Designation: D 3017 – 05

Standard Test Method for Water Content of Soil and Rock in Place by Nuclear Methods (Shallow Depth) [1]

This standard is issued under the fixed designation D 3017; 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 This test method covers the determination of water content of soil and rock by the thermalization or slowing of fast neutrons where the neutron source and the thermal neutron detector both remain at the surface.

1.2 The water content in mass per unit volume of the material under test is determined by comparing the detection rate of thermalized or slow neutrons with previously established calibration data.

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

1.3.1 It is common practice in the engineering profession to concurrently use pounds to represent both a unit of mass (lbm) and of force (lbf). This implicitly combines two systems of units, that is, the absolute system and the gravitational system. This test method has been written using the absolute system for water content (kilograms per cubic metre) in SI units. Conversion to the gravitational system of unit weight in lbf/ft^3 may be made by multiplying by 0.06243 or in kN/m^3 by multiplying by 9.807. The recording of water content in pound-force per cubic foot should not be regarded as non-conformance with this test method although the use is scientifically incorrect.

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

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 1556 Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method

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

D 2922 Test Methods for Density of Soil and Soil Aggregate in Place by Nuclear Methods (Shallow Depth)

D 2937 Test Method for Density of Soil in Place by the Drive-Cylinder Method

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

3. Significance and Use

3.1 The test method described is useful as a rapid, nondestructive technique for the in-place determination of water content of soil and rock.

3.2 The test method is used for quality control and acceptance testing of compacted soil and rock for construction and for research and development. The non-destructive nature allows repetitive measurements at a single test location and statistical analysis of the results.

3.3 The fundamental assumptions inherent in the test method are that the hydrogen present is in the form of water as defined by Test Method D 2216, and that the material under test is homogeneous.

3.4 Test results may be affected by chemical composition, sample heterogeneity, and, to a lesser degree, material density and the surface texture of the material being tested. The technique also exhibits spatial bias in that the apparatus is more sensitive to water contained in the material in close proximity to the surface and less sensitive to water at deeper levels.

4. Interferences

4.1 The chemical composition of the sample may dramatically affect the measurement and adjustments may be necessary. Hydrogen in forms other than water, as defined by Test Method D 2216, and carbon will cause measurements in excess of the true value. Some chemical elements such as boron, chlorine, and minute quantities of cadmium will cause measurements lower than the true value.

4.2 The water content determined by this test method is not necessarily the average water within the volume of the sample involved in the measurement. The measurement is heavily influenced by the water content of the material closest to the surface. The volume of soil and rock represented in the

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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.

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. At 160 kg/m^3 (10 lbf/ft^3), approximately 50 % of the typical measurement results from the water content of the upper 50 to 75 mm (2 to 3 in.).

4.2.1 If samples of the measured 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 fast neutron source and thermal neutron detector. The height of the cylinder to be excavated is approximated by:

Moisture Content		Cylinder Height		Volume	
kg/m^3	lbf/ft^3	mm	in.	m^3	ft^3
80	5	250	10	0.0079	0.29
160	10	200	8	0.0063	0.23
240	15	150	6	0.0047	0.17
320	20	125	5	0.0039	0.15
400	25	112	4.5	0.0035	0.13
480	30	100	4	0.0031	0.12

NOTE 1—The volume of field compacted material sampled by the test can effectively be increased by repeating the test at immediately adjacent (vertically or horizontally) locations and averaging the results.

4.3 Other neutron sources must not be within 8 m (25 ft) of equipment in operation.

5. Apparatus

5.1 While exact details of construction of the apparatus may vary, the system shall consist of:

5.1.1 *Fast Neutron Source*—A sealed mixture of a radioactive material such as americium or radium and a target material such as beryllium.

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

5.1.3 *Readout Device*—A suitably timed scaler(s). Usually the readout device will contain the high-voltage supply necessary to operate the detector, and low-voltage power supply to operate the readout and accessory devices.

5.1.4 *Housing*—The source, detector, readout device, and power supply shall be in housings of rugged construction which shall be water and dust resistant.

5.1.5 *Reference Standard*—A block of hydrogeneous material for checking equipment operation and to establish conditions for a reproducible count rate.

