Letter from Europe

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Accuracy, Precision and Trueness of Measurement Procedures

The Role of Reference Materials

Accuracy, precision, and trueness are important aspects of all measurements. This Letter outlines these themes on the basis of a guideline on "the assessment of the trueness of a measurement procedure by use of a reference material," published by EUROLAB in its *COOK BOOK* www.eurolab.org.

Background

The terms *accuracy*, *trueness* and *precision* are defined in *ISO 5725* and discussed in the chapter on *Uncertainty and Accuracy* of the Springer *Handbook of Metrology and Testing* (Springer 2011). Accuracy as an umbrella term generally means the agreement of a measurement result with the "conventional" true value. For a series of repeated measurements, accuracy can be split up into trueness and precision.

- Precision characterizes the dispersion between the single results.
- Trueness characterizes the difference between the mean value of the series and the "conventional" true value.

Precision strongly depends on the conditions under which measurement results are obtained.

Repeatability conditions mean that all parameters are kept as constant as possible, e.g.,

a. the same measurement procedure
b. the same laboratory
c. the same operator
d. the same equipment
e. repetition within short intervals of time

Reproducibility conditions imply those conditions for a specific measurement that may occur between different laboratories, e.g.,

a. the same measurement procedure
b. different laboratories
c. different operators
d. different equipment

Intermediate conditions have to be specified regarding which factors are varied and which are constant. For within-laboratory reproducibility the following conditions are used:

a. the same measurement procedure
b. the same laboratory
c. different operators
d. the same equipment (alternatively, different equipment)
e. repetition within long intervals of time

While the evaluation of the precision of a measurement procedure (under repeatability conditions) is rather straightforward for a laboratory, the trueness of the procedure is more difficult to assess. Reference materials or reference objects play an important role in the assessment of the trueness of a measurement procedure.

Reference Materials

The definitions of reference materials are given in ISO Guide 30:

- *Reference Material (RM)*: Material or substance one or more of whose property values are sufficiently homogeneous and well established to be used for the calibration of an apparatus, the assessment of a measurement method, or for assigning values to materials.
- *Certified Reference Material (CRM)*: reference material, accompanied by a certificate, one or more of whose property values are certified by a procedure which establishes its traceability to an accurate realization of the unit in which the property values are expressed, and for which each certified value is accompanied by an uncertainty at a stated level of confidence.

Examples of brands for certified reference materials provided by specific RM-producers are: Standard Reference Material SRM® (certified reference material provided by NIST) and European Reference Material ERM® (certified reference material provided by the ERM co-operation).

Reference materials can be categorized according to a variety of criteria, e.g. field of application, form of material, matrix type, intended use in the measurement process and specified properties. The categorization according to the specified properties is useful for a general overview. Reference materials are available for the following categories of specified properties:

A. **Chemical composition**
Reference materials (RMs), being either pure chemical compounds, mixtures thereof, or representative sample matrices, either natural or with added analytes, characterized for one or more chemical or physicochemical properties, e.g. metal RMs (ferrous/non-ferrous and their alloys), environmental RMs (soil, water, biological materials), gases, solutions (e.g. pH buffers).

B. **Biological and clinical properties**
Materials similar to Category A, but characterized for one or more biochemical or clinical functional property, e.g. catalytic activity of an enzyme, taxonomic identity of a microorganism.

C. **Physical properties**
Materials characterized for one or more physical properties, e.g. optical properties (refractive index, spectral absorbance), electrical/magnetic properties (e.g. dielectric strength, magnetic susceptibility), radioactivity, thermodynamic properties (e.g. thermal conductivity, thermal resistance), physicochemical properties (e.g. viscosity, density).

D. **Engineering properties**
Materials characterized for one or more engineering properties, e.g. sizing, hardness, tensile strength, surface characteristics, impact hardness, elasticity, etc.

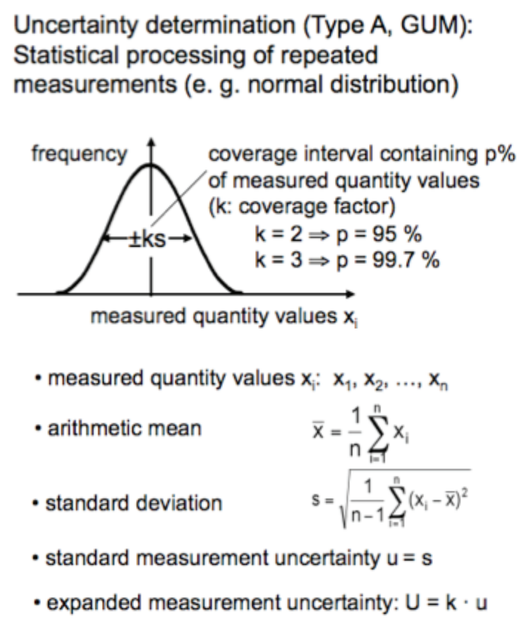
E. **Others**
E.g. materials to determine quality properties of wheat flour like water absorption, processing and dough characteristics.

The following pictures illustrate the broad variety of reference materials and indicate their importance for technology, economy, society and trade.

