeated measurements; however, since F will generally be close to 1, the uncertainty may be assumed to be 0.

12.6 For each sample measurement, calculate the critical activity concentration, L_C, in becquerels per milliliter (Bq/mL), as follows:

$$L_C = \frac{1.65\sqrt{R_b \times t_a \times \left(1 + \frac{t_a}{t_b}\right)}}{\epsilon \times t_a \times F \times V \times e^{-\lambda t}} \quad (6)$$

Other symbols are as defined previously. The measured activity concentration, AC, may be compared to L_C to determine whether tritium is clearly present in the sample.

12.7 When the detection criterion of Section 12.6 is used, calculate the *a priori* minimum detectable activity concentration (MDC) as follows:

$$MDC = \frac{2.71 + 3.29\sqrt{R_b \times t_a \times \left(1 + \frac{t_a}{t_b}\right)}}{\epsilon \times t_a \times F \times V \times e^{-\lambda t}} \quad (7)$$

where:

R_b = background count rate (s^{-1}),
t_a = counting time of sample in seconds, and
t_b = counting time of background in seconds.

13. Quality Control

13.1 In order to provide reasonable assurance that the analytical results obtained using this test 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, including 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:

13.2 *Initial Demonstration of Laboratory/Instrument Quality:*

13.2.1 If a laboratory or analyst has not performed this test before or there has been a major change in the measurement system, a precision and bias study must be performed to demonstrate laboratory/instrument capability. A significant change is defined as any change, repair, or alteration of any component in the system which maybe expected to affect the response of the measurement system. See Practices D3648 for recommended practices.

13.2.2 Analyze seven replicates of a standard solution prepared from an independent reference material (IRM) containing at ^3H concentrations sufficient to reduce the relative standard counting uncertainty to 1 % or less. The matrix used for the demonstration should represent a water sample typical for which the procedure will be used, for example, drinking water.

13.2.3 Calculate the mean and standard deviation of the seven 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. Test Method D2777 should be consulted on the manner by which precision and mean bias are determined from the initial demonstration study. The study should be repeated until the precision and bias are within the given limits.

13.2.4 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, for example, drinking water. The total dissolved solids (TDS) of the matrix should approximate that which may be encountered in normal use.

13.2.5 Calculate the ^3H activity for each of the three blank solutions. This method shall not be used for official samples until the results for each of the blank solutions is below half of the associated MDC.

13.2.6 This method shall not be used for official samples until precision, bias, and blank requirements are met.

13.3 *Laboratory Control Sample (LCS):*

13.3.1 To ensure that the test method is in control, analyze an LCS with each batch of no more than 20 samples. The activity added to reagent water should be appropriate for the type of samples analyzed and should allow sufficient precision to ensure meaningful assessment of accuracy. The LCS must be taken through all the steps of the analytical method including sample preservation and pretreatment. The result for the LCS shall fall with the limit of ±25 % of the expected value.

13.3.2 If the result is not within the limit, analyses should be stopped and the reason for failure identified and resolved. An indication of the occurrence should accompany the reported results.

13.4 *Method Blank (Blank):*

13.4.1 Analyze a reagent water test blank or distilled RWS (if reagent water is known to contain ^3H) with each batch of no more than 20 samples. The concentration of ^3H found in the blank should be less than half the MDC.

13.4.2 If the concentration of ^3H is found above this level, provide an explanation in a case narrative.

13.5 *Matrix Spike (MS):*

13.5.1 Analyze at least one matrix spike sample with each batch of no more than 20 samples by spiking an aliquot of a sample within the batch with a known ^{3}H concentration.

13.5.2 The spike should produce a concentration of ^{3}H that is 2 to 5 times the anticipated sample concentration or as specified by the laboratory, whichever is greater.

13.5.3 The matrix spike must be taken through all the steps of the method.

13.5.4 Calculate the percent recovery of the matrix spike using the following formula:

$$R = \frac{AC_{as} - AC_a}{AC_s} \times 100\,\% \quad (8)$$

where:

AC_{as} = concentration of ^{3}H in Bq/mL measured in the spiked aliquot,
AC_a = concentration of ^{3}H in Bq/mL in the sample, and
AC_s = spiked concentration of 3H in Bq/mL.

13.5.5 The percent recovery, *R*, should fall within ±50 % of the expected value. If the concentration is not within these limits, provide an explanation in a case narrative.

13.6 *Duplicate:*

13.6.1 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.

$$DER = \frac{|\,AC_{original} - AC_{dup}\,|}{\sqrt{u_c^2(AC_{original}) + u_c^2(AC_{dup})}} \quad (9)$$

where:

$AC_{original}$ = original sample activity concentration,
AC_{dup} = duplicate sample activity concentration,
$u_c(AC_{original})$ = combined standard uncertainty of the original sample, and
$u_c(AC_{dup})$ = combined standard uncertainty of the duplicate sample.

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

13.6.3 The value of DER should be less than or equal to 3.0. If the sample duplicate or LCS duplicate result is greater than 3.0 all samples in the batch must be reanalyzed, or an explanation must be provided in a case narrative.

