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TECHNICAL NOTE

The Use of "Accuracy" and Related Terms in the Specifications of Testing and Measurement Equipment

CIE TN 009:2019

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The following members of DR 2-75 “TN on the use of “Accuracy” and related terms in the specifications of testing and measurement equipment” took part in the preparation of this Technical Note. The Reportership comes under Division 2 “Physical measurement of light and radiation”.

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Summary

This Technical Note provides guidance on the correct use of the terms "accuracy", "error", "tolerance", "reproducibility", and "repeatability" in relation to the properties and specifications of testing and measurement instruments on the one hand, and the terms "error" and "uncertainty", and a measurement instrument's sensitivity in relation to a measurement process or a calibration on the other hand. It also summarizes the concepts of quality indices and tolerance intervals and provides guidance for acceptable methods of specifying the performance of equipment and for expressing specifications for the requirements of equipment to be used for a specific purpose. This will be of assistance to equipment manufacturers in producing brochures, manuals, and datasheets as well as tender specification writers in producing technical specifications for procurement of equipment that use the above terms correctly.

1 Introduction

Many measurement instruments have technical specifications and datasheets that say, for example, “Accuracy: 4 %”. This is an inappropriate use of the term “accuracy” because, as described in 4.1 of this document, an “accuracy” is not a quantity and cannot be assigned a value. This document describes how to use the term “accuracy” correctly, as well as giving examples of acceptable expressions that could be used in place of the incorrect expression used in the example here. Furthermore, some other commonly misused terms are discussed, and examples of correct use are given.

The primary reference used for the definitions of these terms is the International Vocabulary of Metrology (VIM), which is produced by the Joint Committee for Guides in Metrology (JCGM 2012a). For the accepted definitions of these terms and selected other related terms, extracted from the VIM, please refer to Clause 2. The remaining clauses give a more practical interpretation of these terms and describe correct use.

However, the terms "accuracy", "tolerance", "reproducibility", and "repeatability" as defined in the VIM are assigned to measurement instruments or test procedures and do not necessarily give a reliable information about the “correctness” of a measurement result in general. The reliability of measurements is dealt with in the “Guide to the expression of uncertainty in measurement” (GUM) (JCGM 2008). This is important to mention, as the uncertainty of a measurement always depends additionally on environmental parameters and other factors influencing the whole measurement process. From this it follows that uncertainty cannot be appointed to a single measurement device but to a measurement value.

2 Definitions

2.1

measurement accuracy
accuracy of measurement
accuracy

closeness of agreement between a measured quantity value and a true quantity value of a measurand

NOTE 1 The concept ‘measurement accuracy’ is not a quantity and is not given a numerical quantity value. A measurement is said to be more accurate when it offers a smaller measurement error.

NOTE 2 The term “measurement accuracy” should not be used for measurement trueness and the term “measurement precision” should not be used for ‘measurement accuracy’, which, however, is related to both these concepts.

NOTE 3 ‘Measurement accuracy’ is sometimes understood as closeness of agreement between measured quantity values that are being attributed to the measurand.

NOTE 4 Rigorously speaking, and according to the GUM, the true quantity value of a measurement is always unknown.

[Source: JCGM 200:2012, Term 2.13; Note 4 added]

2.2
measurement trueness
trueness of measurement
trueness

closeness of agreement between the average of an infinite number of replicate measured quantity values and a reference quantity value

NOTE 1 Measurement trueness is not a quantity and thus cannot be expressed numerically, but measures for closeness of agreement are given in ISO 5725.

NOTE 2 Measurement trueness is inversely related to systematic measurement error, but is not related to random measurement error.

NOTE 3 "Measurement accuracy" should not be used for 'measurement trueness'.

[Source: JCGM 200:2012, Term 2.14]

2.3
measurement precision
precision

closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions

NOTE 1 Measurement precision is usually expressed numerically by measures of imprecision, such as standard deviation, variance, or coefficient of variation under the specified conditions of measurement.

NOTE 2 The 'specified conditions' can be, for example, repeatability conditions of measurement, intermediate precision conditions of measurement, or reproducibility conditions of measurement (see ISO 5725-1:1994 (ISO 1994a)).

NOTE 3 Measurement precision is used to define measurement repeatability, intermediate measurement precision, and measurement reproducibility.

NOTE 4 Sometimes "measurement precision" is erroneously used to mean measurement accuracy.

[Source: JCGM 200:2012, Term 2.15, modified – reference in NOTE 2 added]

2.4
measurement error
error of measurement
error

measured quantity value minus a reference quantity value

NOTE 1 The concept of 'measurement error' can be used both
a) when there is a single reference quantity value to refer to, which occurs if a calibration is made by means of a measurement standard with a measured quantity value having a negligible measurement uncertainty or if a conventional quantity value is given, in which case the measurement error is known, and
b) if a measurand is supposed to be represented by a unique true quantity value or a set of true quantity values of negligible range, in which case the measurement error is not known.

NOTE 2 Measurement error should not be confused with production error or mistake.

