Standard Test Method for
Beta Particle Radioactivity of Water [1]

This standard is issued under the fixed designation D1890; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This test method covers the measurement of beta particle activity of water. It is applicable to beta emitters having maximum energies above 0.1 MeV and at activity levels above 0.02 Bq/mL (540 pCi/L) of radioactive homogeneous water for most counting systems. This test method is not applicable to samples containing radionuclides that are volatile under conditions of the analysis.

1.2 This test method can be used for either absolute or relative determinations. In tracer work, the results may be expressed by comparison with a standard which is defined to be 100 %. For radioassay, data may be expressed in terms of a known radionuclide standard if the radionuclides of concern are known and no fractionation occurred during processing, or may be expressed arbitrarily in terms of some other standard such as ^{137}Cs. General information on radioactivity and measurement of radiation may be found in the literature[2, 3, 4, 5] and Practice D3648.

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

1.4 *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:*[6]

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 of Terms Specific to This Standard:*

3.1.1 *Becquerel*—a unit of radioactivity equivalent to 1 nuclear transformation per second.

3.1.2 *beta energy, maximum*—the maximum energy of the beta-particle energy spectrum produced during beta decay of a given radioactive species.

3.1.2.1 *Discussion*—Since a given beta-particle emitter may decay to several different quantum states of the product nucleus, more than one maximum energy may be listed for a given radioactive species.

3.1.3 *counter background—in the measurement of radioactivity*, the counting rate resulting from factors other than the radioactivity of the sample and reagents used.

3.1.3.1 *Discussion*—Counter background varies with the location, shielding of the detector, and the electronics; it includes cosmic rays, contaminating radioactivity and electrical noise.

3.1.4 *counter beta-particle efficiency—in the measurement of radioactivity*, that fraction of beta particles emitted by a source which is detected by the counter.

3.1.5 *counter efficiency—in the measurement of radioactivity*, that fraction of the disintegrations occurring in a source which is detected by the counter.

3.1.6 *radioactive homogeneous water*—water in which the radioactive material is uniformly dispersed throughout the

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[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.

Current edition approved Jan. 1, 2015. Published February 2015. Originally approved in 1961. Last previous edition approved in 2012 as D1890 – 05 (2012). DOI: 10.1520/D1890-15.

[2] Friedlander, G., et al., *Nuclear and Radiochemistry* , 3rd Ed., John Wiley and Sons, Inc., New York, NY, 1981.

[3] Price, W. J., *Nuclear Radiation Detection*, 2nd Ed., McGraw-Hill Book Co., Inc., New York, NY, 1964.

[4] Lapp, R. E., and Andrews, H. L., *Nuclear Radiation Physics*, 4th Ed., Prentice-Hall Inc., New York, NY, 1972.

[5] Overman, R. T., and Clark, H. M., *Radioisotope Techniques*, McGraw-Hill Book Co., Inc., New York, NY, 1960.

[6] 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.

volume of water sample and remains so until the measurement is completed or until the sample is evaporated or precipitating reagents are added to the sample.

3.1.7 *reagent background—in the measurement of radioactivity of water samples*, the counting rate observed when a sample is replaced by mock sample salts or by reagent chemicals used for chemical separations that contain no analyte.

3.1.7.1 *Discussion*—Reagent background varies with the reagent chemicals and analytical methods used and may vary with reagents from different manufacturers and from different processing lots.

3.2 *Definitions*—For terms not defined in this test method or in Terminology D1129, reference may be made to other published glossaries.

4. Summary of Test Method

4.1 Beta radioactivity may be measured by one of several types of instruments composed of a detecting device and combined amplifier, power supply, and scaler—the most widely used being proportional or Geiger-Müller counters. Where a wide range of counting rates is encountered (0.1 to 1300 counts per seconds), the proportional-type counter is preferable due to a shorter resolving time and greater stability of the instrument. The test sample is reduced to the minimum weight of solid material having measurable beta activity by precipitation, ion exchange resin, or evaporation techniques. Beta particles entering the sensitive region of the detector produce ionization of the counting gas. The negative ion of the original ion pair is accelerated towards the anode, producing additional ionization of the counting gas and developing a voltage pulse at the anode. By use of suitable electronic apparatus, the pulse is amplified to a voltage sufficient for operation of the counter scaler. The number of pulses per unit of time is related to the disintegration rate of the test sample. The beta-particle efficiency of the system can be determined by use of prepared standards having the same radionuclide composition as the test specimen and equivalent residual plated solids. An arbitrary efficiency factor can be defined in terms of some other standard such as cesium-137.

