



# Standard Test Method for Water Content of Soil and Rock In-Place by the Neutron Depth Probe Method<sup>1</sup>

This standard is issued under the fixed designation D 5220; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method covers the calculation of the water content of soil and rock by thermalization or slowing of fast neutrons where the neutron source and the thermal neutron detector are placed at the desired depth in the bored hole lined by an access tube (see Note 1).

1.2 The water content, in mass per unit volume of the material under test, is calculated by comparing the thermal neutron count rate with previously established calibration data (see Annex A1).

1.3 A precision statement has not been developed for this standard at this time. Therefore, this standard should not be used for acceptance or rejection of a material for purchasing purposes unless correlated to other accepted ASTM methods.

1.4 The values expressed in SI units are regarded as the standard. The inch-pound units given in parentheses may be approximate and are provided for information only.

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.* Specific hazards are given in Section 7.

## 2. Referenced Documents

### 2.1 ASTM Standards:

D 1452 Practice for Soil Investigation and Sampling by Auger Borings<sup>2</sup>

D 1586 Method for Penetration Test and Split-Barrel Sampling of Soils<sup>2</sup>

D 1587 Practice for Thin Walled Tube Sampling of Soils<sup>2</sup>

D 2113 Practice for Diamond Core Drilling for Site Investigation<sup>2</sup>

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures<sup>2</sup>

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

Drive-Cylinder Method<sup>2</sup>

D 3017 Test Method for Moisture Content of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)<sup>2</sup>

D 3550 Practice for Ring-Lined Barrel Sampling of Soils<sup>2</sup>

D 4428/D 4228M Test Method for Crosshole Seismic Testing<sup>2</sup>

D 5195 Test Method for Density of Soil and Rock in Place at Depths Below the Surface by Nuclear Methods<sup>3</sup>

## 3. Summary of Test Method

3.1 This test method uses thermalization of neutron radiation to calculate the in-place water content of soil and rock at various depths by placing a probe containing a neutron source and a thermal neutron detector at desired depths in a bored hole lined by an access tube as opposed to surface measurements in accordance with Test Method D 3017.

3.2 Neutrons emitted by the source are thermalized (slowed) by collisions with materials of low atomic numbers. Hydrogenous materials, such as water and other compounds containing hydrogen, are most effective in thermalizing neutrons. In this apparatus the neutrons thermalized by the material under test are detected by the thermal neutron detector.

3.3 In the absence of interference elements as discussed in Section 5, the number of thermalized neutrons is a function of the hydrogen content of the material under test and the water content is proportional to the hydrogen content.

3.4 By the use of a calibration process the water content is calculated by correlating the count rate to known water contents.

## 4. Significance and Use

4.1 This test method is useful as a rapid, nondestructive technique for the calculation of the in-place water content of soil and rock at desired depths below the surface.

4.2 This test method is useful for informational and research purposes. It should only be used for quality control and acceptance testing when correlated to actual water contents using procedures and methods described in A1.2.3.

4.3 The non-destructive nature of this test method allows repetitive measurements to be made at a single test location for

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Investigations.

Current edition approved Feb. 10, 2002. Published May 2002. Originally published as D 5220-92. Last previous edition D 5220-92(1997)

<sup>2</sup> *Annual Book of ASTM Standards*, Vol 04.08.

<sup>3</sup> *Annual Book of ASTM Standards*, Vol 04.09.

statistical analysis and to monitor changes over time.

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

## 5. Interferences

5.1 The sample heterogeneity, density, and chemical composition of the material under test will affect the measurements. The apparatus must be calibrated to the material under test or adjustments made in accordance with Annex A2.

5.1.1 Hydrogen, in forms other than water, as defined by Test Method D 2216 and carbon, present in organic soils, will cause measurements in excess of the true water value. Some elements such as boron, chlorine, and minute quantities of cadmium, if present in the material under test, will cause measurements lower than the true water value.

5.2 This test method exhibits spatial bias in that it is more sensitive to water contained in the material closest to the access tube. The measurement is not necessarily an average water content of the total sample involved.

5.2.1 Voids around the access tube can affect the measurement (see 11.1.2).

5.3 The sample volume is approximately  $0.048 \text{ m}^3$  ( $1.7 \text{ ft}^3$ ) with a water content of  $200 \text{ kg/m}^3$  ( $12.5 \text{ lbf/ft}^3$ ). The actual sample volume is indeterminate and varies with the apparatus and the water content of the material. In general, the greater the water content of the material, the smaller the volume involved in the measurement.

