INTERNATIONAL STANDARD

ISO 15790

First edition
2004-01-15

Graphic technology and photography — Certified reference materials for reflection and transmission metrology — Documentation and procedures for use, including determination of combined standard uncertainty

Technologie graphique et photographie — Matériaux de référence certifiés pour la métrologie par réflexion et transmission — Documentation et procédures à utiliser, y compris la détermination d'une incertitude normale combinée

Reference number
ISO 15790:2004(E)

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Published in Switzerland

Contents

Page

Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. 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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 15790 was prepared by Technical Committee ISO/TC 130, *Graphic technology*.

Introduction

The International Organization for Standardization (ISO), in ISO Guide 30 [1], defines a certified reference material (CRM) as a "reference material, accompanied by a certificate, one or more of whose property values are certified by a procedure which establishes traceability to an accurate realization of the unit in which the property values are expressed, and for which each certified value is accompanied by an uncertainty at a stated level of confidence". Thus, CRMs are well-characterized materials with values traceable to stated references (see 3.1.12). They may be used to calibrate or to determine the performance characteristics of measurement systems in order to facilitate the exchange of data and to assist in quality control. Their use will help to assure the long-term adequacy and integrity of the measurement and quality control processes.

Densitometers, colorimeters and spectrophotometers are widely used to make measurements for quality and process control in the graphic arts, photographic and other imaging industries. The intent of this International Standard is to establish documentation requirements that describe characteristics of reflection and transmission certified reference materials that may be used for verifying performance of these instruments. In many areas (e.g. cyan, magenta, yellow colorants) there are no readily available reference materials that are traceable to international and national standards. This International Standard can still provide guidance in such circumstances by showing how to determine the reproducibility of the results of measurements, even in the absence of CRMs.

Although the calibration reference materials provided with many reflection and transmission instruments used in graphic arts and photography are not identified as CRMs, they could often meet the requirements as such. Instrument manufacturers are encouraged to document the characteristics of their calibration materials as CRMs where appropriate.

This International Standard describes practical procedures to determine values that represent components of the uncertainty of measurements for the graphic arts, photography and other image-technology industries. A computational procedure is also provided to combine these components to determine "combined standard uncertainty" (see 3.1.3). A more rigorous and detailed approach is described in the *Guide to the expression of uncertainty in measurement*.

Furthermore, general procedures are identified for the use and maintenance of these certified reference materials. Through use of this International Standard, manufacturers of CRMs can provide consistent general-use information for the verification of measurement-system performance described above. This International Standard lists appropriate documentation that should accompany CRMs, including the following:

a) areas where a CRM is and is not applicable;

b) physical characteristics of CRMs for density, colour values, uniformity, etc. (see Annex A);

c) traceability of CRM values to stated reference;

d) expected lifetime of a CRM;

e) care and storage of a CRM;

f) general procedures on how to use a CRM.

Other useful documents providing guidance in metrology and the uncertainty of measurement can be found in the Bibliography.

This International Standard provides guidance and is a resource for manufacturers and users of CRMs. Using CRMs as part of quality assurance activities is essential for verification and calibration of measurement systems and can increase confidence in data obtained from measurement instruments. It provides a useful tool in support of ISO 9001 [15] registration and ISO/IEC 17025 [22] accreditation by providing information relevant to graphic technology, photographic and other imaging industries.

Graphic technology and photography — Certified reference materials for reflection and transmission metrology — Documentation and procedures for use, including determination of combined standard uncertainty

1 Scope

This International Standard specifies the documentation requirements for certified reference materials (CRMs), procedures for the use of CRMs, and procedures for the computation and reporting of the combined standard uncertainty of reflectance and transmittance measurement systems used in graphic arts, photographic and other imaging industries.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the reference document (including any amendments) applies.

Guide to the expression of uncertainty in measurement, published jointly by BIPM/IEC/IFCC/ISO/IUPAC/IUPAP/OIML, 1995

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
calibration
set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realized by standards

[adapted from *International vocabulary of basic and general terms in metrology*] [2]

NOTE Contrary to a common misconception, calibration is not the process of adjusting a measurement system such that it produces values that are believed to be correct. Calibration permits either the assignment of values of measurands to the indications (creating a reference table) or the decision to reset or adjust the device. Following the resetting or adjusting of the device, a calibration is normally repeated to ensure that the new device setting(s) provide indications within the accepted ranges.