NOTE 3 The concept of measurement error assumes that the reference quantity value is a "true" quantity value, and hence that the measurement error can be expressed as an absolute amount without uncertainty. The boundary conditions given in NOTE 1 must apply to make this concept consistent.

NOTE 4 According to GUM, the measurement error is defined as the “result of a measurement minus a true value of the measurand” (JCGM 2008, B.2.19). In this concept, measurement error is a generic term which expresses the consistency of the measurement result. As the true quantity value of the measurand is not known, the absolute magnitude of the measurement error would have an uncertainty.

[Source: JCGM 200:2012, Term 2.16, Notes 3 and 4 added]

2.5
repeatability condition of measurement
repeatability condition

condition of measurement, out of a set of conditions that includes the same measurement procedure, same operators, same measuring system, same operating conditions and same location, and replicate measurements on the same or similar objects over a short period of time

NOTE 1 A condition of measurement is a repeatability condition only with respect to a specified set of repeatability conditions.

NOTE 2 In chemistry, the term “intra-serial precision condition of measurement” is sometimes used to designate this concept.

[Source: JCGM 200:2012, Term 2.20]

2.6
measurement repeatability
repeatability

measurement precision under a set of repeatability conditions of measurement

[Source: JCGM 200:2012, Term 2.21]

2.7
intermediate precision condition of measurement
intermediate precision condition

condition of measurement, out of a set of conditions that includes the same measurement procedure, same location, and replicate measurements on the same or similar objects over an extended period of time, but may include other conditions involving changes

NOTE 1 The changes can include new calibrations, calibrators, operators, and measuring systems.

NOTE 2 A specification for the conditions should contain the conditions changed and unchanged, to the extent practical.

NOTE 3 In chemistry, the term “inter-serial precision condition of measurement” is sometimes used to designate this concept.

[Source: JCGM 200:2012, Term 2.22]

2.8
intermediate measurement precision
intermediate precision

measurement precision under a set of intermediate precision conditions of measurement

NOTE Relevant statistical terms are given in ISO 5725-3:1994 (ISO 1994c).

[Source: JCGM 200:2012, Term 2.23, modified – reference in NOTE added]

2.9
reproducibility condition of measurement
reproducibility condition

condition of measurement, out of a set of conditions that includes different locations, operators, measuring systems, and replicate measurements on the same or similar objects

NOTE 1 The different measuring systems may use different measurement procedures.

NOTE 2 A specification should give the conditions changed and unchanged, to the extent practical.

[Source: JCGM 200:2012, Term 2.24]

2.10
measurement reproducibility
reproducibility

measurement precision under reproducibility conditions of measurement

NOTE Relevant statistical terms are given in ISO 5725-1:1994 (ISO 1994a) and ISO 5725-2:1994 (ISO 1994b).

[Source: JCGM 200:2012, Term 2.25, modified – references in NOTE added]

2.11
measurement uncertainty
uncertainty of measurement
uncertainty

non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used

NOTE 1 Measurement uncertainty includes components arising from systematic effects, such as components associated with corrections and the assigned quantity values of measurement standards, as well as the definitional uncertainty. Sometimes estimated systematic effects are not corrected for but, instead, associated measurement uncertainty components are incorporated.

NOTE 2 The parameter may be, for example, a standard deviation called standard measurement uncertainty (or a specified multiple of it), or the half-width of an interval, having a stated coverage probability.

NOTE 3 Measurement uncertainty comprises, in general, many components. Some of these may be evaluated by Type A evaluation of measurement uncertainty from the statistical distribution of the quantity values from series of measurements and can be characterized by standard deviations. The other components, which may be evaluated by Type B evaluation of measurement uncertainty, can also be characterized by standard deviations, evaluated from probability density functions based on experience or other information.

NOTE 4 In general, for a given set of information, it is understood that the measurement uncertainty is associated with a stated quantity value attributed to the measurand. A modification of this value results in a modification of the associated uncertainty.

[Source: JCGM 200:2012, Term 2.26]

2.12
maximum permissible measurement error
maximum permissible error
limit of error

extreme value of measurement error, with respect to a known reference quantity value, permitted by specifications or regulations for a given measurement, measuring instrument, or measuring system

NOTE 1 Usually, the term “maximum permissible errors” or “limits of error” is used where there are two extreme values.

NOTE 2 The term “tolerance” should not be used to designate ‘maximum permissible error’.

[Source: JCGM 200:2012, Term 4.26]

2.13
tolerance interval

interval of permissible values of a property

NOTE 1 Unless otherwise stated in a specification, the tolerance limits belong to the tolerance interval.

NOTE 2 The term ‘tolerance interval’ as used in conformity assessment has a different meaning from the same term as it is used in statistics.

NOTE 3 A tolerance interval is called a ‘specification zone’ in ASME B89.7.3.1:2001 (ASME 2001).

[Source: JCGM 106:2012, Term 3.3.5, modified – reference in NOTE 3 added]

2.14
acceptance interval

interval of permissible measured quantity values

NOTE 1 Unless otherwise stated in the specification, the acceptance limits belong to the acceptance interval.

