Usage of the Uncertainty of Measurement by Accredited Laboratories when Stating Compliance

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DKD

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1. Measurement, Calibration, Uncertainty

Assumption: (Measurement) uncertainty is calculated in accordance with GUM and EA-4/02.

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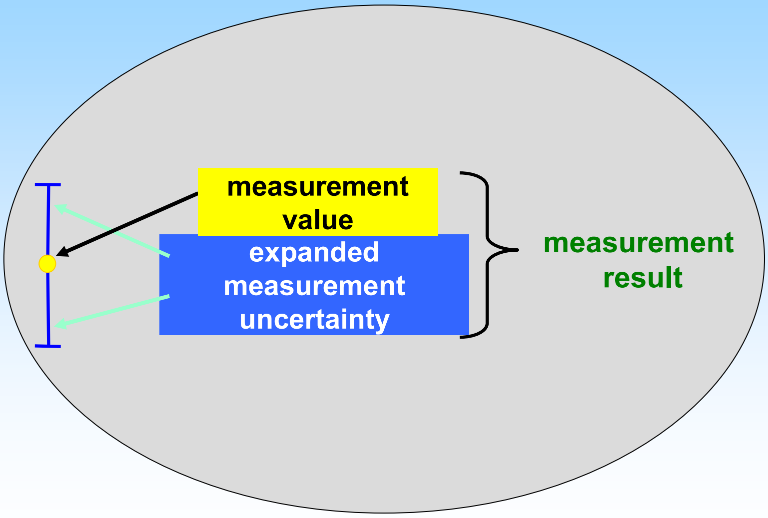
Measurement



Calibration

set of operations that establish, under specific 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 realised by standards.*

E.g. determine and document the error of indication of the instrument from the conventional true value of the measurand.

* DIN Deutsches Institut für Normung (ed.): International Vocabulary of Basic and General Terms in Metrology; Berlin, Köln; 1994

Measurement, Calibration

- measurement value
- calibration: error of indication
  (difference of indication of a measuring system and true value of the input quantity [VIM A6])

The concept to state compliance (or non-compliance) with specifications is applicable to measurements and to calibrations.

As a basis serves the Bayesian approach with pdfs (probability density functions) for the quantities. Normal pdfs are assumed, if not noted otherwise.

2. Determining Compliance according to ISO 14253-1, ILAC-G8, DKD-5

Compliance

Calibration or measurement results are compared with limits:

specifications or

maximum permissible errors (MPE)

Calibration in ISO/IEC 17025: Statement of Compliance

5.10.4.2 The calibration certificate shall relate only to quantities and the results of functional tests. If a statement of compliance with a specification is made, this shall identify which clauses of the specification are met or not met.

When a statement of compliance with a specification is made omitting the measurement results and associated uncertainties, the laboratory shall record those results and maintain them for possible future reference.

When statements of compliance are made, the uncertainty of measurement shall be taken into account. [-> decision rule]

[see for instance DKD-5 and EN ISO 14253-1.]

ISO/IEC 17025: Compliance, opinions, interpretations

5.10.5 Opinions and interpretations

When opinions and interpretations are included, the laboratory shall document the basis upon which the opinions and interpretations have been made. Opinions and interpretations shall be clearly marked as such in a test report.

NOTE 1 Opinions and interpretations should not be confused with inspections and product certifications as intended in ISO/IEC 17020 and ISO/IEC Guide 65.

NOTE 2 Opinions and interpretations included in a test report may comprise, but not be limited to, the following:

– an opinion on the statement of compliance/non-compliance of the results with requirements;
– fulfilment of contractual requirements;
– recommendations on how to use the results;
– guidance to be used for improvements.

NOTE 3 In many cases it might be appropriate to communicate the opinions and interpretations by direct dialogue with the customer. Such dialogue should be written down.

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Statements of compliance within DKD

DKD-5 A 1

1.1 Any certificate issued by an accredited calibration laboratory shall contain, in the appropriate language:

...

