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

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1. Scope*

1.1 *Procedure A*—This guide describes the process and objective of formulating the mathematical relationship between the density system count of a nuclear surface moisture and density gauge and the corresponding wet density value of the density standard upon which the density system response was observed.

1.2 *Procedure B*—This guide describes the process and objective of comparing the wet density measured by a nuclear surface moisture and density gauge and the corresponding density value of the density standard upon which the density system response was observed.

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

1.4 *Procedure A*—This guide describes the process and objective of formulating the mathematical relationship between the water content system 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.

1.5 *Procedure B*—This guide describes the process and objective of comparing the water mass per unit volume measured by a nuclear surface moisture and density gauge and the corresponding water mass per unit volume of the corresponding water content standard upon which the water content system response was observed.

1.6 This guide describes the process and objective of the verification of the measurements of a nuclear surface moisture and density gauge.

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

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

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

1.10 *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 are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined. Within the text of this standard, SI units appear first followed by the inch-pound (or other non-SI) units in brackets.

1.10.1 Reporting of test results in units other than SI shall not be regarded as nonconformance with this guide.

1.11 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.12 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.

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

1.13 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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

D7013/D7013M Guide for Calibration Facility Setup for Nuclear Surface Gauges

D8167/D8167M Test Method for In-Place Bulk Density of Soil and Soil-Aggregate by a Low-Activity Nuclear Method (Shallow Depth)

3. Terminology

3.1 *Definitions*—See Terminology D653 for general definitions. For definitions of common metrology terms used in this standard, refer to the VIM—International Vocabulary of Metrology.[3]

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *density system calibration, n*—a set of processes by which, for each density standard used in the process, a density indication (gauge count or gauge density response) is obtained by the nuclear gauge on the density standard, and a relationship is established between the indications of the gauge and the density of the standard; the uncertainty of the standard and the indication must be established.

3.2.2 *density calibration equation, n*—the mathematical function that relates the density of the medium under measurement by the gauge (the independent variable) to the density system count response of the gauge (the dependent variable).

3.2.3 *density system verification, n*—a set of processes by which the acceptability of the associated density calibration equation of a gauge is determined.

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

3.2.5 *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.

3.2.6 *soil-equivalent density, n*—the density of an average soil (where an "average soil" is defined herein to have a Z/A value of 0.5) that yields the same gauge density count response as a metallic calibration standard; Z is the average atomic number of a material and A is the average atomic mass number of that same material.

3.2.7 *water content system calibration, n*— a set of processes by which, for each water content standard used in the process, a water mass per unit volume indication (gauge count or water mass per unit volume value) is obtained by the nuclear gauge on the water content standard, and a relationship is established between the indication of the gauge and the water mass per unit volume value of the standard; the uncertainty of the standard and the indications must be established.

3.2.8 *water mass per unit volume calibration equation, n*—the mathematical function that relates the water mass per unit volume of the medium under measurement by the gauge (the independent variable) to the water content system count response of the gauge (the dependent variable).

3.2.9 *water content system verification, n*—a set of processes by which the acceptability of the water mass per unit volume calibration equation of a gauge is determined.

4. Summary of Practice

4.1 The summary of the practice is as follows:

4.1.1 *Procedure A*—For new gauges and gauges that fail to meet the required density system verification criteria, for each affected index rod position one must perform a **density calibration** in which one relates the gauge density system response (the gauge counts) to the soil-equivalent density of the standard(s) on which the response is elicited and, in a second step, uses this information to establish a **calibration equation**.

4.1.1.1 The measurement uncertainties of the density standard(s) and the gauge density system counts must be known.

4.1.1.2 The standard(s) used for the determination of uncertainty shall be representative of the range of densities for which the gauge will be used.

4.1.1.3 The mode of density calibration just described is not limited to new gauges or gauges that fail to meet the required density system verification criteria.

4.1.2 *Procedure B*—For gauge index rod positions for which a density calibration equation has been formulated, one has the option of performing a **density calibration** in which one establishes the relation between the soil-equivalent density values of the necessary number of soil-equivalent density standard(s) and the corresponding soil-equivalent density measured by the gauge when used to measure the standards and, in a second step, uses this information to establish the relationship between these two density values.

4.1.2.1 The measurement uncertainties of the density standards and the density measured by the gauge must be known.

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

[3] *International vocabulary of metrology—Basic and general concepts and associated terms (VIM)*, 3rd Edition. Joint Committee for Guides in Metrology, 2012. https://www.bipm.org/utils/common/documents/jcgm/JCGM_200_2012.pdf

4.1.2.2 The standard(s) 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 density system **verification** is to evaluate the current density calibration equation for the gauge and determine if new calibration constants are required.

4.1.4 *Procedure A*—For new gauges and gauges that fail to meet the required water content system verification criteria, one must perform a **water content calibration** in which one establishes the relation between the water mass per unit volume of the necessary number of water content standard(s) and the corresponding water system gauge counts elicited from the gauge when used to measure these standards and, in a second step, uses this information to establish a **calibration equation**.

