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INTERNATIONAL ELECTROTECHNICAL COMMISSION

CONFORMITY ASSESSMENT BOARD (CAB)	**Meeting 17, Geneva, 2005-06-06**

SUBJECT **Agenda item 8.2**

IECEE request to convert IECEE CTL Guide 01, *Application of Uncertainty of Measurement to Conformity Assessment Activities in the Electrotechnical Sector*, into an IEC Guide or other publication

BACKGROUND

This document has been prepared by the IECEE Committee of Testing Laboratories (CTL) to provide guidance on the practical application of the measurement uncertainty requirements of ISO/IEC Standard 17025 to electrical safety testing conducted within the IECEE CB Scheme.

The aim of the CTL, among other tasks, is to define a common understanding of the test methodology with regard to IEC standards, as well as to ensure and continually improve the repeatability and reproducibility of test results among the member laboratories.

The practical approach to measurement uncertainty outlined in this Guide has been adopted for use in the IECEE Schemes, and is also extensively used around the world by testing laboratories engaged in testing of electrical products to national safety standards.

This Guide is complementary to the 1995 publication by IEC, ISO, BIPM and several other international organizations entitled *Guide to the expression of uncertainty in measurement*.

ACTION

The CAB is invited to request the SMB to convert the enclosed IECEE CTL Guide 01, *Application of Uncertainty of Measurement to Conformity Assessment Activities in the Electrotechnical Sector*, into an IEC Guide or other publication.

First Edition
2004-05

IECEE-CTL GUIDE 001

Application of Uncertainty of Measurement to Conformity Assessment Activities in the Electrotechnical Sector

International Electrotechnical Commission 3, rue de Varembé Geneva, Switzerland
Telefax: +41 22 919 0300 e-mail: inmail@iec.ch IEC web site http: //www.iec.ch

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CBTL Procedure: Application of Uncertainty of Measurement

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Introduction

This document has been prepared by the IECEE Committee of Testing Laboratories (CTL) to provide guidance on the practical application of the measurement uncertainty requirements of ISO/IEC Standard 17025 to the electrical safety testing conducted within the IECEE CB Scheme.

The IECEE CB Scheme is a multilateral, international agreement, among over 40 countries and some 60 national certification bodies, for the acceptance of test reports on electrical products tested to IEC standards.

The aim of the CTL is to, among other tasks, to define a common understanding of the test methodology with regard to the IEC standards as well as to ensure and continually improve the repeatability and reproducibility of test results among the member laboratories.

The practical approach to measurement uncertainty outlined in this Guide has been adopted for use in the IECEE Schemes, and is also extensively used around the world by testing laboratories engaged in testing of electrical products to national safety standards.

Part 1
Application of Uncertainty of Measurement Principles

1 General:

1.1 Qualification and acceptance of CB test laboratories, e.g. in the IECEE, is performed to IEC/ISO 17025, General requirements for the competence of calibration and testing laboratories, IEC/ISO 17025 Clause 5.4.6.2 states:

> **“Testing laboratories shall have and apply procedures for estimating uncertainty of measurement. In certain cases, the nature of the test method may preclude rigorous, metrologically and statistically valid, calculation of uncertainty of measurement. In these cases the laboratory shall at least attempt to identify all the components of uncertainty and make a reasonable estimation, and shall ensure that the form of reporting of the result does not give a wrong impression of the uncertainty. Reasonable estimation shall be based on knowledge of the performance of the method and on the measurement scope and shall make use of, for example, previous experience and validation data.”**

"Note 1 The degree of rigor needed in an estimation of uncertainty of measurement depends on factors such as:

- **the requirements of the test method;**
- **the requirements of the client;**
- **The existence of narrow limits on which decisions on conformance to a specification are based."**

"Note 2 In those cases where a well-recognized test method specifies limits to the values of the major sources of uncertainty of measurement and specifies the form of presentation of calculated results, the laboratory is considered to have satisfied this clause by following the test method and reporting instructions (see 5.10)."

1.2 IEC/ISO 17025 Clause 5.10.1 item c states:

"5.10.3.1 In addition to the requirements listed in 5.10.2, test reports shall, where necessary for the interpretation of the test results, include the following:"
"c) where applicable, a statement on the estimated uncertainty of measurement; information on uncertainty is needed in test reports, when it is relevant to the validity of application of the test results, when a client's instruction so requires, or when the uncertainty affects compliance to s specification limit.;"

1.3 IEC/ISO 17025 was written as a general use document, for all industries. Uncertainty of measurement principles are applied to laboratory testing and presentation of test results to provide a degree of assurance that decisions made about conformance of the products tested according to the relevant requirements are valid. Procedures and techniques for uncertainty of measurement calculations are well established[1]. This CB Testing Laboratory (CBTL) Procedure is written to provide more specific guidance on application of uncertainty of measurement principles to reporting of testing results under the CB Scheme.

[1] – BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML: "Guide to the Expression of Uncertainty in Measurement, first edition, 1995.

1.4 Part I of this CBTL procedure focuses on the application of uncertainty of measurement principles under the CB Scheme. While, Part 2 of this CBTL procedure provides guidance on making uncertainty of measurement calculations, including examples.

2 Application of Uncertainty of Measurement Principles:

2.1 A challenge to applying uncertainty of measurement principles to conformity assessment activities is managing the cost, time and practical aspects of determining the relationships between various sources of uncertainty. Some relationships are either unknown or would take considerable effort, time and cost to establish. There are a number of proven techniques available to address this challenge. These techniques include eliminating from consideration those sources of variability, which have little influence on the outcome and minimizing significant sources of variability by controlling them.

3 Background:

3.1 Test methods used under the IECEE CB Scheme are in essence consensus standards. Criteria used to determine conformance with requirements are most often based on a consensus of judgment of what the limits of the test result should be. Exceeding the limit by a small amount does not result in an imminent hazard. Test methods used may have a precision statement expressing the maximum permissible uncertainty expected to be achieved when the method is used. Historically, test laboratories have used state of the art equipment and not considered uncertainty of measurement when comparing results to limits. Safety standards have been developed in this environment and the limits in the standards reflect this practice.

3.2 Test parameters that influence the results of tests can be numerous. Nominal variations in some test parameters have little effect on the uncertainty of the measurement result. Variations in other parameters may have an effect. However, the degree of influence can be minimized by limiting the variability of the parameter when performing the test.