5.1.6 *Site Preparation Device*—A steel plate, straightedge, or other suitable leveling tools which may be used to plane the test site to the required smoothness.

5.2 Calibrate apparatus in accordance with Annex A1.

5.3 Determine the precision of the apparatus in accordance with Annex A2.

6. Hazards

6.1 This equipment utilizes radioactive materials which may be hazardous to the health of the users unless proper precautions are taken.

6.2 Effective operator instruction together with routine safety procedures such as source leak tests, recording and evaluation of film badge data, use of survey meters, etc., are a recommended part of the operation of equipment of this type.

7. Standardization

7.1 All nuclear water content instruments are subject to long-term aging of the radioactive source, detectors, and electronic systems, which may change the relationship between count rate and water content. To offset this aging, instruments are calibrated as a ratio of the measurement count rate to a count rate made on a reference standard. The reference count rate should be in the same or higher order of magnitude than the range of measurement count rates over the useful water range of the equipment.

7.2 Standardization of equipment on the reference standard is required at the start of each day's use and a record of these data shall be retained for a sufficient time to ensure compliance with subsections 7.2.2 and 7.2.3. The standardization shall be performed with the equipment located at least 8 m (25 ft) away from other gages and clear of large masses of water or other items which may affect the gage readings.

7.2.1 Turn on the instrument and allow for stabilization in accordance with the manufacturer's recommendations. If the instrument is to be used either continuously or intermittently during the day, it is generally best to leave it in the "power on" condition to prevent having to repeat the stabilization. This will provide more stable, consistent results.

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

7.2.3 If the value obtained above is within the limits stated below, the equipment 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 obtained is outside these limits, another standardization check should be made. If the second standardization check is within the limits, the equipment may be used, but if it also fails the test, the equipment shall be adjusted or repaired as recommended by the manufacturer.

$$|N_s - N_o| \leq 1.96\sqrt{\frac{N_o}{F}} \tag{1}$$

where:

N_s = value of current standardization check (7.2.2) on the reference standard,

N_o = average of the past four values of N_s taken for prior usage, and

F = value of prescale (A2.2.1).

7.3 The value of N_s will be used to determine the count ratios for the current day's use of the equipment. If, for any reason, measured water content becomes suspect during the day's use, perform another standardization.

8. Procedure

8.1 Standardize the instrument (Section 7).

8.2 Select a location for test where the instrument in test position will be at least 250 mm (10 in.) away from any vertical projection.

8.3 Prepare the test site in the following manner:

8.3.1 Remove all loose and disturbed material, and remove additional material as necessary to reach the top of the vertical interval to be tested. Surface drying and the spatial bias should be considered in determining the depth at which the instrument is to be seated.

8.3.2 Prepare a horizontal area, sufficient in size to accommodate the instrument, by planing to a smooth condition so as to obtain maximum contact between the instrument and material being tested. If the instrument base is to be placed below the surrounding surface, the horizontal area shall be at least twice the area of the base of the instrument. If the depression is greater than 25 mm (1 in.), the condition in 8.2 must be met by clearing a larger area.

8.3.3 The placement of the instrument on the surface of the material to be tested is critical to the successful determination of water. The optimum condition is total contact between the bottom surface of the instrument and the surface of the material being tested. The maximum void beneath the instrument shall not exceed approximately 3 mm (⅛ in.). Use native fines of similar water content or dry quartz sand to fill voids and level the excess with a rigid plate or other suitable tool. The total area filled shall not exceed 10 % of the bottom area of the instrument.

8.4 Proceed with the test in the following manner:

8.4.1 Seat the instrument firmly, place the source in the proper position and take a count for the normal measurement period.

8.4.2 Determine the ratio of the reading to the standard count (Section 7). From this ratio and the calibration and adjustment data, determine the in-place water content per unit volume (Note 2).

NOTE 2—Some instruments have built-in provisions to compute the ratio, the water content per unit volume with adjustments, the dry density, and the water content in percent of dry density (or dry unit weight).

8.5 If the volume tested as defined in 4.2.1 is insufficient for the size of rock contained in the soil (refer to Practice D 4718), take additional tests at adjacent locations and average the results (Note 3).