3.1.2
certified reference material
CRM
reference material, accompanied by a certificate, one or more of whose property values are certified by a procedure which establishes traceability to an accurate realization of the unit in which the property values are expressed, and for which each certified value is accompanied by an uncertainty at a stated level of confidence

[ISO Guide 30] [1]

3.1.3
combined standard uncertainty
u_c
standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of a sum of terms, the terms being the variances or covariances of these other quantities weighted according to how the measurement result varies with changes in these quantities

[*Guide to the expression of uncertainty in measurement*]

3.1.4
coverage factor
k
numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty

[*Guide to the expression of uncertainty in measurement*]

3.1.5
CRM reference value
value of the certified property of a CRM, reported in the documentation supplied with it

3.1.6
expanded uncertainty
U
quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand

[*Guide to the expression of uncertainty in measurement*]

NOTE Expanded uncertainty is the product of the combined standard uncertainty, u_c, and the chosen coverage factor, k.

3.1.7
experimental standard deviation
s
quantity characterizing the dispersion of the results for a series of n measurements of the same measurand and given by the following formula:

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

where

n is the number of measurements;

$\bar{x}$ is the arithmetic mean of the n results considered;

x_i is the result of the ith measurement.

[adapted from *International vocabulary of basic and general terms in metrology*] [2]

NOTE According to ISO 3534-1:1993 [7], 2.34, the standard deviation is the positive square root of the variance.

3.1.8
manufacturer's calibration reference material
physical device or material, certified or non-certified, supplied by the instrument manufacturer, which may be used to calibrate a specific instrument

3.1.9
measurand
particular quantity subject to measurement

[*International vocabulary of basic and general terms in metrology*] [2]

EXAMPLES Density, lightness, transmittance, and reflectance factor.

3.1.10
reference material
material or substance one or more of whose property values are sufficiently homogeneous and well established to be used for the calibration of an apparatus, for the assessment of a measurement method, or for assigning values to materials

[ISO Guide 30] [1]

3.1.11
reproducibility
⟨results of measurements⟩ closeness of the agreement between the results of measurements of the same measurand carried out under changed conditions of measurement

[adapted from *International vocabulary of basic and general terms in metrology*] [2]

NOTE Reproducibility is distinct from repeatability. Repeatability is the closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions, e.g. using a single instrument, by the same observer, in the same location and in a short period of time.

3.1.12
traceability
property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons, all having stated uncertainties

[adapted from *International vocabulary of basic and general terms in metrology*] [2]

3.1.13
uncertainty of measurement
parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

[adapted from *International vocabulary of basic and general terms in metrology*] [2]

NOTE 1 For the purposes of this International Standard, each component of the uncertainty is assumed to have a normal distribution. The concepts and rules for cases where this assumption may not be valid are considered in the *Guide to the expression of uncertainty in measurement*.

NOTE 2 The result of a measurement is only an approximation or estimate of the value of the measurand and thus is complete only when accompanied by a statement of the uncertainty of that estimate (see 3.1.3 and 6.1.7).

3.1.14
uncertainty of CRM
U_{CRM}
measurement uncertainty that is attributed to the reported value of a CRM in the certificate supplied with it, often expressed as an expanded uncertainty with a coverage factor

3.1.15
variance
a measure of dispersion, which is the sum of the squared deviations of observations from their average divided by one less than the number of observations

[adapted from ISO 3534-1:1993] [7]

3.2 Symbols

b_{max} maximum value of the known correction

D_R reflection density

k coverage factor

s experimental standard deviation

S_A influx spectrum based on CIE illuminant A

T_R status T red response

U expanded uncertainty

u_c combined standard uncertainty

u_r uncertainty of reproducibility of results of measurements

U_{CRM} uncertainty of CRM reference values

U_{max} maximum expanded uncertainty

$Y(t)$ measurand function

4 General guidelines for CRM application

CRMs may be used for several purposes:

— to verify the accuracy of a measurement device or system;

— to verify measurement system performance on a routine basis;

— to estimate the uncertainty of reported measurements;

— to improve agreement between/among independently calibrated measurement systems and to determine correlation.

The manufacturer's calibration reference material normally includes properties and values that are designed to work with a specific instrument and for a specific application. A manufacturer's calibration reference material is a CRM if it provides the documentation conforming to 5.1 to 5.3 of this International Standard.