(h) the measurement results and associated uncertainty of measurement and/or a statement of compliance with a defined metrological specification;

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Statements of compliance (I)

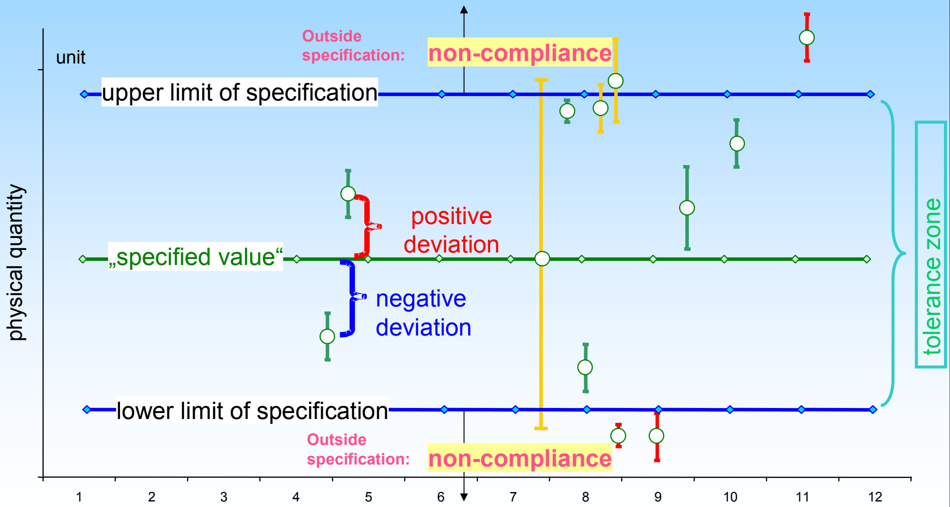
Statement of compliance with a metrological specification

DKD-5 A 2.4

When a parameter is certified to lie within specified tolerances, the difference and the sum of measurement value and expanded uncertainty of measurement calculated in accordance with EA-4/02 [DKD-3] shall also fall within the appropriate specification limits.

Judgement on measurement results

in accordance with EN ISO 14253-1



Statements of compliance,
other method of representation

(i) outside specification, (ii) outside specification with $P < 95\%$
(iv) inside specification, (iii) inside specification with $P < 95\%$

Figure 1 Assessment of Compliance with an Upper Limit

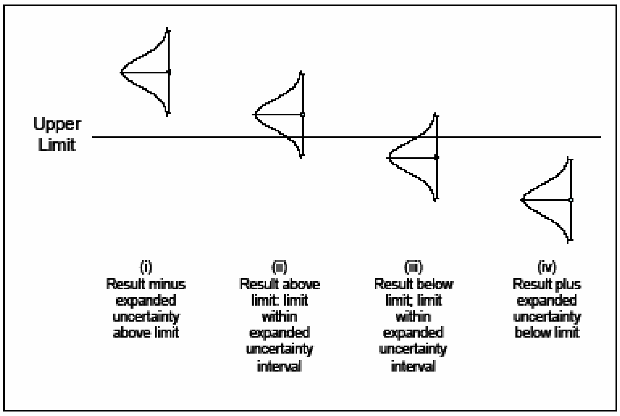


Diagram from EURACHEM/CITAC Guide 2007

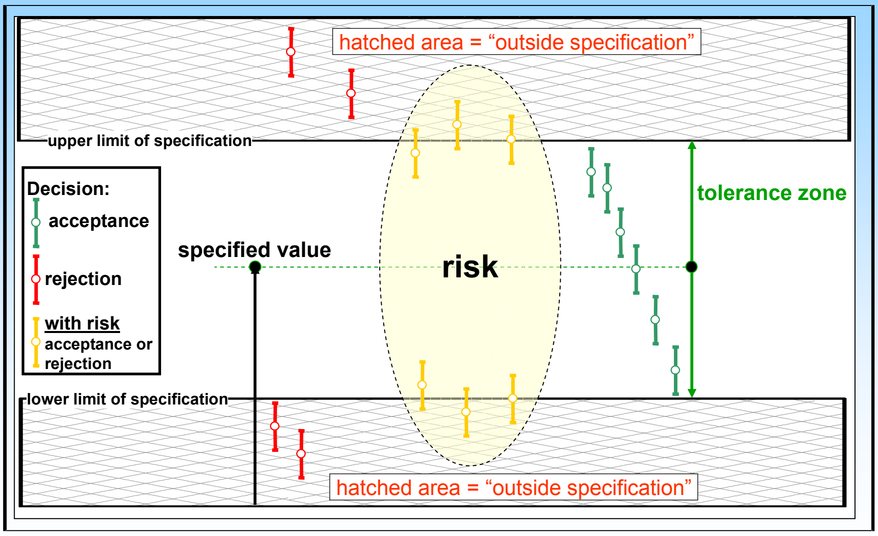
Statements of compliance (II)

Notes:

1 A statement of compliance should only be made if the ratio of the uncertainty of measurement to the specified tolerance is reasonably small.

