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Standard Guide for Nuclear Surface Moisture and Density Gauge Calibration[1]

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1. Scope*

1.1 This guide describes the process and objective of calibrating the density system of a nuclear surface moisture and density gauge, or formulating the mathematical relationship between the density system response (the "density count") of a nuclear surface moisture and density gauge and the corresponding density value of the density standard upon which the density system response was observed.

1.2 This guide describes the process and objective of calibrating the water content system of a nuclear surface moisture and density gauge, or formulating the mathematical relationship between the water content system response (the "water content count") of a nuclear surface moisture and density gauge and the corresponding water mass per unit volume value of the water content standard upon which the water content system response was observed.

1.3 This guide describes the process and objective of verifying the density system of a nuclear surface moisture and density gauge.

1.4 This guide describes the process and objective of verifying the water content system of a nuclear surface moisture and density gauge.

1.5 This guide describes two mathematical processes by which the gauge measurement precision may be computed or measured.

1.6 This guide offers guidance for developing and reporting estimates of uncertainties in measurements made with gauges that have undergone calibration or verification.

1.7 All observed and calculated values shall confirm to the guide for significant digits and rounding established in Practice D6026.

1.8 *Units*—The values stated in either SI units or inch pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.9 *This guide 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 guide to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.10 This guide offers an organized collection of information or a series of options and does not recommend specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D6026 Practice for Using Significant Digits in Geotechnical Data

D6938 Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

D7013 Guide for Nuclear Surface Moisture and Density Gauge Calibration Facility Setup

3. Terminology

3.1 *Definitions*—See Terminology D653 for general definitions.

[1] This practice is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.08 on Special and Construction Control Tests.

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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.

***A Summary of Changes section appears at the end of this standard**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *coverage factor*[3], *n—*a number larger than one by which a combined standard measurement uncertainty is multiplied to obtain an expanded measurement uncertainty.

3.2.2 *definitional uncertainty*[3], *n—*the component of measurement uncertainty resulting from the finite amount of detail in the definition of the measurand. The "measurand" in the case of a nuclear surface moisture density gauge, is typically either in-place density or water mass per unit volume.

3.2.3 *density system calibration, n—*the method by which the values of the fit parameters in the equation that relates the density system response (the "density count") of a nuclear gauge and the corresponding density value of the density standard upon which that density system response was observed are computed. In addition, the uncertainty of measurements taken with gauges calibrated by the specific method must be known at representative density values that span the range of densities for which the calibration is valid.

3.2.4 *density system verification, n—*a set of operations or processes, or both, by which, for each density standard used in the process, the in-place density value(s) measured by the nuclear gauge on the density standard is related to the corresponding value(s) of the standard or standards. In addition, the uncertainty of measurements taken with gauges that meets the established verification criterion or criteria must be known at representative densities that span the range of densities for which the verification is valid.

3.2.5 *detector, n—*a device to detect and measure radiation.

3.2.6 *expanded measurement uncertainty*[3], *n—*product of a combined standard measurement uncertainty and a coverage factor larger than one.

3.2.7 *gamma (radiation) source, n—*a sealed source of radioactive material that emits gamma radiation as it decays.

3.2.8 *in-place density, n—*the total mass (solids plus water) per total volume of soil or soil-aggregates measured in place.

3.2.9 *measurement uncertainty*[3], *n—*non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand. The "measurand" in the case of a nuclear surface moisture density gauge, is typically either in-place density or water mass per unit volume.

3.2.10 *neutron (radiation) source, n—*a sealed source of radioactive material that emits neutron radiation as it decays.

3.2.11 *nuclear gauge, n—*a device containing one or more radioactive sources used to measure certain properties of soil and soil-aggregates.

3.2.12 *prepared standards, n—*density or water content measurement standards prepared of soil, solid rock, concrete, and engineered materials, that have density or water content values, or both, that are established and known to a specified uncertainty.

3.2.13 *standard measurement uncertainty*[3], *n—*measurement uncertainty expressed as a standard deviation.

3.2.14 *test count, N, n—*the measured output of a detector for a specific type of radiation for a given test.

3.2.15 *Type A Uncertainty Evaluation*[3], *n—*evaluation of a component of measurement uncertainty by a statistical analysis of measured quantity values obtained under defined measurement conditions.

3.2.16 *Type B Uncertainty Evaluation*[3], *n—*evaluation of a component of measurement uncertainty by means other than a Type A Evaluation.

3.2.17 *volumetric water content, n—*the volume of water as a percent of the total volume of soil or rock material.

3.2.18 *water content, n—*the ratio of the mass of water contained in the pore spaces of soil or soil-aggregate, to the solid mass of particles in that material, expressed as a percentage (*this is sometimes referred to in some scientific fields as gravimetric water content to differentiate it from volumetric water content*).

3.2.19 *water content system calibration, n—*the method by which the values of the fit parameters in the equation that relates the water content system response (the "water content count") of a nuclear gauge and the corresponding water mass per unit volume value of the water content standard upon which that water content system response was observed are computed. In addition, the uncertainty of measurements taken with the gauges calibrated by the specific method must be known at representative water mass per unit volume values that span the range of water mass per unit volume values for which the calibration is valid.

3.2.20 *water content system verification, n—*a set of operations or processes, or both, by which, for each water content standard used in the process, the in-place water mass per unit volume value(s) measured by the nuclear gauge on water content standard is related to the corresponding value(s) of these standards. In addition, the uncertainty of measurements taken with gauges that meets the established verification criterion or criteria must be known at representative water mass per unit volume values that span the range of water mass per unit volume values for which the verification is valid.

3.2.21 *water mass per unit volume, n—*the ratio of the mass of water contained in the pore spaces of a soil or soil-aggregate to the total volume occupied by that soil or rock material.

4. Summary of Practice

4.1 The objectives of the practice are as follows:

4.1.1 The objective of density system **calibration** is to formulate a mathematical equation, or *density calibration equation*, that relates the gauge density system response (the "density count") to the soil-equivalent density of the standard on which this response is elicited. The maximum uncertainties of subsequent gauge density readings shall be determined for the calibration process that is used. The standards used for the determination of uncertainty shall be representative of the range of densities for which the gauge will be used.

4.1.2 The objective of density system **verification** is to evaluate the current density calibration equation for the gauge and determine if a new calibration is required. The verification method will be based upon relating, at the pertinent density or

[3] JCGM 200:2008: International Vocabulary of Metrology—Basic and General Concepts and Associated Terms (VIM). 2008: Joint Document Committee for Guides in Metrology.

densities for the specific method, the density value of a known density standard to the density measured by the gauge. The maximum uncertainties of subsequent gauge density readings shall be determined for the verification method used. The standards used for the determination of uncertainty shall be representative of the range of densities for which the gauge will be used.

4.1.3 The objective of water content system **calibration** is to formulate a mathematical equation, or *water content calibration equation*, that relates the gauge water content system response (the "water content count") to the water mass per unit volume value of the standard on which this response is elicited. The uncertainties of subsequent gauge water mass per unit volume readings shall be known for, at a minimum, a water mass per unit volume level within 32 kg/m^3 [2.0 lbm/ft^3] of the upper extreme of the water mass per unit volume calibration range (typically 300 kg/m^3 [18.7 lbm/ft^3] or higher).