3.3 An often-used way of accounting for the effects of test parameters on tests results is to define the acceptable limits of variability of test parameters. When this is done, any variability in measurement results obtained due to changes in the controlled parameters is not considered significant if the parameters are controlled within the limits. Examples of application of this technique are requiring:

a) Input power source to be maintained: voltage +/- 2.0 percent, frequency +/- 0.5 percent, total harmonic distortion maximum 3.0 percent.
b) Ambient temperature: 23 +/- 2 degs. C.
c) Relative Humidity: 93 +/- 2 percent.
d) Personnel: documented technical competency requirements for the test.
e) Procedures: documented laboratory procedures.
f) Equipment accuracy: instrumentation with accuracy per CTL Decision 251A.

Note – The acceptable limits in items a through c are given as examples and do not necessarily represent actual limits established.

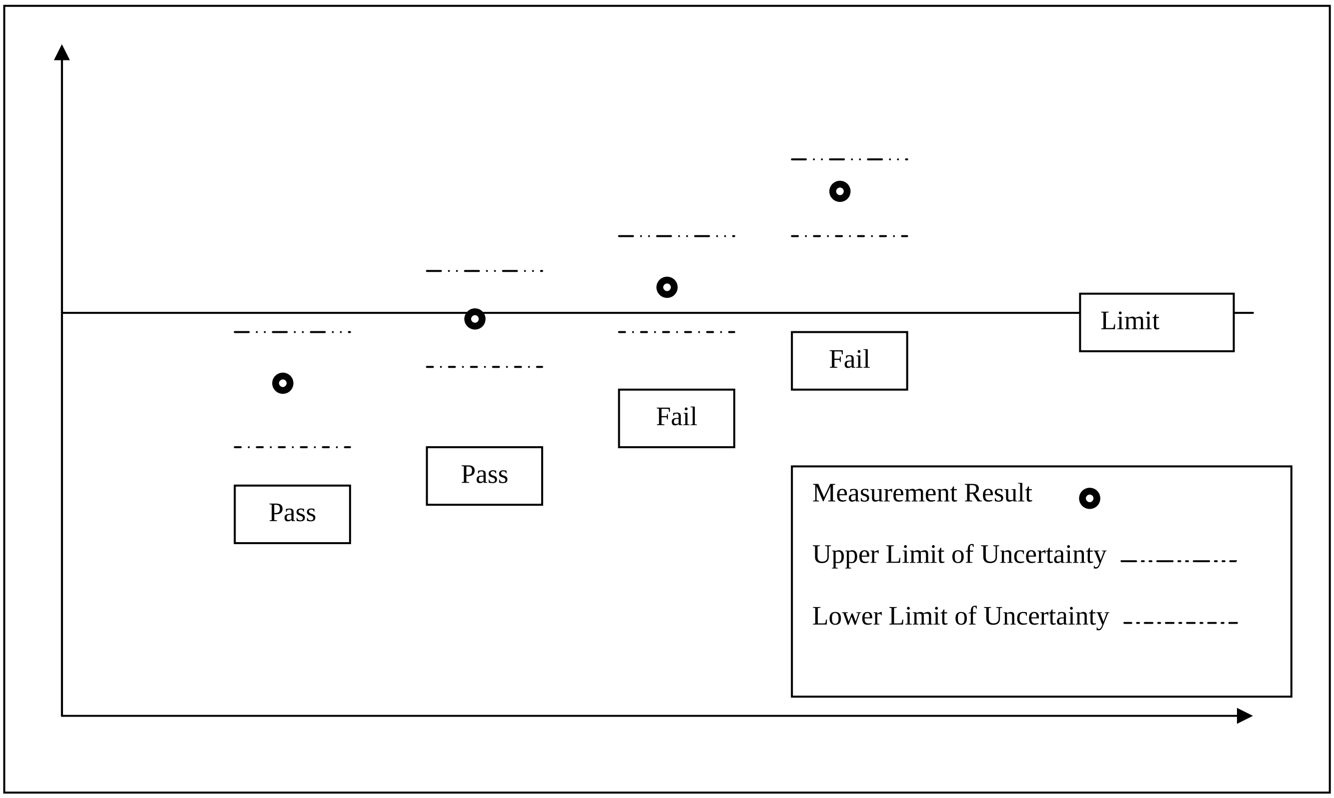
3.4 The end result of controlling sources of variability within prescribed limits is that the measurement result can be used as the best estimate of the measurand. In effect, the uncertainty of measurement about the measured result is negligible with regard to the final pass/fail decision.

4 Application of Uncertainty of Measurement Principles:

4.1 When a test results in measurement of a variable, there is uncertainty associated with the test result obtained

4.2 Procedure 1, Uncertainty of Measurement Calculated – Procedure 1 is used when calculation of uncertainty of measurement is required by IEC/ISO 17025 clause 5.4.6.2 and 5.10.3.1 item c. Calculate uncertainty for measurement (see part 2 of this procedure) and compare the measured result with uncertainty band to defined acceptable limit. The measurement complies with the requirement if the probability it being within the limit is at least 50 percent.