A CRM that is not the instrument manufacturer's calibration reference material should not arbitrarily be used for physically readjusting the instrument. The user of a CRM should first contact the instrument manufacturer regarding the use of a specific CRM for that purpose.

A CRM is usually designed to verify some but not all attributes of a measurement system. It is, therefore, important to understand and follow closely the application information provided with a CRM.

5 Required documentation for CRMs

5.1 Identification of CRM

The following information shall be supplied with a CRM:

— manufacturer's name;

— product identification;

— serial number;

— certification date;

— expiration date or useful life.

This information shall be affixed to a CRM or uniquely associated with it.

5.2 Reporting of CRM reference values

The reference values of CRMs shall be properly identified and reported, with either the combined standard uncertainty u_c (see Example 1), or the expanded uncertainties U and coverage factor k (see Example 2).

EXAMPLE 1 $D_R(45; S_A: 0; T'_R) = 1{,}25$ with $u_c = 0{,}01$; notation for densities according to ISO 5-3 [5]

where

D_R is reflection density;

S_A is the influx spectrum based on CIE standard illuminant A;

T'_R is the status T′ red spectral response.

EXAMPLE 2 $D_R(45; S_A: 0; T'_R) = 1{,}25 \pm 0{,}02 = 1{,}25 \pm U\ [u_c = 0{,}01, (k = 2)]$

where the variables are the same as for Example 1.

Alternatively, the reference values of CRMs may be expressed in some other form such as a table; however, the certificate accompanying a CRM shall clearly show either the combined standard uncertainty or the expanded uncertainty and the coverage factor.

5.3 Traceability

A statement of traceability shall be provided with CRM reference values. A detailed description of this traceability shall be available upon request.

Information about the instrumentation and procedures used to determine CRM reference values shall also be supplied.

5.4 Cautions for use

The manufacturer of a CRM shall provide documentation for those characteristics of a CRM that can affect the stability of the values measured on a CRM. See Annex A for a sample list of characteristics.

The use of CRMs having characteristics that differ from those of materials whose properties are to be measured may yield erroneous measurement results. Consideration should be given to these characteristics when selecting and using a CRM in order that unintended effects are minimized. Documentation should be provided regarding any properties that can adversely affect instrument calibration.

If the spectral characteristics or other properties of a CRM have a noticeable influence on the measurement by the user, they should be provided by the manufacturer. A good example is the property of some colour reference materials to shift colour with temperature. Here, the requirements for temperature control should be stated.

5.5 Care and handling of CRMs

The manufacturer shall provide information regarding pertinent lifetime limitations of a CRM (e.g. physical deformities, change in surface characteristics, colour change).

Information shall include the following, when applicable:

— process for verification and recertification;

— recommended temperature, humidity and light exposure for storage and use;

— handling precautions and recommendations;

— cleaning procedures.

Documentation accompanying a CRM shall include any manufacturer's recommendations for replacement or recertification interval, assuming no significant contamination, damage or other alteration has occurred to a CRM during its use.

In cases where known use conditions are documented as potential causes for change, CRM reference values should be verified through measurement auditing or surveillance.

5.6 Use and procedures

The manufacturer should provide guidelines and examples for the use of a CRM. If there is a possibility that improper use can affect the measurement results, a detailed description of the recommended procedures shall be given (e.g. instrument positioning relative to a CRM, appropriate instrument geometry, aperture size range).

6 Procedures related to the use of CRMs

6.1 Determination of combined standard uncertainty

6.1.1 General

The principle components of the computation of the combined standard uncertainty are discussed in 6.1.2 to 6.1.6. The actual computation, Equation (4), is given in 6.1.7.

The scope of *Guide to the expression of uncertainty in measurement* “establishes the general rules for evaluating and expressing uncertainty in measurement that can be followed at various levels of accuracy and in many fields — from the shop floor to fundamental research”. While this guide should be considered the ultimate document in this area, it is generally not being implemented within the graphic arts or photographic industries. This may be for a number of reasons including ignorance of the document's existence, lack of understanding, and/or impression that implementation is far too rigorous or unnecessary.

