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Introduction

Calibration services leading to calibration certificates are very widely used in industry, laboratories, conformity assessment bodies, enterprises in general and state authorities, in order to meet the requirements of several standards, such as ISO 9001, ISO 14001, ISO 18001, ISO 22000, ISO 17025, ISO 17020, ISO 17021, ISO 17065 etc., as well as other regulatory and legal requirements. In addition, calibration certificates are the main means to provide evidence for the measurement traceability. In this respect, a lot of time and money are spent on dealing with calibration services at any level.

This guide provides a discussion of some practical issues of calibration certificates and practical instructions on how to examine a calibration certificate, understand its contents, check the results and make the necessary interpretations and decisions. In this respect, specific practical case studies of calibration certificates of measuring instruments are presented, analysed and discussed within this guide.

**Remark:** This Guide does not intend to provide details related to the calibration procedures, but instead gives emphasis on the final results, which are normally of interest to the user of the measuring instrument under calibration.

Definitions

**Measurand:** Quantity to be measured.

**Measurement accuracy:** Closeness of agreement between a measured quantity value and a true quantity value of a measurand.

**Measurement precision:** Closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions.

**Measurement error:** Measured quantity value minus a reference quantity value.

**Systematic measurement error:** Component of measurement error that in replicate measurements remains constant or varies in a predictable manner.

**Random measurement error:** Component of measurement error that in replicate measurements varies in an unpredictable manner.

**Measurement uncertainty:** Non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used.

**Reference measurement standard:** Measurement standard designated for the calibration of other measurement standards for quantities of a given kind in a given organization or at a given location.
*Calibration*: Operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.

*Measurement traceability*: Property of a measurement result relating the result to a stated metrological reference through an unbroken chain of calibrations of a measuring system.

*Metrological traceability to a unit*: Metrological traceability of a measurement result to the definition of a measurement through a stated metrological traceability chain.

**1. CALIBRATION CERTIFICATES: some practical issues**

The following cases with practical issues of calibration certificates are discussed and analysed in practical terms. The aim is to understand some basic principles, answer frequently asked questions and clear some misconceptions.

**Case 1**: A Calibration Certificate is issued for a specific measuring instrument.

Manufacturers of measuring instruments quite often issue “Calibration Certificates” or “Calibration Reports”, which however do not correspond to specific measuring instruments, but to a whole batch of measuring instruments. In this case, one needs to understand the real meaning and use of these. There are several simple ways to do that, such as:

a) The serial number (s/n) of the measuring instrument, which is a unique identification, is stated normally on the first page of an actual calibration certificate. If the s/n does not exist, then there should be stated some other identification.

b) There is normally a statement in the footnote in the first page or in every page that this certificate corresponds to a specific instrument and not to a batch or other instruments.

c) An actual calibration certificate normally includes quite analytical results and in most cases, not all, includes more than one page.

d) An actual calibration certificate is uniquely identified by an appropriate number, the date of calibration, the date of issue and original signature of the person authorized for issue.

It is true however, that there are cases, where a calibration certificate corresponds and contains more than one instrument, in fact a set of them, such as weight standards or gauge blocks. But again, in the case of a set, each item of the set is calibrated separately and is uniquely identified within the certificate.

**Case 2**: The presence of a calibration certificate means that the specific measuring instrument is reliable and can be used providing accurate and reliable results. In this respect, one can assume that the respective standard requirements are fully met, taking into account that there is also measurement traceability achieved.

This is not correct. A calibration certificate just provides the results of a series of measurements conducted by a calibration laboratory, characterizing the metrological behaviour of this specific
instrument. The question whether the results are satisfactory, and in this respect the instrument is suitable for use, should be answered by the “USER” of this specific instrument, i.e. by someone who can assess the calibration results according to specific needs and requirements.

The outcome of a calibration certificate for the status and the use of the specific instrument might be:

a) Use of the instrument as is without any further action
b) Adjustment of the instrument, recalibration and use
c) Use by making necessary and appropriate corrections in the indications if adjustment is not feasible
d) Replace the instrument by other instrument with better metrological behaviour to meet the requirements of its use

**Case 3:** A calibration certificate of a specific measurement instrument is the only means to provide evidence for traceability of measurements when using this specific instrument.

The measurement traceability is necessary to establish confidence for reliable and accurate measurements. A calibration certificate provides quantitative data involved in a specific link of the chain of measurement traceability. In addition, it is evident that the calibration certificate provides the identity of the laboratory which serves as a link in traceability chain.

**Case 4:** A calibration certificate is considered to be acceptable and reliable if:

a) It is issued by a National Metrology Institute with published CMC (Calibration Measurement Capability) tables in KCDB BIPM
b) It is issued by an accredited laboratory, according to ISO 17025. In this case, the accreditation logo should be located normally at the top right or left.

In any other case, i.e. not accredited, the Calibration Laboratory should at least meet all the requirements of the paragraph 5.10 of the ISO 17025 standard. This is not a trivial case to handle, taking into account that the Calibration Laboratory should be able to provide appropriate evidence to be examined.

**Case 5:** There is very often the expression “uncertainty of a measuring instrument”

This expression explicitly means the uncertainty of a series of measurements conducted for the calibration of this specific instrument. In this respect, another calibration, i.e. different set of measurements by the same or a third laboratory might lead to different uncertainty results.

**Case 6:** Using a calibrated measuring instrument in conducting measurements, one assumes that the uncertainty stated in the calibration certificate of this specific instrument is exactly equal to the uncertainty of the measurements conducted when using this instrument. Is this right?

This is not absolutely right. This is in fact an assumption. In fact, the measurement uncertainty stated in the calibration certificate corresponds to the measurements conducted within a calibration laboratory under specific conditions (environmental conditions, operator and use of
specific calibration method/procedure used). On the other hand, in using this same instrument, a series of different other measurements are conducted by a different operator, under different conditions, following another method or procedure of measurements.

**Case 7:** After its calibration, an instrument can be used with confidence for the time specified by the recalibration period

This is not true. A calibration certificate provides an “instant picture” of the metrological behaviour of the specific instrument at the specific time of calibration. Any mishandling of the instrument after calibration may lead to deviations in the metrological performance. In this respect, the presence of calibration certificate by itself does not provide a guarantee for accurate and reliable measurements. Instead, proper handling, maintenance and checks in use, should be undertaken.

**Case 8:** The period or interval of recalibration of a measuring instrument is determined by the Calibration Laboratory

This is not true. The recalibration interval should be only specified by the user, according to his needs, the requirements and the risks associated with the use of the instrument. This of course, means that the user has good knowledge and understanding of his needs and the relevant requirements. In conclusion, the Calibration Laboratory can specify the recalibration interval or the date of next calibration, only upon Customer’s request.
2. CHECKING THE CONTENTS OF A CALIBRATION CERTIFICATE

Upon the receipt a Calibration Certificate, the user should check the following fields within the certificate, namely general and technical fields.