5. Significance and Use

5.1 This test method was developed for the purpose of measuring the gross beta radioactivity in water. It is used for the analysis of both process and environmental water to determine gross beta activity.

6. Measurement Variables

6.1 The relatively high absorption of beta particles in the sample media and any material interposed between source and sensitive volume of the counter results in an interplay of many variables which affect the counting rate of the measurement. Thus, for reliable relative measurements, hold all variables constant while counting all test samples and standards. For absolute measurements, appropriate correction factors are applied. The effects of geometry, backscatter radiation, source diameter, self-scatter and self-absorption, absorption in air and detector window for external counters, and counting coincidence losses have been discussed[2, 3, 4, 5] and may be described by the following relation:

$$cps = Bq_b(G_p)(f_{bs})(f_{aw})(f_d)(f_{ssa})(f_c) \tag{1}$$

where:

cps = recorded counts per second corrected for background,

Bq_b = disintegrations per second yielding beta particles,

G_p = point source geometry (defined by the solid angle subtended by the sensitive area of the detector),

f_{bs} = backscatter factor or ratio of *cps* with backing to *cps* without backing,

f_{aw} = factor to correct for losses due to absorption in the air and window of external detectors. It is equal to the ratio of the actual counting rate to that which would be obtained if there were no absorption by the air and window between the source and sensitive volume of the detector. Expressed in terms of absorption coefficient and density of absorber, $f_{aw} = e^{-\mu x}$, where μ = absorption coefficient, in square centimetres per milligram, and x = absorber density in milligrams per square centimetre.

f_d = factor to correct a spread source counting rate to the counting rate of the same activity as a point source on the same axis of the system,

f_{ssa} = factor to correct for the absorption and scatter of beta particles within the material accompanying the radioactive element, and

f_c = factor for coincident events to correct the counting rate for instrument resolving time losses and defined by the simplified equation, $f_c = 1 - nr$, where, n = the observed counts per second, and r = instrument resolving time in seconds. Generally, the sample size or source to detector distance is varied to obtain a counting rate that precludes coincident losses. Information on the effect of random disintegration and instrument resolving time on the sample count rate as well as methods for determining the resolving time of the counting system may be found in the literature.

For most applications, a detector system is calibrated using a single beta emitting radionuclide and an efficiency of detection, f_o, response curve generated for various sample residue weights. The efficiency of detection for each sample residual weight incorporates all the factors mentioned above so that:

$$f_o = cps/Bq = (G_p)(f_{bs})(f_{aw})(f_d)(f_{ssa})(f_c) \tag{2}$$

6.1.1 In tracer studies or tests requiring only relative measurements in which the data are expressed as being equivalent to a defined standard, the above correction factors can be simply combined into a counting efficiency factor. The use of a counting efficiency factor requires that sample mounting, density of mounting dish, weight of residue in milligrams per square centimetre, and radionuclide composition, in addition to conditions affecting the above described factors, remain constant throughout the duration of the test and that the comparative standard be prepared for counting in the same manner as the test samples. The data from comparative studies between independent laboratories, when not expressed in absolute units, are more meaningful when expressed as percentage relationships or as the equivalent of a defined standard. Expressing the data in either of these two ways minimizes the differences in counters and other equipment and in techniques used by the laboratories conducting the tests.

6.2 The limit of sensitivity for both Geiger-Muller and proportional counters is a function of the background counting rate. Massive shielding or anti-coincidence detectors and circuitry, or both, are generally used to reduce the background counting rate to increase the sensitivity.