NOTE 2 An acceptance interval is called an ‘acceptance zone’ in ASME B89.7.3.1 (ASME 2001).

[Source: JCGM 106:2012, Term 3.3.9, modified – reference in NOTE 2 added]

3 Background notes on measurement uncertainty, accuracy, error, and precision

When we take a measurement, the quantity intended to be measured is called "measurand". But we can never actually know what that value is, as the measured value depends on a number of parameters such as environmental and operating conditions, calibration of the measurement devices and the measurement procedure itself. The limited knowledge of these parameters and the uncertainties due to the deviation of the real measured quantity from the definition of the quantity, as well as normal measurement fluctuations, results in a dispersion of the measured values. The *measurement uncertainty* is a non-negative parameter characterizing the dispersion of the values attributed to a measured quantity (see also 2.11). It can be thought of as an estimate of the possible error associated with the measurement, although as described below the concept of measurement error is itself not straightforward.

A rigorous way of evaluating the measurement uncertainty is to construct a measurement model that describes the measurement process and takes into account all of the possible parameters influencing the measurement result. Each component has a magnitude and an associated uncertainty that needs to be evaluated.

Two different types of uncertainty contributions are possible: Type A uncertainties due to statistical variations of measurement results (e.g. noise) and Type B uncertainty contributions due to other effects which are evaluated by scientific judgement (e.g. offsets) (JCGM 2008). Uncertainties with statistical variations can usually be characterized by a probability distribution function, where the mean of the distribution is the best estimate of the measurand and the uncertainty is related to the standard deviation of the distribution. Such an uncertainty distribution would arise, for example, from a photodetector monitoring a stable light source: the photodetector takes repeated readings and, due to lamp fluctuations and electrical noise, the readings differ but are all grouped around an average value.

Uncertainty contributions due to other effects are taken into account by assumptions based on all of the available information on the possible variability of the parameter. The pool of information may include data provided in the calibration certificates, reliable manufacturer's specifications, previous measurement data, experience with or general knowledge of the behaviour and properties of relevant materials and instruments, etc.

An example is readings having low resolution, where it can only be said that the reading was in between two tick marks (e.g. between 2,1 m and 2,2 m). In such cases, the knowledge of the boundary condition (here: the distance between the tick marks and the assumption that every position between the tick marks is equiprobable) is used to calculate an uncertainty value. The same principle applies to the least significant digit for a digital instrument.

A selection of commonly-used fixed assumptions and their respective calculation rules for the uncertainty are published in the GUM document (JCGM 2008). Further guidance for the evaluation of measurement uncertainty in photometry is given in CIE 198 (CIE 2011a), CIE 198-SP1 (CIE 2011b) and CIE 198-SP2 (CIE 2018).

The result of a measurement is then conveniently expressed as $Y = y \pm U$, which is interpreted to mean that the best estimate of the value attributable to the measurand Y is y, and that $y - U$ to $y + U$ is an interval that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to Y. The quantity U denotes the *expanded uncertainty,* which defines an interval about the measurement result that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand (i.e. the level of confidence). In photometry and radiometry a level of confidence of 95 % is usually considered. In many cases, if the final measurement result is determined as a mean value of sufficient ($n > 20$) repeated measurements, the expanded uncertainty U is equal to the standard uncertainty, u, of the measurement multiplied by the coverage factor of $k = 2$ (see also Figure 4). In all cases the level of confidence should be clearly stated.

For example, we could say that the total luminous flux of a lamp is 1 250 lm ± 15 lm at the 95 % level of confidence, which means that there is a 95 % chance that the measurand lies between 1 235 lm and 1 265 lm.

The concept of measurement uncertainty should not be confused with *measurement error,* as the latter is a generic term which expresses the consistency of the measurement result: The term "measurement error" is defined as measured quantity value minus a reference quantity value (see 2.4). The concept of measurement error assumes that the reference quantity value is a “true” quantity value, and hence that the measurement error can be expressed as an absolute amount without uncertainty. However, as the “true” quantity value of the measurand is not known, the absolute magnitude of the measurement error would have an uncertainty. In this context, errors are quantifiable deviations beyond uncertainties, and hence they should be corrected wherever possible. The uncertainty of the correction will be entered into the measurement model of evaluation.

Measurement uncertainty contributions are often categorized as being due to random errors and (not correctable) systematic errors. Measurements that have a low random error component are considered to have a high precision of measurement, i.e. they are precise. Measurements that have a low systematic error component are considered to have a high trueness of measurement. These concepts are illustrated in Figure 1 and Figure 2.

NOTE An error source is not of itself random or systematic but may be either depending on the measurement method. The ISO Guide to the expression of uncertainty in measurement (GUM) (JCGM 2008) does not refer to uncertainties as either random or systematic, but as Type A and Type B. Type A uncertainties are those that can be evaluated by statistical analysis and Type B uncertainties are evaluated by other means. For example, Type B uncertainties may be evaluated by searching for a mathematical description of the physical effect describing the estimated probability distribution function of possible measurements.

