Designation: D 2922 – 05

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

This standard is issued under the fixed designation D 2922; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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

1. Scope

1.1 These test methods cover the determination of the total or wet density of soil and soil-rock mixtures by the attenuation of gamma radiation where the source and detector(s) remain on the surface (Backscatter Method) or the source or detector is placed at a known depth up to 300 mm (12 in.) while the detector(s) or source remains on the surface (Direct Transmission Method).

1.2 The density in mass per unit volume of the material under test is determined by comparing the detected rate of gamma radiation with previously established calibration data.

1.3 The values tested in SI units are to be regarded as the standard. The inch-pound equivalents may be approximate.

1.4 It is common practice in the engineering profession to concurrently use pounds to represent both a unit of mass (lbm) and a unit of force (lbf). This implicitly combines two separate systems of units; that is, the absolute system and the gravitational system. It is scientifically undesirable to combine the use of two separate sets of inch-pound units within a single standard. These test methods have been written using the gravitational system of units when dealing with the inch-pound system. In this system the pound (lbf) represents a unit of force (weight). However, the use of balances or scales recording pounds of mass (lbm), or the recording of density in lbm/ft^3 should not be regarded as nonconformance with these test methods.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific Hazard statements, see Section 6.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))

D 1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D 3017 Test Method for Water Content of Soil and Rock In-Place by Nuclear Methods (Shallow Depth)

D 4253 Test Method for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table

D 4643 Test Method for Determination of Water Content by the Microwave Oven Heating

D 4718 Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles

D 4944 Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester Method

D 4959 Test Method for Determination of Water (Moisture) Content by Direct Heating

3. Significance and Use

3.1 The test methods described are useful as rapid, nondestructive techniques for the in-place determination of density of soil and rock.

3.2 The test methods are suitable for quality control and acceptance testing for construction and for research and development applications.

3.3 The nondestructive nature of the tests allow repetitive measurements to be made at a single test location.

[1] These test methods are under the jurisdiction of ASTM Committee D18 on Soil and Rock and are 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.

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4. Interferences

4.1 The chemical composition of the sample may affect the measurement, and adjustments may be necessary.

4.2 The test methods exhibit spatial bias in that the instrument is more sensitive to the density of the material in close proximity to the surface (Backscatter Method only).

NOTE 1—The nuclear gauge density measurements are somewhat biased to the surface layers of the soil being tested. This bias has largely been corrected out of the direct transmission method and any remaining bias is insignificant. The backscatter method is still more sensitive to the material within the first several inches from the surface.

4.3 Oversize rocks or large voids in the source-detector path may cause higher or lower density determination. Where lack of uniformity in the soil due to layering, rock or voids is suspected, the test volume site should be dug up and visually examined to determine if the test material is representative of the full material in general and if rock correction (see 9.6) is required.

4.4 The sample volume is approximately 0.0028 m^3 (0.10 ft^3) for the Backscatter Method and 0.0057 m^3 (0.20 ft^3) for the Direct Transmission Method when the test depth is 15 cm (6 in.). The actual sample volume is indeterminate and varies with the apparatus and the density of the material. In general, the higher the density the smaller the volume.

5. Apparatus

5.1 *Nuclear Gage*—An electronic counting instrument, capable of being seated on the surface of the material under test, and which contains:

5.1.1 A sealed source of high energy gamma radiation such as cesium or radium.

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

5.2 *Reference Standard*—A block of material used for checking instrument operation and to establish conditions for a reproducible reference count rate.

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

5.4 *Drive Pin*—A pin of slightly larger diameter than the rod in the Direct Transmission Instrument, used to prepare a hole in the material under test for inserting the rod.

5.5 *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.

5.5.1 A 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. Hazards

6.1 This equipment utilizes radioactive materials that may be hazardous to the health of the users unless proper precautions are taken. Users of this equipment must become familiar with applicable safety procedures and government regulations.

6.2 Effective user instructions together with routine safety procedures, such as source leak tests, recording and evaluation of film badge data, and so forth, are a recommended part of the operation and storage of this instrument.