4.1.4 The objective of water content system verification is to evaluate the current water content system calibration equation for the gauge and determine if a new calibration is required. This evaluation will be based upon relating, at the pertinent water mass per unit volume values for the specific method, the water mass per unit volume value of a known water mass per unit volume standard to the water mass per unit volume value measured by the gauge. The uncertainties of subsequent gauge water mass per unit volume readings shall be known for, at a minimum, a water mass per unit volume level within 32 kg/m^3 [2.0 lbm/ft^3] of the upper extreme of the water mass per unit volume calibration range (typically 300 kg/m^3 [18.7 lbm/ft^3] or higher).

4.1.5 The density calibration equation relates the in-place density value measured by the gauge on a test site (the "independent variable") with the density test count measured by the gauge on the test site (the "dependent variable") is typically exponential or polynomial in form, with three fit coefficients.

4.2 Historically, the most successful methods for calibrating the density system of a gauge is done by taking gauge density readings on three or more density standards, combining the independent and dependent variables into data pairs, and using a least-squares or Newton-Rafson fitting algorithm with these data pairs to compute the fit coefficients. These density standards have unique density values that span the range of densities for which the gauge will be used.

4.2.1 The density system calibration of a gauge is not necessarily limited to the process described in 4.2. However, for any method that is used in the density system calibration process, one must know the uncertainties of the in-place density readings measured by devices calibrated in this manner over the range of density values for which the gauge will be used.

4.2.2 For any method that is used in the density system verification process, one must know the uncertainties of the in-place density readings measured by devices calibrated in this manner over the range of density values for which the gauge will be used.

4.2.3 The water content calibration equation that relates the in-place water mass per unit volume value measured by the gauge on a test site (the "independent variable") with the water content test count measured by the gauge on the test site (the "dependent variable") is typically linear in form, with two fit coefficients.

4.3 Historically, the most successful method for calibrating the water content system of a gauge is by taking readings on two water content standards (one of which is a zero water content standard), combining the independent and dependent variables into data pairs, and using a least-squares or fitting algorithm with these data pairs to compute the fit coefficients.

4.3.1 The water content system calibration of a gauge is not necessarily limited to the process described in 4.3. However, for any method that is used in the water content system calibration process, one must know the uncertainties of the water mass per unit volume readings measured by devices calibrated in this manner over the range of mass per unit volume values for which the gauge will be used.

4.3.2 For any method that is used in the water content system verification process, one must know the uncertainties of the water mass per unit volume readings measured by devices calibrated in this manner over the range of mass per unit volume values for which the gauge will be used.

5. Significance and Use

5.1 Gauge calibration is performed for the following purposes:

5.1.1 To formulate a mathematical equation, or density calibration equation, that relates the gauge density system response (the "density count") to the soil-equivalent density of the standard on which this response is elicited.

5.1.2 To formulate a mathematical equation, or water content calibration equation, that relates the gauge water content system response (the "water content count") to the water mass per unit volume value of the standard on which this response is elicited.

5.1.3 To ensure that the gauge has an in-place water mass per unit volume gauge precision level that is consistent with typical gauge response.

5.2 Gauge verification is performed for the following purposes:

5.2.1 To indicate to the party or agency performing the verification when the mathematical relationship between the in-place density reading indicated by the gauge and the corresponding gauge density test count needs to be adjusted so that the gauge calibration meets the required level of measurement uncertainty.

5.2.2 To indicate to the party or agency performing the verification when the mathematical relationship between the water mass per unit volume indicated by the gauge and the corresponding gauge water content test count needs to be adjusted so that the gauge calibration meets the required level of measurement uncertainty.

5.2.3 Gauge verification and calibration require specialized training and equipment. Gauge calibration and verification should only be conducted by those trained in the proper operation of the gauge, the calibration or verification standards, and any tables, charts, graphs, or computer programs required for the proper execution of these operations.

NOTE 1—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Interferences

6.1 Gauge calibration and verification should be performed in an area where the gauge being calibrated can be protected from the outside influences of and background radiation from other nuclear gauges.

6.2 Gauge calibration and verification should be performed in an area where any walls surrounding or in close proximity to the gauge do not cause reflected radiation that can be detected by the gauge.

6.3 Guide D7013 should be consulted in its entirety to ensure that the calibration area is configured properly and that the interferences described in 6.1and 6.2 can be avoided.

6.4 The accuracy and duration of gauge calibrations or verifications may be seriously compromised if the gauge has not undergone routine maintenance or proper servicing prior to calibration or verification.

7. Apparatus

7.1 *Nuclear Density/Moisture Gauge*—While exact details of construction of the apparatus may vary, the system shall consist of:

7.1.1 *Gamma Source*—A sealed source of high-energy gamma radiation such as cesium or radium.

7.1.2 *Gamma Detector*—Any type of gamma detector such as a Geiger-Mueller tube(s).

7.1.3 *Fast Neutron Source*—A sealed mixture of a radioactive material such as americium, radium, and a target material such as beryllium, or a neutron emitter such as californium-252.

7.1.4 *Slow Neutron Detector*—Any type of slow neutron detector such as boron trifluoride or helium-3 proportional counter.

7.2 *Gauge Reference Standard*—A block of material used for checking instrument operation, correction of source decay, and to establish conditions for a reproducible reference count rate.

7.3 *Density Reference Standard*—A standard of a known in-place density value (or values) with a known uncertainty (or uncertainties) that can be used in the process of calibrating or verifying the density systems of a nuclear density/moisture gauge.

7.4 *Water Content Reference Standard*—A standard of a known in-place water mass per unit volume value (or values) with a known uncertainty (or uncertainties) that can be used in the process of calibrating or verifying the water content system of a nuclear density/moisture gauge.

7.5 *Probe*—A slender, elongated device, part of the gauge that is inserted into the soil under measurement by the gauge. This device may contain either a radioactive source, a radiation detection device, or both. Probes containing only a radioactive source are commonly referred to as "source rods."

8. Hazards

8.1 These gauges utilize radioactive materials that may be hazardous to the health of the users unless proper precautions are taken. Users of these gauges must become familiar with applicable safety procedures and government regulations.

8.2 Effective user instructions, together with routine safety procedures and knowledge of and compliance with Regulatory Requirements, are a mandatory part of the operation and storage of these gauges.

9. Density Systems Calibration

9.1 The density systems of the gauge shall undergo a *calibration* initially after manufacture and subsequently after any repairs or modifications that can affect the gauge geometry or the accuracy of the existing calibration curve.

9.2 Each depth at which the nuclear gauge is able to take a density measurement has its own independent density system, and each of these density systems requires a distinct calibration initially after manufacture and subsequently after any repairs or modifications that can affect the gauge geometry or the accuracy of the existing calibration curve.

9.3 The calibration of a given density system consists of the computation and deployment of the mathematical formula that relates the in-place density value measured by the gauge on a density standard (the "independent variable") with the density test count measured by the gauge on a density standard (the "dependent variable"). The resulting fit parameters of this formula are commonly referred to as the "calibration constants" for the density system.