NOTE 3—The water content value obtained should be compared to other water contents obtained for similar soils and conditions. The presence of a large rock particle or void in the soil being tested may give an unrepresentative value of water content. If the value is unusually high or low, another determination of water content should be performed. To avoid preparation of another test site, the gage may be repositioned (such as rotating the gage 90°) at the original site.

9. Calculation

9.1 Calculate the water content, *w*, in percent of dry density (or dry unit weight) of soil as follows:

$$w = \frac{M_m \times 100}{\rho_d} \tag{2}$$

or

$$w = \frac{M_m \times 100}{\rho - M_m} \tag{3}$$

where:

w = water content, percent of dry density,

M_m = water content, kg/m^3(lbf/ft^3),

ρ_d = dry density of soil (kg/m^3) or dry unit weight (lbf/ft^3), and

ρ = wet (total) density of soil (kg/m^3) or wet unit weight (lbf/ft^3).

10. Report

10.1 Report the following information:

10.1.1 Make, model, and serial number of the test device,

10.1.2 Standard count and adjustment data for the date of the tests,

10.1.3 Name of the operator,

10.1.4 Test site identification,

10.1.5 Visual description of material tested,

10.1.6 Count rate for each reading, if applicable,

10.1.7 Water content in kg/m^3 or lbf/ft^3,

10.1.8 Wet and dry densities in kg/m^3 or unit weights in lbf/ft^3,

10.1.9 Water content in percent of dry density or dry unit weight.

11. Precision and Bias

11.1 *Precision*—Criteria for judging the acceptability of the water content results obtained by this test method are given in Table 1. The value in column two is in the units actually measured by the nuclear gage. The figures in column three represent 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 water content as shown in column two, were tested by eight different devices and operators. The water content of each test site was determined three times by each device.[3]

11.2 *Bias*—There is no accepted reference value for this test method, therefore, bias cannot be determined.

12. Keywords

12.1 compaction test; construction control; density; field control; inspection; moisture content; moisture control; nuclear methods; nuclear moisture; quality control; soil moisture; test procedure; water content

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[3] Details of the study are contained in a Research Report available from ASTM Headquarters. Request RR:D18-1005.

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:			
CL	194 (12.1)	5.6 (0.35)	15.5 (0.97)
SP	300 (18.7)	7.4 (0.46)	20.7 (1.29)
ML	314 (19.6)	5.6 (0.35)	15.8 (0.99)
Multilaboratory Precision:			
CL	194 (12.1)	8.3 (0.52)	23.1 (1.44)
SP	300 (18.7)	12.0 (0.75)	33.6 (2.10)
ML	314 (19.6)	9.3 (0.58)	26.1 (1.63)

ANNEXES

(Mandatory Information)

A1. WATER CONTENT CALIBRATION AND 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 unit 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 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 lb/ft^3) on the block(s) on which the gauge was calibrated. This calibration may be done by the gauge manufacturer, the user, or an independent vendor. The block(s) used for calibration should be capable of generating a general curve covering the entire water content range of the materials to be tested in the field. The calibration curve can be established using counts and water contents of standard blocks, previous factory curve information or historical data. Due to the effect of chemical composition, the calibration supplied by the manufacturer with the apparatus will not be applicable to all materials. It shall be accurate for silica and water; therefore, the calibration must be verified and adjusted, if necessary, in accordance with A1.4.

A1.4 Calibration Standards

A1.4.1 Calibration standards may be established using any of the following methods. Prepared containers or standards must be large enough to not change the observed count rate if made larger in any dimension.

NOTE A1.1—Dimensions of approximately 610 by 460 by 360 mm (approximately 24 by 18 by 14 in.) have proven satisfactory. For blocks with width or lengths smaller than the sizes specified, follow the block manufacturers' recommendations for proper installation and use.

A1.4.2 Prepare a homogeneous standard of hydrogenous materials having an equivalent water content determined by comparison (using a nuclear instrument) with a saturated silica sand standard prepared in accordance with A.2.4.2. Metallic blocks used for wet density calibration such as magnesium or aluminum are convenient zero water content standards.