2.1. General Fields in a Calibration Certificate

a) Title: there should be explicitly the title “Calibration Certificate” on the top of every page. It might be also used the title “Calibration Report”, which is not, however, very frequent.

b) Name of the Laboratory: the title of the Calibration Laboratory with its logo on the top and on every page of the certificate.

c) Number of Certificate: there should be a unique identification number of the certificate (normally on the top of the page). This number should be used in case that one needs to make reference to this certificate.

d) Name of the customer: full data of the owner or user of the instrument (name, address, etc.)

e) Description of the instrument: short description of the instrument, i.e. digital thermometer, with the data of the manufacturer and the type

f) Identification of instrument: Serial number and other additional numbers, such as asset number assigned by the owner. In any case, there should be a unique identification of the instrument taking into account that a calibration certificate corresponds to a unique instrument.

g) Calibration Order: The number of Calibration Order, which is defined by the calibration laboratory at the time of receipt of the instrument. The number of calibration order is unique for to a particular instrument and is placed in the calibration register of the laboratory.

h) Date of receipt: the date of receipt of the instrument by the calibration laboratory

i) Date of calibration: the date or the period of calibration (a calibration might take more than one day to me completed and in this case, one should write the date of start and the date of completing the calibration)

j) Date of Issue: the date of issue of the calibration certificate

k) Signature: signed by an authorized person with his name and position title. It is possible, depending upon the policy of the laboratory, to be signed also by an additional person, such as the responsible for conducting the calibration.
l) Statement for copying and generating this certificate. This statement is normally in the footnote in every page of the certificate, stating that reproduction of part of the certificate requires approval of the calibration laboratory.

m) Additional statements: there should be also a statement regarding the uniqueness of the certificate connecting only to the specific calibrated instrument.

2.2. Technical Fields

a) Condition of the instrument: short statement for the state of instrument at the time of receipt, i.e. short description of its condition good or bad, and if any treatment was made, such as cleaning.

b) Environmental conditions: Variation of the conditions, such as temperature, during calibration (normally the minimum and the maximum values during calibration).

c) Measurement Traceability: A statement for measurement traceability. It can be very general, such as “measurement traceability to SI units through the national standards of XXXX” or more analytical providing evidence of this traceability by stating the numbers of calibration certificates of the measurement standards of the laboratory involved & used in the calibration

d) Calibration method/procedure: A short description of the calibration procedure with references to identification numbers and standards, if involved. If non-standard methods are used, then the description should be more detailed (normally 4-5 lines).

e) Calibration Results: They should be normally presented in any appropriate form, such as in a table, equation, graphs or a combination.

f) Uncertainty of measurement: should be explicitly stated to accompany each individual result, followed by a general statement such as “Reported is the expanded uncertainty which results from the standard uncertainty (u) by multiplication with the coverage factor k = 2. It has been evaluated according to the «Guide to the Expression of Uncertainty in Measurements» (2008). Generally, the value of the measuring quantity is found within the attributed interval with a probability of approximately 95%. The reported uncertainty does not include an estimate of long-term variations”
3. ANALYSIS and INTERPRETATION OF CALIBRATION RESULTS: Case Studies

3.1. Calibration of a digital thermometer
(this case was prepared by the project)

3.1.1. Analysis

Considering the calibration of a digital thermometer (Thermometer or Item under Calibration – IuC), the calibration results are normally presented according to the following table.

<table>
<thead>
<tr>
<th>Reference Temperature (°C)</th>
<th>Temperature of IuC (°C)</th>
<th>Error (°C)</th>
<th>Correction (°C)</th>
<th>Uncertainty, U in 95% (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0.1</td>
<td>0.09</td>
<td>-0.09</td>
<td>0.20</td>
</tr>
<tr>
<td>20.00</td>
<td>19.9</td>
<td>-0.10</td>
<td>+0.1</td>
<td>0.19</td>
</tr>
<tr>
<td>40.04</td>
<td>40.1</td>
<td>0.06</td>
<td>-0.06</td>
<td>0.21</td>
</tr>
<tr>
<td>60.00</td>
<td>59.8</td>
<td>-0.20</td>
<td>+0.2</td>
<td>0.22</td>
</tr>
<tr>
<td>80.01</td>
<td>79.4</td>
<td>-0.61</td>
<td>+0.61</td>
<td>0.21</td>
</tr>
</tbody>
</table>

A calibration of a thermometer is conducted in discrete temperature values/points of its scale (very often in 5 different temperature points). The calibration points should be selected however by the user depending upon his needs. For example, when using a thermometer to check the temperature within a chamber operating in the range 2 – 8 °C, then one might select 3 calibration temperature points, i.e. at -2 °C, 4 °C and 8 °C.

The 1st column presents the reference temperature values measured by the use of the reference thermometer (reference measurement standard in this case) of the Calibration Laboratory, which in principle should have better metrological characteristics than the thermometer under calibration.

It is noted, that each value of reference temperature is normally the average of a number of measurement values.

The 2nd column presents the measured temperature at each calibration point as indicated by the thermometer under calibration.

It is noted that each value is the average of a number of measurement values depending upon the method of calibration.

The 3rd column presents the measurement error, which is provided by the relationship

\[
\text{Error} = \text{Measurement of IuC} - \text{Reference Temperature (°C)}
\]

The 4th column presents the correction, which should be added to the respective indication of the Thermometer under Calibration, when used, and it is provided by the relationship

\[
\text{Correction} = -\text{Error}
\]
The 5th column provides the measurement uncertainty at 95% confidence level, i.e. expanded uncertainty U, of the measurement values taken in column 2.

### 3.1.2. Formal Expression of Results

Conducting a measurement by using this digital thermometer, when looking at an indication 20 °C, the formal expression of this result according to the table is:

\[
\text{Temperature} = 20.0 + (-0.09) \pm 0.19 \degree C \text{ at 95% confidence level}
\]

### 3.1.3. Use and Interpretation of Calibration Results

#### 3.1.3.1. Conformity Assessment

Let us consider that the max permissible error when using this digital thermometer is

\[
\text{Max Error} = 0.5 \degree C.
\]

Then, by looking at the 3rd column, one can see that the error at the calibration point 80 °C exceeds the above maximum limit and in this respect the calibration shows that there is a non-conformity. In this case, one has to consider the options:

**Option 1:** To have the thermometer adjusted and recalibrated, if adjustment is feasible

**Option 2:** To use the thermometer, but after making corrections according to the correction values of the 4th column and in any case making use of the formal expression (without however the uncertainty part). In this case, one has to be very careful in adopting and making corrections, especially if there is more than one user involved.

**Option 3:** To replace the digital thermometer with a new one, which has to be also calibrated.

**Question:** What happens if the user needs to use the thermometer in temperature points not included in the table of the calibration results? What values then for error, correction and uncertainty should one assign?

