Designation: D6938 – 23

Standard Test Methods for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)[1]

This standard is issued under the fixed designation D6938; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method describes the procedures for measuring in-place density and moisture of soil and soil-aggregate by use of nuclear equipment (hereafter referred to as "gauge"). The density of the material may be measured by direct transmission, backscatter, or backscatter/air-gap ratio methods. Measurements for water (moisture) content are taken at the surface in backscatter mode regardless of the mode being used for density.

1.1.1 For limitations see Section 5 on Interferences.

1.2 The total or wet density of soil and soil-aggregate is measured by the attenuation of gamma radiation where, in direct transmission, the source is placed at a known depth up to 300 mm (12 in.) and the detector(s) remains on the surface (some gauges may reverse this orientation); or in backscatter or backscatter/air-gap the source and detector(s) both remain on the surface.

1.2.1 The density of the test sample in mass per unit volume is calculated by comparing the detected rate of gamma radiation with previously established calibration data.

1.2.2 The dry density of the test sample is obtained by subtracting the water mass per unit volume from the test sample wet density (Section 11). Most gauges display this value directly.

1.3 The gauge is calibrated to read the water mass per unit volume of soil or soil-aggregate. When divided by the density of water and then multiplied by 100, the water mass per unit volume is equivalent to the volumetric water content. The water mass per unit volume is determined by the thermalizing or slowing of fast neutrons by hydrogen, a component of water. The neutron source and the thermal neutron detector are both located at the surface of the material being tested. The water content most prevalent in engineering and construction activities is known as the gravimetric water content, w, and is the ratio of the mass of the water in pore spaces to the total mass of solids, expressed as a percentage.

1.4 Two alternative procedures are provided.

1.4.1 *Procedure A* describes the direct transmission method in which the probe extends through the base of the gauge into a pre-formed hole to a desired depth. The direct transmission is the preferred method.

1.4.2 *Procedure B* involves the use of a dedicated backscatter gauge or the probe in the backscatter position. This places the gamma and neutron sources and the detectors in the same plane.

1.4.3 Mark the test area to allow the placement of the gauge over the test site and to align the probe to the hole.

1.5 *Units*—The values stated in SI units are to be regarded as standard. The values given in parentheses are provided for information only and are not considered standard. Reporting the test results in units other than SI shall not be regarded as nonconformance with this standard.

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

1.6.1 The procedures used to specify how data are collected, recorded, and calculated in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that should generally be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analysis methods for engineering design.

1.7 *Limitations*—This test method is not applicable to clean gravel or clean crushed rock due to excessive surface voids which have the potential to affect gauge measurements.

1.8 *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] This test method 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

1.9 *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

D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))

D1556 Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method

D1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))

D2167 Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method

D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D2488 Practice for Description and Identification of Soils (Visual-Manual Procedures)

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

D2937 Test Method for Density of Soil in Place by the Drive-Cylinder Method

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

D4253 Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table

D4254 Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density

D4643 Test Method for Determination of Water Content of Soil and Rock by Microwave Oven Heating

D4718 Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles

D4944 Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester

D4959 Test Method for Determination of Water Content of Soil By Direct Heating

D6026 Practice for Using Significant Digits and Data Records in Geotechnical Data

D7013 Guide for Calibration Facility Setup for Nuclear Surface Gauges

D7759 Guide for Nuclear Surface Moisture and Density Gauge Calibration

[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. Terminology

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

3.2 *Definitions of Terms Specific to This Standard:*

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

3.2.2 *thermalization*—the process of "slowing down" fast neutrons by collisions with light-weight atoms, such as hydrogen.

3.2.3 *test count, n*—the measured output of a gamma ray or neutron detector for a specific type of radiation for a given test.

3.2.4 *prepared blocks*—blocks prepared of soil, solid rock, concrete, and engineered materials, that have characteristics of various degrees of reproducible uniformity.

4. Significance and Use

4.1 The test method described is useful as a rapid, nondestructive technique for in-place measurements of wet density and water content of soil and soil-aggregate and the determination of dry density.

4.2 The test method is used for quality control and acceptance testing of compacted soil and soil-aggregate mixtures as used in construction and also for research and development. The nondestructive nature allows repetitive measurements at a single test location and statistical analysis of the results.