A1.4.3 Prepare containers of compacted material with a percent water content determined by (Test Method D 2216) and a wet density calculated from the mass of the material and the inside dimensions of the container. The water content may be calculated as follows:

$$M_m = \frac{\rho\, x\, w}{100 + w} \tag{A1.1}$$

where:

M_m = the volumetric water content, kg/m^3 or lbm/ft^3,
w = water content, percent of dry mass, and
ρ = wet (total) density, kg/m^3 or lbm/ft^3.

A1.4.4 Where neither of the previous calibration standards are available, the gauge may be calibrated by using a minimum of four selected test sites in an area of a compaction project where material has been placed at several different water contents. The test sites shall represent the range of water contents over which the calibration is to be used. At least four replicate nuclear measurements shall be made at each test site. The density at each site shall be measured by making four closely spaced determinations with calibrated equipment in accordance with Test Methods D 2922, D 1556, or D 2937. The water content of each of the density tests shall be determined by Test Method D 2216. Use the mean value of the replicate readings as the calibration point value for each site.

A1.5 Calibration Adjustments

A1.5.1 The calibration of newly acquired or repaired gauges shall be verified and adjusted prior to use. Calibration curves shall be checked prior to performing tests on materials that are distinctly different from material types previously used in obtaining or adjusting the calibration. Sample materials may be selected by either A1.5.1.1 or A1.5.1.2. The amount of water shall be within ±2 % of the water content established as optimum for compaction. Determine the water content in kg/m^3 or lb/ft^3 by Eq A1.1. A microwave oven or direct heater may be utilized for drying materials that are not sensitive to temperature, in addition to the methods listed in A1.4.4. A minimum of four comparisons is required and the mean of the observed differences used as the correction factor.

A1.5.1.1 Container(s) of compacted material taken from the test site may be prepared in accordance with the procedures in A1.4.3.

A1.5.1.2 Test site(s) or the compacted material may be selected in accordance to A1.4.4.

A1.5.2 The method and test procedures used in obtaining the count rate to establish the error must be the same as those used for measuring the water content of the material to be tested.

A1.5.3 The mean value of the difference between the water content of the test samples as determined in A1.5.1.1 or A1.5.1.2 and the values measured with the gauge shall be used as a correction to measurements made in the field. Some gauges utilizing a microprocessor may have provision to input a correction factor that is established by the relative values of water content as a percentage of dry density, thus eliminating the need to determine the difference in mass units of water.

A1.6 Verification of an Exisiting Calibration

A1.6.1 Verify an existing calibration by taking sufficient number of counts on one or more blocks of established water content to ensure the accuracy of the existing calibration within ±16 kg/m^3(±1 lb/ft^3). The water content block(s) should be prepared in accordance with section A1.4.2 and A1.4.3.

A1.6.2 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.

A1.6.3 Calibration blocks used to establish calibration parameters and prepared blocks can be used to verify calibration.

A1.6.4 Prepared blocks that have characteristics of reproducible uniformity maybe used, but care must be taken to minimize changes in density and water content over time.

A1.6.5 The assigned water content of the block(s) used for verification of the instrument shall be stated as part of the verification data.

A2. DETERMINING PRECISION OF APPARATUS

A2.1 Instrument Count Precision

A2.1.1 Instrument count precision is defined as the change in water content that occurs corresponding to a one standard deviation change in the count due to the random decay of the radioactive source. The water content of the material and time period of the count must be stated. It may be determined using calibration data (Eq A1.1) or verification procedures from A1.6.

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 neutrons) in counts per minute (cpm), as follows:

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

where:

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

NOTE A2.1—Displayed gauge counts may be scaled. Contact the manufacturer to obtain the appropriate pres-scale factor.

A2.2 Determine the slope of the calibration curve at the 160-kg/m^3(10-lb/ft.^{3}) point in counts per minute per kilogram per cubic meter (counts per minute per cubic foot). Determine the standard deviation of a minimum of 20 repetitive readings of 1 min each (the gauge is not moved after seating for the first count) taken on material having a water content of 160 ± 10 kg/m^3(10.0 ± 0.6 lb/ft^3). The value of *P* is typically less than 4.8 kg/m^3(0.30 lb/ft^3).