2 If the difference or the sum of measurement value and expanded measurement uncertainty exceeds the specified tolerance while the measurement value itself falls within the tolerance, neither compliance nor non-compliance can be proved. Only the measurement result and the associated uncertainty can then be given in the certificate without any statement of compliance. [for example cases (ii) and (iii)]

Schematic presentation of acceptance terms



Statements of compliance (III)

Omitting the measurement results

DKD-5 A 2.6

When a statement of compliance with a specification is made omitting the measurement results and the associated uncertainties, the laboratory shall record those results and maintain them for possible future reference.

Statements of compliance (IV)

DKD-5 B 2.2.3 Statements of compliance

Statements on the compliance of the object calibrated with metrological specifications can be made in the calibration certificate in connection with the measurement results or without the measurement results being stated. Such specifications may be national or international standards, normative documents such as VDI/VDE guidelines, or other specifications recognized by the DKD Accreditation Body.

When compliance with the maximum permissible errors is stated, the measurement values, including the uncertainty of measurement, must lie within the error limits.

Statements of compliance (V)

DKD-5 B 2.2.3 Statements of compliance

Examples:

- The measurement values extended by the expanded uncertainty of measurement (coverage probability of 95 %) lie within the limits of permissible error according to DIN 12 786, Nov. 1981.

or:

- The calibrated material measures are in compliance with accuracy class ... according to DIN ....

Statements of compliance (VI)

DKD-5 B 2.2.3 Statements of compliance

The statement of compliance may relate only to metrological specifications, compliance with which can be ascertained within the scope of the measurements carried out and which are clearly identified, for example by indication of the section of a standard or guideline. The statement of compliance must be based on measurements for which the laboratory has been accredited.

Statements of compliance (VII)

DKD-5 B 2.2.3 Statements of compliance

Example:

not: The thread gauge is in compliance with DIN 103-9:1985.

but: Under the above measurement and environmental conditions and taking the expanded uncertainties of measurement (coverage probability of 95 %) into account, the measurement values stated above are within the tolerances given in DIN 103-9:1985 for the gauge dimensions.

When the measurement results are not included in the calibration certificate, they are to be kept for later checks.

3. Risks of Decisions

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Risk of wrong decisions

User risk (consumer's risk)**:** risk/probability that a measurement device which showed compliance at the judgement does not fulfil the specifications (a kind of "false positive") **pass-error probability**

Producer risk: risk/probability that a measurement device which showed non-compliance at the judgement does fulfil the specifications (a kind of "false negative") **fail-error probability**

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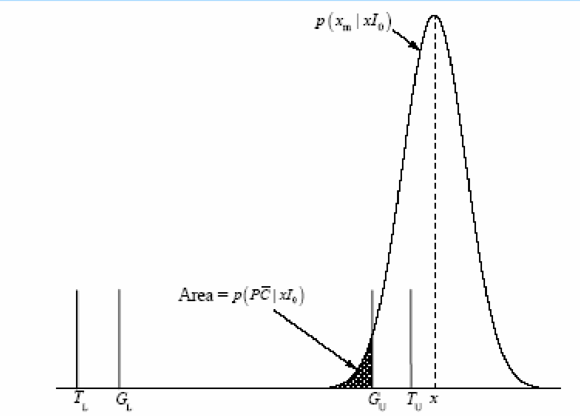
Estimation of user risk (I)

User risk (consumer's risk) R_C

$$R_C = \int_{x \in R} p\left(P\bar{C}x \mid I_0\right)dx$$
$$= \int_{x \in R} p\left(P\bar{C} \mid xI_0\right) \cdot p\left(x \mid I_0\right)dx,$$