4.3 *Density*—The fundamental assumptions inherent in the methods are that Compton scattering is the dominant interaction and that the material is homogeneous.

4.4 *Water Content*—The fundamental assumptions inherent in the test method are that the hydrogen ions present in the soil or soil-aggregate are in the form of water as defined by the water content derived from Test Methods D2216, and that the material is homogeneous. (See 5.2)

NOTE 1—The quality of the result produced by this standard test method 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, and the like. Users of this standard are cautioned that compliance with Practice D3740 does not in itself ensure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

5. Interferences

5.1 *In-Place Density Interferences*

5.1.1 Measurements may be affected by the chemical composition of the material being tested.

5.1.2 Measurements may be affected by non-homogeneous soils and surface texture (see 10.2). Excessive voids in the prepared test surface beneath the gauge can cause density measurements that are lower than the actual soil density. Excessive use of fill material to compensate for these voids may likewise cause biased density measurements, or biased water content measurements, or both.

5.1.3 Measurements in the Backscatter Mode are influenced more by the density and water content of the material in proximity to the surface.

5.1.4 Measurements in the Direct Transmission mode are an average of the density from the bottom of the probe in the soil or soil aggregate back up to the surface of the gauge.

5.1.5 Gravel particles or large voids in the source-detector path may cause higher or lower density measurements. Where lack of uniformity in the soil due to layering, aggregate or voids is suspected, the test site shall be excavated and visually examined to determine whether the test material is representative of the in situ material in general and whether an oversize correction is required in accordance with Practice D4718.

5.1.6 Oversize particles or large voids in the source-detector path may cause higher or lower density measurements. Where lack of uniformity in the soil due to layering, aggregate or voids is suspected, the test site shall be excavated and visually examined to determine if the test material is representative of the in situ material in general and if an oversize correction is required in accordance with Practice D4718.

5.1.7 The measured volume is approximately 0.0028 m^3 (0.10 ft^3) for the Backscatter Mode and 0.0057 m^3 (0.20 ft^3) for the Direct Transmission Mode when the test depth is 150 mm (6 in.). The actual measured volume is indeterminate and varies with the apparatus and the density of the material.

5.1.8 Other radioactive sources must not be within 9 m (30 ft) of equipment in operation.

5.2 *In-Place Water (Moisture) Content Interferences*

5.2.1 The chemical and elemental composition of the material being tested can affect the measurement and adjustments may be necessary (see 10.6). Materials containing high amounts of carbon or molecularly bound hydrogen will cause measurements in excess of the true value. Some chemical elements such as boron, chlorine, and cadmium will cause measurements lower than the true value.

5.2.2 The water content measured by this test method is not necessarily the average water content within the volume of the sample involved in the measurement. Since this measurement is by backscatter in all cases, the value is biased by the water content of the material closest to the surface. The volume of soil and soil-aggregate represented in the measurement is indeterminate and will vary with the water content of the material. In general, the greater the water content of the material, the smaller the volume involved in the measurement. Approximately 50 % of the typical measurement results from the water content of the upper 50 to 75 mm (2 to 3 in.).

5.2.3 Other neutron sources must not be within 9 m (30 ft) of equipment in operation.

6. Apparatus

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

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

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

6.1.3 *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.

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

6.2 *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.

6.3 *Site Preparation Device*—A plate, straightedge, or other suitable leveling tool that may be used for planing the test site to the required smoothness, and in the Direct Transmission Method, guiding the drive pin to prepare a perpendicular hole.

6.4 *Drive Pin*—A pin of slightly larger diameter than the probe in the Direct Transmission Instrument used to prepare a hole in the test site for inserting the probe.

6.4.1 *Drive Pin Guide*—A fixture, generally part of the site preparation device, that keeps the drive pin perpendicular to the test site.

6.5 *Hammer*—Heavy enough to drive the pin to the required depth without undue distortion of the hole.

6.6 *Drive Pin Extractor*—A tool that may be used to remove the drive pin in a vertical direction so that the pin will not distort the hole in the extraction process.