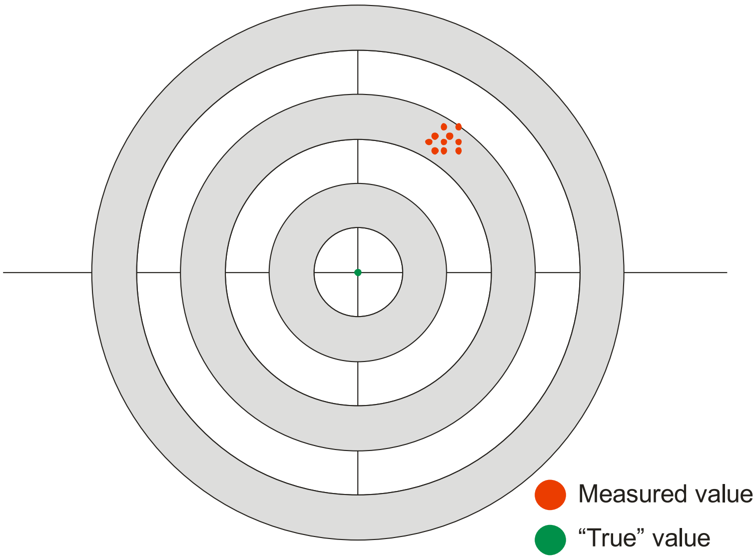


Figure 1 – A series of measurements that have a low magnitude of random errors but a high magnitude of systematic errors, i.e. they are a precise series of measurements that are inaccurate due to lack of trueness

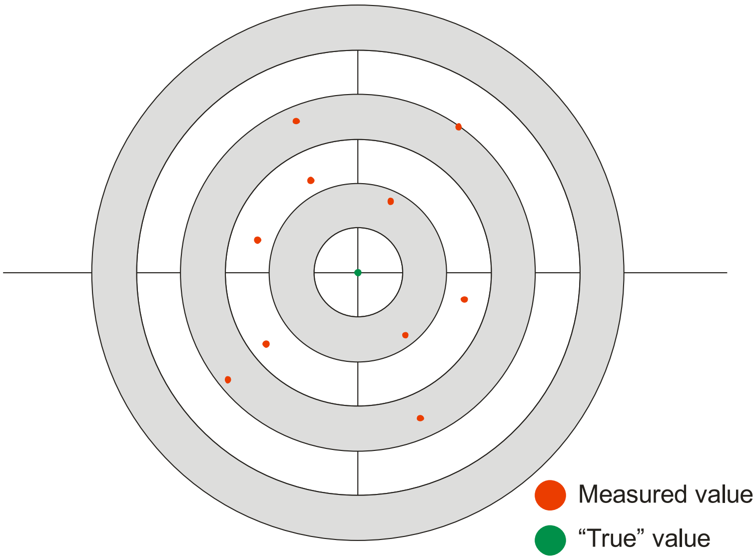


Figure 2 – A series of measurements that have a low magnitude of systematic errors but a high magnitude of random errors, i.e. they are inaccurate due to lack of precision

Measurement uncertainty involves more than just the calibration of an instrument and the variations observed in repeat measurement. For a complete picture we need to take into account other factors such as environmental influences, the test procedure, the operator skill and attention to detail, the properties of the artefact being measured itself, etc. – each of these factors add to the measurement uncertainty. The uncertainty can also be reduced by making additional corrections to the measurement result. Sometimes this can be done using our knowledge of our equipment and the properties of the source, such as applying a spectral mismatch correction factor; other times this may require additional tests. These concepts are illustrated in Figure 3.