For application of the provisions of this International Standard, it is assumed that the input variables are independent of each other, that they have a normal distribution and that their standard deviations are each much smaller than the absolute magnitude of the corresponding input variable. While these assumptions do not always hold, they provide a reasonable basis for the practical use of a CRM. For cases where these assumptions may not be valid, such as for colour difference and chroma, users should follow the concepts and rules presented in the *Guide to the expression of uncertainty in measurement*.

Modelling the measurement process is derived from a knowledge of the measurand. This is not measured directly, but is modelled from a number of other quantities through the following functional relationship f:

$$y = f(x_1, x_2, \ldots x_i, \ldots x_n) \quad (1)$$

where

y is the value of the output quantity;

f is the functional relationship between input and output results;

x_i is the measurement result for the ith input variable.

If some of the x_i are significantly correlated, these correlations must be taken into account. For example, when CIELAB co-ordinates are calculated from spectral values, errors are generated at each sample wavelength. Although the errors at each wavelength are uncorrelated, the act of calculating the derived functions X, Y, Z produces a correlation among the errors of X, Y, Z. In cases such as this, the procedures presented in *Guide to the expression of uncertainty in measurement*, 1995, 5.2, shall be used. See 6.1.2 for a discussion of sensitivity coefficients assuming independent and normally distributed input variables.

6.1.2 Sensitivity coefficients assuming independent and normally distributed input variables

The combined standard uncertainty $u_c(y)$ of a measurement result y that depends on a number of independent and normally distributed input variables x_i is calculated from Equation (2):

$$u_c^2(y) = \left[u(x_1)\frac{\partial f}{\partial x_1}\right]^2 + \left[u(x_2)\frac{\partial f}{\partial x_2}\right]^2 + \ldots \left[u(x_i)\frac{\partial f}{\partial x_i}\right]^2 + \ldots \left[u(x_n)\frac{\partial f}{\partial x_n}\right]^2 \quad (2)$$

where

$u_c(y)$ is the combined standard uncertainty of the measurement result y;

$u(x_i)$ is the standard uncertainty of the input variable x_i;

$\frac{\partial f}{\partial x_i}$ is the value of the partial derivative of the function f with respect to x_i for the value x_i.

The factors $\frac{\partial f}{\partial x_i}$ appearing in Equation (2) are sometimes called the sensitivity coefficients because they reflect the influence of the individual uncertainties on the combined uncertainty. See also Annex B.

6.1.3 Sensitivity coefficients where the process is not functionally known

The sensitivity coefficients can also be determined experimentally if the function f is not known.

EXAMPLE 1 If it has been determined that the colour measurement of certain calibration plaques is influenced by temperature variation, the effect of a temperature change of 1 °C on the measured colour co-ordinate can be determined and this will be considered as the sensitivity coefficient.

A general unknown process P which is a function of several test variables $x_1, x_2, \ldots x_i, \ldots x_n$, can be expressed just as the function above for the function f. The process can then be expressed, even if unknown, as $P(x_1, x_2, \ldots x_i, \ldots x_n)$. The sensitivity coefficient relative to any variable x_i can be determined experimentally by making an incremental change of magnitude ε in that x_i.

$$\frac{\partial P}{\partial x_i} \approx \frac{P\left[x_1, x_2, \ldots, (x_i + \varepsilon), x_n\right] - P(x_1, x_2, \ldots x_i \ldots, x_n)}{\varepsilon} \quad (3)$$

The result may then be used to replace the pertinent partial derivative in Equation (2). To obtain the product within the brackets of Equation (2), each experimentally determined sensitivity coefficient is multiplied by the standard uncertainty of the pertinent variable, expressed in units of the variable.

EXAMPLE 2 The sensitivity coefficient for temperature in Example 1 is multiplied by the standard uncertainty of the temperature expressed in degrees Celsius.

Equation (3) can more conveniently be used to calculate the sensitivity coefficient if the functional relationship is known but very complex. A small change of one input variable from a typical value while leaving the other input variables unchanged allows the computation of the sensitivity coefficient for that variable.

6.1.4 Sensitivity coefficients assuming correlated and normally distributed input variables

Equation (2) is valid only if the input values x_i are independent or uncorrelated. If some of the x_i are significantly correlated, these correlations shall be taken into account.

For example, when CIELAB co-ordinates are calculated from spectral values, errors are generated at each sample wavelength. Although the errors at each wavelength are uncorrelated, the act of calculating the derived functions X, Y, Z produces correlation in the errors of X, Y, Z. In cases like this, the procedures shown in *Guide to the expression of uncertainty in measurement*, 1995, 5.2, shall be used.