9.4 The mathematical formula that is computed as the result of the calibration of a density system should be stored in the memory of the gauge, printed on tables, or shown graphically in such a manner that the test readings acquired with the gauge can be used in the formula to compute the corresponding in-place density value, either by the user or by the instrument itself.

9.5 The method and test procedure used in collecting the density test count data to be used in the density calibration constant formulation shall be the same as those used for obtaining the field test count data.

9.6 The density system calibration may be done by the gauge manufacturer, the user, or an independent vendor.

9.7 Whereas the process used to calibrate the gauge density systems is at the discretion of the party or agency performing the calibration, the calibration process should comply with the requirements of 4.2.1.

9.8 For a density system that has just completed a density system calibration, the maximum permissible measurement error for in place density measured by the gauge on a density standard used in the calibration typically does not exceed 16 kg/m^3 [1 lbm/ft^3] of the density value assigned to the standard. This assigned density of this standard is based upon the density response of a typical gauge of this type on the standard.

9.9 For any specific density system calibration process, the uncertainty in density measurements over the range of densities for which gauges calibrated in this manner are used shall be known. Uncertainties shall be known for a single maximum uncertainty value applicable to the entire density range of the gauge, or, at a minimum, one value from each of the following three density levels:

9.9.1 At a density level within 5 % of the lower extreme of the density calibration range (typically 1755 kg/m^3 [109.6 lbm/ft^3]).

9.9.2 At a density level within 5 % of the mid value of the density calibration range (typically 2145 kg/m^3 [133.9 lbm/ft^3]).

9.9.3 At a density level within 5 % of the upper extreme of the density calibration range (typically 2612 kg/m^3 [163.1 lbm/ft^3]).

9.10 Using the procedure described in either 15.1.1 or 15.1.2, ensure a gauge count precision of at least one-half the gauge count precision required for field use, assuming field use measurement of one-minute duration.

9.11 The density system of the gauge shall undergo a calibration or a verification at periods not to exceed twelve months.

10. Density Systems Verification

10.1 For gauges that have undergone at least one previous density systems calibration and have not undergone any repairs or modifications that can affect the gauge geometry or the accuracy of the existing calibration curve, one may perform a density systems verification in lieu of a density system calibration. The frequency of density systems calibrations is given in 9.11.

10.2 The density system verification may be done by the gauge manufacturer, the user, or an independent vendor.

10.3 For any specific density system verification process, the uncertainty in density measurements over the range of densities for which gauges verified in this manner are used shall be known. Uncertainties shall be known for a single maximum uncertainty value applicable to the entire density range of the gauge, or, at a minimum, one value from each of the following three density levels:

10.3.1 At a density level within 5 % of the lower extreme of the density calibration range (typically 1755 kg/m^3 [109.6 lbm/ft^3]).

10.3.2 At a density level within 5 % of the mid value of the density calibration range (typically 2145 kg/m^3 [133.9 lbm/ft^3]).

10.3.3 At a density level within 5 % of the upper extreme of the density calibration range (typically 2612 kg/m^3 [163.1 lbm/ft^3]).

10.4 For a density system that has just completed a successful density system verification, the maximum permissible measurement error for in place density measured by the gauge on a density standard typically does not exceed 32 kg/m^3 [2 lbm/ft^3] of the density value assigned to the standard. This assigned density of this standard is based upon the density response of a typical gauge of this type on the standard.

NOTE 2—In 9.9 and 10.3, *three* density levels are specified as points at which the gauge density measurement uncertainty must be knows for the specific calibration method. Three points are used because, at a minimum, three points define the mathematical form of the calibration curve for the density measurement system. The values of the three ranges were selected to reflect the range of the typical low density, mid density, and high density calibration standards used for the calibration of these gauges.

11. Standards Used for Density Systems Calibration and Verification

11.1 The density value(s) of any manufactured metallic, natural stone, or non-soil standard used in the calibration or verification of the density system of the gauge shall be determined in such a manner that the estimated standard deviation of the measurement results used in this determination shall not exceed 0.5% of the measured standard density or densities.

11.2 The density value(s) assigned to a standard that is comprised of materials that have the potential to change over time in density, such as soil, concrete, or solid rock, typically need to be reestablished or verified at periods not exceeding twelve months. If the standard material is shown to maintain its density within the estimated standard deviation described in 11.1 for the environment in which it is stored and used, then the reestablishment or verification period can be extended accordingly.

11.3 The density response of a nuclear gauge is influenced by both the density of the material and the elemental composition of the material. The contribution of the elemental composition of the material to the density response of the gauge must be taken into consideration when establishing the density value of a density standard.

NOTE 3—Different nuclear density calibration techniques often utilize different nuclear physics principles to determine how the elemental composition of the material influences the density response of the instrument. As a result, there may be a statistically significant bias between the density values read between gauges that are calibrated using different density calibration techniques. Consequently, gauge users who take measurements with gauges calibrated using different density calibration techniques may need to adjust measurement results to compensate for this bias.

11.4 If the density standard is a solid block of material, the physical dimensions of the density standard should be sufficient in size so that the count rate of the gauge used to read the standard will not change if the standard is enlarged in any dimension.

NOTE 4—For density standards that are solid blocks of material, minimum surface dimensions of approximately 610 by 430 mm [24 by 17 in.] have proven satisfactory. For the backscatter method a minimum depth of 230 mm [9 in.] is adequate; while for the direct transmission method the depth should be at least 50 mm [2 in.] deeper than the deepest rod penetration depth. A larger surface area should be considered for the backscatter/air-gap method. For blocks with widths or lengths smaller than the sizes specified, follow the block manufacturer's recommendations for proper installation and use.

The most successful standards that have been established for density system calibration and verification have been blocks made of magnesium, aluminum, aluminum/magnesium, granite, and limestone. These blocks have been used in combination with each other, with historical curve information, and with other prepared block(s) to produce accurate and reliable density system adjustments and calibrations.

12. Water Content System Calibration

12.1 The water content system of the gauge shall undergo a calibration initially after manufacture and subsequently after any repairs or modifications that can affect the gauge geometry or the accuracy of the existing calibration curve.

12.2 The calibration of a water content system consists of the computation of and deployment of the mathematical formula that relates the water mass per unit volume value measured by the gauge on a water content standard (the "independent variable") with the water content test count measured by the gauge on a water content standard (the "dependent variable"). The resulting fit parameters of this formula are commonly referred to as the "calibration constants" for the water content system.

12.3 The mathematical formula that is computed as the result of a calibration of the water content system should be stored in the memory of the gauge, printed on tables, or shown graphically in such a manner that the test readings acquired with the gauge can be used in the formula to compute the corresponding water mass per unit volume value, either by the user or by the instrument itself.

12.4 The method and test procedure used in collecting the water content test count data to be used in the water content system calibration shall be the same as those used for obtaining the field test count data.

12.5 The water content system calibration may be done by the gauge manufacturer, the user, or an independent vendor.

12.6 The water content system of a nuclear gauge is not only affected by the water contained in the material under measure, but also, to a lesser extent, by the elemental composition of the material being measured. Consequently, the water mass per unit volume values measured by the gauge may not correspond, to the desired level of accuracy, with the water mass per unit volume value of some materials being measured. The gauge calibration shall be accurate for silica and water; however, for other materials the water content system may require adjustment to achieve the desired level of calibration accuracy.