**Answer:** values to be determined by interpolation or sometimes with extrapolation with a higher risk in the latter case.

#### 3.1.3.2. Use and Interpretation of Uncertainty

**Case A:** Considering measurement uncertainty when the measurement results should be within acceptance limits

Considering a case that a digital thermometer, with a calibration uncertainty about 0.4-0.5 °C, is used to monitor the temperature within a room or a chamber where a standard requirement applies for maximum deviation d=±1 °C from a reference (target) temperature 80 °C, one can see that this specific thermometer is not appropriate. This is taking into account this uncertainty of calibration (about 0.4-0.5 °C) and the value of d (= 1 °C). Working and using the thermometer to measure and keep the temperature inside the range d=±1 °C, it is very likely that many measurements will be outside this acceptable range. If the calibration uncertainty however could
be reduced to 0.2 °C, as in the example of calibration above, then this would be more acceptable, taking into account that the ratio d/U increases from 2 to 5.

Case B: Considering measurement uncertainty in everyday use of instrument

In fact, one should keep in mind that using this thermometer in everyday life, the uncertainty in use will be higher than the uncertainty determined by the calibration in the certificate. This is normal, taking into account that the conditions of calibration are almost ideal compared to those of everyday life and use.

3.2. Calibration of a Weight Standard

(This case was jointly prepared by Kosovo Metrology Agency and the project)

3.2.1. Analysis

Considering the calibration of a weight standard of 20 kg nominal mass value and F1 claimed OIML accuracy class, the aim of this calibration is to determine:

- a) Its conventional mass value.
- b) The associated uncertainty of the conventional mass value.
- c) The OIML accuracy class based on specific criteria of the OIML R 111 standard.

Note: The conventional mass value is not the actual mass of the weight standard, which is actually needed in some cases. The actual mass value can be derived by the conventional mass value by using an appropriate formula.

The calibration results are normally expressed as follows in the calibration certificate:

<table>
<thead>
<tr>
<th>Nominal Value of Mass</th>
<th>Conventional Mass Value</th>
<th>Uncertainty</th>
<th>OIML Accuracy Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 kg</td>
<td>20 kg – 35 mg</td>
<td>11 mg</td>
<td>F1</td>
</tr>
</tbody>
</table>

The calibration procedure involves measurements on a mass comparator using the weight standard under calibration and a reference weight standard of better OIML accuracy class than the one under calibration, namely 20 kg of E2 OIML class. In this respect, cycles of measurements are conducted, exchanging the two standards on the mass comparator.

The 1st column in this table of the results above presents the nominal value of the standard weight under calibration, which is in fact an almost ideal value.

The 2nd column presents the conventional mass values. In this example, the value -35 mg is the error as it was determined in the calibration by performing measurements.

The 3rd column presents the expanded uncertainty, namely at 95% confidence level, which is associated with the conventional mass value following the measurements conducted during calibration. In this example, the value of the expanded uncertainty is 11 mg.
The 4th column expresses the accuracy class of the weight standards based on the specific requirements of the OIML R 111 standard, which makes use of the max permissible error and the expanded uncertainty. In this example, apparently the criteria of OIML are successfully met.

### 3.2.2. Formal Expression of Results

The result of the calibration is expressed exactly as in the table above. Namely:

- Conventional mass, \( m_c = 20 \text{ kg} - 35 \text{ mg} \) or 19,999.965 g,
- uncertainty \( U(m_c) = 11 \text{ mg} \) and
- F1 OIML accuracy class based on OIML R 111

### 3.2.3. Use and Interpretation of Calibration Results

#### 3.2.3.1. Conformity Assessment

In this case of calibration, we have a conformity assessment according to the criteria of OIML R 111 leading to the classification on the weight standard to F1 accuracy class. In case that the specifications of OIML R 111 were not met, then the classification would most likely lead to a lower accuracy class, such as F2.

*Remark: Deviations of weight standards regarding their accuracy class can be attributed to their handling by the user, such as mainly dust, corrosion or even scratches, which lead to changes of the value of mass. The classification of weight standards according to OIML R 111 makes use of several requirements, additional to the above specific requirements.*

#### 3.2.3.2. Use and Interpretation of Uncertainty

The user may use this weight standard according to OIML R 111 in cases where F1 OIML accuracy class is required, such as:

a) To check the accuracy of a Non-Automatic Weighting Instrument

b) To check the accuracy, mainly the mass values, of other weight standards of lower accuracy, i.e. F2, M1, M2.

c) To conduct calibrations of other weight standards of lower accuracy, i.e. F2, M1, M2.

d) To conduct calibrations of Non-Automatic Weighing Instruments, using also additional weight standards with different nominal values.

The user of this weight standard normally makes use of the conventional mass value (20 kg – 35 mg) and its associated uncertainty (11 mg). The USER however can also make use, for practical reasons, of the nominal value of the weight (= 20 kg) and in this case the associated uncertainty can be taken by the maximum permissible error specified by OIML R 111 divided by the square root of 3 (= mpe/√3).
Remark: Looking at the error determined in this calibration (=35 mg) and its associated expanded uncertainty (=11 mg) and making the comparison with the maximum permissible error specified by OIML R 111, it is clear that the laboratory conducts quite careful calibration work.

3.3. Calibration of a Non-Automatic Weighing Instrument  
(this case was jointly prepared by General Directorate for Metrology - Albania and the project)

3.3.1. Analysis

Considering the calibration of a Non-Automatic Weighing Instrument (or mass balance) of maximum load Max=220 g and resolution d=0.1 mg, the tests of measurements to be performed for the calibration can be determined in consultation with the client, in accordance with the normal use of the instrument. In any case, the method with the measurement tests for this calibration is provided by the EURAMET Guide cg.18. The results of the tests performed are presented as follows:

<table>
<thead>
<tr>
<th>Repeatability Test</th>
<th>Eccentricity Test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Load</strong></td>
<td><strong>Eccentric loading</strong></td>
</tr>
<tr>
<td>100 g</td>
<td>100 g</td>
</tr>
<tr>
<td><strong>Readings</strong></td>
<td><strong>Reading (1, 2, 3, 4, 5)</strong></td>
</tr>
<tr>
<td>1</td>
<td>100.0005</td>
</tr>
<tr>
<td>2</td>
<td>100.0003</td>
</tr>
<tr>
<td>3</td>
<td>100.0004</td>
</tr>
<tr>
<td>4</td>
<td>100.0006</td>
</tr>
<tr>
<td>5</td>
<td>100.0004</td>
</tr>
<tr>
<td>6</td>
<td>100.0005</td>
</tr>
</tbody>
</table>

**ΔE = 0.0002 g**

Regarding the above two tests:
The **repeatability test** is carried out by the use of a single standard weight (100 g of E2 OIML class) to repeat 6 measurements under the same conditions. The aim of this test is to determine the standard deviation (=s) of these 6 measurements.
The **eccentricity test** is conducted by placing a load (weight standard 100 g of E2 OIML class) in 6 positions 1 – 2 – 3 – 4 – 5 – 1 as shown in the above scheme. The aim of this test is to determine the maximum difference (=ΔE) between the 4 measurements in the positions 2-3-4-5 and the 2 measurements at the central position (1-6).