## 6. Apparatus (See Fig. 1)

6.1 The apparatus shall consist of a nuclear instrument capable of measuring water content at various depths below the surface containing the following:

6.1.1 A sealed mixture of a radioactive material such as americium or radium with a target element such as beryllium, and a suitable thermal neutron detector, and

6.1.2 A suitable timed scaler and power source.

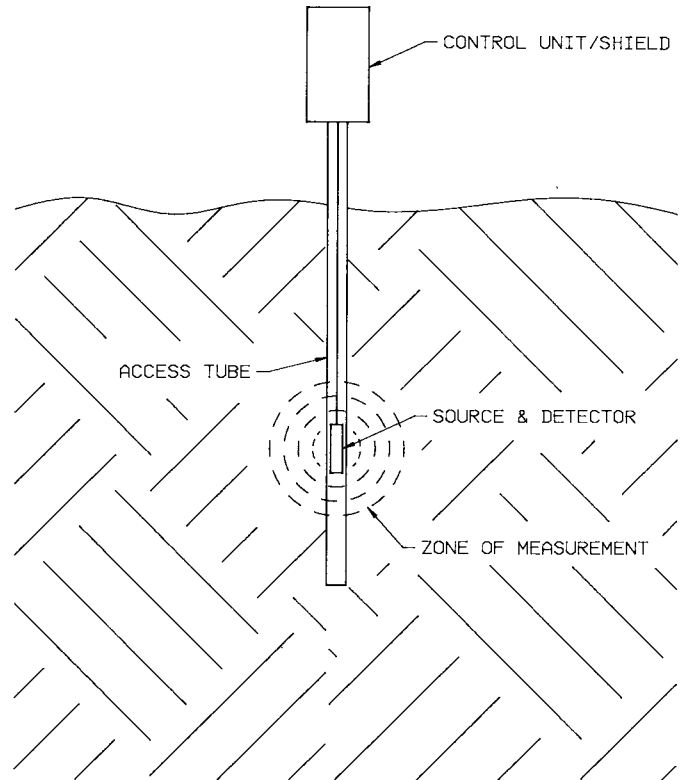
6.2 The apparatus shall be equipped with a cylindrical probe containing the neutron source and detector, connected by a cable of sufficient design and length, that is capable of being lowered down the cased hole to desired test depths.

6.3 The apparatus shall be equipped with a reference standard, a fixed shape of hydrogenous material used for checking apparatus operation and to establish conditions for a reproducible reference count rate. It may also serve as a radiation shield.

6.4 *Apparatus Precision*—See Annex A3 for the precision of the apparatus.

6.5 *Accessories:*

6.5.1 *Access Tubing*—The access tubing (casing) is required for all access holes in nonlithified materials (soils and poorly consolidated rock) that cannot maintain constant borehole diameter with repeated measurements. If access tubing is required the tubing shall be of a material such as aluminum, steel, or polyvinyl chloride, having an interior diameter large enough to permit probe access without binding. The tubing shall be as thin-walled as possible to provide close proximity of the probe to the material under test. The same type of tubing shall be used in the field as is used in calibration.



**FIG. 1 Schematic Diagram; Water Content by Neutron Depth Probe Method**

6.5.2 Hand auger or power drilling equipment that can be used to establish the access hole. Any drilling equipment that provides a suitable clean open hole for installation of access tubing and insertion of the probe shall be acceptable. The equipment used shall be capable of maintaining constant borehole diameter to ensure that the measurements are performed on undisturbed soil and rock. The type of equipment and methods of advancing the access hole should be reported.

6.5.3 *Dummy Probe*—A cylindrical probe the same size as the probe containing the neutron source and a chain or cable of sufficient design and length to permit lowering the dummy probe down the cased hole to desired test depths.

## 7. Hazards

7.1 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 completely familiar with possible safety hazards and with all applicable regulations concerning the handling and use of radioactive materials. Effective user instructions together with routine safety procedures are a recommended part of the operation of this apparatus.