R range of integration: all values of *x* outside conformance zone defined by tolerance limits (T_L,T_U)



From Tyler Estler, JCGM/WG1/SC3, 2003

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Estimation of user risk (II)

User risk (consumer's risk) R_C

The last fig. illustrates the probability $p(P\bar{C} \mid xI_0)$ that measurement of a characteristic *X* with a true value x that does not conform to specification yields a measurement result that leads to acceptance. For this particular item, *x* is too large, lying beyond the upper tolerance limit T_U . The curve shows the distribution $p(x_m \mid xI_0)$ of probable values of x_m that might reasonably result when measuring a characteristic with true value *x*. The probability that the characteristic passes inspection and is accepted is equal to the fraction of the area under the curve $p(x_m \mid xI_0)$, shown crosshatched, within the acceptance zone defined by the gauging limits (G_L,G_U) .

From Tyler Estler, JCGM/WG1/SC3, 2003

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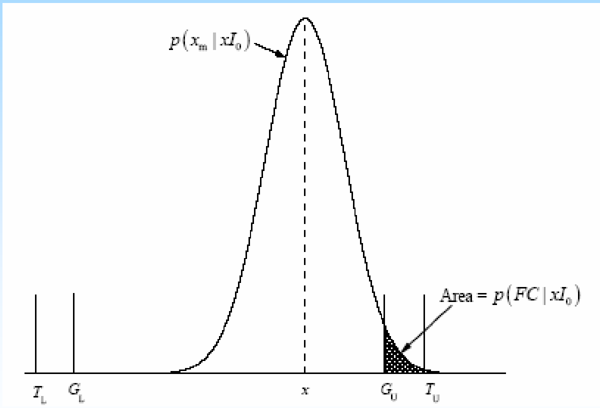
Estimation of producer risk (I)

Producer risk R_P

$$R_P = \int_{T_L}^{T_U} p(FCx \mid I_0)\,dx = \int_{T_L}^{T_U} p(FC \mid xI_0) \cdot p(x \mid I_0)\,dx,$$

Range of integration: all values of x inside conformance zone defined by tolerance limits $[T_L, T_U]$



From Tyler Estler, JCGM/WG1/SC3, 2003

Estimation of producer risk (II)

Producer risk R_P

The last fig. illustrates the probability $p(FC \mid xI_0)$ that a measurement of a characteristic X with a true value x that conforms to specification yields a measurement that leads to rejection. For this particular item, x lies within the tolerance zone. The curve shows the distribution $p(x_m \mid xI_0)$ of probable values of x_m that might reasonably result when measuring a characteristic with true value x. The probability that the characteristic fails inspection and is rejected is equal to the fraction of the area under the curve $p(x_m \mid xI_0)$, shown cross-hatched, that lies outside of the acceptance zone defined by the gauging limits (G_L, G_U). For this particular item there is a negligible probability that x_m would be less than the lower gauging limit G_L.

From Tyler Estler, JCGM/WG1/SC3, 2003

4. Measurement Capability Index and Acceptance Zone

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Measurement capability index (I)

Measurement capability index C_m :
in the case of measuring a characteristic for conformance [compliance] to a two-sided tolerance zone of width *T*,

$$C_m = T / 4\, u_m ,$$

where u_m is the standard uncertainty associated with the estimate of the characteristic;
for a one-sided tolerance zone of width *T*, $C_m = T / 2\, u_m$;
in the case of calibration or verification of a measuring instrument with specified maximum permissible error ±*MPE*,

$$C_m = MPE / 2\, u_e ,$$

where u_e is the standard uncertainty associated with the estimate of the instrument error.
(Tyler Estler, JCGM/WG1/SC3, 2003)

$C_m = MPE / U$, with expanded uncertainty *U*

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Measurement capability index (II)

Measurement capability index C_m :

Useful parameter

- to assess the quality of a compliance test and
- for testing conditions:

maximal (expanded) uncertainty: $U_{max} \leq MPE / C_m$

Usual values of C_m are between 2 and 5.