6.1.5 Reproducibility of results of measurements

Uncertainty associated with reproducibility shall be considered as one source of uncertainty of the final measured result. This uncertainty is affected by elements such as procedure, operator, time, environment, etc. In determining reproducibility, care should be taken to collect data representative of the population of measurements that can be expected to result from the measurement process when carried out with expected changes in the four above-mentioned (and any other) elements. Reproducibility of the results of measurement shall be determined over a period of time to include normal changes in procedure, recalibration, operator techniques, environmental conditions and other variables using the following procedure.

a) Select a uniform and stable test specimen appropriate to the measurement system being evaluated. A reference material may be used if its relevant properties are the same as those of the type of samples normally measured.

b) Maintain calibration of the instrument using normal procedures and reference materials.

c) Make a statistically significant number of measurements representative of the measurement results expected under normal practice (that is, encompassing all of the causes of casual variation which one normally encounters, such as changes in operator, warm-up period of the instrument, etc.), and record all values obtained. Calculate the experimental standard deviation of these measurement results. The experimental standard deviation thus obtained is a measure of the reproducibility of the results of measurements and is a very important component used in Equation (4) given in 6.1.7 below for the computation of the combined standard uncertainty u_r. An example is provided in Annex B.

This International Standard assumes a normal distribution of measurement results, however, the results will not necessarily be normally distributed. If it is suspected that the distribution is not normal, a statistical test for normality is recommended. If the distribution is shown not to be normal, a different descriptor of the dispersion of the measurement results should be used; see ISO 3534-1 [7] and ISO 3534-2 [8].

NOTE 1 Reproducibility may depend on the result of the measurement or on the type of sample. For density measurements, it is typical that the reproducibility at densities of 0,1 is lower than at 2,0. Also, the reproducibility for reading the neutral area of a particular colour photographic paper may be significantly different from that of another type of such paper with the same nominal density.

NOTE 2 Issues beyond the control of the user are dealt with in 6.1.2, 6.1.3, 6.1.4 and 6.1.6.

6.1.6 CRM uncertainty

The uncertainty of the certified value of a CRM shall be considered to be one component of uncertainty in the final measured result. This uncertainty shall be appropriately combined with other uncertainties of the measurement process. If the value is reported simply as uncertainty, that value shall be assumed to be one standard deviation and used as U_{CRM}. If the value is stated as an expanded uncertainty U with a coverage factor k the value of U_{CRM} shall be U/k.

Historically, in many graphic arts applications, the uncertainty of the certified value of a CRM assumes a normal distribution and is stated in terms of a given value for a multiple of the standard deviation (sigma) of such a distribution (e.g., ± 0,001 3 density at 2 σ). In such cases, the value should be divided by the number of sigmas to obtain a one-standard-deviation equivalent. [Again, this is the number that is necessary for use in Equation (4) of 6.1.7.] Where a value is given without an indication of its statistical property, it should be assumed to represent one standard deviation.

6.1.7 Computation of combined standard uncertainty

The combined standard uncertainty $u_{\text{c}}(y)$ of the measurement result for parameter y shall be computed using the uncertainty associated with reproducibility u_r, the uncertainty of a CRM's certified value U_{CRM} and the uncertainties from all other sources that did not apply when determining the reproducibility of measurement, according to Equation (4), derived from the basic model Equation (1):

$$u_{\text{c}}(y) = \sqrt{u_r^2 + U_{\text{CRM}}^2 + u_{x_1}^2 + u_{x_2}^2 + \ldots + u_{x_n}^2} \qquad (4)$$

where $u_{x_1}^2; u_{x_2}^2; \ldots , u_{x_n}^2$ are equal to the experimental variances.

Each of the above values is equal to the square of the experimental standard deviation (if the source of uncertainty has been estimated statistically) or other estimate of the variance (if determined by means other than statistics) associated with all other components of the uncertainty. The experimental variances or their estimates used to express the uncertainties of variances shall all be expressed in terms of the measured quantity.

For example, if a reflection-density measurement uncertainty is introduced by temperature variation, then the effect of this temperature variation on the measured density can be determined, and should be expressed as a density variance, not as a temperature variance.