12.7 Whereas the process used to calibrate the gauge water content system is at the discretion of the party or agency performing the calibration, the calibration process should comply with the requirements of 4.3.1.

12.8 For a water content system that has just completed a water content system calibration, the maximum permissible measurement error for water mass per unit volume measured by the gauge on a water content standard used in the calibration typically does not exceed 5 % of the water mass per unit volume value assigned to the standard. This assigned water mass per unit volume value of this standard is based upon the water mass per unit volume response of a typical gauge of this type on the standard. However, the 5 % measurement error limit does not apply for intrinsic moisture standards used as zero water mass per unit volume standards, since in this case a percentage-based error limit on a zero value standard has no significance. The maximum permissible measurement error for water mass per unit volume measured by the gauge on a zero water mass per unit volume standard used in the calibration typically does not exceed 16 kg/m^3 [1 lbf/ft^3].

12.9 For any specific water mass per unit volume calibration process, the uncertainty in water mass per unit volume measurements over the range of water mass per unit volume values for which gauges calibrated in this manner are used shall be known. Uncertainties shall be known for, at a minimum, a water mass per unit volume level within 32 kg/m^3 [2.0 lbm/ft^3] of the upper extreme of the water mass per unit volume calibration range (typically 300 kg/m^3 [18.7 lbm/ft^3] or higher).

12.10 Using the procedure described in either 15.1.1 or 15.1.2, ensure a gauge count precision of at least one-half the gauge count precision required for field use, assuming field use measurement of one-minute duration.

12.11 The water content system of the gauge shall undergo a calibration or a verification at periods not to exceed twelve months.

13. Water Content System Verification

13.1 For gauges that have undergone at least one previous water content system calibration and have not undergone any repairs or modifications that can affect the gauge geometry or the accuracy of the existing calibration curve, one may perform a moisture content system verification in lieu of a density system calibration. The moisture system of the gauge must periodically undergo a moisture system verification to ensure the accuracy of the moisture system of the gauge. The frequency of water content system verification is given in 12.11.

13.2 The water content system verification may be done by the gauge manufacturer, the user, or an independent vendor.

13.3 Whereas the process used to verify the water content system is at the discretion of the party or agency performing the verification, the verification process should comply with the requirements of 4.3.2.

13.4 For a water content system that has just completed a successful water content system verification, the maximum permissible measurement error for water mass per unit volume measured by the gauge on a water content standard typically does not exceed 5 % of the water mass per unit volume value assigned to the standard. This assigned water mass per unit volume value of this standard is based upon the water content response of a typical gauge of this type on the standard. However, the 5 % measurement error limit does not apply for intrinsic moisture standards used as zero water mass per unit volume standards, since in this case a percentage-based error limit on a zero value standard has no significance. The maximum permissible measurement error for water mass per unit volume measured by the gauge on a zero water mass per unit volume standard typically does not exceed 16 kg/m^3 [1 lbf/ft^3].

13.5 For any specific water mass per unit volume calibration verification process, the uncertainty in water mass per unit volume measurements over the range of water mass per unit volume values for which gauges verified in this manner are used shall be known. Uncertainties shall be known for, at a minimum, a water mass per unit volume level within 32 kg/m^3 [2.0 lbm/ft^3] of the upper extreme of the water mass per unit volume calibration range (typically 300 kg/m^3 [18.7 lbm/ft^3] or higher).

14. Standards Used for Water Content System Calibration and Verification

14.1 *Properties and Calibration Intervals of the Standards:*

14.1.1 The water mass per unit volume value(s) of any standard used in gauge water content system calibration and verification shall have its water mass per unit volume value(s) measured and established upon manufacture. After this initial establishment of the water mass per unit volume value(s), the standard shall be calibrated at a period established by the manufacturer. If the calibration reveals that the water mass per unit volume value(s) has/have changed, then the new water mass per unit volume value(s) of the standard shall be determined.

14.1.2 The water mass per unit volume value(s) assigned to a standard that is comprised of materials that have the potential to change over time in water content, such as soil, concrete, or solid rock, shall be reestablished or verified at periods not exceeding twelve months.

14.1.3 If the water content standard is a solid block of material, the physical dimensions of the water content standard should be sufficient in size so that the water content system count rate of the gauge used to read the standard will not change if the standard is enlarged in any dimension.

NOTE 5—For water content standards that are solid blocks of material, minimum surface dimensions of approximately 610 mm long by 460 mm wide by 200 mm deep [approximately 24 in. by 18 in. by 8 in.] have proven satisfactory. For blocks with width or length smaller than the sizes specified, follow the block manufacturer's recommendation for proper installation and use.

The most successful high water content standards that have been established for water content system calibration and verification have been blocks made of alternating sheets of magnesium and polyethylene or alternating sheets of aluminum and polyethylene. The most successful zero water content standards that have been established for water content system calibration and verification have been the metallic density standards used for calibration and verification of the density calibration system, such as magnesium and aluminum (see Note 4). These blocks have been used in combination with each other, with historical curve information, and with other prepared block(s) to produce accurate and reliable density system adjustments and calibrations.

14.2 *Establishing the Water Mass Per Unit Volume Values of Water Content Calibration and Verification Standards:*

14.2.1 Typically, the water content standards used in the water content system calibration and verification of nuclear gauges do not contain any water. Instead, they are homogenous blocks containing hydrogen-bearing (hydrogenous) materials that thermalize the neutrons emitted by the gauge in a similar manner to the hydrogen in water. Consequently, these standards typically have water mass per unit volume value assigned to them by either (a) comparing gauge response on them to gauge response on soil with a known water mass per unit volume value, or (b) calculating and using the water-equivalent hydrogen density of the block.

14.2.2 To determine the water mass per unit volume value of a standard, the following method may be used:

14.2.2.1 Prepare containers of compacted material with a water content determined by oven dry (Test Method D2216) and an in-place density calculated from either the mass of the material and the inside dimensions of the container, or from the mass of specimen(s) of known volume sampled from the material. The water mass per unit volume of the material in this container may be calculated as follows:

$$\rho_{wm} = \frac{\rho \times w}{100 + w} \tag{1}$$

where:

ρ_{wm} = water mass per unit volume, kg/m^3 or lbm/ft^3,
w = water content, percent of dry mass, and
ρ = in-place (wet) density, kg/m^3 or lbm/ft^3.

14.2.2.2 Measure the container(s) described in 14.2.2.1 with a nuclear gauge, and formulate the mathematical relationship between the water mass per unit volume values of the material(s) and the corresponding gauge moisture count response.

14.2.2.3 Measure the standard with the nuclear gauge, and use the mathematical relationship in Eq 1 to determine the water mass per unit volume (and its uncertainty) for the standard.

14.2.3 Alternatively, the water mass per unit volume value (and its uncertainty) for a standard may be calculated based upon the known hydrogen density of the standard and the elemental composition of the standard.