13.7 *Independent Reference Material (IRM):*

13.7.1 In order to verify the quantitative value produced by the test method, analyze an IRM sample, which was submitted on at least a single-blind basis (if practical) to the laboratory at least once per quarter. The concentration of analyte in the traceable reference material should be appropriate to the typical purpose for which the method is used. The value obtained shall demonstrate acceptable performance as defined by the program or the outside source.

13.7.2 In the absence of other acceptance criteria for the IRM sample, compare the IRM sample result to the IRM known value as follows:

$$R = \frac{|\,IRM_{found} - IRM_{known}\,|}{\sqrt{u_c^2(IRM_{found}) + u_c^2(IRM_{known})}} \quad (10)$$

where:

R = relative difference,
IRM_{found} = found concentration of the IRM,
IRM_{known} = known concentration of the IRM
$u_c(IRM_{found})$ = combined standard uncertainty of the IRM found concentration, and
$u_c(IRM_{known})$ = combined standard uncertainty of the IRM known concentration.

13.7.3 The value of R should be less than or equal to 3.0. If the value of *R* is greater than 3.0, the method should be investigated to determine the cause.

14. Precision and Bias[8]

14.1 The collaborative test conducted on this test method included fifteen laboratories each with one operator. Three activity levels between 0.26 and 11.10 Bq/mL were tested with three replicates per level. The determinations 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 *Precision*—The overall and single operator precision have been found to vary with level as presented in Table 1.

14.4 *Bias*—The bias of this test method, based upon the collaborative test data, was found to vary with level as presented in Table 1.

15. Keywords

15.1 drinking water; ^{3}H; liquid scintillation; radioactivity; radioisotope; tritium

[8] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D19-1146. Contact ASTM Customer Service at service@astm.org.

TABLE 1 Observed Tritium Precision and Bias Data

Added, Bq/mL	Measured Bq/mL	Absolute Bias, Bq/mL	Percent	Precision S_o	Precision S_t
0.26	0.25	0.01	−3.8	0.015	0.035
1.01	0.95	0.06	−5.9	0.020	0.120
11.4	10.5	0.9	−7.9	0.170	1.370

APPENDIX

(Nonmandatory Information)

X1. DETERMINATION OF THE NECESSARY COUNTING TIME FOR A REQUIRED DETECTION LIMIT (SENSITIVITY)

X1.1 Section 141.25 (c) of the National Interim Primary Drinking Water Regulations (NIPDWR) defines detection limit as follows:

For the purpose of monitoring radioactivity concentrations in drinking water, the required sensitivity of the radioanalysis is defined in terms of a detection limit. The detection limit shall be that concentration which can be counted with a precision of ±100 % at the 95 % confidence level (1.96 σ_N where σ_N is the standard deviation of the net counting rate of the sample).

X1.1.1 In this definition, the following equation is implied:

$$\sigma_N = \frac{N}{1.96} \tag{X1.1}$$

where:

N = net count rate, $R_a - R_b$.

X1.1.2 Also, the standard deviation of the net count rate can be calculated from the equation:

$$\sigma_N = \sqrt{\frac{R_a}{t_a} + \frac{R_b}{t_b}} \tag{X1.2}$$

where:

R_a = gross count rate (s^{-1}),
R_b = background count rate (s^{-1}),
t_a = counting time for the sample aliquant (seconds), and
t_b = counting time for the background (seconds).

X1.1.2.1 Let $t_a = t_b = t$. Then

$$\sigma_N = \sqrt{\frac{R_a + R_b}{t}} \tag{X1.3}$$

and

$$\sigma_N^2 = \frac{R_a + R_b}{t}$$

X1.1.3 Since the gross count rate, R_a, is equal to the net count rate, N, plus the background count rate, R_b, $R_a = N + R_b$. So,

$$\sigma_N^2 = \frac{N + 2R_b}{t} \tag{X1.4}$$

X1.1.3.1 Now, combine Eq X1.1 and Eq X1.4:

$$\sigma_N^2 = \frac{N + 2R_b}{t} = \left(\frac{N}{1.96}\right)^2 \tag{X1.5}$$

Solve for t:

$$t = \frac{3.84 \times N + 7.68 \times R_b}{N^2} \tag{X1.6}$$

X1.2 *Example*—The required detection limit for tritium in drinking water is 0.037 Bq/mL. Determine the counting time that is required to meet that detection limit when a 10-mL sample aliquot is counted at a detection efficiency of 15 % and a background count rate of 0.27 s^{-1}.

X1.2.1 *Calculation*—Calculate the absolute tritium activity, in becquerels, present in a 10 mL sample aliquot when the sample is at the required detection limit:

$$0.037\ Bq/mL \times 10\ mL = 0.37\ Bq = 0.37\ s^{-1}$$

Multiply the absolute activity by the measured detection efficiency to predict the net count rate:

$$0.37\ s^{-1} \times 0.15 = 0.0555\ s^{-1} = N$$

X1.2.2 Substitute N = 0.0555 s^{-1} and R_b = 0.27 s^{-1} in Eq X1.5. The required counting time would be as follows:

$$t = \frac{3.84 \times (0.0555\ s^{-1}) + 7.68 \times (0.27\ s^{-1})}{(0.0555\ s^{-1})^2} = 742\ s \tag{X1.7}$$