6.7 *Slide Hammer,* with a drive pin attached, may also be used both to prepare a hole in the material to be tested and to extract the pin without distortion to the hole.

6.8 *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."

7. Hazards

7.1 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.

7.2 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.

8. Calibration

8.1 Gauge calibration shall be performed in accordance with Guides D7013 and D7759.

9. Standardization

9.1 Nuclear moisture density gauges are subject to long-term aging of the radioactive sources, which may change the relationship between count rates and the material density and water content. To correct for this aging effect, gauges are calibrated as a ratio of the measurement count rate to a count rate made on a reference standard or to an air-gap count (for the backscatter/air-gap ratio method).

9.2 Standardization of the gauge shall be performed at the start of each day's use, and a record of these data shall be retained for the amount of time required to ensure compliance with either subsection 9.2.3 or Annex A3, whichever is applicable. Perform the standardization with the gauge located at least 9 m (30 ft) away from other nuclear moisture density gauges and clear of large masses of water or other items which can affect the reference count rates.

9.2.1 Turn on the gauge and allow for stabilization according to the manufacturer's recommendations.

9.2.2 Using the reference standard, take a reading that is at least four times the duration of a normal measurement period (where a normal measurement period is typically one minute) to constitute one standardization check.

9.2.3 When available, the procedure recommended by the gauge manufacturer shall be used to establish the compliance of the standard measurement to the accepted range. Without specific recommendations from the gauge manufacturer, use the procedure described in Annex A3.

9.2.4 If for any reason the measured density or moisture becomes suspect during the day's use, perform another standardization check.

10. Procedure

10.1 When possible, select a test location where the gauge will be placed at least 600 mm (24.0 in) away from any object sitting on or projecting above the surface of the test location, when the presence of this object has the potential to modify gauge response. Any time a measurement must be made at a specific location and the aforementioned clearance cannot be achieved, such as in a trench, follow the gauge manufacturer's correction procedure(s).

10.2 *Prepare the test site in the following manner:*

10.2.1 Remove all loose and disturbed material and additional material as necessary to expose the undisturbed surface of the material to be tested.

10.2.2 Prepare an area sufficient in size to accommodate the gauge by grading or scraping the area to a smooth condition so as to obtain maximum contact between the gauge and material being tested.

10.2.3 The depth of the maximum void beneath the gauge shall not exceed 3 mm (⅛ in.). Use either native material that does not contain gravel or fine sand to fill the voids, and then smooth the surface with the site preparation device or other suitable tool. The depth of the filler shall not exceed approximately 3 mm (⅛ in.).

10.2.3.1 If the grading or scraping of the test area dislodges rocks that leave a void greater than 3 mm (⅛ in.), the dislodged rock can be replaced, or a smaller rock in combination with fine sand or native material that does not contain gravel can be used to fill the void. The fine sand or native material that does not contain gravel used to fill the remainder of the void not filled by a smaller rock shall not exceed approximately 3 mm (⅛ in.).

10.2.4 The placement of the gauge on the surface of the material to be tested is critical to accurate density measurements. The optimum condition is total contact between the bottom surface of the gauge and the surface of the material being tested. The total area filled shall not exceed approximately 10 percent of the bottom area of the gauge.

10.3 Turn on and allow the gauge to stabilize (warm up) according to the manufacturer's recommendations (see Section 9.2.1).

10.4 *Procedure A—The Direct Transmission Procedure:*

10.4.1 Select a test location where the gauge in test position will be at least 150 mm (6 in.) away from any vertical projection.

10.4.2 Make a hole perpendicular to the prepared surface using either (*a*) the drive pin guide, the guide pin extractor, a hammer, and drive pin, (*b*) a slide hammer, or (*c*) a drill. The hole shall be a minimum of 50 mm (2 in.) deeper than the desired measurement depth and of an alignment that insertion of the probe will not cause the gauge to tilt from the plane of the prepared area.

10.4.3 Mark the test area to allow the placement of the gauge over the test site and to align the probe to the hole. Follow the manufacturer's recommendations if applicable.

10.4.4 Remove the hole-forming device carefully to prevent the distortion of the hole, damage to the surface, or loose material to fall into the hole.