## 8. Calibration, Standardization, and Reference Check

8.1 Calibrate the instrument in accordance with Annex A1.

8.2 Adjust the calibration in accordance with Annex A2 if adjustments are necessary.

8.3 *Standardization and Reference Check:*

8.3.1 Nuclear apparatus are subject to the long-term decay of the radioactive source and aging of detectors and electronic

system, that may change the relationship between count rate and water content. To offset these changes, the apparatus may be calibrated as the 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 a higher order of magnitude than the range of measurement count rates over the useful water content range of the apparatus.

8.3.2 Standardization of equipment should be performed at the start of each day's work and a permanent record of these data retained. Perform the standardization with the apparatus located at least 10 m (30 ft) away from other apparatus containing neutron emitting radioactive sources and clear of large masses of water or other items which may affect the reference count rate.

8.3.2.1 If recommended by the apparatus manufacturer to provide more stable and consistent results: turn on the apparatus prior to use to allow it to stabilize; and leave the power on during the day's testing.

8.3.2.2 Using the reference standard, take at least four repetitive readings at the manufacturer's recommended measurement period and determine the mean. If available on the apparatus, one measurement at a period of four or more times the recommended period is acceptable. These measurements constitute one standardization check.

8.3.2.3 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 is outside these limits, allow additional time for the apparatus 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 apparatus may be used, but if it also fails the test, the apparatus shall be adjusted or repaired as recommended by the manufacturer. The limits are as follows:

$$N_s < = N_o + \frac{2.0\sqrt{N_o}}{\sqrt{F}}$$

and

$$N_s > = N_o - \frac{2.0\sqrt{N_o}}{\sqrt{F}}$$

where:

- $N_s$  = value of current standardization check,
- $N_o$  = average of the past four values of  $N_s$  taken previously,
- and
- $F$  = value of prescale.

NOTE 1—Some instruments have built-in provisions to compute and display the results of a statistical test of the standardization counts and to indicate if the apparatus is in satisfactory condition.

8.3.3 Use the value of  $N_s$  to determine the count ratios for the current day's use of the apparatus. If, for any reason, the measured water content becomes suspect during the day's use, perform another standardization check.

8.3.4 If the instrument was calibrated in the field using methods described in Annex A1.2.3 the count rate on any trial reading may be adjusted by a correction factor determined in initial calibration.

## 9. Procedure

### 9.1 Installation of Access Tubing (Casing):

9.1.1 Drill the access tube hole and install access tubing in a manner dependent upon the material to be tested, the depth to be tested, and the available drilling equipment.

9.1.2 The access hole must be clear enough to allow installing the tubing yet must provide a snug fit. Voids along the sides of the tubing may cause erroneous readings.

9.1.2.1 If voids are suspected to be caused by the drilling process they can be grouted using procedures in Test Method D 4428.

9.1.2.2 The only method to determine the presence of voids is to perform field calibrations provided in Annex A2.2.3.

9.1.3 Record and note the position of the ground water table, perched water tables, and changes in strata as drilling progresses.

9.1.3.1 If ground water is encountered or saturated conditions are expected to develop, seal the tube at the bottom to prevent water seepage into the tube using procedures given in Test Method D 4428 or the manufacturer's recommended procedures. This will prevent erroneous readings and possible damage to the probe.

9.1.4 The tubing should project above the ground and be capped to prevent foreign material from entering. The access tube should not project above the ground so high that it might be damaged by equipment passing over it.

9.1.4.1 Install all tubes at the same height above the ground as this enables marking the cable to indicate the measured depth to be used for all tubes.

9.2 Lower a dummy probe down the access tube to verify proper clearance before lowering the probe containing the radioactive source.

9.3 Standardize the apparatus.

9.4 Proceed with the test as follows:

9.4.1 Seat the apparatus firmly over the access tube, then lower the probe into the tube to the desired depth. Secure the probe by cable clamps (usually provided by the apparatus manufacturer).

9.4.2 Take a measurement count at the selected timing period.

NOTE 2—The above procedure is performed in an installed access tube that will allow repeated in-place measurements. In some field situations it may be more appropriate to use a drilling technique involving alternating before access tubing and one of the following: a large diameter hollow stem auger, a split-spoon sampler, or a thin-walled volumetric sampler. This technique is destructive and only one measurement can be made at each depth per hole.

## 10. Interpretation

10.1 Determine the ratio of the reading obtained compared to the standard count. Then using the calibration data combined with appropriate calibration adjustments, or apparatus direct readout features, calculate the water content in mass per unit volume of the material under test.