NOTE 6—Because of the different approaches of the different acceptable methods of assignment of water mass per unit volume values to calibration standards, there may be a statistically significant bias between the water mass per unit volume values read between gauges that are calibrated using different water mass per unit volume calibration techniques. Consequently, gauge users who take measurements with gauges calibrated using different water mass per unit volume calibration techniques may need to adjust measurement results to compensate for this bias.

15. Gauge Precision

15.1 Gauge precision is defined as the change in density or water mass per unit volume that occurs corresponding to a one standard deviation change in the count due to the random decay of the radioactive source. The density of the material and time period of the count must be stated.

Calculate using the methods in either 15.1.1 or 15.1.2. For in-place density, use a material having a density of 2000 ± 80 kg/m^3 [125.0 ± 5.0 lbm/ft^3]. Typical values of P are < 10 kg/m^3 [0.6 lbm/ft^3] in backscatter or backscatter/air-gap; and < 5 kg/m^3 [0.3 lbm/ft^3] for direct transmission measured at a 15 cm [6 in.] depth. Use a water mass per unit volume value of 160 ± 10 kg/m^3 [10.0 ± 0.6 lbm/ft^3] for determining slope and count rates. The value of P is typically less than 4.8 kg/m^3 [0.3 lbm/ft^3].

15.1.1 *Gauge Precision—Slope Method:* Determine the gauge precision of the system, P, from the slope of the calibration curve, S, and the standard deviation, σ, of the signals (detected gamma rays or detected neutrons) in counts per minute (cpm), as follows:

$$P = \frac{\sigma}{S} \tag{2}$$

where:

P = precision,
σ = standard deviation, cpm, and
S = slope, cpm/kg/m^3 or cpm/lbm/ft^3.

NOTE 7—Displayed gauge counts may be scaled. Contact the manufacturer to obtain the appropriate pre-scale factor.

15.1.2 *Gauge Precision—Repetitive Method:* Determine the standard deviation of a minimum of 20 repetitive readings of one minute each, without moving the gauge between readings. Calculate the standard deviation of the resulting readings. This is the gauge precision.

16. Report

16.1 When a density system calibration is performed on a gauge, the report shall include, as a minimum, the following:

16.1.1 The serial number of the gauge, or any other information that uniquely identifies the gauge.

16.1.2 The date when the calibration was performed.

16.1.3 The density reference standard count at the time that the density calibration was performed.

16.1.4 The density count quantities used to compute the calibration constants for the gauge.

16.1.5 The assigned density values of each density standard used in the density system calibration, and any corrections between the assigned density value and its in-place density value.

16.1.6 The gauge precision value for the density system.

16.1.7 An identification of the density system calibration method used.

16.1.8 Either:

16.1.8.1 The uncertainty of a one-minute in-place density reading for the calibration method and density system at a low density value as defined in 9.9.1, and

16.1.8.2 The uncertainty of a one-minute in-place density reading for this calibration method and density system at a mid density value as defined in 9.9.2, and

16.1.8.3 The uncertainty of a one-minute in-place density reading for this calibration method and density system at a high density value as defined in 9.9.3, or

16.1.8.4 The maximum uncertainty value of those described in 16.1.8.1 – 16.1.8.3.

16.1.9 A signature and title, or an equivalent identification of the person(s) responsible for the content of the report.

16.1.10 An identification of the special limitations of use.

16.1.11 A statement that the results listed on the report relate only to the gauge that is listed on the report.

16.1.12 If more that one density system in the gauge undergoes a calibration, then the aforementioned information for each of these systems can be included in the same report.

16.1.13 If the gauge is adjusted or repaired, the calibration results before and after the adjustment or repair must also be part of the report.

16.2 When a density systems verification is performed in lieu of a density systems calibration, the report should include, as a minimum, the following:

16.2.1 The serial number of the gauge, or any other information that uniquely identifies the gauge.

16.2.2 The date when the density system verification was performed.

16.2.3 The density reference standard count at the time of the verification.

16.2.4 For each density standard used in the verification, the difference in the density value measured by the gauge and the corresponding density value of the density standard for the density system being calibrated.

16.2.5 Either:

16.2.5.1 The uncertainty of a one-minute in-place density reading for the verification method and density system at a low density value as defined in 10.3.1, and

16.2.5.2 The uncertainty of a one-minute in-place density reading for this verification method and density system at a mid density value as defined in 10.3.2, and

16.2.5.3 The uncertainty of a one-minute in-place density reading for this verification method and density system at a high density value as defined in 10.3.3, or

16.2.5.4 The maximum uncertainty value of those described in 16.2.5.1 – 16.2.5.3.

16.2.6 A signature and title, or an equivalent identification of the person(s) responsible for the content of the report.

16.2.7 An identification of the special limitations of use.

16.2.8 A statement that the results listed on the report relate only to the gauge that is listed on the report.

16.2.9 If more that one density system in the gauge undergoes a verification at the same time, then the aforementioned information for each of these systems can be included in the same report.

16.3 When a water content system calibration is performed on a gauge, the report shall include, as a minimum, the following:

16.3.1 The serial number of the gauge, or any other information that uniquely identifies the gauge.

16.3.2 The date when the water content system calibration was performed.

16.3.3 The water content reference standard count at the time that the water content system calibration was performed.

16.3.4 The water content count quantities used to compute the calibration constants for the gauge.

16.3.5 For each water content standard used in the calibration, the assigned water mass per unit volume values of the water content standard used in this water content system calibration. If a water content standard has different water mass per unit volume values assigned to it for different measurement orientations, then these values must be identified as such.

16.3.6 The computed calibration constants for the completed water content system calibration.

16.3.7 The gauge precision value for the water content system for which the calibration was performed.

16.3.8 An identification of the water content system calibration method used.

16.3.9 The uncertainty of a one-minute water mass per unit volume reading for this calibration method at a high water mass per unit volume value as defined in 12.9.

16.3.10 A signature and title, or an equivalent identification of the person(s) responsible for the content of the report.

16.3.11 An identification of the special limitations of use.

16.3.12 A statement that the results listed on the report relate only to the gauge that is listed on the report.

16.3.13 If a water content system calibration is performed at the same time as a density system calibration on the same gauge, then the information for both reports can be consolidated into the same report.

16.4 When a water content system verification is performed on a gauge, the report should include, as a minimum, the following:

16.4.1 The serial number of the gauge, or any other information that uniquely identifies the gauge.

16.4.2 The date when the water content verification was performed.

16.4.3 The water content reference standard count at the time of the water content system verification.

16.4.4 For each water content standard used in the verification, the difference in the water mass per unit volume value measured by the gauge and the corresponding water mass per unit volume value of the water content standard.

16.4.5 The uncertainty of a one-minute water mass per unit volume reading for this verification method at a high water mass per unit volume value as defined in 13.5.

16.4.6 A signature and title, or an equivalent identification of the person(s) responsible for the content of the report.

16.4.7 An identification of the special limitations of use.

16.4.8 A statement that the results listed on the report relate only to the gauge that is listed on the report.

16.4.9 If a water content system verification is performed at the same time as density systems verifications on the same gauge, then the information for both reports can be consolidated into the same report.