Procedure 1

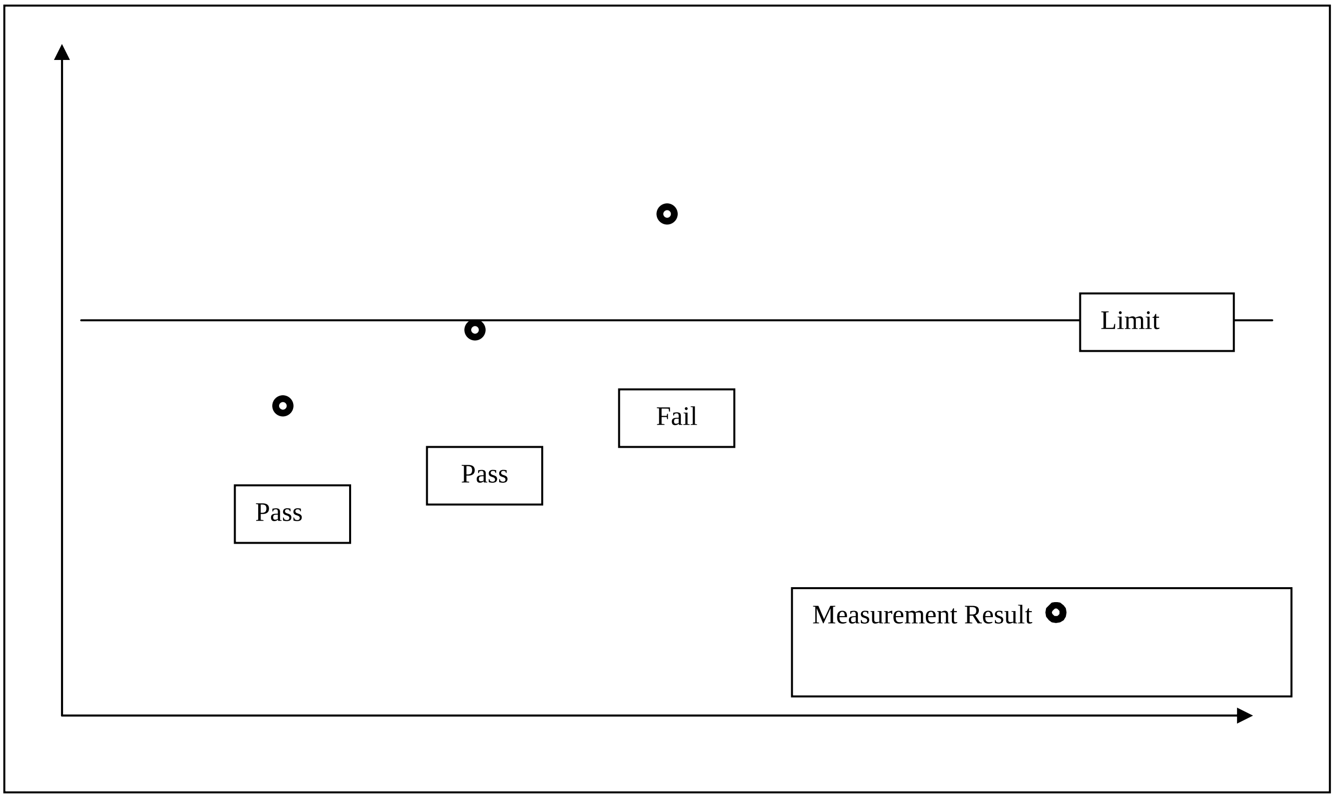


4.3 Procedure 2, "Accuracy Method" – Procedure 2 is used when IEC/ISO 17025 clause 5.4.6.2 Note 2 applies. Procedure 2 is the traditional method used under the CB Scheme and has been referred to as the "Accuracy Method". Test performed is routine. Sources of uncertainty are minimized so that the uncertainty of the measurement need not be calculated to determine conformance with the limit. Variability in test parameters is within acceptable limits. Test parameters such as power source voltage, ambient temperature and ambient humidity are maintained within the defined acceptable limits for the test. Personnel training and laboratory procedures minimize uncertainty of measurement due to human factors. Instrumentation used has an uncertainty within prescribed limits.

Note – The name "accuracy method" comes from the concept of limiting uncertainty due to instrumentation by using instruments within prescribed accuracy limits. For this purpose, the accuracy specification for an instrument is considered the maximum uncertainty of measurement attributable to the instrument.

4.4 The measurement result is considered in conformance with the requirement if it is within the prescribed limit. It is not necessary to calculate the uncertainty associated with the measurement result.

Procedure 2



Example – Procedure 2

<u>Power Supply Output Voltage Measurement Test</u>:

Method

Connect the power supply to a mains source of rated voltage, +/- 2,0 percent, and rated frequency. Measure output voltage from power supply while loaded to rated current, +/- 2,0 percent, with a non-inductive resistive load. The test is to be performed in an ambient temperature of 23 +/- 2 degrees C.

Use meters having accuracy conforming to CTL Dec. 251A.

The power supply conforms to the requirements if the output voltage is +/- 5 percent of rated value.

Results

Power supply rating: 240 volts, 50 Hertz input; 5 volts dc, 2 amperes output.

Input		**Output**	
U, volts	**Freq., Hz**	**I, amperes**	**U, volts**
242	50	2,01	5,1

Test ambient temperature: 24 degrees C.

Accuracy of instruments used:

Meter	**Calibrated Accuracy for Scale Used for Measurement**	**CTL Dec. 251A, max.**
Thermometer	+/- 1,0 degrees C	+/- 2,0 degrees C
Voltmeter	+/- 0,5 percent	+/- 1,5 percent
Frequency	+/- 0,2 percent	+/- 0,2 percent
Current	+/- 0,5 percent	+/- 1,5 percent

Conclusion

The power supply conforms to the requirement.

5 Conclusion:

5.1 The traditional approach to addressing uncertainty of measurement for conformity assessment activities under the CB Scheme, has been the application of the “accuracy method”. This method minimizes sources of uncertainty associated with the performance of routine tests so that the measurement result can be directly compared with the test limit to determine conformance with the requirement. This method conforms to the requirements in IEC/ISO 17025. The “accuracy method” takes less time and costs less to implement than detailed uncertainty of measurement calculations and the conclusions reached are valid with regard to the final pass/fail decision.

5.2 In situations where the traditional, “accuracy method” does not apply, uncertainty of measurement values are calculated and reported along with the variables results obtained during testing.

Part 2

Guidance on Making Uncertainty of Measurement Calculations

Including Examples of How to Perform the Calculations.

1 General Principles:

1.1 This Part 2 is meant to be a short and simplified summary of the steps to be taken by a CBTL when the need to estimate uncertainties arises.

1.2 It is by no means a comprehensive paper about measurement uncertainty (MU), its sources and estimation in general, but supposed to offer a practical approach for most applicable circumstances within a CBTL in the IECEE CB Scheme.

1.3 No measurement is perfect and the imperfections give rise to error of measurement in the result. Consequently, the result of a measurement is only an approximation to the measured value (measurand) and is only complete when accompanied by a statement of the uncertainty of that approximation. Indeed, because of measurement uncertainty, a "true value" can never be known.

1.4 The total uncertainty of a measurement is a combination of a number of component uncertainties. Even a single instrument reading may be influenced by several factors. Careful consideration of each measurement involved in the test is required to identify and list all the factors that contribute to the overall uncertainty. This is a very important step and requires a good understanding of the measuring equipment, the principles and practice of the test and the influence of environment.

1.5 The ISO "Guide to the Expression of Uncertainty in Measurement" (GUM) has adopted the approach of grouping uncertainty components into two categories based on their method of evaluation, 'Type A' and 'Type B'. This categorization of the methods of evaluation, rather than of the components themselves, avoids certain ambiguities.

1.6 **Type A** evaluation is done by calculation from a series of repeated observations, using statistical methods.

1.7 **Type B** evaluation is done by means other than that used for 'Type A'. For example, by judgement based on:

Data in calibration certificates:	This enables corrections to be made and type B uncertainties to be assigned.
Previous measurement data:	For example, history graphs can be constructed and yield useful information about changes with time.
Experience with or general knowledge:	Behavior and properties of similar materials and equipment.
Accepted values of constants:	Associated with materials and quantities.
Manufacturers' specifications.	
All other relevant information.	

1.8 Individual uncertainties are evaluated by the appropriate method and each is expressed as a standard deviation and is referred to as a standard uncertainty.