<table>
<thead>
<tr>
<th>Accuracy Test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Load (g)</strong></td>
</tr>
<tr>
<td>100.0002</td>
</tr>
<tr>
<td>99.9999</td>
</tr>
<tr>
<td>100.0001</td>
</tr>
<tr>
<td>100.0000</td>
</tr>
<tr>
<td>100.0002</td>
</tr>
<tr>
<td>s=0.00013 g</td>
</tr>
</tbody>
</table>
The accuracy test is carried out by using 5 different weight standards to cover the measurement range of the mass balance. The aim of the accuracy test is to determine the errors in the last column as the difference between the readings of the mass balance and the mass value of the respective weight standard.

Additional information stated in the calibration certificate include a statement for adjustment of the mass balance and the values of some parameters as follows:

- Temperature difference in the area of calibration $\Delta T = 5^\circ C$
- Temperature Coefficient $TC = 1.5 \text{ ppm/}^\circ C$

### 3.3.2. Formal Expression of Results

The final calibration results, which are of interest to the user, who is not always interested to know and understand the details of the calibration procedure applied by the calibration laboratory, are normally expressed by the use of a linear equation, i.e. $y = a*x+b$, as follows.

The error $E$ as a function of the Load, $L$, is expressed as follows in this specific calibration case:

$$E(L) = 4.27E^{-6}L,$$ where $L$ is in g and $E(L)$ in g (1)

The uncertainty of the error, $U(E)$ at 95% level of confidence as a function of the Load, $L$, is expressed as follows:

$$U(E) = 1.56E^{-6}L,$$ where $L$ is in g and $U(E)$ in g (2)

In addition, based on information provided by the user, the calibration laboratory can also provide the following expressions of the uncertainty in use:

The uncertainty of the reading, $R$, of the balance, $U(R)$, when corrections (=errors) are applied, is expressed as follows:

$$U(R) = 0.0003 + 3.0E^{-6}R,$$ where $R$ is in g and $U(R)$ in g (3)

The global uncertainty of reading, $R$, of the balance, $U_{gl}(R)$, without the need to make the corrections (=errors) in the readings of the mass balance, is expressed as follows:

$$U_{gl}(R) = 0.0003 + 7.2E^{-6}R,$$ where $R$ is in g and $U_{gl}(R)$, in g (4)
3.3.3. Use and Interpretation of Calibration Results

Let us consider a case of weighing a sample of a chemical substance of about 5 g in this balance with a max permissible error, according to a technical specification, ε = ±0.1% of this value, namely 0.005 g (=5 mg). The question for the USER of the balance is, if can use this balance to achieve an error lower than this one specified.

The owner can use the last equation (4) to determine the global uncertainty which also includes the error when weighing a sample of 5 g.

In this respect, using this equation (4) for R=5 g, the global uncertainty is $U_{gl}(5) = 0.3$ mg, which is much lower than the max limit of 5 mg, and in this respect, the user can make use of this balance without any problem.

3.4. Calibration of a Caliper
(this case was prepared by the project)

3.4.1. Analysis

Considering the calibration of a caliper by using the calibration method of the standard VDE 2618, the calibration results can be presented according to following form:

a) The results of internal measurements by using a ring as a reference standard as follows:

<table>
<thead>
<tr>
<th>Ring Diameter (mm)</th>
<th>Measured Value (mm)</th>
<th>Error (mm)</th>
<th>Uncertainty (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.000</td>
<td>24.95</td>
<td>-0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

b) The results of external measurements by using several gauge blocks as a reference standards, as follows:

<table>
<thead>
<tr>
<th>Length of Gauge Block (mm)</th>
<th>Measured Value (mm)</th>
<th>Error (mm)</th>
<th>Uncertainty (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>2.50</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>5.1</td>
<td>5.10</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>7.7</td>
<td>7.70</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>10.3</td>
<td>10.30</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>12.9</td>
<td>12.90</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>15</td>
<td>15.00</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>17.6</td>
<td>17.60</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>20.2</td>
<td>20.20</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>22.8</td>
<td>22.80</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td><strong>25</strong></td>
<td><strong>24.95</strong></td>
<td><strong>-0.05</strong></td>
<td><strong>0.03</strong></td>
</tr>
</tbody>
</table>
c) The results of depth measurements by using just one gauge block as a reference standard, as follows:

<table>
<thead>
<tr>
<th>Length of Gauge Block (mm)</th>
<th>Measured Value (mm)</th>
<th>Error (mm)</th>
<th>Uncertainty (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>75.00</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

In each of the above tables:

The 1st column presents the nominal value of: a) the diameter of the ring, b) the length of each gauge block and c) the length (=75 mm) of a gauge block.

The 2nd column presents the measured value of the reference standard (diameter of ring or length of gauge block) by using the caliper under calibration.

The 3rd column presents the measurement error, which is provided by the relationship

\[
\text{Error} = \text{Measured Value} - \text{Standard Reference Value}
\]

The 4th column presents the expanded uncertainty, namely at 95% confidence level, which is associated with the measured value (presented in the 2nd column) of the diameter or gauge block by using the caliper under calibration.

3.4.2. Formal Expression of Results

The results of the calibration are expressed exactly as in the table above.

3.4.3 Use and Interpretation of Calibration Results

3.4.3.1. Conformity Assessment

We consider that the USER of this caliper has a rule for using this caliper, namely:

The error in calibration shall not be outside the limit of ±0.05 mm

Then in this case, the USER:

- Can make use of this caliper for measuring lengths of objects up-to 22.8 mm
- Takes a risk in making measurements in the range between 25 mm and 50 mm
- Can make use of this caliper in the range between 50 and 125 mm

3.4.3.2. Use and Interpretation of Uncertainty
The user should be aware of the value of the uncertainty, which is 0.03 mm, much higher than the resolution of the caliper (d=0.01 mm). Especially, in high values of length the combination of the uncertainty and the error can be close to 0.1 mm.