4.1.4.1 The measurement uncertainties of the water content standard(s) and the gauge counts must be known.

4.1.4.2 The standard(s) used for the determination of uncertainty shall be representative of the range of water mass per unit volume for which the gauge will be used.

4.1.4.3 The mode of water content system calibration just described is not limited to new gauges or gauges that fail to meet the required water content system verification criteria.

4.1.5 *Procedure B*—For gauges for which the calibration constants of a water mass per unit volume calibration equation have been formulated, one may perform a **water content calibration** in which one establishes the relation between the water mass per unit volume value of the necessary number of water content standard(s) and the corresponding water mass per unit volume measured by the gauge when used to measure these standard(s) and, in a second step, uses this information to establish the relationship between these two water mass per unit volume values.

4.1.5.1 The measurement uncertainties of the water content standards and the water mass per unit volume measured by the gauge must be known.

4.1.5.2 The standards used for the determination of uncertainty shall be representative of the range of water mass per unit volume values for which the gauge will be used.

4.1.6 The objective of water content system **verification** is to evaluate the current water content calibration equation for the gauge and determine if new calibration constants are required.

4.2 The density calibration equation relates the wet 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") and is typically exponential or polynomial in form, with three fit coefficients.

4.2.1 Historically, the most successful methods for computing the density calibration equation for 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-Raphson 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.

4.2.2 The computation of the density calibration equation is not necessarily limited to the process described in 4.2.1. However, for any method that is used in the density system calibration process, one must know the uncertainties of the wet 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 water mass per unit volume value measured by the gauge on a test site (the "independent variable") with the water mass per unit volume 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 computing the water content calibration equation 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 computing the fit coefficients.

4.3.1 The computation of the water content calibration equation 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 water mass per unit volume values for which the gauge will be used.

4.4 See Appendix X1 for a flowchart of the calibration and verification processes.

5. Significance and Use

5.1 Gauge calibration is performed for the following purposes:

5.1.1 When necessary, to compute the calibration constants of a 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 When necessary, to compute the calibration constants of a 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 establish the relationship between the density measured by the gauge to the soil-equivalent density of the standard on which this response is elicited.

5.1.4 To establish the relationship between the water mass per unit volume measured by the gauge to the water mass per unit volume of the standard on which this response is elicited.

5.1.5 To ensure that the gauge has an in-place density gauge precision level that is consistent with typical gauge response.

5.1.6 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 measurement errors do not exceed the specified absolute maximum measurement error for the calibration method used.

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 measurement errors do not exceed the specified absolute maximum measurement error for the calibration method used.

5.2.3 Gauge verification and calibration require specialized training and equipment. Gauge calibration and verification are best conducted by those trained in the proper operation of the gauge, the calibration 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 shall 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 shall be performed in an area where any walls surrounding or in proximity to the gauge do not cause reflected radiation that can be detected by the gauge.

6.3 Consult Guide D7013/D7013M in its entirety to ensure that the calibration area is configured properly and that the interferences described in 6.1 and 6.2 can be avoided.

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

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 and 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 and 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, Procedure A (Curve Fitting Method)

9.1 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 and independent calibration. The methods described herein as Procedure A, or the methods described in Procedure B, may be followed.

9.2 The density systems of the gauge shall undergo the calibration method described in 4.1.1, Procedure A, after manufacture and subsequently after any repairs or modifications that can affect the gauge geometry or the accuracy of the existing calibration equation, or at the discretion of the gauge owner or the calibrating agency.

9.2.1 The calibration of a given density system by Procedure A consists of the computation and deployment of the mathematical formula that relates the in-place wet 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.

9.2.2 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.

9.2.3 Whereas the process used to compute the calibration constants for a gauge density systems is at the discretion of the party or agency performing the calibration, the selected process for computing the calibration constants should comply with the requirements of 4.2.2.

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

10. Density Systems Calibration, Procedure B (Direct Comparison Method)

10.1 Any gauge density system that already has an established calibration equation from the past performance of the calibration method Procedure A may undergo the Procedure B calibration procedure described herein without first repeating the calibration method Procedure A.

10.2 This calibration procedure of a given density system consists of directly observing the relationship between the in-place density value measured by the gauge on a density standard and the soil-equivalent wet density of the density standard.

10.3 Whereas the procedure (A or B) used to calibrate the gauge density system is at the discretion of the party or agency performing the calibration, the selected calibration process shallcomply with the requirements of 4.1.1.1 - 4.1.1.3 or 4.1.2.1 - 4.1.2.2.

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

11. Density Systems Calibration, Estimated Measurement Uncertainties

11.1 For any specific density system that undergoes either the Procedure A or Procedure B calibration method, 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 one value from each of the following three density levels:

11.1.1 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]).

11.1.2 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]).

11.1.3 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]).

NOTE 2—In 11.1, *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 equation 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.

12. Density Systems Verification

12.1 The verification of the density system means that it fulfills specified requirements. Those specified requirements are that the measurement errors of the wet density readings obtained by the calibrated gauge under specified conditions do not exceed a specified density value.

12.2 The verification for a density system of the gauge shall be performed at the conclusion of either Procedure A or Procedure B calibrations.