NOTE 3—Some instruments have built-in provisions to compute and display the ratio and corrected water content per unit volume.

10.2 If water content as a percentage of dry density is required, the in-place density may be determined by using

either the same apparatus or a different apparatus that determines density at depths below the surface by the nuclear method (see Test Method D 5195) or by a method such as density determination of soil in-place by the drive-cylinder method (see Test Method D 2937).

## 11. Report

11.1 Report the following information:

11.1.1 Make, model, and serial number of the apparatus,

11.1.2 Date of calibration,

11.1.3 Method of calibration, such as field, factory, etc.

11.1.4 Calibration adjustments,

11.1.5 Date of test,

11.1.6 Standard count(s) for the day of the test,

11.1.7 Any adjustment data for the day of the test,

11.1.8 Test site identification including tube location(s), tube number(s),

11.1.9 Tube type and tube installation methods (method of drilling, installing and any initial gravimetric and count data),

11.1.10 Geologic log of the borehole, and

11.1.11 Depth, measurement count data, and calculated water content of each measurement.

## 12. Precision and Bias

12.1 *Precision*—The precision of this test method is operator dependent and a function of the care exercised in installing the access tubing and performing the steps of the procedures properly. Interferences as described in Section 5, such as voids, large rocks, and varying densities and water contents at different depths of the access tube would also prevent developing a meaningful precision statement.

12.2 *Bias*—No methods are presently available that provide sufficiently accurate values of water content of soil and rock in-place against which these methods can be compared.

## 13. Keywords

13.1 depth probe; in-place water content; in situ water content; neutron probe; nuclear methods

## ANNEXES

### (Mandatory Information)

#### A1. APPARATUS CALIBRATION

A1.1 At least once each year, establish or verify calibration curves, tables, or equations by determining the count rate of at least three samples of different known water contents. These data may be presented in the form of a graph, table, equation coefficients, or stored in the apparatus, to allow converting the count rate data to water content. The method and test procedures used in establishing these count ratios must be the same as those used for obtaining the count ratios for in-place material. The water content of materials used to establish the calibration must vary through a range to include the water content of materials to be tested and be of a similar density.

A1.2 Calibration standards may be established using one of the following methods. The standards must be verified to be of sufficient size to not change the count rate if enlarged in any dimension. Access tubing used in the standards must be the same type and size as that to be used for in-place measurements.

A1.2.1 Prepare homogeneous standards of hydrogenous materials having a water content determined by comparison (using a nuclear instrument gage) to a saturated silica sand standard with a known water content. As an alternate, determine the equivalent water content by calculation if the hydrogen, carbon, and oxygen content is known or can be calculated from the specific gravity and chemical composition. A zero water content standard can be prepared by using a non-hydrogenous material, such as magnesium, as the standard.

A1.2.2 Prepare containers of soil and rock compacted to uniform densities with a range of water contents. Determine the percent water content of the materials by oven drying (see Test Method D 2216) and a wet density calculated from the

mass of the material and the inside dimensions of the container. Whenever possible, use soil and rock obtained from the test site for this calibration.

A1.2.3 Where neither of the previous calibration standards are available or a higher accuracy of calibration is required, the apparatus may be calibrated in the field by using the following methods:

A1.2.3.1 Use a minimum of three selected test sites containing a homogeneous material with as wide a range of water contents as possible. As the access hole is drilled, take gravimetric samples from the soil or rock samples taken by any suitable drilling and sampling method appropriate for the material (see Method D 1586 and Practices D 1452, D 1587, D 2113, and D 3550) and determine the percent water content by oven drying (see Test Method D 2216). Note the sampling intervals for the gravimetric samples. (See Note A1.1.)

NOTE A1.1—For agricultural purposes it is highly practical to obtain the gravimetric samples (see Practice D 1452) above the water table in shallow installations. The gravimetric sample will represent a mixture of materials over the interval samples. For a higher level of calibration accuracy it is recommended to obtain samples directly in the measurement interval by other referenced methods.

A1.2.3.2 As soon as possible after the access tubing has been installed, take sufficient measurements at the desired depths in accordance with Section 8 and calculate the count ratio and measured volumetric water content.

A1.2.3.3 The test measurement counts are to be taken at approximate depths that will correspond to the depth location of the gravimetric samples.