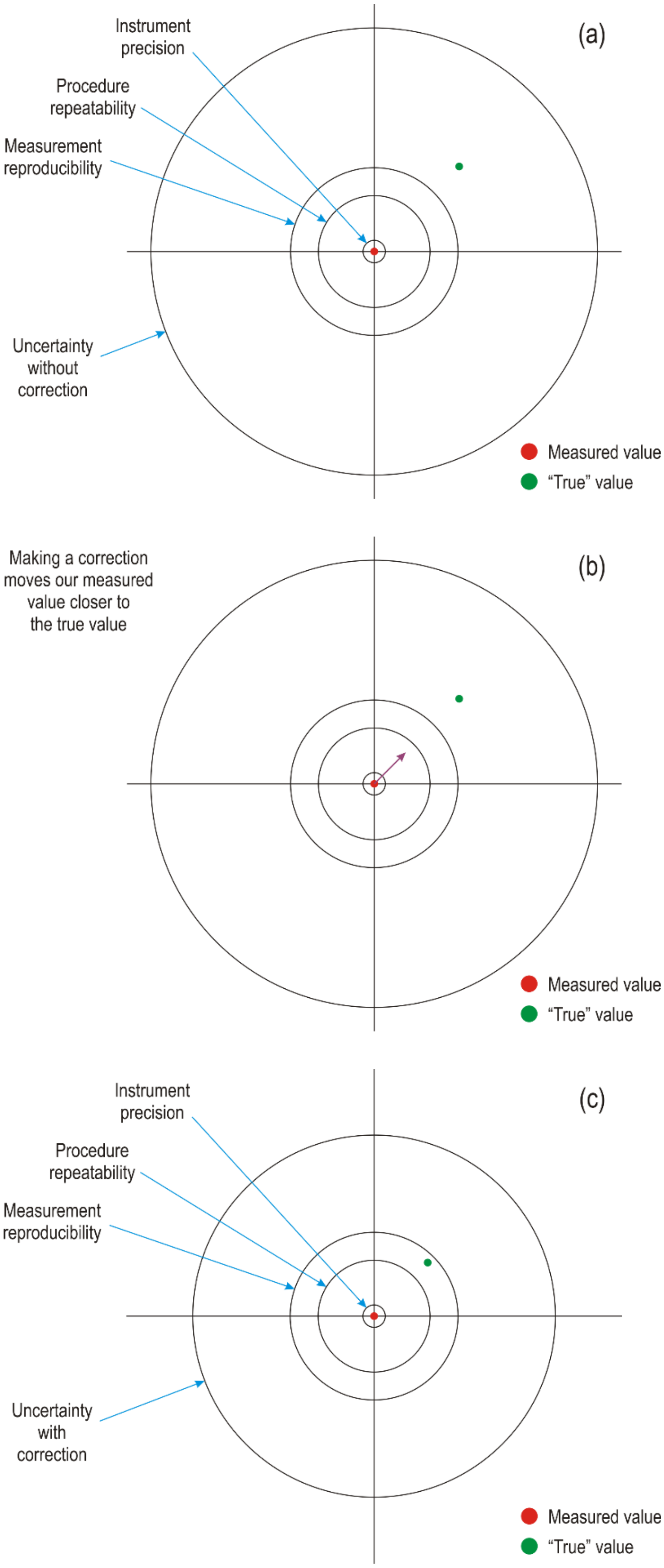


Figure 3 – Illustrations of concepts and their relationship with one another
(a) Measured value, "true" value, and contributions to measurement uncertainty
(b) Making a correction to the measurement result
(c) Improved situation after making a correction

NOTE The target centre in the illustrations of Figure 3 is the average of an infinite number of replicate measured quantity values. Instrument precision is the standard deviation of repeated measurements over a short period of time where conditions are maintained constant. Procedure repeatability is the precision for repeats of all stages of the procedure. Measurement reproducibility is the precision of values obtained from different equipment, techniques etc. measuring the same quantity. Uncertainty with correction includes all known contributions and corrects for some systematic effects (lack of trueness) whereas “uncertainty without correction” treats these systematic effects as random.

It is worth emphasizing that, while the figures in this clause refer to “true” values, the “true” value is never really known, as explained in the notes to 2.4.

4 Correct use of terms

This clause describes the correct use of some terms and explains the distinction between them.

4.1 Accuracy, error, uncertainty, and tolerance

Measurement accuracy, or just accuracy, is an expression of how closely a measured quantity value (a measurement result) represents the “true” quantity value of a measurand (see also 2.1) – in other words, how close our measurement result is to the “true” value of what we are trying to measure. Measurement accuracy itself is not a quantity and it cannot be assigned a value; hence it is not acceptable to assign an accuracy value to an instrument. However, if a particular instrument has a demonstrated superior performance to another instrument then it is acceptable to say that this instrument is more accurate than the other instrument as it will achieve a higher level of measurement accuracy. Clause 6 provides recommendations for acceptable expressions that can be used to provide an indication of the accuracy of an instrument.

It is very important to keep in mind that a measurement result and the corresponding measurement uncertainty are not just a property of an instrument. The device under test (DUT), environment, test procedure, operator skill and any other ancillary equipment such as power supplies and power analysers will all have an impact on the measurement result and measurement uncertainty. A measurement uncertainty is not just a statistical variation in a reading, and the uncertainty of a measurement made on an object using a particular piece of equipment might be quite different to the same measurement made on the same object and using the same piece of equipment on another day.

If a measurement made on a DUT in one laboratory is different from a measurement made on the same DUT in another laboratory (or likewise for comparisons of measurements between different instruments within the one laboratory) then it does not necessarily mean that a measurement has an error or that one of the items of equipment is in error by the difference between the two measurements. Firstly, it is important to establish that the measurements were reproducible (see 4.2). Secondly, there are statistical means of determining whether the two measurements are compatible; for example, a normalized error ratio, which takes into account the measurement uncertainty of the two measurements when determining if a measurement comparison is satisfactory. If an instrument shows a regular discrepancy with other instruments in a series of intercomparisons in reproducible conditions that cannot be accounted for within the measurement uncertainties, then this may indicate that the instrument requires calibration or further characterization or that it is being used to perform a measurement for which it is not fit for purpose. Alternatively, it may mean that the conditions are not as reproducible as they were thought to be: there may actually be some unanticipated differences in ambient temperature, voltage/current setting, etc. (and their associated uncertainties).