12.3 The verification process for a calibration performed using Procedure A may be accomplished by next performing the calibration procedure defined in Procedure B for each density system, then computing the absolute measurement error for each comparison of the density value measured by the gauge and the associated soil-equivalent density of the density standard upon which the measurement was made.

12.3.1 In the instance where the density system verification process follows 12.3, the maximum permissible absolute measurement error for in place density measured by the gauge on a density standard used in the calibration process 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.

12.4 In the instance where the density system calibration is performed using Procedure A and the verification process is performed using other empirical, historical, or statistical evaluations not directly related to the empirical method described in 12.3, the maximum permissible absolute measurement error for in place density calculated by this method on a density standard 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.

12.5 In the instance where the density system calibration was performed using Procedure B and new calibration constants were **not** computed prior to this calibration, the maximum permissible absolute measurement error for in place density calculated by this method 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.

12.6 In instances where there are more than three density calibration standards used in either a Procedure A or Procedure B calibration, the permissible absolute measurement error could exceed the values described in 12.3 through 12.5 due to regression errors and/or regression residuals.

12.7 Failure to meet the specified measurement errors requires that the calibration constants be calculated again, so Calibration Procedure A must be performed.

12.8 The density content system of the gauge shall undergo a calibration and verification at periods not to exceed twelve months.

13. Standards Used for Density Systems Calibration

13.1 The density value(s) of any manufactured metallic, natural stone, or non-soil standard used in the calibration 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.

13.2 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 13.1 for the environment in which it is stored and used, then the reestablishment or verification period can be extended accordingly.

13.3 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.

13.4 If the density standard is a solid block of material, the physical dimensions of the density standard shall 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. Otherwise, follow the block manufacturer's recommendations; lateral abutting plates or other density standards may be positioned so that the count rate will not be affected.

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 shall be at least 50 mm [2 in.] deeper than the deepest rod penetration depth. A larger surface area may be necessary 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 equation information, and with other prepared block(s) to produce accurate and reliable density system adjustments and calibrations.

14. Water Content System Calibration, Procedure A (Curve Fitting Method)

14.1 The water content system of the gauge shall undergo the calibration method described in 4.1.4 initially after manufacture and subsequently after any repairs or modifications that can affect the gauge geometry or the accuracy of the existing calibration equation.

14.2 This 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.

14.3 The mathematical formula that is computed as the result of a calibration of the water content system shall 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.

14.4 Whereas the process used to compute the calibration constants for a gauge water content calibration system is at the discretion of the party or agency performing the calibration, the selected process for computing the calibration constants shall comply with the requirements of 4.3.1.

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

15. Water Content System Calibration, Procedure B

15.1 Any gauge water content system that already has an established calibration equation from the past performance of the calibration method described in Procedure A may undergo the Procedure B calibration procedure described herein without first repeating the calibration method described in Procedure A.

15.2 This calibration procedure of the gauge water content system consists of observing the relationship between the inplace water mass per unit volume value measured by the gauge on a water content standard and the water mass per unit volume value of the water content standard.

15.3 Whereas the procedure (A or B) used to calibrate the gauge water content system is at the discretion of the party or agency performing the calibration, the calibration process shall comply with the requirements of 4.1.4.1 - 4.1.4.3 or 4.1.5.1 - 4.1.5.2.

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

16. Water Content System Calibration, Estimated Measurement Uncertainty

16.1 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).

17. Water Content System Verification

17.1 The verification of the gauge water content system means that it fulfills specified requirements. Those specified requirements are that the measurement errors of the water mass per unit volume readings obtained by the calibrated gauge under specified conditions do not exceed a specified water mass per unit volume value.

17.2 The verification for the water content system of the gauge shall be performed at the conclusion of either Procedure A or Procedure B calibrations.

17.3 The verification process for a calibration performed using Procedure A may be accomplished by next performing the calibration procedure defined in Procedure B for the gauge, then computing the absolute measurement error for each comparison of the water mass per unit volume value measured by the gauge and the associated water mass per unit value of the water content standard upon which the measurement was made.

17.4 The verification process for a calibration performed using Procedure A may consist of using other empirical, historical, or statistical evaluations not directly related to the empirical method described 17.3.

17.5 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].

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

18. Standards Used for Water Content System Calibration

18.1 *Properties and Calibration Intervals of the Standards:*

18.1.1 The water mass per unit volume value(s) of any standard used in gauge water content system calibration 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.

18.1.2 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.

18.1.3 If the water content standard is a solid block of material, the physical dimensions of the water content standard shall 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. Otherwise, follow block manufacturers recommendations; lateral abutting plates or density standards may be positioned so that the count rate will not be affected.

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 equation information, and with other prepared block(s) to produce accurate and reliable density system adjustments and calibrations.

18.2 *Establishing the Water Mass Per Unit Volume Values of Water Content Calibration Standards:*

18.2.1 Typically, the water content standards used in the water content system calibration 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.

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

18.2.2.1 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:

$$\rho_{wm} = \frac{\rho \times w}{100 + w} \quad (1)$$

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.

18.2.2.2 Measure the container(s) described in 18.2.2.1 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.

18.2.2.3 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.