7. Calibration

7.1 Calibration of the instrument will be in accordance with Annex A1.

8. Standardization and Reference Check

8.1 Nuclear gages are subject to long-term aging of the radioactive source, detectors, and electronic systems, which may change the relationship between count rate and material density. To offset this aging, the gage may be calibrated as the ratio of the measured count rate to a count rate made on a reference standard or to an air-gap count (for the backscatter air-gap technique, see 9.5.1.3). The reference count rate should be of the same order of magnitude as the measured count rate over the useful density range of the instrument.

8.2 Standardization of the gage shall be performed at the start of each day's work, and a record of these data shall be retained for a sufficient time to ensure compliance with subsections 8.2.3 and 8.2.3.1. Perform the standardization with the gage located at least 8 m (25 ft) away from other sources of radioactive material, and clear of large masses or other items which may affect the reference count rate.

8.2.1 If recommended by the instrument manufacturer to provide more stable and consistent results: (*1*) turn on the gauge prior to use to allow it to stabilize, (*2*) leave the power on during the use of the gage for that day.

8.2.2 Using the reference standard, take at least four repetitive readings at the normal measurement period and determine the mean. If available on the gage, one measurement period of four or more times the normal period is acceptable. This constitutes one standardization check.

8.2.3 If the value obtained above is within the limits stated below, the gage is considered to be in satisfactory condition, and the value may be used to determine the count ratios for the day of use. If the value is outside these limits, allow additional time for the gage to stabilize, make sure the area is clear of sources of interference, and then conduct another standardization check. If the second standardization check is within the limits, the gage may be used, but if it also fails the test, the gage shall be adjusted or repaired as recommended by the manufacturer. The limits are as follows:

$$|N_s - N_o| \le 1.96\sqrt{\frac{N_o}{F}} \quad (1)$$

where:

N_s = value of current standardization count,
N_o = average of the past four values of N_s taken for prior usage, and
F = value of prescale. [The prescale value (F) is a divisor which reduces the actual value for the purpose of display. The manufactor will supply this value if other than 1.0.] Some instruments may have provisions to compute and display these values.

8.2.3.1 If the instrument standardization has not been checked within the previous three months, perform at least four new standardization checks, and use the mean as the value for N_o.

8.3 Use the value of N_s to determine the count ratios for the current day's use of the instrument. If for any reason the measured density becomes suspect during the day's use, perform another standardization check.

9. Procedure for Field Use

9.1 Standardize the gage. (See Section 8.)

9.2 Select a test location. If the gage will be closer than 250 mm (10 in.) to any vertical mass that might influence the result, such as in a trench or alongside a pipe, follow the manufacturer's correction procedure.

9.3 Remove all loose and disturbed material. Remove additional material as necessary to reach the material that represents a valid sample of the zone or stratum to be tested. Surface drying and spatial bias should be considered in determining the depth of material to be removed.

9.4 Plane or scrape a smooth horizontal surface so as to obtain maximum contact between the gage and the material being tested. The placement of the gage on the surface of the material to be tested is always important, but is especially critical to the successful determination of density when using the backscatter method. The optimum condition in all cases, is total contact between the bottom surface of the gauge and the surface of the material being tested. To correct for surface irregularities, use of native fines or fine sand as a filler may be necessary. The depth of the filler should not exceed approximately 3 mm (⅛ in.) and the total area filled should not exceed 10 % of the bottom area of the instrument. The maximum depth of any void beneath the gage that can be tolerated without filling shall not exceed approximately 3 mm (⅛ in.). Several trial seatings may be required to achieve these conditions.

9.5 Proceed with the test in the following manner:

9.5.1 *Backscatter Procedure*:

9.5.1.1 Seat the gage firmly on the prepared test site.

9.5.1.2 Keep all other radioactive sources away from the gauge to avoid affecting the measurement so as not to affect the readings.