While it is possible to indicate a level of deviation that is deemed acceptable, i.e. a tolerance or tolerance interval, it is not acceptable to state that an instrument has a tolerance of a given value (see Note 2 of 2.12).

4.2 Reproducibility and repeatability

It is common to hear the terms reproducibility and repeatability used interchangeably. This is incorrect: the two terms are intended for different purposes (see also 2.5 to 2.10).

Repeatability relates to the level of deviation which could be expected for an instrument to perform repeat measurements of the same DUT (or similar DUTs) under the same measuring conditions. When considering the repeatability of an instrument in measuring a given DUT, it is important to consider only normal instrumental fluctuations, e.g. instrumental noise and scale fluctuations, and not fluctuations or drift in the DUT.

Reproducibility relates to measurements that are made of the same or similar DUT in different locations and/or by different operators, different instruments, different times, etc. In other words, it is similar to repeatability but relates to situations when one or more of the measurement conditions have changed. Even just switching the DUT off and on again relates more to reproducibility because it is testing repeatability of both an instrument and a DUT and it may not be possible to ensure that all of the environmental and electrical conditions are the same. Tests of reproducibility of equipment or measurement setups should be made using DUTs which have demonstrated consistency of performance, e.g. a lamp that is known to have very repeatable output from one operation to the other. It is also important to establish a reliable set of test conditions in testing reproducibility using different locations, operators, instruments, etc., e.g. by use of an established measurement standard.

In summary, repeatability is about “what happens if I repeat my measurement?”, whereas reproducibility is about “what happens if I change something: how well do I reproduce my measurement result?”.

5 The concepts of quality indices and tolerance intervals

In the field of photometry and radiometry it is common to define quality indices to characterize the performance of instruments (ISO/CIE 2014). Quality indices are physical quantities characterizing selected properties of an instrument. They are normalized response values, which do not describe errors directly and thus cannot be used for correction.

A quality index is symbolized by the symbol "f_x" where the subscript "x" specifies the considered property. The values are:

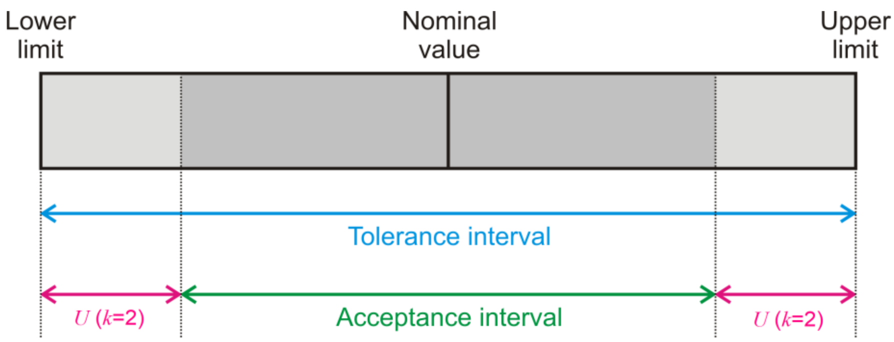
- evaluated by formulae specific for each property, from data determined under specified measurement conditions;
- typically stated as a percentage, with associated uncertainties; and
- ideally zero.

The quality indices alone do not allow the estimation of the measurement uncertainty for a specific measurement task. Nevertheless, it is generally true that instruments with smaller f_x values, in most cases, allow smaller measurement uncertainties than instruments with larger f_x values, i.e. they are more accurate.

While there are some quality indices that specify a maximum error from an ideal value, such as the linearity index, f_3, of a photometer, not all quality indices have the same interpretation. The quality index relating to the spectral mismatch error of a photometer, the general $V(\lambda)$ mismatch index, f_1', for example, is a representation of the match of the spectral response of the photometer to the ideal photopic spectral efficiency function and it does not represent the maximum error that could be observed when measuring any source. So, while we could state that the linearity index, f_3, of an instrument represents a maximum error due to non-linearity that could be expected for a given range of measurements, it is not acceptable to state that an instrument that has a general $V(\lambda)$ mismatch index f_1' = 1,5 % will have a corresponding maximum error or uncertainty of 1,5 % due to spectral mismatch.

In all cases, it should be kept in mind that quality indices are generalized parameters for a typical instrument. When considering the uncertainty for a measurement made with a specific instrument it is always necessary to undertake a full characterization of the instrument and not just rely on the instrument's published quality indices.

It is important to note the concept of tolerance intervals and acceptance intervals, as defined in 2.13 and 2.14. A tolerance interval represents a range of acceptable "true" values, and therefore this interval includes both the measured parameter and also the associated measurement uncertainty. For example, a specification states that the maximum acceptable wavelength error of a spectrometer must be ≤ 0,3 nm (the tolerance interval). Say our uncertainty in determining the maximum wavelength error is 0,1 nm. Then the highest acceptable measured maximum wavelength error is 0,2 nm (the acceptance interval). The acceptance interval is the tolerance interval minus the uncertainty in determining the parameter, as shown in Figure 4. The concepts of tolerance intervals and acceptance intervals are very important in all aspects of conformity assessment: when verifying that an instrument conforms to a requirement, the uncertainty must always be included. For more information see (JCGM 2012b).