2 Summary of steps when estimating uncertainty:

2.1 Identify the factors that may significantly influence the measured values and review their applicability. There are many possible sources in practice, mainly including:

a. Contribution from calibration of the measuring instruments, including contribution from reference or working standards.

b. Temperature error at beginning and end of a test (e.g. winding resistance method).

c. Uncertainty related to the loading applied and measurement of it.

d. Velocity of air flow over the test sample and uncertainty in measuring it.

e. For digital instruments, there are the number of displayed digits and the stability of the display at the time the reading is taken. In addition, the reported uncertainty of an instrument does not necessarily include the display.

f. Instrument resolution, limits in graduation of a scale.

g Approximations and assumptions incorporated in the measurement method.

h. Uncertainty due to the procedures used to prepare the sample for test and actually testing it.

i. If a computer is used to acquire the readings from the instrument, there is uncertainty associated with the processing of the data due to calculations or other manipulations within the computer such as analog to digital conversions, and conversions between floating point and integer numbers.

k. Rounded values of constants and other parameters used for calculations.

m. Effects of environmental conditions (e.g. variation in ambient temperature) or measurement of these on the measurement.

   --> Negligible in case environmental conditions are stable (*assumed and expected from a CBTL*).

n. Variability of the power supply source (voltage, current, frequency) the sample is connected to and the uncertainty in measuring it.

   --> Negligible in case stabilized supply sources are used (*assumed and expected from a CBTL*).

o. Personal bias in reading analogue instruments
(e.g. parallax error or the number of significant figures that can be interpolated).

--> Negligible in case of digital displays or in case of appropriate training (assumed and expected from a CBTL).

p. Variation between test samples and in case the samples are not fully representative. Unless the IEC standard specifies tests on multiple samples, only one sample is tested.

--> The variation between test samples is assumed to be negligible by CBTLs

Note: This list is not stating all of the items that can contribute to MU. Other factors may have to be identified and considered by each laboratory respectively.

2.2 Transform influencing factors x_i to the unit of the measured value ("quantify"), for which you are going to estimate the uncertainty, if not already given in that unit, (e.g. if the unit of the measured value is [V] and a resistor's tolerance in [Ω] is one of the influencing factors, transform the change of resistance to the resulting contribution in [V]).

Once the uncertainty contributions associated with a measurement process have been identified and quantified, it is necessary to combine them in some manner in order to provide a single value of uncertainty that can be associated with the measurement result.

2.3 **Determine the probability distribution**

The probability distribution of the measured quantity describes the variation in probability of the true value lying at any particular difference from the measured or assigned result. The form of the probability distribution will often not be known, and an assumption has to be made, based on prior knowledge or theory, that it approximates to one of the common forms. It is then possible to calculate the standard uncertainty, $U(x_i)$, for the assigned form from simple expressions. The four main distributions of interest are:

- Normal
- Rectangular
- Triangular
- U-shaped

2.4 **Normal distribution** is assigned when the uncertainty is taken from, for example, a calibration certificate/report where the coverage factor, k, is stated. The standard uncertainty is found by dividing the stated uncertainty from the calibration certificate by its coverage factor k, which is k=2 for a level of confidence of approx. 95% (recommended for CBTL in the IECEE CB scheme). It may be necessary to confirm k with the calibration laboratory in case it is not stated on the certificate.

Normal: $u(x_i) = \frac{\text{uncertainty}}{k}$

2.5 **Rectangular distribution** means that there is equal probability of the true value lying anywhere between two prescribed limits. A rectangular distribution should be assigned where a manufacturer's specification limits are used as the uncertainty, unless there is a statement of confidence associated with the specification, in which case a normal distribution can be assumed.

Rectangular: $u(x_i) = \frac{a_i}{\sqrt{3}}$

2.6 **U shaped distribution** is applicable to mismatch uncertainty. The value of the limit for the mismatch uncertainty, M, is associated with the power transfer at a junction is obtained from

$100((1 \pm |\Gamma_G||\Gamma_L|)^2 - 1)\%$ or $20\log_{10}(1 \pm |\Gamma_G||\Gamma_L|)dB$ (logarithmic units), where GG and GL are the reflection coefficients for the source and load. The mismatch uncertainty is asymmetric about the measured result however, the difference this makes to the total uncertainty is often insignificant and it is acceptable to use the larger of the two limits.

U shaped distribution is used for EMC purposes, but also for climatic control of temperature and humidity.

U shaped: $u(x_i) = \frac{M}{\sqrt{2}}$

2.7 **Triangular distribution** means the probability of the true value lying at a point between two prescribed limits increases uniformly from zero at the extremities to the maximum at the center. A triangular distribution should be assigned where the contribution has a distribution with defined limits and where the majority of the values between the limits lie around the central point.

Triangular: $u(x_i) = \frac{a_i}{\sqrt{6}}$

2.8 A detailed approach to the determination of probability distribution can be found in the ISO Guide (GUM).

2.9 **Correlation -** For the statistical approach to the combination of individual uncertainty contributions to be valid, there must be no common factors associated with these contributions. The input quantities must be independent of each other.

2.10 The effect of correlated input quantities may be to increase or decrease the combined standard uncertainty. For example, if the area of a rectangle is determined by measurement of it's width and height using the same measuring implement the correlation will increase the uncertainty. On the other hand, if a gauge block were to be measured by comparison with another of identical material, the effect of uncertainty due to temperature will depend on the difference in temperature between the two blocks, and will therefore tend to cancel.

2.11 If the correlation is such that the combined standard uncertainty will be increased, the most straightforward approach is to add the standard uncertainties for these quantities before combining the result statistically with other contributions.

2.12 If, however, the correlation is such that the combined standard uncertainty will be decreased, as in the gauge block comparison above, the difference in standard uncertainty would be used as the input quantity.

2.13 A detailed approach to the treatment of correlated input quantities can be found in the ISO Guide (GUM).

2.14 **Establish the uncertainty budget m_x**, containing the standard uncertainties of each influencing factor ("quantity") $u(x_i)$. Usually $u(x_i)$ will represent already the uncertainty contribution $u_i(y)$ of each factor. A convenient way to do that is to write the identified and potential contributing factors and their estimates into a table (see examples). The uncertainty contribution $u(m_x)$ is calculated by the formula:

$$u(m_x) = SQRT\ (\ u_1(y)^2 + u_2(y)^2 + \ldots + u_i(y)^2\ )$$

2.15 **Calculate the expanded uncertainty U**, considering your level of confidence. The expanded uncertainty is calculated by multiplying the standard uncertainty with the coverage factor k, which is k=2 for a level of confidence of approx. 95% (recommended for CBTL in the IECEE CB scheme), or k=3 for approx. 99% level of confidence.

$$U = k * u(m_x)$$

2.16 **Report the result** of the measurement comprising the measured value, the associated expanded uncertainty U and the coverage factor k.