10.4.4.1 When preparing an access hole in cohesionless soils, care shall be taken in the preparation of the access hole; measurements have the potential to be affected by changes to the density of surrounding material during the hole formation.

10.4.5 Place the gauge on the material to be tested, ensuring maximum surface contact as described previously in 10.2.4.

10.4.6 Lower the probe into the hole to the desired test depth. Pull the gauge gently toward the back, or detector end, so that the back side of the probe is in intimate contact with the side of the hole in the gamma measurement path.

NOTE 2—As a safety measure, it is recommended that a probe containing radioactive sources not be extended out of its shielded position prior to placing it into the test site. When possible, align the gauge so as to allow placing the probe directly into the test hole from the shielded position.

10.4.7 Keep all other radioactive sources at least 9 m (30 ft) away from the gauge to avoid any effect on the measurement.

10.4.8 If the gauge is so equipped, set the depth selector to the same depth as the probe.

10.4.9 Secure and record one or more one-minute density and water content readings. Read the in-place wet density directly or determine one by use of the calibration curve or table previously established.

10.4.10 Read the water content directly or determine the water content by use of the calibration curve or table previously established.

10.5 *Procedure B—The Backscatter or Backscatter/Air-Gap Ratio Procedure:*

10.5.1 Seat the gauge firmly (see 10.4.5).

10.5.2 Keep all other radioactive sources at least 9 m (30 ft) away from the gauge to avoid affecting the measurement.

10.5.3 Set the gauge into the Backscatter (BS) position.

10.5.4 Secure and record one or more set(s) of one-minute density and water content readings. When using the backscatter/air-gap ratio mode, follow the manufacturer's instructions regarding gauge setup. Take the same number of readings for the normal measurement period in the air-gap position as in the standard backscatter position. Calculate the air-gap ratio by dividing the counts per minute obtained in the air-gap position by the counts per minute obtained in the standard position. Many gauges have built-in provisions for automatically calculating the air-gap ratio and wet density.

10.5.5 Read the in-place wet density or determine one by use of the calibration curve or table previously established.

10.5.6 Read the water content or determine one by use of the calibration curve or previously established table (see Section 10.6).

NOTE 3—Gauge measurements acquired using either Procedure A or Procedure B yield both density and water content values for the material under test. It is good practice to record gauge density and water counts corresponding to the density and water values at the time of measurement in the event that data recording errors or improper probe depth errors are of concern.

10.6 *Water Content Correction and Oversize Particle Correction*

10.6.1 For proper use of the gauge and accurate values of both water content and dry density, both of these corrections need to be made when applicable.

10.6.1.1 Prior to using the gauge-derived water content on any new material, the value shall be verified by comparison to another ASTM method such as Test Methods D2216, D4643, D4944, or D4959. As part of a user developed procedure, occasional samples shall be taken from beneath the gauge and comparison testing done to confirm gauge-derived water content values. All gauge manufacturers have a procedure for correcting the gauge-derived water content values.

10.6.2 When oversize particles are present, the gauge can be rotated about the axis of the probe to obtain additional readings as a check. When there is any uncertainty as to the presence of these particles it is advisable to sample the material beneath the gauge to verify the presence and the relative proportion of the oversize particles. A rock correction can then be made for both water content and wet density by the method in Practice D4718.

10.6.3 When sampling for water content correction or oversize particle correction, the sample should be taken from a zone directly under the gauge. The size of the zone is approximately 200 mm (8 in.) in diameter and a depth equal to the depth setting of the probe when using the direct transmission mode; or approximately 75 mm (3 in.) in depth when using the backscatter mode.

11. Calculation of Results

11.1 *Determine the Wet Density:*

11.1.1 On most gauges read the value directly in kg/m^3 (lbm/ft^3). If the density reading is in "counts", determine the in-place wet density by use of this reading and the previously established calibration curve or table for density.