3.5. Calibration of a Ruler
(this case was prepared by the project)

3.5.1. Analysis

Considering the calibration of a ruler by using another appropriate ruler as the reference standard in the calibration, the calibration results can be presented according to following form:

a) Measurement of the thickness, d, of the scale line of the rule:
   \[ d = 0.5 \text{ mm} \pm 0.2 \text{ mm} \]

b) Measurement results:

<table>
<thead>
<tr>
<th>Ruler reading (mm)</th>
<th>Error (mm)</th>
<th>Ruler reading (mm)</th>
<th>Error (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-0.2</td>
<td>2000</td>
<td>0.2</td>
</tr>
<tr>
<td>10</td>
<td>0.0</td>
<td>2001</td>
<td>0.2</td>
</tr>
<tr>
<td>11</td>
<td>0.0</td>
<td>2999</td>
<td>0.2</td>
</tr>
<tr>
<td>999</td>
<td>0.0</td>
<td>3000</td>
<td>0.2</td>
</tr>
<tr>
<td>1000</td>
<td>0.0</td>
<td>3001</td>
<td>0.2</td>
</tr>
<tr>
<td>1001</td>
<td>0.0</td>
<td>3999</td>
<td>0.3</td>
</tr>
<tr>
<td>1999</td>
<td>0.2</td>
<td>4000</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Statement for the Measurement Uncertainty: The calibration uncertainty for the measurement of differences from scale line to scale line is \( U = 0.4 \text{ mm} \) at a confidence level of 95%.

In the above table:

The 1\textsuperscript{st} column presents the values of readings taken by using the ruler under calibration.

The 2\textsuperscript{nd} column presents the error, which has been derived by the calibration laboratory using the following relationship:

\[ \text{Error} = \text{Measured Value} - \text{Standard Reference Value} \]

Remarks: In this example, the calibration laboratory does not provide the reference measurement values, i.e. the values measured by using the reference ruler.
3.5.2. Formal Expression of Results

The results of the calibration are expressed exactly as in the table above.

3.5.3. Use and Interpretation of Calibration Results

We consider that the user of this ruler has a restriction for using this ruler, namely:

The total error when using this ruler cannot exceed the limit of ±0.6 mm

Looking at the errors, in the calibration results, one can see that in the range of measurements 2000 mm up to 4000 mm the error together with the uncertainty, i.e. total 0.7-0.8 mm, exceeds the above limit, 0.6 mm. In this respect, the user, when using the ruler in the above range, needs to make the appropriate corrections in the readings taken.

3.6. Calibration of a variable –volume piston pipette

*(this case was jointly prepared by Bureau of Metrology - Macedonia and the project)*

3.6.1. Analysis

The calibration of a variable–volume piston pipette is conducted in discrete points of its nominal volume \( V_n \) (usually four measuring points \( 0.1V_n \); \( 0.50V_n \); \( 0.75V_n \); \( V_n \)). The nominal volume is the maximum volume to be selected by the user and specified by the manufacturer. The procedure for the calibration of a piston pipette is performed in accordance to the ISO 8655-6 standard “Piston operated volumetric apparatus – Gravimetric methods for the determination of measurement error”.

Considering the calibration of a variable –volume piston pipette (pipette or *Item under Calibration – IuC*), the calibration results are normally presented according to the following table.

<table>
<thead>
<tr>
<th>Reference volume (µL)</th>
<th>Measured volume IuC (µL)</th>
<th>Error (µL)</th>
<th>Uncertainty, U in 95% (µL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100.00</td>
<td>100.51</td>
<td>+0.51</td>
<td>0.47</td>
</tr>
<tr>
<td>500.00</td>
<td>498.23</td>
<td>-1.77</td>
<td>3.01</td>
</tr>
<tr>
<td>750.00</td>
<td>760.81</td>
<td>+10.81</td>
<td>3.24</td>
</tr>
<tr>
<td>1000.00</td>
<td>1004.86</td>
<td>+4.86</td>
<td>3.93</td>
</tr>
</tbody>
</table>

The 1st column presents the pre-determined volume that shall be tested \( (0.1V_n; 0.5V_n; 0.75V_n; V_n) \) determined from the specified volume range by the manufacturer.

The 2nd column presents the value of the measured volume of the pipette (IuC). The measured volume is determined gravimetrically by the use of an appropriate balance under specified environmental conditions.
It is noted that each value of measured volume is normally the average of a number of measurement values (10).

The 3rd column presents the measurement error, which is provided by the relationship
\[
\text{Error} = \text{Measured value} - \text{Reference value (µL)}
\]

The 4th column provides the measurement uncertainty at 95% confidence level, i.e. expanded uncertainty U, of the measurement values taken in column 2.

3.6.2. Formal Expression of Results

The user of the results gets certificate with results expressed in a form of table (as it is shown before) and graphically where the results are expressed with linear equation \(y = a \times x + b\), in order to determine values for the error/correction for the other points.

\[y = 1.0083x - 1.2738\]

3.6.3. Use and Interpretation of Calibration Results

The maximum permissible systematic errors for the nominal volumes of variable-volume piston pipettes are laid down in ISO 8655-2: 2002/ AC2009 Piston pipettes.

Let us consider that the max permissible systematic error for pipettes of type A for the nominal volume of 1000 µL is ±0.8 % or 8 µL.

The absolute systematic error calculated for the calibration point 750 µL is +10.81 µL, so the user can notice that this value, i.e. 10.81 µL exceeds the maximum limit, i.e. 8.00 µL, and in this respect the calibration results in no conformity. In this case, there are the following options for the user:

Option 1: To have the pipette adjusted and recalibrated, if adjustment is feasible
Option 2: To use the pipette, but after making corrections in accordance to the results/ errors given in the table
Option 3: To replace the pipette with a new one, which has also to be calibrated.

3.7. Calibration of an Electrical Multi-meter for AC/DC Volt and Resistance

*(this case was jointly prepared by Bureau of Metrology - Montenegro and the project)*
3.7.1. Analysis

Considering the calibration of an electrical multi-meter, the calibration results are normally presented according to the following tables.

**Table 1 - The result of direct (DC) voltage measurement**

<table>
<thead>
<tr>
<th>Us (V)</th>
<th>Ur (V)</th>
<th>Ux (V)</th>
<th>E (V)</th>
<th>U (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,9999920</td>
<td>2</td>
<td>0,9999912</td>
<td>-0,0000008</td>
<td>0,0000010</td>
</tr>
</tbody>
</table>

**Table 2 - The result of alternating (AC) voltage measurement**

<table>
<thead>
<tr>
<th>Us (V)</th>
<th>f (Hz)</th>
<th>Ur (V)</th>
<th>Ux (V)</th>
<th>E (V)</th>
<th>U (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,00001</td>
<td>50</td>
<td>2</td>
<td>1,00000</td>
<td>-0,00001</td>
<td>0,00010</td>
</tr>
</tbody>
</table>

**Table 3 - The result of resistance measurement – four wires**

<table>
<thead>
<tr>
<th>Rs (Ω)</th>
<th>Rr (Ω)</th>
<th>Rx (Ω)</th>
<th>E (Ω)</th>
<th>U (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9,99995</td>
<td>20</td>
<td>9,99993</td>
<td>-0,00002</td>
<td>0,00001</td>
</tr>
</tbody>
</table>

The calibration of the digital multimeter is normally carried out at the points indicated by the EURAMET Calibration Guide cg. 15, following the manufacturer’s instructions provided in the user’s manual. The results presented in the above tables correspond to the calibration of an electrical multi-meter on: DC voltage, AC voltage and Resistance. A full calibration of this multi-meter normally includes in addition: AC and DC current measurements, namely two extra tables.