17. Measurement Uncertainty

17.1 *Principle*

17.1.1 A calibration procedure or a verification procedure are frequently classified in terms of gauge measurement uncertainty, as evaluated using the uncertainty approach. Specifically, the measurement uncertainty of interest is the uncertainty in a single reading of a calibrated gauge or a gauge that has passed the verification process, either density or water mass per unit volume.

17.1.2 Calibration and verification measurement uncertainty in this application are generally used by the laboratory performing the calibrations and the user who is utilizing the calibration or verification service to evaluate the method employed. This evaluation is done by analysis of the dispersion (or "spread") in the measurement of gauges calibrated or verified by this method. This dispersion is due to the systematic and random errors in the calibration and gauge measurement process, and is generally evaluated as a standard deviation. This measurement uncertainty relates to the results obtained in the laboratory conducting the verification or calibration, as opposed to a precision and bias statement for field measurements, which are covered in Test Method D6938.

17.1.3 The verification and calibration measurement uncertainty in this application allow the user to implement statistical techniques to make judgments regarding the acceptability of verification or calibration results.

17.1.4 A nuclear surface moisture and density gauge is calibrated to measure over a **range** of densities and water mass per unit volume quantities that one would ordinarily encounter in a field application. Consequently, for the gauge calibration method used, one should know the measurement uncertainty for gauges calibrated in this manner at a representative number of values of the quantity being measured. See Note 2 for the rationale behind the number of quantities at which the uncertainties should be evaluated and their values.

17.1.5 For an individual agency or organization performing nuclear surface moisture gauge calibrations or verifications, the corrections or methods, or both, used in assigning quantity values to the measurement standards shall be consistent for a specific calibration or verification type within that agency or organization. The "measurement standards" are the in place density standards and the water mass per unit volume standards.

17.1.6 There is currently no inter-laboratory proficiency program for nuclear surface moisture gauge calibrations or verifications. Consequently, different individual agency or organization performing nuclear surface moisture gauge calibrations or verifications may select different methods or corrections in assigning quantity values to the measurement standards. As a result, the uncertainties that the agency or organization assigns to calibration or verification methods are, strictly speaking, *definitional* uncertainties, limited to their specific method. Therefore—as mentioned in Note 3 and Note 6—these different approaches present a possibility of biases between instruments calibrated using different techniques. The user should consider this potential bias when comparing the measurement responses of such instruments.

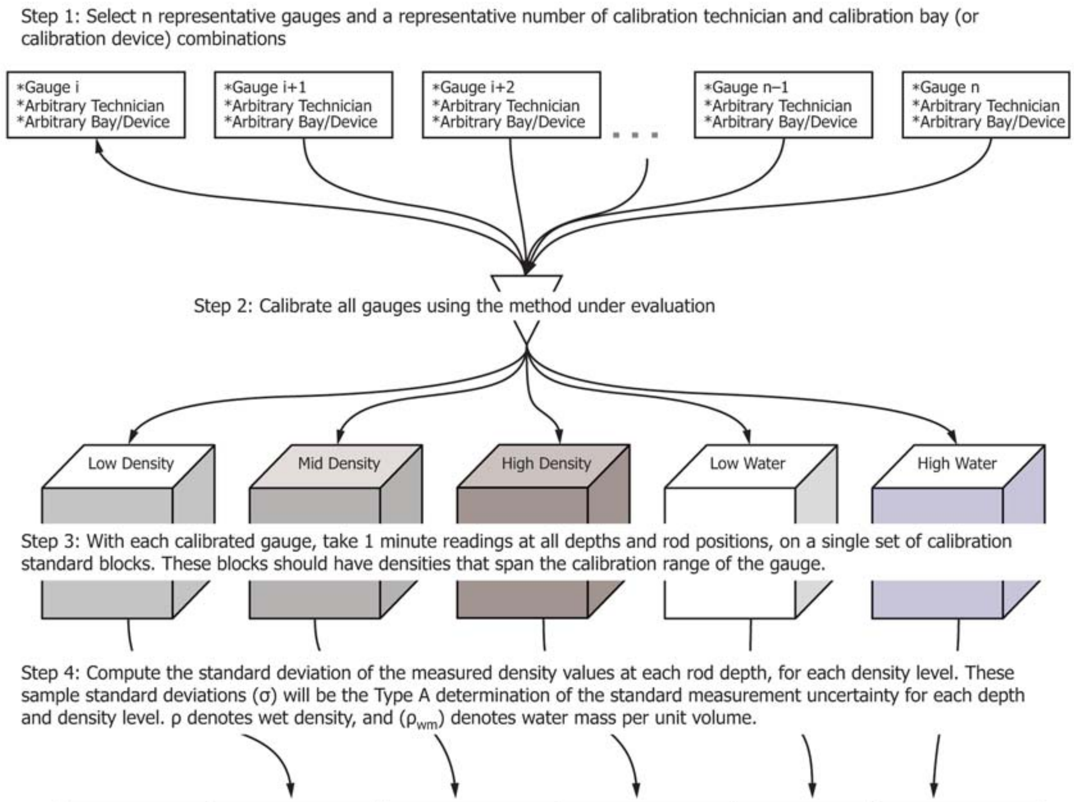
17.2 The Type A method of uncertainty determination described in 17.3 is one way of estimating the uncertainties of a particular calibration or verification process . Other Type A methods, Type B methods, or combinations of Type A and Type B methods can be utilized. (See Fig. 1)

17.3 *Type A Measurement Uncertainty for Gauges Calibrated by a Specific Method* (See Fig. 2)

17.3.1 Randomly select a representative group of gauges of various ages that has been calibrated by the calibration method under analysis. These gauges should have the maximum length of source rod (typically 305 mm [12 in.]) of gauges that are calibrated in the calibration method under analysis. If applicable to the calibration facility in question, let these calibrations be performed by as many different technicians and calibration bays/devices as practically possible.

17.3.2 Take each calibrated gauge, one at a time, to one specific set of standards. This set of standards should consist of three density standards: low density, mid density, and high density, based upon the measurement range of the gauge. This set of standards should also contain two water mass per unit volume standards: zero water content and high water content, based upon the measurement range of the gauge. All of these standards should be clear of any outside interferences.

17.3.3 Take a standard count with the gauge, and then take one minute density measurements on each density standard at each index rod position. Record the results.