11.1.2 Record the density to the nearest 1 kg/m^3 (0.1 lbm/ft^3).

11.2 *Water Content:*

11.2.1 Use the gauge reading for w if the gauge converts to that value.

11.2.2 If the gauge determines water mass per unit volume in kg/m^3 (lbm / ft^3), calculate w using the formula:

$$w = \frac{M_m \times 100}{\rho_d} \quad (1)$$

or,

$$w = \frac{M_m \times 100}{\rho - M_m} \quad (2)$$

where:

w = water content
ρ_d = dry density in kg/m^3 or (lbm/ft^3),
ρ = wet density in kg/m^3 or (lbm/ft^3), and
M_m = water mass per unit volume in kg/m^3 or (lbm/ft^3)

11.2.3 If the water content reading was in "counts," determine the water mass per unit volume by use of this reading and previously established calibration curve or table. Then convert to gravimetric water content in accordance with 11.2.2.

11.2.4 Record water content to the nearest 0.1 %.

11.3 *Determine the Dry Density of the soil by one of the following methods:*

11.3.1 If the water content is obtained by nuclear methods, use the gauge readings directly for dry density in kg/m^3 (lbm/ft^3). The value can also be calculated from:

$$\rho_d = \rho - M_m \quad (3)$$

11.3.2 If the water content is to be determined from a sample of soil taken as prescribed in (10.6.3), follow the procedures and perform the calculations of the chosen Test Method (D2216, D4643, D4944, or D4959).

11.3.3 With a water content value from 11.3.2 calculate the dry density from:

$$\rho_d = \frac{100 \times \rho}{100 + w} \quad (4)$$

11.3.4 Report the dry density to the nearest 1 kg/m^3 (0.1 lbm/ft^3).

11.4 *Determine the Percent Compaction:*

11.4.1 It may be desired to express the in-place dry density as a percentage of a laboratory density such as Test Methods D698, D1557, D4253, or D4254. This relationship can be calculated by dividing the in-place dry density by the laboratory maximum dry density and multiplying by 100. Procedures for calculating relative density are provided in Test Method D4254, which requires that Test Method D4253 also be performed. Corrections for oversize material, if required, shall be performed in accordance with Practice D4718.

12. Report: Test Data Sheet(s)/Form(s)

12.1 See 1.6 regarding the manner in which observed and calculated values are to be recorded.

12.2 *Record as a minimum the following general information (data):*

12.2.1 Test Number or Test Identification.

12.2.2 Location of test (for example, Station number or GPS or Coordinates or other identifiable information).

12.2.3 Visual description of material tested.

12.2.4 Lift number or elevation or depth.

12.2.5 Name of the operator(s).

12.2.6 Make, model and serial number of the test gauge.

12.2.7 Test mode, Method A (direct transmission and test depth), or Method B (backscatter, backscatter/air-gap),

12.2.8 Standardization and adjustment data for the date of the tests.

12.2.9 Any corrections made in the reported values and reasons for these corrections (that is, over-sized particles, water content).

12.2.10 Maximum laboratory density value in kg/m^3 or lbm/ft^3.

12.3 *Record as a minimum the following test specimen data:*

12.3.1 The following values measured by the gauge shall be recorded to the number of significant digits available from the resolution of the value displayed by the gauge:

12.3.1.1 Dry density in kg/m^3 or lbm/ft^3.

12.3.1.2 Wet density in kg/m^3 or lbm/ft^3.

12.3.1.3 Water content in percent.

12.3.1.4 Percent Compaction.

12.3.1.5 Source rod position in inches or millimeters.

13. Precision and Bias

13.1 *Precision:*

13.1.1 *Precision: Wet Density*—Criteria for judging the acceptability of wet density test results obtained by this test method are given in Table 1.[3] The values given are based upon an interlaboratory study in which five test sites containing soils, with wet densities as shown in column two were tested by eight different nuclear gauges and operators. The wet density of each test site was measured three times by each device.

13.1.2 *Precision: Water Mass Per Unit Volume*—Criteria for judging the acceptability of the water mass per unit volume results obtained by this test method are given in Table 2. The values given are based upon an inter-laboratory study in which five test sites containing soils with water mass per unit volume as shown in column two were tested by eight different nuclear gauges and operators. The water mass per unit volume of each test site was measured three times by each device.

