INTERNATIONAL STANDARD

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# Soil quality — Determination of water content in the unsaturated zone — Neutron depth probe method



*Qualité du sol — Détermination de la teneur en eau de la zone non saturée — Méthode à la sonde à neutrons de profondeur*



Reference number
ISO 10573:1995(E)

## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 10573 was prepared by Technical Committee ISO/TC 190, *Soil quality*, Subcommittee SC 5, *Physical methods.*

Annexes A, B, C, D and E of this International Standard are for information only.





International Organization for Standardization
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# Soil quality — Determination of water content in the unsaturated zone — Neutron depth probe method

**WARNING — Neutron depth probes contain radioactive sources which will present health and environmental hazards if a probe is improperly used, stored or disposed of. National and international legislation and regulations must be complied with.**

## 1 Scope

This International Standard specifies an *in situ* method for the determination of water content in the unsaturated zone of soils using a neutron depth probe. It is applicable when investigations into the water storage, water balance and water distribution in the unsaturated zone of the soil are carried out. Because the method is non-destructive, it is particularly suitable for repeated measurements at fixed locations. Water content profiles can be obtained by measuring at a series of depths down to any depth within the range of the phreatic level at the site.

The advantage of the method compared with some others, for example the gamma probe method, is the rapidity with which measurements can be carried out. A disadvantage, however, is the relatively poor depth resolution of the measurements.

## 2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 11272:—[1]), *Soil quality — Determination of dry bulk density.*

ISO 11461:—[1]), *Soil quality — Determination of soil water content calculated on a volume basis — Gravimetric method.*



## 3 Definitions

For the purposes of this International Standard, the following definition applies.

**3.1 water content volume fraction, $\theta$ :** The volume of water evaporating from soil when dried to constant mass at 105 °C, divided by the original bulk volume of the soil.

NOTES

1 The water content may be expressed as a percentage by volume or a volume fraction.

2 In this International Standard, water content as defined above may also be referred to as "free water".

1) To be published.

3 The procedure for drying soil to constant mass at 105 °C is described in ISO 11461.

4 The procedure for determination of the bulk volume of soil is described in ISO 11272.

## 4 Principle

A neutron depth probe, consisting of a neutron source and detector, is lowered into a vertical access tube in the soil. The neutron source, usually of the $^{241}$Am-Be type, emits neutrons of high kinetic energy. The neutrons lose part of their energy when they collide with atomic nuclei. After several collisions, their energy level is reduced to the thermal energy level corresponding to the prevailing temperature. This level is reached most rapidly when neutrons collide with hydrogen nuclei because their masses are almost equal.

The thermal neutrons form a stable cloud, the concentration of which is determined by the detector in the probe. The number of thermal neutrons registered by the detector per unit time (the count rate) is therefore a measure of the concentration of hydrogen nuclei in the soil around the probe. In general, the majority of those nuclei are in water molecules and therefore the count rate is also a measure of the soil water content. A calibration curve is used to convert the neutron count rate to soil water content.

NOTES

5 The neutron count rate obtained is influenced by the presence of all the atomic nuclei in the soil. However, the count rate at a given water content may be increased in some soils because of the thermalization of neutrons by collisions with nuclei of certain soil elements, or because much hydrogen is present in substances other than free water. However, the count rate may be decreased because of absorption of neutrons by nuclei with a large atomic absorption cross-section. See annex A.

6 The soil volume (measuring volume) to which the measurement refers approximates a sphere. For a given type of neutron probe, the radius of the sphere depends on the total density of atomic nuclei in the soil. For the majority of probes used in practice, the radius of the volume from which 95 % of the neutrons counted by the detector are generated ("the sphere of importance" [1]) can vary from 0,1 m to 0,2 m in wet soil to 0,8 m or more in dry (sandy) soil. Consequently, the measurement obtained at a given depth is influenced by the water content distribution within the measuring volume at that time, and by any other gradients in soil composition. Therefore, reproduction of the measurement of a given water content at a certain depth is only possible when the distributions of water content and of soil composition within the measuring volume are time-invariant. This requirement (local time-invariant gradients) is important for the calibration of the neutron depth probe. See annex A.

7 The shape and parameters of the calibration curve depend on the following (see [2] in annex E):

— the chemical composition of the soil horizon considered and its bulk density;

— the gradients in this composition that occur within the measuring volume;

— the gradients in soil water content that occur within the measuring volume;

— the method of access tube installation;

— the characteristics of the access tubing;

— the specifications of the apparatus used.