(K.-D. Sommer et al., PTB-Mitt. 116 (2006) 1, p.40-49)

Measurement capability index (III)

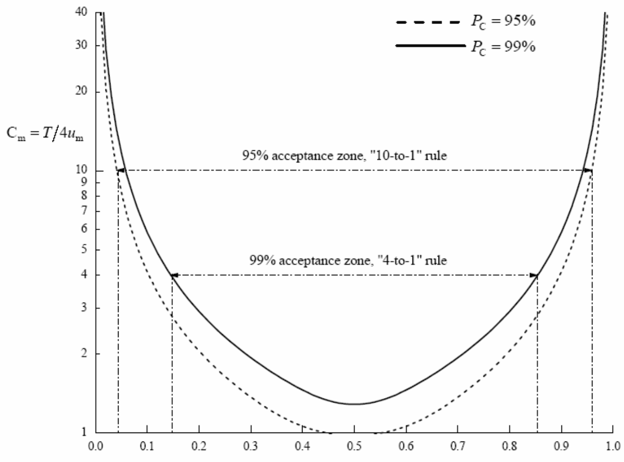

Figure 9. *Illustrating how a required level of confidence in the conformance of individual workpieces defines an acceptance zone. For a given level of confidence the width of the acceptance zone increases with better measurement quality (i.e. larger values of measurement capability index* $C_m = T/4u_m$ *.)*

P_c =probability of conforming specification [compliance]

from Tyler Estler, JCGM/WG1/SC3, 2003

Measurement capability index (IV)

Acceptance zone

- increases with measurement capability index C_m
- decreases with probability of compliance with specification P_c

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5. Probability of Compliance / Non-compliance

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Guard Band (I)

Guard band *g* **:** the magnitude of the offset from a specification limit to an acceptance or rejection zone boundary
(Tyler Estler, JCGM/WG1/SC3, 2003).

$g = h \cdot U$
U = expanded uncertainty
h = guard band multiplier

h may be adjusted in a way to achieve a specific probability of compliance or non-compliance.

Decision rule in ISO 14253-1 and DKD-5 corresponds to $h = 1$.

Guard Band (II)

Adjustment of the guard band

Probability of compliance P_c	Guard band multiplier h
0.80	0.42
0.85	0.52
0.90	0.64
0.95	0.82
0.99	1.16
0.999	1.55

Table from Tyler Estler, JCGM/WG1/SC3, 2003

Calculation of compliance

Probability of compliance / non-compliance can be calculated by integration (also numerical, Monte Carlo) using the pdfs,
if measurement/calibration result (expectation value) and its pdf are known.

Often normal pdfs or rectangular (uniform), trapezoidal pdfs occur.

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6. Compliance in Comparison Measurements of Accredited Calibration Laboratories

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Compliance with a reference value

Reference value is a measurement value whose assigned uncertainty is smaller than the measurement uncertainty of the laboratory.

Reference value is used as 'specification'.

Compliance depends on distance between measurement value and reference value, when taking the uncertainties into account:

Can be described by the E_n value.

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Performance Criteria for Comparisons

In calibration:

$$|E_n| = \left| \frac{x_{lab} - x_{ref}}{\sqrt{U_{lab}^2 + U_{ref}^2}} \right| < 1$$

Assumption: no correlation; coverage factor of 2

x_{lab} : measurement value of the laboratory
x_{ref} : reference value
U_{lab} : expanded uncertainty of the laboratory
U_{ref} : expanded uncertainty assigned to reference value
$U_{ref} \leq U_{lab}$

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Literature

- GUM, 1995
- EA-4/02: Expression of the Uncertainty of Measurement in Calibration, December 1999
- VIM, now ISO/IEC Guide 99:2007
- EN ISO 14253-1:1998
- ILAC-G8:1996 (under revision at present)
- DKD-5 (edition 07/2005)
- EN ISO/IEC 17025:2005
- EURACHEM/CITAC Guide Use of uncertainty information in compliance assessment, 2007
- T. Estler, Measurement Uncertainty And Conformance Testing: Risk Analysis, JCGM/WG1/SC3, 2003 (draft)
- K.-D. Sommer et al., PTB-Mitt. 116 (2006) 1, p.40-49
- EA-2/03 (EAL-P7), 1996
- W. Wöger, PTB-Mitt. 109 (1999) 1, p.24-27
- I. Lira, Metrologia 36 (1999), p.397-402

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