13.1.3 *Precision: Water Content*—Criteria for judging the acceptability of the water content results obtained by this test method are given in Table 3. The values given are based upon an inter-laboratory study in which five test sites containing soils, with water content as shown in column two were tested by eight different nuclear gauges and operators. The water content of each test site was measured three times by each device.

13.2 *Bias:*

13.2.1 There are no accepted reference values for these test methods; therefore, bias cannot be determined.

14. Keywords

14.1 acceptance testing; compaction test; construction control; dry density; field density; in-place density; nuclear methods, nuclear gauge; quality control; water content; wet density

[3] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D18-1004.

TABLE 1 Results of Statistical Analysis (Wet Density)[A]

Material[B]	Average kg/m^3 or (lbm/ft^3)	Repeatability Standard Deviation kg/m^3 or (lbm/ft^3)	Reproducibility Standard Deviation kg/m^3 or (lbm/ft^3)	95 % Repeatability Limit on the Difference Between Two Test Results kg/m^3 or (lbm/ft^3)[C]	95 % Reproducibility Limit on the Difference Between Two Test Results kg/m^3 or (lbm/ft^3)[C]
Direct Transmission:					
ML	2084 (130.1)	7.4 (0.46)	12.3 (0.77)	21 (1.3)	34 (2.1)
CL	1837 (114.7)	5.4 (0.34)	10.6 (0.66)	15 (0.9)	30 (1.9)
SP	1937 (120.9)	4.2 (0.26)	11.0 (0.68)	12 (0.7)	31 (1.9)
Backscatter:					
ML	1997 (124.6)	16.0 (1.00)	32.0 (2.00)	45 (2.8)	90 (5.6)

[A] The data used to establish this precision statement are contained in a Research Report available from ASTM Headquarters.[3]
[B] Materials are distinguished by soil types. For definitions of soil types see Practices D2487 and D2488.
[C] Two separate readings at a singular site with constant gauge orientation and settings.

TABLE 2 Results of Statistical Analysis (Water Mass Per Unit Volume)[A]

Material[B]	Average kg/m^3 or (lbm/ft^3)	Repeatability Standard Deviation kg/m^3 or (lbm/ft^3)	Reproducibility Standard Deviation kg/m^3 or (lbm/ft^3)	95 % Repeatability Limit on the Difference Between Two Test Results kg/m^3 or (lbm/ft^3)[C]	95 % Reproducibility Limit on the Difference Between Two Test Results kg/m^3 or (lbm/ft^3)[C]
ML	313 (19.6)	5.7 (0.36)	8.1 (0.50)	16 (1.0)	23 (1.4)
CL	193 (12.1)	6.1 (0.38)	8.5 (0.53)	17 (1.1)	24 (1.5)
SP	320 (20.0)	4.3 (0.27)	10.3 (0.64)	12 (0.7)	29 (1.8)

[A]The data used to establish this precision statement are contained in a Research Report available from ASTM Headquarters.[3]
[B]Materials are distinguished by soil types. For definitions of soil types see Practices D2487 and D2488.
[C]Two separate readings at a singular site with constant gauge orientation and settings.

TABLE 3 Results of Statistical Analysis (% Water Content)[A]

Material[B]	Average %	Repeatability Standard Deviation %	Reproducibility Standard Deviation %	95 % Repeatability Limit on the Difference Between Two Test Results %[C]	95 % Reproducibility Limit on the Difference Between Two Test Results %[C]
ML	17.7	0.39	0.59	1.1	1.7
CL	11.8	0.40	0.58	1.1	1.6
SP	19.8	0.32	0.81	0.9	2.3

[A]The data used to establish this precision statement are contained in a Research Report available from ASTM Headquarters.[3]
[B]Materials are distinguished by soil types. For definitions of soil types see Practices D2487 and D2488.
[C]Two separate readings at a singular site with constant gauge orientation and settings.

ANNEXES

(Mandatory Information)

A1. GAUGE PRECISION

A1.1 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 A1.1.1 or A1.1.2. For wet 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).

A1.1.1 *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:

$$P = \sigma / S \quad (A1.1)$$

where:

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

NOTE A1.1—Displayed gauge counts may be scaled. Contact the manufacturer to obtain the appropriate pre-scale factor.

A1.1.2 *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.