The calibration curve usually differs for each soil layer. In homogeneous layers that are thicker than the measuring volume, calibration curves are generally linear, their parameters depending on the soil composition. In the case of thin or non-homogeneous soil layers, however, calibration curves will often be non-linear due to the different effects of gradients in soil composition and water content under wet and dry conditions.



## 5 Apparatus

**5.1 Neutron depth probe**, consisting of a fast neutron source and a thermal neutron detector combined with a read-out unit.

**5.2 Thin-walled access tubing**, with an inner diameter slightly larger than that of the neutron probe. The tubing shall consist of material that is very "transparent" to fast and thermal neutrons (e.g. aluminium, aluminium alloy) and which is resistant to chemical corrosion and to deformation due to installation activities. Stainless steel, galvanized iron and plastics (polyethylene) are also suitable, though less transparent to neutrons.

**5.3 Equipment for installing access tubes.**

**5.4 Equipment for drying and cleaning the access tubes**, if necessary, a dummy probe for testing the tubing performance.

**5.5 Calibration curves**, for conversion of count rate to water content.

**5.6 Usual apparatus for taking soil samples**, for carrying out a field calibration to determine the volumetric water content $\theta$ gravimetrically according to ISO 11461.

## 6 Procedure

### 6.1 Installation of access tubes

The location shall be representative of the immediate surroundings and care shall be taken to avoid surface water from concentrating on the spot. Use a platform to prevent damage to surrounding vegetation and compaction of the soil surface whilst installing a tube. Ensure that radial soil compaction around the tube, compaction below it and the creation of voids adjacent to it are prevented as far as possible.

Install access tubes by either of the following methods.

a) Push the tube into the soil using a hammer and empty it using an auger. It is recommended that the lower end of the tube be closed with quick drying cement or a stopper, to prevent infiltration of ground water.

b) Push the tube into a prepared hole of the same or slightly smaller diameter and of the required depth, then seal the lower end as in 6.1.1. Alternatively, the lower end of the tube may be sealed before insertion.

Holes can be prepared using a guide tube or an auger or by a combination of these two methods. Close the top of the tube with a tight rubber stopper to keep out rain or surface water. The tubing shall always be dry inside.

NOTES

8 It is recommended that access tubes be cut to protrude above the soil surface as little as the apparatus permits, so as to minimize the radiation dose received by the operator when lowering the probe.

9 More specific guidelines for installation are given in [3] and [4] in annex E.

After installation, take great care to minimize disturbance of the soil and vegetation at the site whilst conducting measurements in the access tube.



## 6.2 Calibration

In most cases, calibration curves supplied by neutron probe manufacturers, and those published in the literature, give only a rough indication of the absolute soil water content, because no or insufficient recognition can be given to the specific influences of the site mentioned in note 7 in clause 4 (see also annex A).

The influence of chemical composition and bulk density (see A.2) is accounted for in calibrations derived theoretically from the macroscopic neutron-interaction cross-section of the soil concerned (see [1], [4], [9] in annex E).

The combined influence of gradients in water content, chemical composition and bulk density is only accounted for by a field calibration. Therefore an *in situ* field calibration is necessary for accurate measurements of absolute water content.

The field calibration is based on simultaneous determination of the neutron count rate and sampling for the determination of the volumetric water content of each soil layer in accordance with ISO 11461, under several different hydrological conditions, to derive a calibration curve for each layer.

NOTE 10 The subdivision of the soil profile into layers is determined initially by differences in soil composition, but the form of soil water content gradients that systematically recur should also be considered. Further divisions may be necessary to meet the objectives of the investigation.

The hydrological conditions under which the calibration is conducted shall differ as much as possible so that the calibration curves are representative of the range of conditions which occur at the site. To meet the requirement for time invariant gradients that do not vary with time as much as possible, the calibration shall not be conducted after heavy rain or irrigation applications, or immediately after the sudden beginning of extremely warm weather.

Determine the calibration curves by analysing the various combinations of neutron count rate and water content for each soil layer by regression analysis. The count rate is considered as the independent variable ($x$) and the water content as the dependent variable ($y$). Calibration curves so derived are specific to the neutron probe used. Use of reference counts to normalize the count rate measurements used in the regression allows calibrations to be used with different probes of the same geometry (see annex C).