Example: 10.5V ± 0.4V (coverage factor k = 2, for a level of confidence of approx. 95%)

3 Simple Example

"Estimation of measurement uncertainty for a temperature rise test with thermocouples":

The following example has been chosen to demonstrate the basic method of evaluating the uncertainty of measurement. It has been simplified in order to provide transparency for the reader. It is intended to be a general guidance on how to proceed. The contributions and values are not intended to imply mandatory or preferred requirements. The input quantities are regarded not correlated.

3.a Identification of significant influencing factors:

Quantity X_i	Source of Uncertainty	Source of error quantity $s_p(x_i)$
δ_{TC}	**uncertainty of thermocouple**	**e.g. from specifications**
δ_{HR}	**uncertainty of hybrid recorder**	**e.g. from calibration certificate of calibration laboratory, including their inherited uncertainty and the listed coverage factor of k=3.**
δ_{Fixing}	**influence of fixing method of thermocouples**	**e.g. from laboratory's own investigation campaign**
$\delta_{ambient}$	**uncertainty of ambient temperature measurement**	**e.g. measured by a separate instrument, data taken from manufacturer's specifications.**

3.b Relating influencing factors to the measured value:

The relationship between the influencing factor and the measured value evaluated at the point of measurement is known as the sensitivity coefficient. In this simple example, there is a 1 to 1 relationship between the influencing factors and the measured value. Therefore the sensitivity coefficient is 1. For more complex relationships, the sensitivity coefficient can take on other values.

Quantity X_i	Estimate x_i	Sensitivity coefficient	Error quantity $s_p(x_i)$
δ_{TC}	**-40°C to +350°C**	**1**	**0.5°C**
δ_{HR}	**worst case of calibrated items e.g. -25°C to +250°C**	**1**	**1.8°C**
δ_{Fixing}	**worst case of investigated temperatures e.g. 25°C, 85°C, 150°C**	**1**	**2.4°C**
$\delta_{ambient}$	**usually used in the vicinity of 25°C**	**1**	**1.25°C**

3.c Uncertainty budget, m_x:

Quantity X_i	Estimate x_i	Error quantity $s_p(x_i)$	Probability distribution	Standard uncertainty $u(x_i)$	Sensitivity coefficient	Uncertainty contribution $u_i(y)$
δ_{TC}	**-40°C to +350°C**	**0.5°C**	**Rectangular**	**0.29°C**	**1**	**0.29°C**
δ_{HR}	**-25°C to +250°C**	**1.8°C**	**Normal**	**0.6°C**	**1**	**0.6°C**
δ_{Fixing}	**25°C, 85°C, 150°C**	**2.4°C**	**Normal**	**2.4°C**	**1**	**2.4°C**
$\delta_{ambient}$	**-----**	**1.25°C**	**Rectangular**	**0.72°C**	**1**	**0.72°C**
m_x	**25°C to 150°C**					$u(m_x)$= 2.63°C

$u(m_x) = \sqrt{(u_1^2 + u_2^2 + u_3^2 + ...)}$

$\sqrt{3} = 1.73$, $\sqrt{6} = 2.45$

3.d Expanded uncertainty U:

$$U = k \times u(m_x) = 2 \times 2.63°C = 5.27°C = \text{approx. } 5.3°C$$

3.e Reported result:

"The measured temperature rise is xx.x °K ± 5.3 °C"

"The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k = 2, which for a normal distribution corresponds to a coverage probability of approximately 95%."

4 Definitions of Terms:

4.1 **Coverage factor**: A number that, when multiplied by the combined standard uncertainty, produces an interval (the expanded uncertainty) about the measurement result that may be expected to encompass a large, specified fraction (e.g. 95 %) of the distribution of values that could be reasonably attributed to the measurand.

4.2 **Combined standard uncertainty:** The result of the combination of standard uncertainty components.

4.3 **Error of measurement:** The result of a measurement minus a true value of the measurand (not precisely quantifiable because true value lies somewhere unknown within the range of uncertainty).

4.4 **Expanded uncertainty:** Obtained by multiplying the combined standard uncertainty by a coverage factor.

4.5 **Level of confidence:** The probability that the value of the measurand lies within the quoted range of uncertainty.

4.6 **Measurand:** The specific quantity subject to measurement.

4.7 **Quantity Xi:** Source of uncertainty.

4.8 **Standard deviation**: The positive square root of the variance.

4.9 **Standard uncertainty:** The estimated standard deviation.

4.10 **Uncertainty:** A parameter, associated with the result of a measurement, which characterizes the dispersion of the values that could reasonably be attributed to the measurand.

4.11 **Type A evaluation method**: The method of evaluation of uncertainty of measurement by the statistical analysis of series of observations.

4.12 **Type B evaluation method:** The method of evaluation of uncertainty of measurement by means other than the statistical analysis of series of observations.

ANNEX 1

Examples - Uncertainty of Measurement Calculations

For Product Conformity Assessment Testing

prepared by CTL - WG1

IECEE CTL WG 1 on Uncertainty of Measurement has prepared a set of example calculations to illustrate the application of uncertainty of measurement to conformity assessment activities carried out under the IECEE CB Scheme.

Example 1 – Input Test

Example 2 – Input Power Test

Example 3 – Leakage Current Measurement Test

Example 4 – Distance measurement using Caliper gauge

Example 5 – Torque measurement

Example 6 – Pre-conditioning for ball pressure test

These examples have been simplified to illustrate various steps of the process for performing uncertainty of measurement calculations.

Example 1

Test Name: Input Test

Result: Uncertainty of input current expressed in percent of reading in amperes.

Description: Input current is measured to product connected to mains power source. Input current to product is proportional to voltage applied.