7. Interferences

7.1 Material interposed between the test sample and the instrument detector, as well as increasing density in the sample containing the beta emitter, produces significant losses in sample counting rates. Liquid samples are evaporated to dryness in dishes that allow the sample to be counted directly by the detector. Since the absorption of beta particles in the sample solids increases with increasing density and varies inversely with the maximum beta energy, plated solids shall remain constant between related test samples and should duplicate the density of the solids of the plated standard.

7.2 Most beta radiation counters are sensitive to alpha, gamma, and X-ray radiations, with the degree of efficiency dependent upon the type of detector.[2, 3, 4, 5] The effect of interfering radiations on the beta counting rate is more easily evaluated with external-type counters where appropriate absorbers can be used to evaluate the effects of interfering radiation.

8. Apparatus

8.1 *Beta Particle Counter,* consisting of the following components:

8.1.1 *Detector*—The end-window Geiger-Muller tube and the internal or external sample gas-flow proportional chambers are the two most prevalent commercially available detector types. The material used in the construction of the detector should be free from detectable radioactivity. When detectors contain windows, the manufacturer shall supply the window density expressed in milligrams per square centimetre. To establish freedom from undesirable characteristics, the manufacturer shall supply voltage plateau and background counting rate data. Voltage plateau data shall show the threshold voltage, slope, and length of plateau. Detectors requiring external positioning of the test sample are mounted on a tube support of low-density material (aluminum or plastic) and positioned so the center of the window is directly above the center of the test sample. The distance between the detector window and test sample plays an important part in determining the geometry of the system and can be varied for external counters to correspond more favorably with such factors as activity level, source size, sensitivity requirements, energy of beta particles, etc. A convenient arrangement is to combine the tube mount with a sample holder containing slots for positioning the sample at three or four distances from the detector window, varying from approximately 5 to 100 mm from tube flange.

8.1.2 *Detector Shield*—The detector assembly is surrounded by an external radiation shield of massive metal equivalent to approximately 51 mm of lead and lined with 3.2-mm thick aluminum. The material of construction should be free from detectable radioactivity. The shield has a door or port for inserting or removing specimens. Detectors having other than completely opaque windows are light sensitive. The design of the shield and its openings shall eliminate direct light paths to the detector window; beveling of door and opening is generally satisfactory. The percentage of the beta particles scattered from the walls of the shield into the detector can be reduced by increasing the internal diameter of the shield. The use of a detector without a shield will significantly increase the background and the detection capability.

8.1.3 *Scaler*—Normally the scaler, mechanical register, power supply, and amplifier are contained in a single chassis, generally termed the scaler. The power supply and amplifier sections are matched by the manufacturer with the type of detector to produce satisfactory operating characteristics and to provide sufficient range in adjustments to maintain controlled conditions. The manufacturer shall provide resolving time information for the counting system. The scaler shall have capacity for storing and visually displaying at least 10^6 counts and with a resolving time no greater than 250 µs for use with Geiger Muller detectors or 5 µs for use with proportional detectors. The instrument shall have an adjustable input sensitivity matched and set by the manufacturer to that of the detector, and a variable high-voltage power supply with indicating meter.

8.2 *Sample Mounting*—Sample mounting shall utilize dishes having a flat bottom of a diameter no greater than that of the detector window preferably having 3.2-mm high side walls with the angle between dish bottom and side equal to or greater than 120° to reduce side-wall scattering (Note 1). Dishes shall be of a material that will not corrode under the plating conditions and should be of uniform surface density preferably great enough to reach backscatter saturation.[2, 3, 4, 5]

NOTE 1—Sample dishes with vertical side walls may be used but the exact positioning of these dishes relative to the detector is very important. This factor becomes critical for dishes having the same diameter as the detector. Dishes having side walls more than 3.2 mm in height are not recommended. Stainless steel has been found to be satisfactory for this purpose.