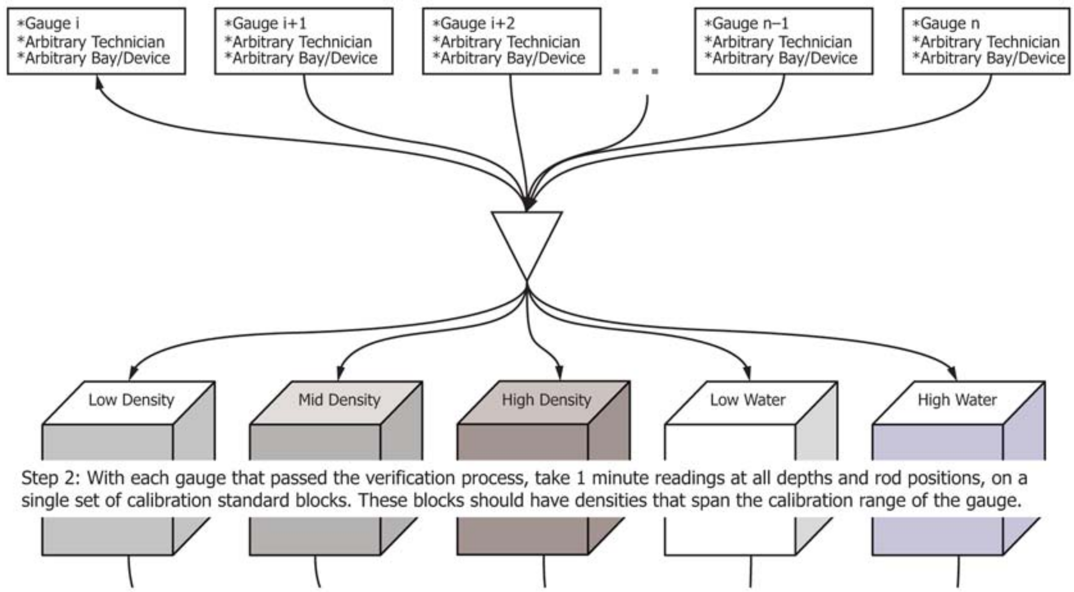
Source rod Position	Low Density σ	Mid Density σ	High Density σ	Zero Water σ	High Water σ
Backscatter	$\sigma(\rho_{Low},BS)$	$\sigma(\rho_{Mid},BS)$	$\sigma(\rho_{High},BS)$	$\sigma((\rho_{wm})_0,BS)$	$\sigma((\rho_{wm})_{High},BS)$
51 mm	$\sigma(\rho_{Low},51\text{ mm})$	$\sigma(\rho_{Mid},51\text{ mm})$	$\sigma(\rho_{High},51\text{ mm})$		
76 mm	$\sigma(\rho_{Low},76\text{ mm})$	$\sigma(\rho_{Mid},76\text{ mm})$	$\sigma(\rho_{High},76\text{ mm})$		
.	.	.	.		
.	.	.	.		
.	.	.	.		
305 mm	$\sigma(\rho_{Low},305\text{ mm})$	$\sigma(\rho_{Mid},305\text{ mm})$	$\sigma(\rho_{High},305\text{ mm})$		

Step 5: Using n, the number of gauges used to compute the standard measurement uncertainties, calculate the coverage factor, and then the expanded measurement uncertainty as the final uncertainty value for the one-minute measurements a gauge calibrated by this method. The coverage factor, k, is equal to $t_{0.05,n-1}$ (two-tailed) at the 95% confidence level.

Source Rod Position	**Low Density expanded measurement uncertainty**	**Mid Density expanded measurement uncertainty**	**High Density expanded measurement uncertainty**	**Zero water expanded measurement uncertainty**	**High water expanded measurement uncertainty**
Backscatter	$k\sigma(\rho_{Low},BS)$	$k\sigma(\rho_{mid},BS)$	$k\sigma(\rho_{High},BS)$	$K\sigma((\rho_{wm})_0,BS)$	$K\sigma((\rho_{wm})_{High},BS)$
51 mm	$k\sigma(\rho_{Low},51\text{ mm})$	$k\sigma(\rho_{Mid},51\text{ mm})$	$k\sigma(\rho_{High},51\text{ mm})$		
76 mm	$k\sigma(\rho_{Low},76\text{ mm})$	$k\sigma(\rho_{Mid},76\text{ mm})$	$k\sigma(\rho_{High},76\text{ mm})$		
.	.	.	.		
.	.	.	.		
.	.	.	.		
305 mm	$k\sigma(\rho_{Low},305\text{ mm})$	$k\sigma(\rho_{Mid},305\text{ mm})$	$k\sigma(\rho_{High},305\text{ mm})$		

FIG. 1 Graphical Representation of the Type A Uncertainty Analysis for Calibrated Gauges Described in 17.2

Step 1: Select n representative gauges that have passed the verification process with a representative number of calibration technicians and verification standard combinations



Step 2: With each gauge that passed the verification process, take 1 minute readings at all depths and rod positions, on a single set of calibration standard blocks. These blocks should have densities that span the calibration range of the gauge.

Step 3: Compute the standard deviation of the measured density values at each rod depth, for each density level. These sample standard deviations (σ) will be the Type A determination of the standard measurement uncertainty for each depth and density level. ρ denotes wet density, and (ρ_{wm}) denotes water mass per unit volume.

Source rod Position	Low Density σ	Mid Density σ	High Density σ	Zero Water σ	High Water σ
Backscatter	$\sigma(\rho_{Low}, BS)$	$\sigma(\rho_{Mid}, BS)$	$\sigma(\rho_{High}, BS)$	$\sigma((\rho_{wm})_0, BS)$	$\sigma((\rho_{wm})_{High}, BS)$
51 mm	$\sigma(\rho_{Low}, 51\ mm)$	$\sigma(\rho_{Mid}, 51\ mm)$	$\sigma(\rho_{High}, 51\ mm)$		
76 mm	$\sigma(\rho_{Low}, 76\ mm)$	$\sigma(\rho_{Mid}, 76\ mm)$	$\sigma(\rho_{High}, 76\ mm)$		
.	.	.	.		
.	.	.	.		
.	.	.	.		
305 mm	$\sigma(\rho_{Low}, 305\ mm)$	$\sigma(\rho_{Mid}, 305\ mm)$	$\sigma(\rho_{High}, 305\ mm)$		

Step 4: Using n, the number of gauges used to compute the standard measurement uncertainties, calculate the coverage factor, and then the expanded measurement uncertainty as the final uncertainty value for the one-minute measurements a gauge calibrated by this method. The coverage factor, k, is equal to $t_{0.05,n-1}$ (two-tailed) at the 95% confidence level.

Source Rod Position	**Low Density expanded measurement uncertainty**	**Mid Density expanded measurement uncertainty**	**High Density expanded measurement uncertainty**	**Zero water expanded measurement uncertainty**	**High water expanded measurement uncertainty**
Backscatter	$k\sigma(\rho_{Low}, BS)$	$k\sigma(\rho_{Mid}, BS)$	$k\sigma(\rho_{High}, BS)$	$K\sigma((\rho_{wm})_0, BS)$	$K\sigma((\rho_{wm})_{high}, BS)$
51 mm	$k\sigma(\rho_{Low}, 51\ mm)$	$k\sigma(\rho_{Mid}, 51\ mm)$	$k\sigma(\rho_{High}, 51\ mm)$		
76 mm	$k\sigma(\rho_{Low}, 76\ mm)$	$k\sigma(\rho_{Mid}, 76\ mm)$	$k\sigma(\rho_{High}, 76\ mm)$		
.	.	.	.		
.	.	.	.		
.	.	.	.		
305 mm	$k\sigma(\rho_{Low}, 305\ mm)$	$k\sigma(\rho_{Mid}, 305\ mm)$	$k\sigma(\rho_{High}, 305\ mm)$		

FIG. 2 Graphical Representation of the Type A Uncertainty Analysis for Verified Gauges Described in 17.3

17.3.4 After the density reading are complete, take a one minute water mass per unit volume measurement on the zero moisture standard and the high moisture content standard. Record the results.