The calibration certificate normally contains the following statements:

1) DC voltage and resistance measurements are conducted after short-circuiting the input and setting the instrument reading to zero (for each range used). In this case, no adjustment of the multi-meter was carried out.

2) Before conducting any operation with the instrument, the instrument was placed, with power on, in the laboratory for thermal stabilization for 24 hours.

3) The following preliminary operations were performed:
   - Functional self-verification procedure: positive result.
   - Self-calibration procedure: no faults in the operating procedure.

4) Statement for the Measurement Uncertainty: *Expanded measurement uncertainty is given as standard measurement uncertainty multiplied by coverage factor k=2 that, when normal distribution is applied, corresponds to the desired confidence level equalling to approximately 95%. The standard measurement uncertainty was determined according to the JCGM 100:2008 Evaluation of measurement data — Guide to the expression of uncertainty in measurement and EA-4/02 M:2013 Evaluation of the Uncertainty of Measurement in Calibration.*

In the above tables:
The 1st column presents the reference quantity values of the measurand. 
The 2nd column presents the measuring range within which the calibration was performed. 
The 3rd column presents measured values indicated on the item under calibration. 
The 4th column presents difference between the measured and the reference quantity value. 
The 5th column provides the measurement uncertainty at 95% confidence level, i.e. expanded uncertainty U.

3.7.2. Formal Expression of Results

The results of the calibration are expressed exactly as in the table above.

3.7.3. Use and Interpretation of Calibration Results

3.7.3.1. Significance and Use of the Results

The calibration results reflect the measuring instrument status at the time of calibration and they relate only to the calibration item with its serial number as stated on the first page of the present Certificate. The obtained results carry no implication to the long-term stability of the calibration item.

If the user needs to use the multi-meter in measuring points not included in the table of the calibration results, values will be determined by interpolation or sometimes with extrapolation with a higher risk in the latter case.

3.7.3.2. Use and Interpretation of Uncertainty

The user may evaluate the compliance with manufacturer specification. If the evaluation of compliance with specification comprises more quantities (and/or measurands) each measurement value should be evaluated independently.

There are 3 possible cases:

Case 1: All measured values comply with the specification limit(s); 
Case 2: For some of the measured values it is not possible to make a statement of compliance with specification (this covers situations where some of the measurements demonstrate neither compliance nor non-compliance with specification); 
Case 3: Some of the measured values do not comply with specifications.

The applied criteria are as follows:

Criterion 1: If the specification limit is not breached by the measurement result plus the expanded uncertainty, then compliance with the specification can be stated. 
Criterion 2: If the specification limit is exceeded by the measurement result minus the expanded uncertainty, then noncompliance with the specification can be stated.
Criterion 3: If the measurement result plus/minus the expanded uncertainty overlaps the limit, it is not possible to state compliance or non-compliance.

3.8. Calibration of a Barometer
*(this case was prepared by the project)*

### 3.8.1. Analysis

Considering the calibration of a barometer measuring absolute pressure the calibration procedure normally follows the Recommendation DKD-R 6-1. The calibration is carried out by comparing the pressure value realized by the reference standard to the respective indication of the device under calibration. The procedure comprises the following steps:

a) One pre-loading to the upper and lower limit of calibration pressure value of the device

b) One increasing and one decreasing measurement series within the calibration range of the device under calibration

c) Recording at each calibration point the indications of the reference standard and the item under calibration, under stabilized pressure conditions, for a period of at least 2 minutes.

In this respect, the calibration results applying the above procedure are normally reported in the Calibration Certificate as follows:

<table>
<thead>
<tr>
<th>Absolute Reference Pressure (hPa)</th>
<th>M1 (increasing)</th>
<th>M2 (decreasing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>939.546</td>
<td>942</td>
<td>1.95</td>
</tr>
<tr>
<td>965.830</td>
<td>969</td>
<td>2.67</td>
</tr>
<tr>
<td>980.425</td>
<td>983</td>
<td>2.58</td>
</tr>
<tr>
<td>1000.873</td>
<td>1004</td>
<td>3.13</td>
</tr>
<tr>
<td>1015.466</td>
<td>1017</td>
<td>1.53</td>
</tr>
<tr>
<td>1035.906</td>
<td>1038</td>
<td>2.09</td>
</tr>
</tbody>
</table>

The following table provides the evaluation of the results:

<table>
<thead>
<tr>
<th>Absolute Reference Pressure (hPa)</th>
<th>Mean Measured Pressure (hPa)</th>
<th>Error (hPa)</th>
<th>Uncertainty (k=2) (hPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>939.546</td>
<td>942</td>
<td>1.95</td>
<td>0.82</td>
</tr>
<tr>
<td>965.830</td>
<td>969</td>
<td>2.67</td>
<td>0.81</td>
</tr>
<tr>
<td>980.425</td>
<td>983</td>
<td>2.58</td>
<td>0.58</td>
</tr>
<tr>
<td>1000.873</td>
<td>1004</td>
<td>3.13</td>
<td>0.58</td>
</tr>
<tr>
<td>1015.466</td>
<td>1017</td>
<td>1.53</td>
<td>0.58</td>
</tr>
<tr>
<td>1035.906</td>
<td>1038</td>
<td>2.09</td>
<td>0.58</td>
</tr>
</tbody>
</table>
In each of the above tables:

The 1\textsuperscript{st} column presents measurement values taken by using the reference standard.

The 2\textsuperscript{nd} column presents the mean measured pressure, which expresses the average of all increasing and decreasing series of measurements, for each reference pressure value.

The 3\textsuperscript{rd} column presents the measurement error (or sometimes called also deviation), which is provided by the relationship

\[ \text{Error} = \text{Mean Measured Value} - \text{Standard Reference Value} \]

The 4\textsuperscript{th} column presents the expanded uncertainty, namely at 95\% confidence level, which is associated with the measured value (presented in the 2\textsuperscript{nd} column).

\textbf{Note:} The combined uncertainty is estimated by taking contributions from the reference standard, the calibration method and the characteristics of the barometer under calibration.

\textbf{3.8.2. Formal Expression of Results}

The results of the calibration are expressed exactly as in the table above.

\textbf{3.8.3 Use and Interpretation of Calibration Results}

We consider that the use of this barometer can be made only if it is classified to calibration sequence B according to DKD-R 6-1 (2003). This classification however requires a maximum uncertainty 0.52 hPa.

In our specific case, we can see that the values of the uncertainty of calibration (last column) are higher than the above max limit (= 0.52 hPa) and in this respect, this specific barometer fails to be classified to calibration sequence B, according to the recommendation DKD-R 6-1 (2003) as stated in its paragraph 9.3.