8.3 *Alpha Particle Absorber*—Aluminum or plastic, having a uniform density such that total absorbing medium (air plus window plus absorber) between sample and sensitive volume of detector is approximately equal to 7 mg/cm^2 of aluminum. The absorber diameter shall be equal to or greater than the detector window and should be placed against the window to minimize scattering of the beta particles by the absorber. This absorber is not used when counting beta particles with maximum energies below 0.35 MeV due to the high-count rate loss by absorption (about 48 % at 0.35 MeV in 7 mg/cm^2 of aluminum). The alpha particle absorber is not recommended for use with internal beta particle detectors, especially when either the composition or activity ratios of the radionuclides or radioactivity level might vary significantly between samples. Chemical separation of the alpha and beta particle emitters produces a higher degree of accuracy for internal detector measurements. Use published information[2, 3, 4, 5] on beta particle absorption as a guide.

9. Reagents

9.1 *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. [7] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without increasing the background of the measurement.

NOTE 2—Some chemicals, even of high purity, contain naturally occurring radioactive elements, for example, rare earths and potassium compounds. Also, some chemical reagents, including organic compounds, have been found to be contaminated with artificially produced radionuclides. Consequently, when carrier chemicals are used in the analysis of low-radioactivity samples, the radioactivity of the carriers shall be determined under identical analytical conditions as used for the sample, including amounts of residual solids in the dish. The radioactivity of the reagents may be considered as background and subtracted from the test sample counting rate. This increased background reduces the sensitivity of the measurement.

9.2 *Purity of Water*—Unless otherwise indicated, reference to water shall be understood to mean reagent water conforming to Specification D1193, Type III.

9.3 *Cesium-137 Solution*—A ^{137}Cs solution containing approximately 200 Bq/mL with a calibration that is traceable to National Institute of Standards and Technology (NIST).

9.4 *Nitric Acid* (sp gr 1.42)—Concentrated nitric acid (HNO_3).

10. Sampling

10.1 Collect the sample in accordance with Practices D3370.

10.2 Preserve the sample in a radioactively homogeneous state.

NOTE 3—A sample may be made homogeneous by addition of a reagent in which the radionuclides or compounds of the radionuclides present in the sample would be soluble in large concentrations. Addition of acids, complexing agents, or chemically similar stable carriers may be used to obtain homogeneity. Consideration of the chemical nature of the radionuclides and compounds present and the subsequent chemistry of the method will indicate the action to be taken. The addition of chemicals (HCl) corrosive to the mounting dish shall be avoided to prevent increased absorption of beta particles by the increased residual solids.

11. Establishing Gas Proportional Counter Operating Plateau

11.1 Put the instrument into operation according to the manufacturer's instructions. Place the counter's quality control standard (Note 4) having an approximate disintegration rate of 170 Bq in the counting position closest to the detector and begin counting. Slowly increase the high voltage until the first counts are observed and record the" threshold" voltage. Raise the voltage 20 to 25 V (or some other convenient unit) above threshold, stop counting, reset the scaler to zero, and determine the count rate. Advance the voltage in small equal increments of 20 or 25 V, determining the count rate at each voltage. The count rate should rise initially, reach an approximately constant value (plateau), and then increase rapidly at the end of the plateau. The operating time at voltages above the plateau shall be minimized to avoid extensive arcing of the detector. If the plateau is 150 V in length, additional measurements are not necessary. Some newer computer controlled gas proportional counters (commercially available) have software that automatically measures the detector plateau through the use of an algorithm that controls the high voltage and scaler units of the system.

NOTE 4—The counter's quality control standard may be any available radionuclide having a high percentage of beta particle emission, a half-life sufficiently long to minimize decay corrections, and a maximum beta particle energy above 0.5 MeV. Knowledge of its true beta disintegration rate is not essential. The radionuclide shall be fixed permanently to the dish and distributed uniformly over an area preferably smaller than the dish bottom; electrodeposition and flaming of a salt-free solution are the two methods most generally used. The standard may be covered by thin aluminum or plastic of sufficient thickness to exclude any alpha particles originating from the source and to protect against damage. The dish shall be securely mounted for reproducible positioning. Any loss of activity in the control standard, other than by natural decay, requires establishment of a new control chart (see Section 12). For external counters, the ratio of control standard source diameter to detector window diameter should not exceed 0.33 to avoid the effect of a spread source on the counting geometry.