17.3.5 When all gauges have completed the measurements described in 17.3.2 – 17.3.4, compute the standard deviation of the density values measured for each standard and each depth measurement. These standard deviations are the **standard measurement uncertainties**. There will be three standard measurement uncertainties for each source rod position: at the upper, mid, and lower density ranges, for the calibration method under analysis.

17.3.6 Once the standard measurement uncertainties described in 17.3.5 are computed, calculate the corresponding **expanded measurement uncertainties** by multiplying each standard measurement uncertainty by the associated **coverage factor**. The coverage factor, generally denoted by k, is equal to the two-tailed t-factor $t_{0.05,n-1}$, where n is the number of gauges used in the evaluation of the standard measurement uncertainty. For example, if $n = 10$, then $k = t_{0.05,n-1} = t_{0.05,9} = 2.26$.

17.3.7 In the reporting, express the gauge measurement uncertainty for each density system at the three (or more) density levels in terms of the expanded measurement uncertainty.

17.3.8 In the reporting, express the gauge measurement uncertainty for the water content system at the two (or more) water mass per unit volume levels in terms of the expanded measurement uncertainty.

17.4 *Type A Measurement Uncertainty for Gauges That Have Passed a Specific Verification Process*

17.4.1 Randomly select a representative group of gauges of various ages that have met the criteria established by the verification method under analysis. These gauges should have the maximum length of source rod (typically 305 mm [12 in.]) of gauges that are verified in the verification method under analysis. If applicable to the test facility in question, let these verifications be performed by as many different technicians and calibration bays/devices as practically possible.

17.4.2 Take each verified gauge, one at a time, to one specific set of standards. This set of standards should consist of three density standards: low density, mid density, and high density, based upon the measurement range of the gauge. This set of standards should also contain two water mass per unit volume standards: zero water content and high water content, based upon the measurement range of the gauge. All of these standards should be clear of any outside interferences.

17.4.3 Take a standard count with the gauge, and then take one minute density measurements on each density standard at each index rod position. Record the results.

17.4.4 After the density readings are complete, take a one minute water mass per unit volume measurement on the zero moisture standard and the high moisture content standard. Record the results.

17.4.5 When all gauges have completed the measurements described in 17.4.2 – 17.4.4, compute the standard deviation of the density values measured for each standard and each depth measurement. These standard deviations are the **standard measurement uncertainties**. There will be three standard measurement uncertainties for each source rod position: at the upper, mid, and lower density ranges, for the calibration method under analysis.

17.4.6 Once the standard measurement uncertainties described in 17.4.5 are computed, calculate the corresponding **expanded measurement uncertainties** by multiplying each standard measurement uncertainty by the associated **coverage factor**. The coverage factor, generally denoted by k, is equal to the two-tailed t-factor $t_{0.05,n-1}$, where n is the number of gauges used in the evaluation of the standard measurement uncertainty. For example, if $n = 10$, then $k = t_{0.05,n-1} = t_{0.05,9} = 2.26$.

17.4.7 In the reporting, express the gauge measurement uncertainty for each density system at the three (or more) density levels in terms of the expanded measurement uncertainty.

17.4.8 In the reporting, express the gauge measurement uncertainty for the water content system at the two (or more) water mass per unit volume levels in terms of the expanded measurement uncertainty.

17.5 Depending on the gauge tube efficiency and source strengths, as well as other mechanical and electronic factors, different gauges have different measurement precisions. Measurement precision is a contributing factor to overall measurement uncertainty of the gauge. The measurement uncertainties of a particular calibration procedure may be further subclassified according to the level of the instrumental measurement uncertainty if this level of detail is required by the user.

NOTE 8—The verification of an existing density or moisture system calibration of a nuclear gauge is typically done in lieu of a full calibration. Verification is usually performed when it is impractical (and, occasionally, impossible due to regional regulations) to gain access to a full set of calibration standards. Given these constraints, verification has historically been done using a single measurement on a single density standard for each source rod position undergoing verification. Moisture system verifications are also typically done on a single moisture standard. If the gauge measurement result on the standard lies within a specified range of the density (or water mass per unit volume) value assigned to the standard, then the gauge calibration is considered to be verified at that index rod position.

Because of the conditions under which verifications are typically performed, the user conducting the verification typically does not have access to a set of calibration standards that span the range of densities or water mass per unit volume values, or both, for which the gauge calibration is being validated. This means that, in all likelihood, this user does not have the resources to compute the required density measurement uncertainty and moisture measurement uncertainties of their verification method for more than one density or moisture value per index rod position. In such instances, the user should contact the gauge manufacturer, the standard(s) manufacturer, or an independent agency, with the resources to perform the measurement uncertainty measurements and determination described in the "Measurement Uncertainty" section of this standard.

18. Rationale

18.1 There were two factors that compelled section D18.08.01 to consider the development of a new guide on nuclear gauge calibration. The first was the desire of D18.08.01 to place the focus of Test Method D6938 on providing the gauge user with a guide for using their gauge for making measurements and interpreting these measurements. D18.08.01 felt that the appendices on gauge calibration and calibration verification in Test Method D6938, while providing important information, were not really a comfortable fit in a standard whose main focus was on everyday use of the gauge. Consequently, D18.08.01 felt that this information should be referenced in Test Method D6938, but not necessarily included therein.

18.2 The second factor was a desire by section D18.08.01 to expand on the practice of nuclear gauge calibration. There currently exist several approaches, procedures, and apparatuses for performing, verifying, and checking nuclear gauge calibrations. By creating a comprehensive standard guide that addresses only the practices of gauge calibration and verification, D18.08.01 felt that the objectives, differences and similarities, and possibilities and limitations of these different approaches could be adequately addressed.

18.3 From a practical perspective, the gauge user should be able to read this guide and decide which calibration or verification approach would be best for their device. The organization that is using the guide to perform the calibration or verification, in turn, should be able to read the standard guide and design their calibration or verification procedure to meet the specific need of the gauge user. Whereas the organization that performs gauge calibrations, verifications, and checks would be the primary user, the everyday gauge user would also be interested in this guide to ensure that they are obtaining the service from the calibration/verification that best suits their needs.

19. Keywords

19.1 calibration; calibration block; calibration constants; calibration curve; calibration standard; curve fit; gauge; in-place density; nuclear gauge; uncertainty; verification; water content; water mass per unit volume

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this guide since the last issue, D7759–12a, that may impact the use of this guide. (Approved June 1, 2014)

(1) Deleted 3.2.13, *source rod*, from the "Terminology" section and added a modified definition to 7.5 of the "Apparatus" section.
(2) Modified 12.8 of the "Water Content System Calibration" section to address the incongruity of assigning a percentage-based tolerance limit on a standard with an intrinsic water mass per unit volume value of zero.
(3) Modified 13.4 of the "Water Content System Verification" section to address the incongruity of assigning a percentage-based tolerance limit on a standard with an intrinsic water mass per unit volume value of zero.
(4) Added to the "Scope" section a clear statement of the system of units used and the applicable caveat.
(5) Added to the "Significance and Use" section a note referencing Practice D3740. Since this addition was made, D3740 is also added to the "Referenced Documents" section.