Quantity X_i	Source of Uncertainty	X_i	Type	Relative Error Quantity, $S_p(X_i)$	Probability Shape	Distribution Division Factor, k	Relative Standard Uncertainty, $u(X_i)$	Sensitivity Coefficient, C_i	Relative Uncertainty Contribution, $u_i(y)$
δ_R	**Repeatability of measurement**	**X_R**	**A**		**Normal**		**0,2 %**	**1**	**0,2 %**
δ_{instr}	**Specification for Instrument**	**X_{instr}**	**B**	**0,5%**	**Rectangular**	$\sqrt{3}$	**0,3%**	**1**	**0,3%**
$\delta_{reading}$	**Reading Error**	**$X_{reading}$**	**B**	**0,3%**	**Rectangular**	$\sqrt{3}$	**0,17 %**	**1**	**0,17 %**
δ_{power}	**Specification for power mains fluctuation**	**X_{power}**	**B**	**0,17%**	**Rectangular**	$\sqrt{3}$	**0,1 %**	**1**	**0,1 %**
					Relative Combined Standard Uncertainty , u_c				0,41%
					Coverage Factor kp = 2 Confidence level: 95%				-
					Relative Expanded Uncertainty, $U = u_c * K_P$				0,81%

Reported Result - The measured input current is m_x (1 +/- 0,0081) Amperes, , k =2, 95% confidence level

δ_R **: Repeatability of Measurement -** uncertainty due to repeatedly making the same measurement - Type A with a normal distribution

$$u_1 = \overline{\sigma}_{n-1} = \sqrt{\frac{\sum\left(x_i - \overline{x}\right)^2}{n(n-1)}} = 0{,}2\ \%$$

δ_{instr} **: Specification for instrument -** uncertainty due to instrument used for measurements. Determined from specifications in instrument manual (MPE) see VIM 5.2.1. Meter is 0.5 class. Error is ± 0,5%. Distribution is Rectangular, k=$\sqrt{3}$.

$u_{2=}$ = 0,5 / $\sqrt{3}$ = 0,3 %

$\delta_{reading}$ **: Reading of Instrument -** uncertainty due to technician reading the instrument. When testing meter is 0,5 A per graduation and 100 graduations, estimating reading error is 1/10 graduation. In the practice testing, reading value is 34,8 line. Rectangular distribution; k=$\sqrt{3}$.

u_3 = = [(0,1)(0,5)] / [(34,5)(0,5) $\sqrt{3}$] * 100 = 0,17 %

δ_{power} **: Power Mains Flucuation -** uncertainty due to fluctuations in power mains voltage. Uncertainty of the regulator is 0,2%, Rectangular distribution; k=$\sqrt{3}$. Sensitivity coefficient = 1.

u_4 = 0,2 / $\sqrt{3}$ = 0,1 %

Example 2

Test Name: Input Power Test

Result: uncertainties expressed in percent of input power in watts.

Description: Input power is measured to product operating in stabile condition while connected to regulated mains power source. Input power measured by analog or digital power meter.

Quantity X_i	Source of Uncertainty	X_i	Type	Relative Error Quantity, $S_p(X_i)$	Probability Shape	Distribution Division Factor, k	Relative Standard Uncertainty, $u(X_i)$	Sensitivity Coefficient C_i	Relative Uncertainty Contribution $u_i(y)$
δ_R	**Repeatability of measurement**	**X_R**	**A**		**Normal**		**0,2%**	**1**	**0,2%**
δ_{instr}	**Specification for instrument**	**X_{instr}**	**A**	**0,2%**	**Normal**	**2**	**0,1%**	**1**	**0,1%**
$\delta_{reading}$	**Reading of instrument**	**$X_{reading}$**	**B**	**0,45%**	**Rectangular**	$\sqrt{3}$	**0,26%**	**1**	**0,26%**
δ_{power}	**Specification for power mains flucuation**	**X_{power}**	**B**	**0,35%**	**Rectangular**	$\sqrt{3}$	**0,2%**	**1**	**0,20%**
					Relative Combined Standard Uncertainty, u_c				0,40%
					Coverage Factor kp = 2 Confidence level: 95%				-
					Relative Expanded Uncertainty, $U = u_c * K_P$				0,80%

Reported Result - The measured input power is m_x (1 +/- 0,008) Watts, , k =2, 95% confidence level

δ_R : Repeating Error Repeatability of Measurement - uncertainty due to repeatedly making the same measurement - Type A with a normal distribution

$$u_1 = \overline{\sigma}_{n-1} = \sqrt{\frac{\sum \left(x_i - \overline{x}\right)^2}{n(n-1)}} = 0.2\ \%$$

δ_{instr} : Specification for instrument - uncertainty due to instrument used for measurements. Determined from calibration laboratory report. Expanded uncertainty reported is +/- 0,2. Distribution is Normal, k= 2.

$u_{2=}$ = 0,2 /2 = 0,1 %

$\delta_{reading}$: Reading of instrument - uncertainty due to technician reading instrument - estimated.

δ_{power} : Specification of power mains fluctuation - uncertainty due to fluctuations in power mains voltage

Example 3

Test Name: Leakage Current Measurement

Result: Uncertainties of leakage current expressed in micro-amperes.

Description: Leakage current is measured with product operating under normal working conditions. Leakage current is measured directly by leakage current meter. Measurement carried out under following conditions:

(1) Between any pole of the power source and metal parts that can be easily touched or the metal foil on the insulating materials that can be easily touched, not exceeding 20 cm by 10 cm.

(2) Between any pole of the power source and the metal parts only using basic insulation to separate live parts of 1 stage apparatus.

(3) Before and after humidity conditioning.

Tested parts are:

(A) Between live parts and the enclosure isolated from the live part by only basic insulation.
(B) Between the live parts and shell with re-enforced insulation.

Quantity, X_i	Source of Uncertainty	X_i	Type	Error Quantity $S_p(X_i)$, uA	Probability Shape	Distribution Division Factor, k	Standard Uncertainty $u(X_i)$, uA	Sensitivity Coefficient C_i	Uncertainty Contribution $u_i(y)$, uA
δ_R	**Repeatability of measurement**	**X_R**	**A**		**Normal**		**1**	**1**	**1**
δ_{inher}	**Calibration of instrument**	**X_{inher}**	**A**	**15 norm 18 after**	**Normal**	**3**	**5 norm 6 after**	**1**	**5 norm 6 after**
δ_{instr}	**Quantum error of instrument**	**X_{instr}**	**B**	**0,5**	**Rectangular**	$\sqrt{3}$	**0,3**	**1**	**0,3**
δ_{range}	**Range of measurement**	**X_{range}**	**B**	**0,0**	**Rectangular**	$\sqrt{3}$	**0,0**	**1**	**0,0**
δ_{temp}	**Ambient temperature fluctuation**	**X_{temp}**	**A**	**3,2 norm 3,7 after**	**Normal**	**3**	**1 norm 1,2 after**	**1**	**1 norm 1,2 after**
$\delta_{humidity}$	**Relative humidity**	**$X_{humidity}$**	**B**	**3,7**	**Rectangular**	$\sqrt{3}$	**2 after**	**1**	**2,1 after**
δ_{power}	**Specification of power mains fluctuation**	**X_{power}**	**B**	**2**	**Rectangular**	$\sqrt{3}$	**1,2**	**1**	**1**
					Combined Standard Uncertainty, u_c				5,3 normal 6,6 after
					Coverage Factor kp = 2 Confidence level: 95%				-
					Expanded Uncertainty U = u_C* k_P				11 normal 13 after