9.5.1.3 Secure and record one or more readings for the normal measurement period in the backscatter position.

NOTE 2—When using the backscatter air-gap procedure, follow the instrument manufacturers instructions regarding apparatus set up. Take the same number of readings for the normal measurement period in the air-gap position as in the standard backscatter position. Determine the air-gap ratio by dividing counts per minute obtained in the air-gap position by counts per minute obtained in standard backscatter position.

9.5.1.4 Determine the ratio of the reading to the standard count or to the air gap count. From this count ratio and the appropriate calibration and adjustment data, determine the in-place wet density.

9.5.2 *Direct Transmission Procedure*:

9.5.2.1 Make a hole perpendicular to the prepared surface using the guide and the hole-forming device (5.4), or by drilling if necessary. The hole shall be of such depth and alignment that insertion of the probe will not cause the gage to tilt from the plane of the prepared area. The depth of the hole must be deeper than the depth to which the probe will be placed. The guide shall be the same size as the base of the gauge, with the hole in the same location on the guide as the probe on the gauge. The corners of the guide are marked by scoring the surface of the soil. The guide plate is then removed and any necessary repairs are made to the prepared surface.

9.5.2.2 Proceed with testing in the following manner:

9.5.2.3 Set the gage on the soil surface, carefully aligning it with the marks on the soil so that the probe will be directly over the pre-formed hole.

9.5.2.4 Insert the probe in the hole.

9.5.2.5 Seat the gage firmly by rotating it about the probe with a back and forth motion.

9.5.2.6 Pull gently on the gage in the direction that will bring the side of the probe against the side of the hole that is closest to the detector (or source) location in the gauge housing.

9.5.2.7 Keep all other radioactive sources away from the gage to avoid affecting the measurement.

9.5.2.8 Secure and record one or more readings for the normal measurement period.

9.5.2.9 Determine the ratio of the reading to the standard count. From this count ratio and the appropriate calibration and adjustment data, determine the in-place wet density.

NOTE 3—Some instruments have built-in provisions to compute the ratio, wet density, and to enter an adjustment bias. Additionally some instruments may have provisions to measure and compute moisture content, and dry density.

9.6 If the volume tested as defined in 4.4 has excess oversize material with respect to the limitations in the appropriate Test Methods D 698, D 1557 or D 4253, then a correction for wet density (unit weight) and water content must be applied. This correction will be done in accordance with Practice D 4718. This test method requires sampling from the actual test volume.

9.6.1 If samples of the measure material are to be taken for purposes of correlation with other test methods or rock correction, the volume measured can be approximated by a 200 mm (8 in.) diameter cylinder located directly under the center line of the radioactive source and detector(s). The height of the cylinder to be excavated will be the depth setting of the source rod when using the Direct Transmission method or approximately 75 mm (3 in.) when using the Backscatter Method.

9.6.2 An alternative to the correction for oversize particles, that can be used with mass density methods or minimal oversize situations, involves multiple tests. Tests may be taken at adjacent locations and the results averaged to get a representative value. Comparisons need to be made to evaluate whether the presence of a single large rock or void in the soil is producing unrepresentative values of density. Whenever values obtained are questionable, the test volume site should be dug up and visually examined.

10. Calculation of Results

10.1 The in-place wet density is determined as outlined in 9.5. If dry density is required, the in-place water content shall be determined using either gravimetric samples and laboratory determination of water content (Test Methods D 2216, D 4643, D 4959, D 4944), or an instrument which determines water content by neutron thermalization (Test Method D 3017).

10.1.1 If the water content is determined by nuclear methods, Test Method D 3017, subtract the kg/m^3(lbf/ft^3) of moisture from the kg/m^3 (lbf/ft^3) of wet density, and obtain dry density in kg/m^3 (lbf/ft ^{3}).

10.1.2 If the water content is determined by other methods, and is in the form of percent, proceed as follows:

$$\rho_d = \frac{100\rho_m}{100 + W} \quad (2)$$

where:

ρ_d = dry density in kg/m^3 (lbf/ft^3),
ρ_m = wet density in kg/m^3 (lbf/ft^3), and
W = water as a percent of the dry mass.