NOTE U is the measurement uncertainty, k is the coverage factor.

Figure 4 – Illustration of the tolerance interval and acceptance interval, where the acceptance interval is the tolerance interval reduced by the measurement uncertainty

6 Recommended expressions for specifications of testing and measurement equipment

As advised in 4.1, it is not acceptable to state that an instrument has an "accuracy" of a given value. For example, it is not acceptable to state that a photometer has an accuracy of 3 % in measurement of illuminance; or that a spectroradiometer has a wavelength accuracy of 0,3 nm. However, it is important to be able to establish a value or values which are representative of an instrument in order to communicate the expected performance of the instrument and to be able to compare different models of equipment performing the same measurement function. This clause provides guidelines on acceptable expressions to use in this concept.

NOTE The examples given in this clause are samples only and should only be used as a guide. They are not intended to be complete and do not represent exact wording that must be used.

6.1 Expressions relating to properties of an instrument

There are properties which are inherent to an instrument itself and which do not relate to a specific measurement. These include properties such as errors due to range change or non-linearity in a photometer, accuracy of wavelength scale in a spectrometer, accuracy of angle scale in a goniometer, etc. While it is not acceptable to simply state an accuracy, it is possible to establish a maximum permissible error which could be reasonably attributed to an instrument when operating within its designed conditions of measurement. Some examples of permissible ways of expressing these are given in 6.1.1. It is also acceptable to state compliance to a standard which has defined parameters such as test methods and quality index limits for a given quality class. Some examples of possible expressions are given in 6.1.2.

6.1.1 Example formats for expressing conformity to tolerance intervals/limits and quality indices

- *Maximum wavelength error: ± 0,3 nm over the wavelength range 380 nm to 780 nm*
- *Linearity index f_3 < 0,2 %*
- *Stray light < 0,1 % acc. to ASTM E387 when evaluated according to CIE Standard Illuminant A, GG495, λ = 420 nm*

6.1.2 Example formats for expressing compliance with a standard

- *Quality class: CIE Class 4* (according to CIE 231:2019)*
- *Complies with the requirements of CIE S 025/E:2015*

6.2 Expressions relating to an instrument's measurement performance

It has become common place for an instrument to be assigned an accuracy in relation to a particular measurement function. This is not only an incorrect use of the term "accuracy", but it is also potentially misleading because somebody reading the product specification may assume that this value represents a maximum error that may be encountered in performing a measurement with the instrument. But the assigned “accuracy” cannot possibly take into account all of the influences on the measurement, such as the properties of the DUT, environmental factors, the quality of the calibration of the instrument, the test method, the operator skill in operating the instrument, stray light or other forms of offsets, the influences of other ancillary equipment such as power supplies and power analysers, etc.

However, it is useful to establish a value or set of values that are representative of the performance of the instrument so that these can be used in the specifications of the instrument to communicate its relative performance compared with other equipment or to assess its fitness for a particular purpose. In order to do this, it is acceptable to make a series of assumptions about the measurement conditions and provide a typical uncertainty of measurement that would be expected for use of the instrument in performing the measurement function. The assumptions are as follows:

1) The equipment is operating within its designed manufactured specifications.
2) The equipment is provided with a manufacturer's calibration or a calibration performed by a typical industrial public testing laboratory.
3) The DUT is “ideal”, i.e. it is operating as intended (e.g. CIE Source A) and it is not exhibiting any fluctuations or is influenced by ancillary equipment.
4) The measurement conditions are not influenced by external factors such as extreme environmental conditions or offsets such as external (room) stray light.
5) The equipment is being operated as it is designed to be operated by a skilled operator.
6) The measurement uncertainties are expanded uncertainties, given with a confidence interval of 95 %.

The typical measurement uncertainties are determined in the same way that uncertainties of measurement are evaluated for a measurement made using the instrument on a real source, in a manner that is consistent with (JCGM 2008) or (CIE 2011a, CIE 2011b). Individual uncertainty components that relate to the source only (e.g. source fluctuations, current setting, etc.) are set to zero, so that the source is considered to be ideal. However individual uncertainty components that relate to the instrument itself and how the instrument interacts with the source (e.g. spectral mismatch, fatigue, etc.) are retained.

The typical measurement uncertainties must be accompanied by a brief statement clarifying any limiting aspects of the application; such as the spectral content of a source, a measurement range, the thickness of a sample, etc. They are usually quoted to a maximum of two significant figures only and rounded up to the nearest 0,5 %, e.g. 1,8 % rounds up to 2,0 % and 2,25 % rounds up to 2,5 %. Many specifications also include the instrument repeatability of measurement; this is also acceptable under the same assumptions above. Some examples of appropriate expressions are given in 6.2.1 to 6.2.3.