11.2 Plot the counting rate of the control standard against the indicated voltage. The voltage setting that corresponds to a value approximately 75 V above the "knee" of the curve shall be used as the operating voltage, provided this voltage is 50 V below the highest voltage on the plateau; otherwise the operating voltage shall be that at approximately the mid-point of the plateau (Note 5). A plateau slope of less than 3 %/100 V is desirable, but slopes between 3 and 6 %/100 V can be tolerated if a stable power supply is used. Refer to Practice D3648 for additional details relative to operating voltage plateaus for gas proportional counters. Check the voltage plateau and operating voltage of the instrument on a regular schedule determined by experience and after any repair or major adjustment of the instrument. Shortening of the plateau length or an increase in slope are indications of a deteriorating detector.

NOTE 5—The counting life of the detector may be shortened by operation at a voltage higher than required for reliable performance. Consequently, the lowest voltage that meets the above conditions and will provide reproducible data should be chosen as the operating voltage.

12. Control of Instrument Operation

12.1 Tolerance or statistical control charts are used to assure that the instrument is operating to within pre-specified limits of the initial calibration. Repetitive measurements of a quality control source are taken to develop the tolerance or statistical control chart. The QC source is then used on a daily or prior to use basis to ensure proper operation. Refer to Practice D3648 for the preparation of a tolerance or statistical control chart.

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[7] *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 *Analar Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmaceutical Convention, Inc. (USPC), Rockville, MD.

13. Calibration and Standardization for General Measurements

13.1 Place a known amount of cesium-137 standard (approximately 200 Bq) into a volume of water having a dissolved salts content equivalent to those of the test samples and prepare for counting as directed in Section 15. Throughout the experiment, the evaporation, mounting, counting, and density of plate solids of this reference standard shall be identical with those of the test samples. Count for a length of time required to produce the desired statistical precision (typically 1 %; refer to Practice D3648). The combined efficiency factor, f_o, for each dissolved salt weight is then expressed as a fraction of the disintegration rate, Bq, of the reference standard according to Eq 2.

14. Calibration and Standardization for Tracer Experiments

14.1 Add a known quantity of activity of a reference solution of the tracer (approximately 200 Bq) to a radioactivity-free standard test sample and process in accordance with Section 15.

15. Procedure

15.1 Place an appropriate volume of the test specimen in a glass beaker, make 0.5 *M* with HNO_3, and evaporate to 1 to 2 mL. Quantitatively transfer to the mounting dish and evaporate to dryness. Adjust the heat carefully to prevent spattering or boiling. A ring heater having a continuously variable voltage control, or adjustable infrared heat lamps, is the preferable heat source for the final evaporation and drying. Uniform spreading of the residual salts is necessary for reliable comparative data. The salts shall be thoroughly mixed to assure uniform and homogeneous distribution of the radioactive nuclides in the deposit. Inhomogeneity may result in poor reproducibility. Cool hygroscopic solids in a dry atmosphere and store in a desiccator until the start of counting. Place the sample in the counter and count for a time interval sufficient to obtain the desired statistical uncertainty. Record the scaler reading. Transfer of large volume samples to smaller beakers as evaporation nears completion makes for easier transfer of the test specimen to the mounting dish. All transfers shall be made with reagent water. The sample size shall be chosen with consideration for the absorption of beta particles in the residual solids. Information[2, 3, 4, 5] on the range energy relationship of beta particles in aluminum should be used as a guide to obtain the desired results.

15.2 Precipitation methods may be used to expediently concentrate the radioactive material into small amounts of precipitate. The precipitate is separated and washed free of precipitant by centrifugation or filtration. Choose the method of separation that will produce a uniform deposit of precipitate after quantitatively transferring to the mounting dish or filter paper for counting. Calibrate the instrument under counting conditions identical to those used for the samples. More detailed information on the techniques and equipment for separation and mounting of the precipitate may be found in the literature.[2, 3, 4, 5]

16. Calculation

16.1 Results may be expressed in observed counts per second per millilitre or Bq/mL. This test method is useful for comparing activities of a group of samples, as in tracer experiments. Results may also be reported in terms of equivalent cesium-137 activity or other standard radionuclide activity, using the empirical efficiency determined by use of a reference standard. If it is known that only one nuclide is present, its disintegration rate may be determined by use of the efficiency factor determined from a reference standard of that nuclide obtained from the National Institute of Standards and Technology (NIST) or from a NIST-traceable standard. Calculate the results as follows:

$$beta\ concentration\ (Bq/mL) = C_{net}/(f_o \times V) \tag{3}$$

where:

C_{net} = net count rate (s^{-1}),
V = test specimen, mL, and
f_o = detector efficiency factor.