An example of the computation of combined standard uncertainty where no interdependence of components exists and all component sensitivities are equally weighted is presented in Annex B. A computational procedure and examples where a more complex set of component sensitivities exists is presented in Annex C.

6.2 Computation of expanded uncertainty

The expanded uncertainty U shall be computed by multiplying the combined standard uncertainty $u_{\text{c}}(y)$ by a coverage factor k.

With normal distributions, choosing a coverage factor $k = 2$ produces an interval having a level of confidence of approximately 95 %. For graphic technology applications, a coverage factor of 2 generally should be used in comparing the uncertainty in measured data values with specific application requirements. Detailed recommendations, especially the “effective degrees of freedom”, are included in the *Guide to the expression of uncertainty in measurement*, 1995, particularly in 3.3.7 and in Clause 6.

6.3 Calibration of a measurement system

It is recommended that calibration be made, using a CRM, when a new instrument is received or after repair or adjustment (see 3.1.1 and Clause 4).

After following the manufacturer's procedures for setting up the instrument, measure a CRM and compare the measured value to its reference value from the CRM's certificate.

For this comparison to be meaningful, it is necessary to determine the combined standard uncertainty of the result of the measurement. In order to determine this combined standard uncertainty, it is necessary to first estimate the uncertainties of each component of the process. (These estimates may be determined by statistical or other methods.) This process requires a knowledge of all sources of uncertainty, including reproducibility u_r (see 6.1.5), CRM uncertainty U_{CRM} (see 6.1.6), and other known sources of measurement uncertainty. When each component of the uncertainty is expressed as a variance (for normal distributions, this is the equivalent of the square of one standard deviation) or an estimate thereof, the positive square root of the sum of the variances (and estimates thereof) is equal to the combined standard uncertainty (assuming that all of the sources of uncertainty are independent, that is, they are not correlated); see 6.1.7.

The uncertainty of a measurement result determined for the measurement of a CRM might not be equal to the uncertainty of results of measuring other materials, even though they may have been evaluated with the same measurement process. For example, the gloss of a reflection-density CRM is one characteristic of a CRM which might not affect the instrument's ability to accurately measure the density of a CRM. However, if specimens with a gloss which differs from that of a CRM are measured with the same measurement process, this gloss difference may affect the uncertainty of the measured results. In such a case, the effect of gloss should be determined, and combined with other sources of uncertainty. See Annex A for the characteristics of CRMs which may also need to be considered when evaluating measurement uncertainties.

Once the combined standard uncertainty of the measurement system has been determined, the instrument calibration should then be verified using a CRM. If the absolute value of the difference between the measured value and CRM reference value is equal to or less than the combined standard uncertainty, no correction need be applied. If the absolute value of the difference between the measured value and reference value is greater than the combined standard uncertainty, a correction should be applied to the measurement result. Corrections may be made by addition (the value added to the uncorrected result is termed the “correction”) or by multiplication (the value by which the uncorrected result is multiplied is termed the “correction factor”). Alternatively, the instrument may be adjusted using procedures provided by the manufacturer. The example calculations of combined standard uncertainties containing a CRM uncertainty in Annexes B and C will be based on the additive-type “correction”.

Whether or not the performance of an instrument is “acceptable” depends on the application. Systematic errors cannot be eliminated, but can often be reduced. If a systematic error arises from a recognized effect, and the effect can be quantified, a correction can be applied to compensate for the effect. After correction, the expected value of the error arising from the systematic effect is zero.

When the result of the calibration is equal to or within the specification, the performance is verified and system adjustment is not required. When the result of the calibration falls outside the application's specification, there is potentially a problem with the method of measurement, the frequency of calibration, the instrument or a CRM.

7 Reporting measurement results and their uncertainty

Uncertainties shall be reported with measurement results. The measurement result y shall be reported together with the combined standard uncertainty of the measurement process u_{c} (see Example 1) or shall be reported with the expanded uncertainty U and the coverage factor k (see Example 2).

EXAMPLE 1 $D_{\text{R}}(45; S_{\text{A}}: 0; T'_{\text{G}}) = 1{,}43$ with $u_{\text{c}} = 0{,}02$; the notation of the density conforms to ISO 5-3 [5]

where

D_{R} is the reflection density;

S_{A} is the influx spectrum based on CIE illuminant A;

T'_{G} is the status T green spectral response;

U is the expanded uncertainty;

k is the coverage factor.