Furthermore, because the typical measurement uncertainties are relying on a set of assumptions (given above) about the equipment, the DUT and the measurement conditions, either a reference must be made to this publication so that the assumptions given earlier in this clause can be assumed or the assumptions themselves need to be explicitly stated.

NOTE 1 These typical measurement uncertainties are advisory only and should not be used as a substitute for evaluation of measurement uncertainty for measurements made using the instrument. The examples given in this clause are examples only and are not necessarily complete or designed for a particular application.

NOTE 2 The typical measurement uncertainties are assumed to be relative unless otherwise stated.

6.2.1 Example format of expressing the performance of a photometer

Typical measurement uncertainties (according to CIE TN 009:2019):

Measurement of illuminance (CIE Source A, 100 lx): 2,5 %
Measurement of illuminance (warm white LED, 100 lx): 3,5 %
Measurement of illuminance (cool white LED, 100 lx): 4,0 %

6.2.2 Example format of expressing the performance of a colorimeter

Typical expanded measurement uncertainties[1]:

Source	*Measurement uncertainty in*		
	x Coord	*y Coord*	*CCT*
CIE Source A	*0,002*	*0,002*	*25 K*
3 000 K LED	*0,003*	*0,003*	*50 K*
4 000 K LED	*0,003*	*0,004*	*85 K*
6 500 K LED	*0,004*	*0,004*	*180 K*

[1] *Evaluated according to CIE TN 009:2019*

6.2.3 Example format of expressing the performance of a spectrophotometer

Typical expanded measurement uncertainties (according to CIE TN 009:2019):

Spectral transmittance in wavelength range from 250 nm to less than 360 nm:
0,1 to 1,0 transmittance: 0,002 or 1 % of value, whichever is greater
0,01 to 0,1 transmittance: 0,001 or 2 % of value, whichever is greater
Spectral transmittance in wavelength range from 360 nm to 830 nm:
0,1 to 1,0 transmittance: 0,001 or 0,5 % of value, whichever is greater
0,01 to 0,1 transmittance: 0,0005 or 1 % of value, whichever is greater

6.3 Expressions for specifying an instrument's required measurement performance

In tenders or specifications for the requirements of testing and measurement equipment which will be purchased, it is often desirable to indicate an expected performance of the instrument. In such cases, it is not acceptable to specify an "accuracy" requirement, but it is acceptable to express maximum acceptable error limits, to refer to an instrument's quality class or to specify a requirement for an instrument's typical measurement uncertainties under the assumptions outlined in 6.2. Some examples of ways of expressing this are given in 6.3.1 to 6.3.3.

6.3.1 Example formats for expressing conformity to tolerance intervals/limits and quality indices

- *Required maximum wavelength error: 0,3 nm over the wavelength range from 380 nm to 780 nm*
- *Required linearity index $f_3 \leq 0{,}2$ %*
- *Stray light $\leq 0{,}1$ % acc. to ASTM E387 when evaluated according to CIE Standard Illuminant A, GG495, $\lambda = 420$ nm*

6.3.2 Example formats for expressing required compliance with a standard

- *Required quality class: CIE Class 3*or better (according to CIE 231:2019)*
- *The supplied equipment must comply with the requirements of CIE S 025/E:2015*

6.3.3 Example format for expressing the required performance of an integrating sphere system

Requirements for typical expanded measurement uncertainties (evaluated according to CIE TN 009:2019):

Measurement of luminous flux (incandescent, 100 lm to 3 000 lm): ≤ 2,0 %
Measurement of luminous flux (LED, 100 lm to 3 000 lm): ≤ 3,0 %
Measurement of luminous flux (CFL, 100 lm to 3 000 lm): ≤ 3,0 %
Measurement of CCT (incandescent, 2 600 K to 3 500 lm): ≤ 30 K
Measurement of CCT (LED & CFL, 2 600 K to less than 3 500 K): ≤ 50 K
Measurement of CCT (LED & CFL, 3 500 K to less than 5 000 K): ≤ 100 K
Measurement of CCT (LED & CFL, 5 000 K to 7 000 K): ≤ 150 K

6.4 Combined expressions

It is also acceptable to use combinations of the example formats given in 6.1 to 6.3 within the one specification. The following is an example of this, written in terms of performance requirements for a tender.

<u>Example format for expressing the required performance of a goniophotometer system:</u>

Requirements for typical expanded measurement uncertainties (evaluated according to CIE TN 009:2019):

Measurement of luminous intensity (cool white LED, 1 cd to 10 000 cd): ≤ 3,0 %
Measurement of luminous flux (cool white LED, 100 lm to 100 000 lm): ≤ 3,0 %

Requirements for performance of the goniometer:

Maximum angular error: ± 0,2° about the vertical axis
Maximum angular error: ± 0,3° about the horizontal axis

Requirements for performance of the photometer:

Quality class: CIE Class 3 or better (according to CIE 231:2019)*
Nonlinearity error $f_3 \leq 0{,}2$ %

Requirements for conformance with standards:

The goniophotometer system must be compatible with CIE S 025/E:2015

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