\textbf{3.9. Calibration of a proving tank (100 L)}

\textit{(this case was jointly prepared by Directorate of Measures and Precious Metals - Serbia and the project)}

\textbf{3.9.1 Analysis}

The results of the calibration of a proving tank by using the volumetric method (EURAMET cg-21) are normally presented in the Calibration Certificate as follows.

\textit{Remark: According to EURAMET cg-21, the volume standards are standard capacity measures and, depending on the nominal volume, can be divided in two types: standard test measures from 1 L to}
20 L and proving tanks for more than 20 L. In this respect, in this specific case study, we deal with a proving tank.

<table>
<thead>
<tr>
<th>Volume of calibration, ( V ) (L)</th>
<th>Medium value of volume, ( V_{sr} ) (L)</th>
<th>Correction, ( \Delta V ) (L)</th>
<th>Measurement uncertainty, ( U ) (L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>100.01</td>
<td>-0.01</td>
<td>0.03</td>
</tr>
</tbody>
</table>

In the above table:

The 1st column represents the volume of calibration, or the nominal value of the volume of the proving tank (= 100 L). This is the value indicated on the label of the proving tank as the desired (ideal) value of the fluid volume content at a reference temperature at 15 °C.

The 2nd column represents the mean value of the volume measured within the calibration laboratory. In this case, the mean value of the volume is 100.01 L. This value represents the actual value of the contained volume of the proven tank at a reference temperature of 15 °C.

The contained volume of the measuring vessel is the volume contained in the tank, when it is filled with liquid to the line at the measuring length, indicating the nominal value of the tank.

The 3rd column represents the value of the correction, which should be added to the apparent value of the liquid volume of the proving tank in use.

\[
\text{Correction} = \text{- error}
\]

The 4th column represents the value of the expanded measurement uncertainty that has been estimated (calculated) with a probability of overlapping / covers approximately 95%.

Note 1: If it is technically feasible, on the request of the client, to move the measuring ruler on the proving tank, then this can be carried out in order to adjust the measuring ruler to the level that corresponds to the level of the nominal volume value. In this case, the calibration certificate displays the results of the calibration before settings and after adjusting the measuring ruler. After adjusting the measuring ruler, the value of 0 is displayed in the third column.

Note 2: Apart from calibration results, the calibration certificate of a proving tank indicates the discharge time of the proving tank and also the opening time. Before measurements, users of measuring vessel, must fill and unload the measuring vessel according to the defined discharge time of the measuring vessel in the calibration certificate.

Note 3: In addition to the results of the calibration, the intended use of a proving tank is stated in the respective calibration certificate and may be to provide:

- The contained volume, namely the volume of liquid contained within the tank
- The delivered volume, namely the volume of liquid delivered out of the tank

It is important that the calibration method is applied according to the intended use of the proving tank, which is should be defined before the start of the calibration.
Note 4: Apart from calibration results, the calibration certificate of a proving tank contains the reference temperature, which depends on the specific use of the tank, and it is specified below:
- 15°C, for tanks used for measuring of liquid fuels and liquid petroleum gas,
- 4°C, for tanks used for measuring milk systems,
- 20°C, for tanks used for water meters verification.

3.9.2. Formal Expression of Results

The formally expressed result of the calibration of the proving tank, which is expected to contain a volume of liquid at a reference temperature of 15 °C, is as follows:

Volume = 100.01 L ± 0.03 L

3.9.3 Use and interpretation of calibration results

3.9.3.1. Conformity assessment

Example of measuring vessel calibration, where conformity assessment is performed according to the criteria of the international recommendation OIML R120, is related to:

- The maximum permissible error for the classification of the proving tank,
- The expanded measurement uncertainty of this classification.

According to the criterion stated in the international recommendation OIML R120, the maximum permissible error of the proving tank is ± 1/2000 of the nominal volume, which in this specific case with a nominal value of 100 L is:

\[
\frac{1}{2000} \times 100 \, \text{L} = 0.05 \, \text{L}
\]

Taking into account that the measurement error of the proving tank is 0.01 L (the negative correction value shown in the 3rd column of the table) is less than the maximum permissible error, which in this case is 0.05 L, it can be concluded that the OIML R120 criterion is met.

3.9.3.2. Use and interpretation of measuring uncertainty

Use and interpretation of the expanded measurement uncertainty of the calibration of this specific proving tank of 100 L, will be presented in a case of it in a verification process of a fuel dispenser.

According to the Measurement Rulebook (MID Directive for Measuring Instruments – 2014/32), the maximum permissible error of the fuel dispenser is ± 0.5%.

0.5 % od 100 L is counted: \[0.5 \times \frac{100 \, \text{L}}{100} = 0.5 \, \text{L}\]
The criterion for proving tanks in use, according to OIML R120, with respect to the expanded measurement uncertainty, is that the expanded measurement uncertainty of the proving tank for the verification must be less than one third of the maximum permissible error of the fuel dispenser.

A third of value of the maximum permissible error of the fuel dispenser is counted as following:

\[
\frac{1}{3} \times 0.5L = 0.17L
\]

Looking at the value of the expanded measurement uncertainty of measuring vessel calibration presented in the fourth column of the table, which is 0.03 L, it can be concluded the following:

- The declared value in the calibration certificate is less than 0.17 L,
- The criterion in the Rulebook is met
- The proving tank can be used for the intended use (verification the fuel dispenser).

### 3.10. Calibration of gauge blocks by interferometry

*(this case was jointly prepared by Directorate of Measures and Precious Metals - Serbia and the project)*

#### 3.10.1 Analysis

Looking at the calibration of a gauge block of nominal length of 50 mm, class K, sometimes 0 (interferometric method) or classes 0, 1 and 2 (comparison method), the result of the calibration is most often presented using some of the columns in the following table. Gauge blocks classes are defined according to ISO 3650: 1998 Standard.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Length (mm)</td>
<td>Deviation in central length ( \text{l}_{UC} ) (( \mu \text{m} ))</td>
<td>Measured Central Length of ( \text{l}_{UC} ) (mm)</td>
<td>Measurement Uncertainty ((k = 2) ) (( \mu \text{m} ))</td>
<td>Variation (( \mu \text{m} ))</td>
</tr>
<tr>
<td>50</td>
<td>0.04</td>
<td>50.0004</td>
<td>0.03</td>
<td>0.05</td>
</tr>
</tbody>
</table>

The calibration of gauge blocks of the highest accuracy class using the gauge block interferometer is carried out by directly comparing the actual length of the gauge block in laboratory conditions (more precisely, in ambient conditions of temperature, relative humidity, pressure within interferometer housing case during measurement) with the wavelength laser radiation representing the standard for measurement traceability.

The calibration of a gauge block of lower accuracy class is carried out on a comparator for gauge blocks by the method of comparing the central length of the reference gauge block (known from the calibration certificate) and the central length of the gauge block under calibration. The
A reference gauge block can be directly interferometrically measured, or linked by one or several comparisons with the reference gauge block interferometrically measured. The data on the central length of the gauge block is used to ensure the traceability of the measurement results.