11. Report

11.1 Report the following information:

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

11.1.2 Make, model and serial number of the test instrument.

11.1.3 Name of the operator(s).

11.1.4 Test site identification.

11.1.5 Visual description of material tested.

11.1.6 Test mode (backscatter or direct transmission) and test depth (if applicable).

11.1.7 Wet and dry densities in kg/m^3 or unit weights in lb/ft^3.

11.1.8 Water content in percent of dry mass or dry unit weight.

12. Precision and Bias

12.1 *Precision*:

12.1.1 *Precision*—Criteria for judging the acceptability of wet density test results obtained by this test method are given in Table 1. The figure in column three represents the standard deviations that have been found to be appropriate for the materials tested in column one. The figures given in column four are the limits that should not be exceeded by the difference between the results of two properly conducted tests. The figures 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 devices and operators. The wet density of each test site was determined three times by each device.[3]

[3] The data used to establish this precision statement is contained in a Research Report available from ASTM Headquarters. Request RR:D18-1004.

TABLE 1 Results of Statistical Analysis

Precision and Soil Type	Average kg/m^3 (lb/ft^3)	Standard Deviation, kg/m^3 (lb/ft^3)	Acceptable Range of Two Results kg/m^3 (lb/ft^3)
Single Operator Precision:			
Direct Transmission:			
CL	1837 (114.7)	5.4 (0.34)	15.1 (0.94)
SP	1937 (120.9)	4.3 (0.27)	11.9 (0.74)
ML	2084 (130.1)	7.4 (0.46)	20.5 (1.28)
Backscatter:			
ML	1996 (124.6)	19.4 (1.21)	54.3 (3.39)
Multilaboratory Precision:			
Direct Transmission:			
CL	1837 (114.7)	10.6 (0.66)	29.8 (1.86)
SP	1937 (120.9)	10.9 (0.68)	30.6 (1.91)
ML	2084 (130.1)	12.3 (0.77)	34.4 (2.15)
Backscatter:			
ML	1996 (124.6)	38.1 (2.38)	107 (6.67)

12.1.2 An instrument count precision of 8 kg/m^3 (0.5 lbf/ft^3) for the Backscatter Method and 4 kg/m^3 (0.25 lbf/ft^3) Direct Transmission Method are typical on a material of approximately 2000 kg/m^3 (125 lbf/ft^3) density, with a measurement time of one minute.

12.1.2.1 Instrument count precision is defined as the change in density 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 the time period of the count must be stated. It may be determined from a series of 20 or more counts taken without moving the instrument, or alternately from the calibration data using the assumption that σ is equal to the – count at that density. The count must be the true instrument count corrected for any pre-scaling (see 8.2.3).

$$P = \frac{\sigma}{S} \quad (3)$$

where:

P = instrument precision in density (kg/m^3 or lbf/ft^3)
σ = one standard deviation of the count
S = the slope of the calibration curve at the defined density value.

12.2 *Bias*:

12.2.1 There is no accepted reference value for this test method, therefore, bias cannot be determined.

13. Keywords

13.1 density; field density; nuclear methods

ANNEXES

(Mandatory Information)

A1. WET DENSITY CALIBRATION & VERIFICATION

A1.1 **Calibration**—Newly acquired gauges shall be calibrated initially. Existing gauges shall be calibrated after repairs that may affect the instrument geometry. Existing gauges shall be calibrated to re-establish calibration curves, tables, or equivalent coefficients if the gauge does not meet the specified tolerances in the verification process. If the owner does not establish a verification procedure, the gauge shall be calibrated at a minimum frequency of 24 months.

A1.2 **Verification**—Existing gauges shall be verified at a minimum frequency of 12 months. The verification process and resultant tolerances obtained over the depths the gauge is used shall be formally recorded and documented. If the verification process indicates a variance beyond the specified tolerances, the gauge shall be calibrated.