A1.2.4 Report any anomalous values, such as voids, grout plugs, changes in strata, or perched water layers, and their

probable causes obtained from this calibration.

A1.3 For the highest level of calibration, obtain gravimetric samples from each access hole over the measurement intervals to be tested using the methods given in A1.2.3. At a minimum, obtain gravimetric samples at 2 m intervals and at changes in strata.

A1.3.1 As soon as possible after the access tubing has been installed, take sufficient measurements at the desired depths in

accordance with Section 8 and calculate the count ratio and measured water content. The test measurement counts are to be taken at approximate depths that will correspond to the depth location of the gravimetric samples. The initial count profile and adjusted water content data should be reported with later readings to review changes in water content with subsequent readings.

## A2. CALIBRATION ADJUSTMENTS

A2.1 Check the calibration response prior to performing tests on materials that are distinctly different from the material types used in establishing the calibration. Also check the calibration response on newly acquired or repaired apparatus.

A2.2 Take sufficient measurements and compare them to samples obtained by other accepted methods such as a volumetric sampling (see Test Method D 2937) to establish a correlation between the apparatus calibration and the other method.

A2.2.1 Adjust the existing calibration to correct for the difference or establish a new calibration in accordance with Annex A1.

NOTE A2.1—Some apparatus utilizing a microprocessor may have provision to input a correction factor that is established by determining the correlation between the apparatus measurement and oven drying (see Test Method D 2216).

## A3. PRECISION OR APPARATUS

A3.1 The precision of the apparatus at a water content of 200 kg/m<sup>3</sup> (12.5 lbf/ft<sup>3</sup>) shall be better than 5 kg/m<sup>3</sup> (0.3 lbf/ft<sup>3</sup>) at the manufacturer's stated period of time for the measurement (see Note A3.1). Other timing periods may be available that may be used where higher or lower precisions are desired for statistical purposes. The precision shall be determined by the procedure defined in A3.2 or A3.3.

NOTE A3.1—While 30 s is the usual timing period and may be used for comparison of various apparatus, the intent of this test method is to require a measurement period that produces the stated precision for all acceptance testing.

A3.2 The precision of the apparatus is determined from the slope of the calibration response and the statistical deviation of the count (detected neutrons) for the period of measurement:

$$P = \sigma/S \quad (\text{A3.1})$$

where:

$P$  = apparatus precision in water content (kg/m<sup>3</sup> or lbf/ft<sup>3</sup>),  
 $\sigma$  = standard deviation in counts per measurement period,  
 and

$S$  = slope in change in counts per measurement period divided by the change in water content (kg/m<sup>3</sup> or lbf/ft<sup>3</sup>).

A3.2.1 The counts per measurement period shall be the total number of thermal neutrons detected during the timed period. The displayed value must be corrected for any prescaling that is built into the apparatus. The prescale value ( $F$ ) is a divisor

that reduces the actual value for the purpose of display. The manufacturer will supply this value if other than 1.0.

A3.2.2 The standard deviation in counts per measurement period shall be obtained by:

$$\sigma = \sqrt{CF} \quad (\text{A3.2})$$

where:

$\sigma$  = standard deviation in counts per measurement period,  
 $C$  = counts per measurement period (before prescale correction) at a water content of 200 kg/m<sup>3</sup> (12.5 lbf/ft<sup>3</sup>);  
 and  
 $F$  = value of prescale (see A3.2.1).

A3.2.3 The counts per measurement period (before prescale correction) may be obtained from the calibration curve, tables, or equation by multiplying the count ratio by the apparatus standard count.

A3.2.4 The slope of calibration response in counts per measurement period (before prescale correction) at a water content of 200 kg/m<sup>3</sup> (12.5 lbf/ft<sup>3</sup>) shall be determined from the calibration curve, tables, or equation.

A3.3 Compute the precision by determining the standard deviation of at least 20 repetitive measurements (apparatus not moved after the first measurement) on material having a water content of 160 to 240 kg/m<sup>3</sup> (10 to 15 lbf/ft<sup>3</sup>). In order to perform this procedure, the resolution of the count display, calibration response, or other method of displaying water content must be equal to or better than  $\pm 1$  kg/m<sup>3</sup> ( $\pm 0.1$  lbf/ft<sup>3</sup>).



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