EXAMPLE 2 $D_R(45; S_A: 0; T'_G) = 1{,}43 \pm 0{,}04 = 1{,}43 \pm U\,[u_c = 0{,}02, (k = 2)]$

where the variables are the same as for Example 1.

For Examples 1 and 2, the true value of the measured density falls within the range of 1,39 to 1,47 with a probability of approximately 95 %.

If it is not feasible to apply corrections to measurement results for known significant systematic effects, then the uncertainty shall be reported according to the *Guide to the expression of uncertainty in measurement*, 1995, F.2.4.5. In such situations, the results of measurements are often reported as follows:

$$Y(t) = y(t) \pm (U_{max} + b_{max}) \quad (5)$$

where

$Y(t)$ represents a measurand Y defined over a range of values of parameter t;

U_{max} is the maximum expanded uncertainty over the range of values of t;

b_{max} is the maximum value of the known correction over the range of values of t.

EXAMPLE 3 CIE $\Delta E^*_{ab} = 2{,}4 \pm [0{,}03 + 0{,}01]$

where

U_{max} of 0,03 is the maximum expanded uncertainty over the range of values of ΔE^*_{ab};

b_{max} of 0,01 is the maximum value of the known correction over the range of values of ΔE^*_{ab}.

Annex A
(informative)

Characteristics of CRMs

The following is a non-exhaustive list of characteristics of CRMs that may affect the calibration of measuring instruments:

— area

— background

— colour

— density

— dots

— fluorescence

— gloss

— opacity

— permeability

— polarization

— reflectance

— shape

— sharpness

— size

— spectral characteristics (of reflectance, of transmittance)

— stability (with time, light exposure, temperature, humidity, etc.)

— structure (layers)

— texture

— translucency

— transmittance

— uniformity

Annex B
(informative)

Example of computation of combined standard uncertainty (with component sensitivities equally weighted)

B.1 Introduction

This annex gives an example of how to determine the reproducibility of results of measurement and the computation of combined standard uncertainty where no interdependence of components exists and all component sensitivities are equally weighted. This example is presented only for the purpose of illustrating the application of this International Standard and includes an example of an assessment of the reproducibility of the measurement process as described in 6.1.5. (A computational procedure and examples of a more complex set of component sensitivities are given in Annex C.)

Procedures to determine reproducibility, in accordance with this International Standard, should truly simulate the casual variations encountered in actual use, and efforts should be made to identify as many as possible of the causes of variations that may be encountered in actual practice.

B.2 Example

The reproducibility of the results of the measurement is a function of such things as the following:

— number of different operators making measurements;

— the number of locations in which an instrument is used;

— the environment in which the instrument is used;

— the time between calibration/adjustment.

To determine the reproducibility of the results of the measurements in a particular application environment, it is important to conduct an experiment that simulates the typical operation. For example, in one test the red density of the cyan patch on a graphic arts press-sheet sample was measured using a spectro-densitometer reporting status T_R values. One operator in each of three laboratories made measurements five times on each of three different days using the same instrument. Before each group of five measurements, the instrument was calibrated using the manufacturer's calibration reference and procedures in order to simulate actual use.

Reproducibility of the results of the measurement u_r may be expressed as a standard deviation. For this example, the experimental standard deviation was calculated as 0,007 using the equation in 3.1.7.

The following is an example of the computation of combined standard uncertainty for a special, though common, case where no interdependence of components exists and all component sensitivities are equally weighted and normally distributed.

The following conditions apply:

— the measurement process yields an experimental standard deviation of 0,007;

— the combined standard uncertainty of the CRM from its certificate is 0,012;

— no other sources of uncertainty have to be included.

The substitution of these values into Equation (B.1) [Equation (4) from 6.1.7] for the combined standard uncertainty u_c yields

$$u_c(y) = \sqrt{u_r^2 + U_{CRM}^2 + u_{x_1}^2 + u_{x_2}^2 \dots + u_{x_n}^2} \quad \text{(B.1)}$$

which reduces the mathematical expression to the following form:

$$u_c = \sqrt{(0{,}007)^2 + (0{,}012)^2} = 0{,}014 \quad \text{(B.2)}$$

Annex C
(informative)

Examples of computation of combined standard uncertainty (including weighting of component sensitivities)

C.1 Introduction

This annex gives the computational procedures and examples for more complex component sensitivities, based on the *Guide to the expression of uncertainty in measurement*. After a determination of the combined standard uncertainty, a CRM should be measured to determine if a correction or adjustment is needed in the measurement system. Verification of a measurement system is recommended on a routine schedule. (Annex B gives an example of the simpler case of how to determine the reproducibility of results of measurement and the computation of combined standard uncertainty where no interdependence of components exists and all component sensitivities are equally weighted.)