Reported Result - The measured leakage current is 320 uA ± 11uA and 370 uA ± 13 uA after humidity, , k =2, 95% confidence level

δ_R : **Repeating Error Repeatability of Measurement -** uncertainty due to repeatedly making the same measurement - Type A with a normal distribution

$$u_1 = \overline{\sigma}_{n-1} = \sqrt{\frac{\sum\left(x_i - \overline{x}\right)^2}{n(n-1)}} = \text{ 1 uA}$$

δ_{inher} : **Calibration of Instrument -** Leakage Current of basic insulation is 320 uA under operating condition and 370 uA under humidity conditioning. According to certificate of calibration, system error of the measured instrument is ± 5 %, normal, k=3.

u_2= 0.05 * 320 / 3 = 5 uA normal condition

u_2= 0.05 * 370 / 3 = 6 uA humidity condition

δ_{instr} : **Quantum error of instrument -** uncertainty due to instrument used for measurements(MPE) see VIM 5.2.1. When testing, used 2 mA measuring range, resolution is 0,001 mA, quantization error of instrument is the in same probability distribution in 0,001/2 mA range. Note - MPE =max. permissible error given by the manufacturer

$$U_3 = \frac{0{,}001/2}{\sqrt{3}} mA = 0{,}3uA$$

δ_{range} **Range of Measurement -** Can be ignored because of its small value.

$u_4 = 0$

δ_{temp}: **Ambient Temperature Fluctuation -** For each 10 ^{0}C in environmental temperature, the variation of indicated value is no more than ±1.5%. when testing. For common electronic and electro-mechanical and assembled apparatus, the temperature should be kept 20 ± 5 C^0 , we can consider that limit of variation of the indicated value is ±1%. Normal distribution, k=3.

U_{5} = (320 uA x 0,01)/ 3 = 1,1 uA normal
U_5= (370 uA x 0,01)/ 3= 1,2 uA after

$\delta_{humidity}$: Relative humidity - When tested under normal operation , it can be ignored. During humidity testing, the relative humidity should be kept 93% RH ± 2% RH. If it varies each 1%, Leakage Current of basic insulation change 1%. Rectangular distribution; k=$\sqrt{3}$.

U_6 = 0 normal

U_6 = (370 uA x 0,01) / $\sqrt{3}$ = 2,1 uA

$\delta_{power:}$ Power mains fluctuation - The u_7 reflects the influence of output power and voltage. For the electric heating apparatus and microwave oven, $\Delta P = (0.25\% \times measuring.range + 0.25\% \times reading.value) \leq 10W$ Leakage Current variation doesn't go over 2 uA. Rectangular distribution; k=$\sqrt{3}$.

$$u_7 = \frac{2}{\sqrt{3}} = 1,2uA$$

Example: 4

Test Name: Calliper gauge (analog)

Result: Budget of uncertainty of distance for a calliper gauge (analog)

Description: Distance measurement with a calliper gauge by an expert.

Quantity X_i	Source of Uncertainty	X_i	Type	Error Quantity, $S_p(X_i)$	Probability Shape	Distribution Division Factor, k	Standard Uncertainty, $u(X_i)$	Sensitivity Coefficient C_i	Uncertainty Contribution $u_i(y)$
δ_{INST}	Specification for instrument	X_{INST}	**B**	**50 um**	**Rectangular**	$\sqrt{3}$	**29 um**	**1**	**29 um**
δ_{read}	Reading of instrument (e.g. because of parallax)	X_{read}	**B**	**5 um**	**Rectangular**	$\sqrt{3}$	**2,89 um**	**1**	**2,89 um**
δ_{temp}	Ambient temperature fluctuation	X_{temp}	**B**	**0,1 um**	**Rectangular**	$\sqrt{3}$	**0,0577 um**	**1**	**0,0577 um**
δ_{calibr}	Calibration of guage	X_{calibr}	**B**	**0,5 um**	**Rectangular**	$\sqrt{3}$	**2,89 um**	**1**	**2,89 um**
δ_{abbe}	Canting of position of the measuring surface	X_{abbe}	**B**	**60 um**	**Rectangular**	$\sqrt{3}$	**35 um**	**1**	**35 um**
δ_{user}	Differences in contact pressure by user	X_{user}	**B**	**100 um**	**Rectangular**	$\sqrt{3}$	**60 um**	**1**	**60 um**
					Combined Standard Uncertainty u_c				75 um
					Coverage Factor kp = 2 Confidence level: 95%				-
					Expanded Uncertainty $U = u_C{}^* \, k_P$				150 um

Reported Result – The measured distance is m_x um ± 150 um, k =2, 95% confidence level

δ_{INST} : MPE =maximum permissible error given by the manufacturer. According to technical information of manufacturer, MPE = 0,05 mm.

Distribution is rectangular, k= $\sqrt{3}$, u_1= 0,05mm/ $\sqrt{3}$ = 29 um

δ_{read}: Reading error - depends on human influences and practical experience. Estimated as +/-0.005 mm

Distribution is rectangular, k= $\sqrt{3}$, u_2= 0,005mm/ $\sqrt{3}$ = 2,89 um

δ_{temp}: Temperature error - Because of the specific range of the caliper, influence of temperature can be neglected

Distribution is rectangular, k= $\sqrt{3}$, u_3= 0,0001mm / $\sqrt{3}$ = 0,0577 um

δ_{calibr}: calibration of gauge - According to calibration certificate

Distribution is rectangular, k= $\sqrt{3}$, u_4= 0,005mm / $\sqrt{3}$ = 2,89 um

δ_{abbe}: Canting - canting because of position of the measuring surface

Distribution is rectangular, k= $\sqrt{3}$, u_5= 0,06mm / $\sqrt{3}$ = 35 um

δ_{user}: Contact pressure - Influence of user, depends about practical experience of the expert

Distribution is rectangular, k= $\sqrt{3}$, u_6=0.1mm / $\sqrt{3}$ = 60 um

Example 5

Test Name: Torque measurement.

Result: uncertainty of torque measured.

Description: The complete measurement chain consists of a torque/speed sensor with uncertainty contributions due to eccentricity, internal friction (bearings), repeatability, influence of measuring amplifier and plotting unit (computer).