Further guidelines for carrying out a field calibration are given in [2], [3], [4] in annex E and in annex B.

NOTES

11 The calibration curves may change in time due to the following processes:

— changes in the chemical composition of the soil including that of the soil water, and changes in bulk density. This can be corrected for, to a certain extent, on the basis of known (chemical) properties (see [3] in annex E);

— decrease of the source strength of the probe due to radioactive decay, and/or decrease in the sensitivity of the detector. This can be corrected for by the use of reference counts made in a medium with invariant characteristics (see annex C).

12 The guidelines given here apply to the measurement of absolute water content. When only relative measurements (i.e. changes of water content in time) are to be assessed, the requirements for calibration and demands on accuracy may be less stringent.

## 6.3 Measurements

The neutron depth probe shall be used in accordance with the manufacturer's instructions as much as possible, and particularly with respect to technical handling and safety.

Lower the probe in the access-tube to the depth at which it is required to make the measurement.

Conduct the counts according to one of the following methods:

a) with a fixed counting time; in this case the number of thermal neutrons detected is recorded;

b) with a fixed number of detected thermal neutrons; in this case the counting time is recorded.

NOTES

13 When changes of water content in time are to be determined, precise positioning of the probe at a specified depth is important.

14 The second method mentioned for taking the counts has the advantage that the accuracy of the measurement is relatively constant (i.e. precision of the count rate), whereas the accuracy depends on the water content in the first method.

Instead of conducting a single count for a long time, it can be advantageous to make a number of counts for a short time because this provides quantitative information about the spread of the measurements. This information allows detection of certain types of failure in the apparatus.

It is recommended that reference counts in a medium with invariant characteristics, such as a large water barrel (see C.3.1), be made at frequent intervals to check the overall performance of the instrument. For example, a reference count might be carried out before and after each series of measurements in a specific access tube. A certain amount of drift in the reference count is to be expected. However, a sudden change from the general pattern almost certainly indicates a failure of the apparatus, which should be repaired or replaced.



## 6.4 Safety and maintenance

**SAFETY PRECAUTIONS — The radioactive source within a neutron depth probe is a potential hazard to the operator, the public and the environment. Most governments and organizations have legally enforceable regulations concerning the acquisition, operation, transport, storage and disposal of radioactive devices, which must be adhered to. In the absence of specific radiological safety regulations, the guidelines of the International Atomic Energy Agency [6], [7] and of the International Commission on Radiological Protection [8] should be consulted.**

The half-life (458 years) of the americium commonly used in neutron depth probes is longer than the time over which the integrity of the source container (e.g. about 30 years) can be expected to last. When a neutron depth probe is no longer required, the radioactive source must be disposed of at a repository for radioactive waste.

Neutron depth probes shall only be used by suitably trained operators. Maintenance shall only be conducted by appropriately skilled persons. Periodic checks to test for leakage from the sealed source shall be carried out by a competent agency.

## 7 Expression of results

Calculate the count rate $R$, which is the number of detected thermal neutrons per unit of time, using the following equation:

$$R = \frac{N}{t}$$

where

$R$ is the count rate, in counts per minute;

$N$ is the number of counted thermal neutrons;

$t$ is the counting time, in minutes.

Calculate the water content $\theta$, using the equation:

$$\theta = f(R, p)$$

where

$\theta$ is the water content, expressed as a volume fraction;

$f$ is the calibration function (calibration curve) calculated by regression analysis;

$R$ is the count rate, in counts per minute;

$p$ represents the parameters of the calibration curve.

When necessary, the count rate can be corrected for the difference between the actual reference count rate ($R_s$) and the expected reference count rate ($R_{se}$). In most cases, a correction of the type $R' = R(R_{se}/R_s)$ may apply, where $R'$ is the corrected count rate. For further explanations, see annex C.

## 8 Accuracy

**8.1** The accuracy of the water content determined with the neutron probe is influenced principally by the following error sources.

a) The scatter in individual counts or count times as a result of the random variation in the number of neutrons emitted by the neutron source.

The magnitude of this error is usually expressed as the standard deviation of the number of neutrons counted. As the emission process follows a Poisson distribution, the resulting standard deviation in the number of detected neutrons is

$$s_N = \sqrt{N}$$