C.2 Example 1 — Densitometry application

The status T'_R densities of the cyan solid and the unprinted paper patch on a sample were measured using a spectrodensitometer reporting status T'_R densities. One operator each in three laboratories made measurements five times on each of three different days using the identical type of instrument (e.g., the same serial number). Before each group of five measurements, in order to simulate actual use, the instrument was calibrated with the manufacturer's calibration reference material and then adjusted according to the manufacturer's instructions. The measurement results were normally distributed. Using the data gathered from the 45 measurements on each patch, the mean values and the experimental standard deviations were computed, the latter by using the formula in 3.1.7. The results are given in Table C.1.

It is desirable to periodically verify measurement system performance with a CRM. It is important to compute the combined standard uncertainty (see 6.1.7) as the uncertainty of a CRM is required as an input. According to the certificate, one of the CRM sample areas, a cyan, has a value stated as "$D_R(45; S_A: T'_R; 0) = 1{,}52$ with $u_c = 0{,}012$". A second sample area, for paper white, has a value stated as "$D_R(45; S_A: T'_R; 0) = 0{,}05$ with $u_c = 0{,}012$". Substituting these values into Equation (4) yields the values for the combined standard uncertainty, u_c, in Table C.1. This is also the uncertainty of a single status T'_R measurement with the given instrument on the type of sample used for determining the reproducibility.

Table C.1 — Results of reproducibility test

	Mean of results	Standard deviation	Uncertainty of CRM	Combined standard uncertainty
Quantity	$D_R(45; S_A: T'_R; 0)$	u_r	U_{CRM}	u_c
Cyan solid	1,52	0,005 6	0,012	0,013
Paper	0,07	0,001 3	0,012	0,012

The standard deviation, u_r, represents the reproducibility values, as defined in 6.1.5, for the status T'_R density measurement with the given instrument. Since the values are significantly different for high (0,005 6) and low (0,001 3) densities, these cases must be treated separately.

C.3 Example 2 — Difference between two densities

The combined standard uncertainty of the difference D_r between the two reflection densities given in Table C.1 is calculated according to Equation (C.1):

$$D_r = f(D_s, D_p) = D_s - D_p \tag{C.1}$$

where

D_r is the difference of the densities, i.e., a relative density;

f is the functional relationship between input and output quantities;

D_s is the density of the solid;

D_p is the density of the paper.

The sensitivity coefficients become

$$\frac{\partial f}{\partial D_s} = 1 \text{ and } \frac{\partial f}{\partial D_p} = -1 \tag{C.2}$$

The substitution of these values into Equation (C.2), together with the combined standard uncertainty values for D_s and D_p from Table C.1, yields the result

$$u_c(D_r) = 0{,}018 \tag{C.3}$$

C.4 Example 3 — Mechanical ghosting computed from density measurements

The degree of mechanical ghosting from density measurements on two cyan solids during a press commissioning operation is calculated from the following equation:

$$G = \frac{D_2 - D_1}{D_2} \times 100 \tag{C.4}$$

where

G is a percentage measure of ghosting;

D_2 is the density of a solid without ghosting;

D_1 is the density of a solid with ghosting.

The sensitivity coefficients are

$$\frac{\partial f}{\partial D_1} = -\frac{1}{D_2} \times 100 \text{ and } \frac{\partial f}{\partial D_2} = \frac{D_1}{D_2^2} \times 100 \tag{C.5}$$

The densities $D_1 = 1{,}45$ and $D_2 = 1{,}60$ were evaluated with the same colour setting of the instrument as for Example 1 in C.2. The substitution of 0,013, the appropriate uncertainty from Table C.1, into Equation (2) from 6.1.2 results in the following form of the equation.

$$u_c(G) = \sqrt{\left(\frac{1}{1{,}60} \times 1{,}3\right)^2 + \left(\frac{1{,}45}{1{,}60^2} \times 1{,}3\right)^2} = 1{,}10 \tag{C.6}$$