Quantity X_i	Source of Uncertainty	X_i	Type	Relative Error Quantity $S_p(X_i)$	Probability Shape	Distribution Division Factor, k	Relative Standard Uncertainty $u(X_i)$	Sensitivity Coefficient C_i	Relative Uncertainty Contribution $u_i(y)$
$\delta_{friction}$	**Internal friction**	$X_{riction}$	**B**	**0,05 %**	**Rectangular**	$\sqrt{3}$	**0,0289 %**	**1**	**0,0289 %**
δ_{MPE}	**Measurement amplifier**	X_{MPE}	**B**	**0,1 %**	**Rectangular**	$\sqrt{3}$	**0,0577 %**	**1**	**0,0577 %**
$\delta_{plotter}$	**Plotting unit**	$X_{plotter}$	**B**	**0,1 %**	**Rectangular**	$\sqrt{3}$	**0,0577 %**	**1**	**0,0577 %**
δ_{eccent}	**Eccentricity of axes**	X_{eccent}	**B**	**0,1 %**	**Rectangular**	$\sqrt{3}$	**0,0577 %**	**1**	**0,0577 %**
δ_{repeat}	**Repeatability of measurement**	X_{repeat}	**B**	**0,5 %**	**Rectangular**	$\sqrt{3}$	**0,289 %**	**1**	**0,289 %**
					Relative Combined Standard Uncertainty u_c				0,307%
					Relative Coverage Factor kp = 2 Confidence level: 95%				-
					Relative Expanded Uncertainty $U = u_C * k_P$				0,61%

Reported Result – The measured torque is m_x (1 ± 0,0061) N - m , k = 2, 95 % confidence interval

$\delta_{friction}$: loss because of mechanical friction (clamping unit). Because of practical experience this error is estimated as +0,1% of final result. Estimation: Average 0,05% +/- 0,05%

Distribution is rectangular, $k=\sqrt{3}$, u_1= 0,05% / $\sqrt{3}$ = 0,0289%

δ_{MPE}: Standard measuring amplifier; MPE = 0.1% (accuracy class I)

Distribution is rectangular, $k=\sqrt{3}$, u_2= 0,1%/ $\sqrt{3}$ =0,0577%

$\delta_{plotter}$: Normally signals from torque sensors are sampled electronically to be evaluated statistical by plotting unit (e.g. computers and specific measuring boards). Because of practical experience error is assumed as +/-0,1% of final value

Distribution is rectangular, $k=\sqrt{3}$, u_3= 0,1% / $\sqrt{3}$ =0,0577%

δ_{excent}: Because of misalignment of axes (eccentricity) there are superposed torques (dynamic and static rates of torque) which lead to additional losses. Because of practical experience error is assumed as +/-0,1% of final value.

Distribution is rectangular, $k=\sqrt{3}$, u_4= 0,1%/ $\sqrt{3}$ =0,0577%

δ_{repeat}: Because of non-identical settings of the measuring device and clamping situation (often because of high/lower experienced staff) there are repeatability errors. Because of practical experience error is assumed as +/-0,5% of final value.

Distribution is rectangular, $k=\sqrt{3}$, u_5= 0,5%/ $\sqrt{3}$ =0,289%

Example: 6

Test Name: Pre conditioning for ball pressure test.

Result Variable: Uncertainty of temperature of test sample

Description: Influence by possible factors: - set point of the heater, reading accuracy, spatial temperature gradient based on the thermal isolation of the heater, influence of the two-stage heater control, thermal/ temporal inertia of the system, surface/volume ratio of the test specimen (the smaller the ratio, the greater the thermal inertia), uncertainty of thermocouple.

Quantity X_i	Source of Uncertainty	X_i	Type	Error Quantity $S_p(X_i)$	Probability Shape	Distribution Division Factor, k	Standard Uncertainty $u(X_i)$	Sensitivity Coefficient C_i	Uncertainty Contribution $u_i(y)$
δT_R	**spatial temperature gradient and fluctuation**	**X** T_R	**B**	**0,1°C**	**Rectangular**	$\sqrt{3}$	**0,0577 °C**	**1**	**0,0577°C**
δIndic	**Rough scale for temperature set**	**X** Indic	**B**	**0,5°C**	**Rectangular**	$\sqrt{3}$	**0,289 °C**	**1**	**0,289°C**
δT_{contr}	**Function of heating control**	**X** T_{contr}	**B**	**1°C**	**Rectangular**	$\sqrt{3}$	**0,577 °C**	**1**	**0,577°C**
δ_{Recr}	**Influence of recorder**	X_{Rec}	**B**	**1,5°C**	**Rectangular**	$\sqrt{3}$	**0,866 °C**	**1**	**0,866°C**
δTr_{res}	**Transition of resistance**	XTr_{res}	**B**	**0,25°C**	**Rectangular**	$\sqrt{3}$	**0,144 °C**	**1**	**0,144°C**
δ_{ref}	**Calibration of reference thermocouple**	X_{ref}	**B**	**0,1°C**	**Rectangular**	$\sqrt{3}$	**0,0577 °C**	**1**	**0,0577°C**
					Combined Standard Uncertainty u_c				**1,093°C**
					Coverage Factor kp = 2 Confidence level: 95%				**-**
					Expanded Uncertainty U = u_C* k_P				**2,2°C**

Reported Result: The measured temperature is 70.6 °C ± 2,2°C, k =2, 95% confidence interval.

T_{INVP}: Constant Value: 75 °C; Temperature set with control dial.

T_R: Constant Value: 4,4 °C; According to manufacturer's specification, the spatial temperature gradient is +/- 2% of maximum temperature (220°C). Practical experience shows that this value can be divided into one systematic and one random failure. Extreme estimate for systematic fluctuation: due to thermal loss, there is a spatial temperature difference of -4,4°C

δ_{TR}: Extreme estimate for random fluctuation: The mean values fluctuate at intervals [0,08; -0,03]. An approximate spatial temperature fluctuation of +/- 0,1°C can be specified

Distribution is rectangular, $k=\sqrt{3}$, u_1= 0,1°C/$\sqrt{3}$ = 0,0577°C

δ_{Indic}: Due to the rough scale, the temperature of the warming cabinet can only be set with a tolerance of +/- 0,5 °C (estimated value).

Distribution is rectangular, $k=\sqrt{3}$, u_2= 0,5°C $\sqrt{3}$ = 0,289 °C

$\delta\ T_{contr}$: Distribution is rectangular, $k=\sqrt{3}$, u_3= 1,0°C/$\sqrt{3}$ = 0,577 °C

δ_{Recr}: Summarized all impacts on uncertainty of the recorder

Distribution is rectangular, $k=\sqrt{3}$, u_4= 1,5°C / $\sqrt{3}$ = 0,866 °C

$\delta\ Tr_{res}$: estimated impact of transition resistance based on practical experience.

Distribution is rectangular, $k=\sqrt{3}$, u_5= 0,25°C / $\sqrt{3}$ = 0,144 °C

δ_{ref}: estimated impact of reference element (PT100 based on practical experience)

Distribution is rectangular, $k=\sqrt{3}$, u_6= 0,1°C / $\sqrt{3}$ = 0,0577°C