Measurement Procedure and the Assessment of Trueness

Measurement begins with the definition of the measurand, the quantity intended to be measured. The specification of a measurand requires knowledge of the kind of quantity and the characteristics of the object carrying the quantity. When the measurand is defined, it must be related to a measurement standard, the realization of the definition of the quantity to be measured. The measurement procedure is a detailed description of a measurement according to a measurement principle and to a given measurement method. It is based on a measurement model, including any calculation to obtain a measurement result. The basic features of a measurement procedure are the following:

- Measurement principle: the phenomenon serving as a basis of a measurement
- Measurement method: a generic description of a logical organization of operations used in a measurement
- Measuring equipment: a set of one or more measuring instruments calibrated to a measurement standard to give information used to generate measured quantity values within specified intervals for quantities of specified kinds.
- Measurement uncertainty: a nonnegative parameter characterizing the dispersion of the quantity values being attributed to a measurand. A basic method to determine uncertainty of measurements the Guide to the expression of uncertainty in measurement (GUM)



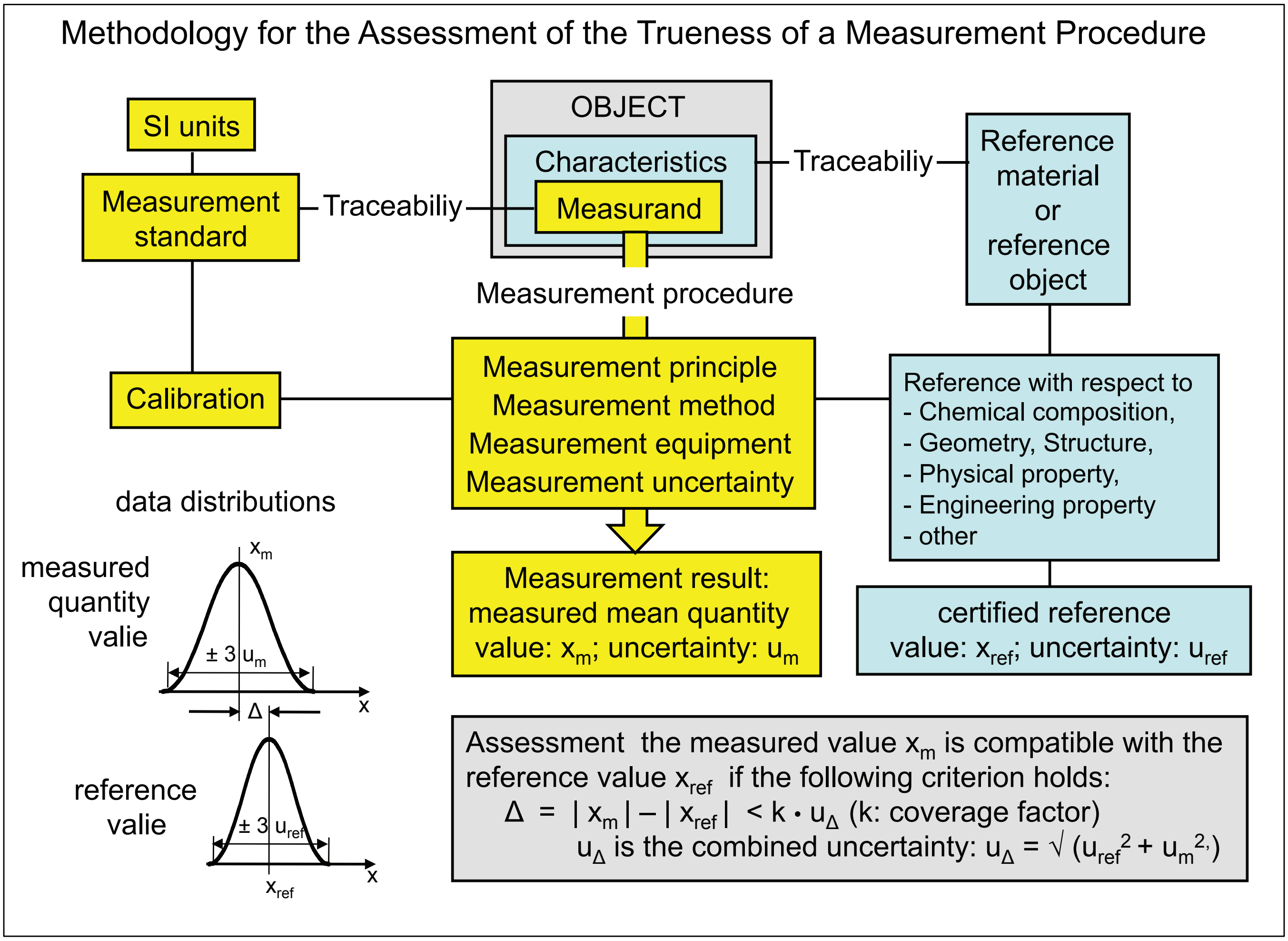
- Measurement result: the result of a measurement has to be expressed as a quantity value together with its uncertainty, including the unit of the measurand.

An assessment of the trueness of a measurement procedure can be made if a "certified" reference material is available whose reference quantity can be measured with the measurement procedure in question:

1. The reference quantity of the RM is measured n times providing the single measured quantity values x_i, the mean value x_m, the standard deviation s, and the standard measurement uncertainty u = s.
2. The absolute value of the difference Δ between the certified reference value x_{ref} and the mean measured value x_m is determined: $\Delta = |x_m| - |x_{ref}|$.

3. The difference Δ is compared with the uncertainty u_Δ, which is the combined uncertainty of the reference value u_{ref}, taken from the certificate and the uncertainty of the measured mean value u_m.
4. The measured mean x_m value is compatible with the reference value x_{ref} (i.e. there is no experimental evidence for a bias), if Δ is smaller than $k \bullet u_\Delta$, where k is the coverage factor, which is usually chosen as $k = 2$, which corresponds with a confidence interval of the uncertainty of approximately 95 %.

The methodology of the assessment of the trueness of a measured procedure by use of a reference material is depicted in the following box.



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