The total propagated uncertainty of the beta concentration is calculated as:

$$\sigma_{Bq/mL} = Bq/mL \times [(\sigma_{Cnet/Cnet})^2 + (\sigma_{fo}/f_o)^2 + (\sigma_V/V)^2]^{1/2} \tag{4}$$

where:

$\sigma_{Cnet/Cnet}$ = relative counting uncertainty,
σ_{fo}/f_o = relative detector efficiency uncertainty, and
σ_V/V = relative uncertainty in the sample volume measurement.

The net count rate and counting uncertainty,σ_{Cnet}, are defined as:

$$C_{net} = CR_S - CR_B = C_s / t_s - C_B v / t_B \tag{5}$$

$$^{\sigma}C_{net} = (C_s / t_s^2 + C_B / t_B^2)^{\frac{1}{2}} \tag{6}$$

where:

CR_s = sample count rate (s^{-1}),
CR_B = background count rate (s^{-1}),
C_s = sample counts,
C_B = background counts,
t_s = counting time of sample(s), and
t_B = counting time of background(s).

The *a priori* minimum detectable concentration (*MDC*) is calculated using the equation:

$$MDC = 2.71/(t_s \times k) + 4.65 \times \sigma_B / k \tag{7}$$

where:

σ_B = $(CR_B/t_s)^{1/2}$, and
k = $f_o \times V$.

A more detailed discussion on the minimum detectable concentration concept can be found in Practice D3648.

17. Precision and Bias

17.1 The overall precision and bias of this test method within its designated range varies with the quantity being tested according to Table 1.

17.2 This collaborative test for the determination of gross beta activity in water was conducted by six laboratories at three concentration levels ranging from 4.6 to 46.5 Bq/mL and

TABLE 1 Determination of Precision and Bias

Amount Added, Bq/mL	Average Calculated Amount, Bq/mL	± Bias	± % Bias	Statistically Significant (5 % C.I.)	Precision	
					S_t	S_o
4.60 ± 0.12	4.6 ± 1.0	0.0	0.0	No	0.997	0.288
18.55 ± 0.50	20.0 ± 1.0	+ 1.5	+ 7.8	Yes	1.04	0.617
46.5 ± 1.2	50.6 ± 2.6	+ 4.1	+ 8.8	Yes	2.63	1.50

containing 8 mg, 19.5 mg, and 40 mg of solids, respectively. Each laboratory processed three replicates per level.

17.3 The precision and bias statements for this test method were obtained using Practice D2777 – 86.

17.4 These test data were obtained using select water matrices. For other matrices these data may not apply.

18. Quality Control

18.1 Before this test method is utilized for the analysis of samples, a counter quality control or tolerance chart shall be established to ensure that the counting system is operating within prescribed limits. The quality control or tolerance chart shall be established at the time the counting system is calibrated.

18.2 Prepare a quality control or tolerance chart as recommended in Practice D3648. The counting system shall be checked by analyzing a QC source daily or prior to use. The result of the QC analysis shall be tabulated or plotted on the control or tolerance chart and evaluated according to Practice D3648.

18.3 Evaluate the counting system's background periodically. The background data shall be maintained in a logbook or plotted on a trend chart.

18.4 Precision and bias can be assessed in the following manner: the precision of an individual measurement can be approximated by the total propagated uncertainty and bias can be assessed by the analysis of NIST traceable spiked samples with known quantities of radioactivity.

19. Keywords

19.1 gross beta radioactivity; gross radioactivity measurement; proportional counter; water