The comparison method can also be used to determine the variation in the length of the gauge block. The length variation represents the difference between the maximum and the minimum gauge block measured values in the four angles of the measuring surface (deviations from the central length) and it is always a positive value. Practically, the variation of a gauge block indicates the deviation from the ideal parallelism of its measuring surfaces. Measurement traceability is not achieved through it.

Usually in the calibration certificate, in addition to columns 1 and 4 (5), only one of the columns, 2 or 3 (starred) is used to display the calibration results. The indications of the measured length of the examined gauge blocks in columns 2 and 3 are equivalent.

The **1st column** presents the nominal length of the gauge block, as indicated on the standard.

The **2nd column** presents the measured deviation of the central length of the gauge block under calibration from its nominal length (error). The most common term used in the calibration certificate is deviation, and not the term error.

*Note: The correction value, i.e. the negative value of the error/deviation, is not provided in the Calibration Certificate, since the term correction, refers to the deviation of the measured value from the actual value and not to the deviation from the nominal value.*

The **3rd column** provides the measured value of the central length of the gauge block under calibration (l_uC, item under calibration).

It is noted that the measured length (deviation) of the gauge block is always provided at a reference temperature T=20 °C, using the value of the coefficient of linear thermal expansion of the construction material of the gauge block (stainless steel in most cases).

The **4th column** presents the expanded uncertainty, namely at 95% confidence level, which is associated with the measured value (presented in the 2\textsuperscript{nd} column) of the length of the gauge block.

The **5th column** presents the variation of the length of the gauge block.

In the case of the calibration of an entire set of gauge blocks, it is common, that the measurement uncertainty is presented outside the table in the form of a linear equation as a function of the measured length, as in the following examples:

\[
U = (0.02 + 0.20 \times L) \ \mu m \ (L \ in \ m) - \text{interferometric method, or}
\]

\[
U = (0.05 \ \mu m + 0.5 \times 10^{-6} \times L) \ (L \ in \ mm) - \text{first order of the comparison method}
\]
In general, the measurement uncertainty can be displayed in nanometres, nm, and also in micrometres, μm.

Each calibration certificate should also include data for the coefficient of linear thermal expansion of the construction material of the gauge block. This coefficient is used to reduce the calibration results to any temperature. The value of the coefficient of linear thermal expansion is provided in the following form (this specific example is for stainless steel):

Coefficient \( \alpha = (11.5 \pm 1) \times 10^{-6} \, ^\circ C^{-1} \)

**3.10.2. Formal expression of the results**

The calibration result for a single gauge block is expressed as in the table above and can be presented as follows:

Measured length \( L = 50 \, mm + 0.03 \, \mu m = 50 \, mm + 30 \, nm = 50.00003 \, mm \)

Measurement uncertainty \( U(L) = 0.04 \, \mu m = 40 \, nm \)

In the case of a set of gauge blocks, the result of the calibration is expressed as in the table above with one of the columns 2 or 3, and the measurement uncertainty expressed in the form of the above linear equation as follows:

\[ U(L) = a + b \cdot L \]

Where:
\( a \) - components of uncertainty that do not depend on the measured length
\( b \) - uncertainty components that depend on the measured length

**3.10.3 Use and interpretation of calibration results**

**3.10.3.1 Conformity Assessment**

The most important information on the gauge block obtained by the calibration is the value of its central length at 20 °C with its associated measurement uncertainty. In order to assess the compliance with the requirements of ISO 3650 regarding to the accuracy class, it is necessary to take into account the measurement uncertainty. A reliable confirmation of the accuracy class is only possible if the measurement uncertainty is within the tolerances and if the other requirements of ISO 3650 are met, namely dimension of the gauge block, material properties, stability, parallelism and topography of measuring surfaces, etc.). If the measurement uncertainty and the established tolerances (the permissible error limits) are of the same order of magnitude (in the example table: measured deviation from the nominal length of 40 nm, measurement uncertainty 30 nm, tolerance 50 nm), the accuracy class of the gauge block cannot be clearly determined.

The length variation is usually measured only by the comparison method on the comparator. The measurement of the length variation in the four angles of the gauge block gives the result of measurement with only an approximate statistical probability, since the maximum variation in
length does not necessarily have to appear in the four measured angles. Therefore, the length variation data can be used to check the quality of the gauge block, but it is not suitable for the determination of the accuracy class of the gauge block with metrologically satisfactory accuracy, namely with low measurement uncertainty.

The most valuable and useful information provided by a calibration for a gauge block, is its central length with the associated measurement uncertainty.

From all of the above, it follows that there is no metrological sense to use the gauge block only with information if it meets or not, some of the requirements for accuracy classification according to ISO 3650. Formally, information on compliance with an accuracy class is not metrologically relevant. Since the measured value of the central length is presented in the calibration certificate, it is irrelevant from the metrological point of view if the tolerances are met or not.

The main requirement of ISO 3650 (Compliance Assessment) to be considered is maximum permissible variation in the central length of the gauge block within one year. This information indicates the stability of the construction material of the gauge block in time. If the change in the length of the gauge block is higher than the change stated in the standard, while the standard has no visible damages, it is very likely that the material is not well thermally processed and in this respect this gauge block has to be replaced. This kind of evaluation, however, can be only made on the basis of repeated calibration, which lead to an appropriate calibration history of this gauge block.

3.10.3.2 Use and interpretation of measurement uncertainty

The tolerance values for the central length and the length variation for the gauge block of the nominal length of 50 mm and the accuracy class K according to the ISO 3650 standard are provided as follows:

For centre length: ± 0.2 μm or ± 200 nm.

For variation of length: 0.05 μm or 50 nm.

The values obtained through the calibration (table from the example) are as follows:

Central length: 40 nm.
Measurement uncertainty: 30 nm.
Variation: 50 nm.

From the example, it can be seen that the gauge block meets the tolerance requirements for the accuracy class K when it comes to the central length of the gauge block. However, when it comes to the length variation (which also defines a class of accuracy), the situation is not so simple anymore. If the measurement uncertainty and the established tolerances, according to a standard of the same order of magnitude, are the same, like in our case, the accuracy class of the gauge block cannot usually be clearly defined.

It is noted that much more important than making a classification to a certain accuracy class, is the question of whether the gauge block can be calibrated without limitations, such as presence of
scratches or corrosion and spots on measuring surfaces, wear, reduced adhesion and reflection properties, especially in the central part of the measuring surfaces.

The most important measurement data in the calibration certificate of the gauge block is its calibrated central length with the associated uncertainty. The information on accuracy classification in the calibration certificate is information that refers to the quality of the production of a gauge block than it has a larger, from the metrological point of view, practical value. The same applies to the length variation data obtained by the comparison method on the comparator.