A1.3 **Calibration Response**—The calibration response of the gauge shall be within ±16 kg/m^3 (±1.0 lb/ft^3) on the block(s) on which the gauge was calibrated. This calibration may be done by the manufacturer, the user, or an independent vendor. Nuclear instrument response is influenced by the chemical composition of measured materials. This response must be taken into account in establishing the assigned standard block density. The block(s) used for calibration shall be capable of generating a general and reliable curve covering the entire density range of the materials to be tested in the field. The density of these standard block(s) shall be determined to an accuracy of ±0.2 %.

A1.3.1 Sufficient data shall be taken on each density standard block to ensure an instrument count precision of at least one-half the instrument count precision required for field use, assuming field use measurement of 1 min duration and 4 min duration used for calibration, or an equivalent relationship. The data may be presented in the form of a graph, table, equation coefficients, or stored in the gauge, to allow converting the count rate data to density.

A1.3.2 The method and test procedures used in establishing the calibration count rate data shall be the same as those used for obtaining the field count rate data.

A1.4 Calibration Standards

A1.4.1 The material type, actual density, or assigned standard block density of each calibration standard used to establish or verify the instrument calibration shall be stated as part of the calibration data for each measurement depth.

A1.4.2 The standards should be sufficient in size to not change the count rate if enlarged in any dimension.

NOTE A1.1—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 block manufacturers' recommendations for proper installation and use.

A1.4.3 The most successful standards that have been established for calibration have been made of magnesium, aluminum, aluminum/magnesium, granite, and limestone. These standards have been used in combination with each other, with historical curve information, and with other prepared block(s) to produce accurate and reliable calibration.

A1.4.4 Standards of soil, rock, and concrete that have stable characteristics for reproducibility and uniformity are difficult to prepare. These standards may be of use for specialty verification or field calibration where local site material chemistry or background situations require special adaptation.

A1.5 Verification of an Existing Calibration

A1.5.1 Verify an existing calibration by taking a sufficient number of counts at each measurement depth on one or more blocks of established density to ensure the accuracy of the existing calibration within ±32 kg/m^3 (±2.0 lb/ft^3) at each measurement depth.

A1.5.2 Sufficient data shall be taken to ensure an instrument count precision of at least one-half the instrument count precision required for field use assuming field use measurement of 1 min duration and 4 min duration used for calibration, or an equivalent relationship.

A1.5.3 Calibration block(s) which are used for calibration of the gauge or prepared block(s) which are capable of generating a general and reliable curve covering the entire density range of the materials to be tested in the field can be used to verify gauge calibration.

A1.5.4 Block(s) prepared of soil, rock, concrete, asphalt, and engineered blocks that have characteristics of reproducible uniformity may be used, but care must be taken to minimize changes in density and water content over time.

A1.5.5 Density values of prepared blocks shall be determined to an accuracy of ±0.5 % at each measurement depth.

A1.5.6 The assigned block density for each calibration depth used to verify the instrument calibration shall be stated as part of the verification data.

A2. DETERMINING PRECISION OF APPARATUS
(Moved from Precision and Bias Section of the standard to an Annex)

A2.1 **Instrument Count Precision**:

A2.1.1 Instrument count precision is defined as the change in density 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. It may be determined using calibration data (Eq A2.1) or A2.2.

A2.1.2 Determine the instrument precision of the system, *P*, from the slope of the calibration curve, *S*, and the standard deviation, σ, of the signals (detected gamma rays) in counts per minute (cpm), as follows:

$$P = \sigma/S \quad \text{(A2.1)}$$

where:

P = precision
σ = standard deviation, cpm
S = slope, cpm/kg/m^3(cpm/lb/ft^3)

A2.2 Determine the slope of the calibration curve at the 2000 kg/m^3 (125 lb/ft^3) point in counts per minute per kilogram per cubic meter (counts per minute per pound per cubic foot). Determine the standard deviation of a minimum of 20 repetitive readings of 1 min each (gauge is not moved after seating for the first count) taken on material having a density of 2000 kg ± 80 kg/m^3 (125.0 ± 5.0 lb/ft^3). The value of *P* is typically less than 10 kg/m^3 (0.6 lb/ft^3) in the backscatter method and 5 kg/m^3 (0.3 lb/ft^3) in the direct transmission method at a 6 in. depth.

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