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Calibration of a road tanker loading rack
in a fuel storage plant

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JEAN-FRANÇOIS MAGANA
BIML DIRECTOR

OIML Strategic Plan

Following the discussions held in Cape Town on the OIML Long-Term Strategy and Action Plan and taking into account additional comments sent in by Members since that meeting, Alan Johnston (CIML President) has finalized and adopted the *OIML Strategic Plan*.

The Plan provides the OIML with a very clear vision of its orientations and priorities for the coming years, notably highlighting the following key objectives:

- Strive towards building a Global Legal Metrology System,
- Support all legal metrology stakeholders,
- Facilitate domestic and international trade in measuring instruments, goods and commodities,
- Facilitate a wider exchange of knowledge and skills between OIML Members,
- Facilitate the participation of Developing Countries and better reflect their needs in OIML work, and
- Improve the overall efficiency of OIML technical work.

Based on this Strategic Plan, a detailed Action Plan has also been drawn up; it will be submitted to the CIML for approval at its 42nd CIML Meeting this coming October in Shanghai.

This Strategic Plan is essentially an internal OIML working document, but it is also an important tool that we can use in our regular awareness-raising mission concerning legal metrology as a whole. ■

Plan Stratégique de l'OIML

A la suite des discussions tenues à Cape Town sur la Stratégie à long terme et le Plan d'Action de l'OIML, et en prenant en compte les commentaires complémentaires adressés par les Membres depuis cette réunion, le Président du CIML, Alan Johnston, a finalisé et adopté le *Plan Stratégique de l'OIML*.

Ce plan donne à l'OIML une vision très claire de ses orientations et priorités pour les années à venir, en particulier en soulignant les objectifs clés suivants:

- S'attacher à la construction d'un Système Global de Métrologie Légale,
- Apporter un soutien à toutes les parties concernées par la métrologie légale,
- Faciliter le commerce national et international d'instruments de mesure, de biens et de marchandises,
- Faciliter un plus large échange de connaissances et de compétences parmi les Membres de l'OIML,
- Faciliter la participation des Pays en Développement et mieux répondre à leurs besoins dans les travaux de l'OIML, et
- Améliorer l'efficacité globale des travaux techniques de l'OIML.

Sur la base de ce Plan Stratégique, un Plan d'Action détaillé a également été préparé; il sera soumis à l'approbation du CIML lors de sa 42ème réunion en octobre prochain à Shanghai.

Ce Plan Stratégique est essentiellement un document de travail interne de l'OIML, mais il est aussi un outil important que nous pouvons utiliser dans notre mission de sensibilisation à la métrologie légale. ■

Problems in calibrating standard capacity measures for liquids other than water

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Abstract

The periodic verification of measuring systems for legal volumes of liquids is, generally, more complex than the corresponding laboratory calibration because of the necessity to operate directly in field, without disconnecting the meter from the distribution network. For this reason, guaranteeing a lower uncertainty than the tolerance limits prescribed by the various applicable international standards is often difficult.

This paper describes the principal methods (gravimetric and volumetric) for the calibration and verification of standard capacity measures used in the legal control of volumetric meters for liquids other than water, widely used for measuring volumes in commercial transactions and in the fiscal checking of oil products. It also describes the hierarchy of standard capacity measures that guarantees traceability to national standards and that transfers the unit of volume measurement to the primary standards owned by the local metrology authority (CCIAA), and to the working standards used in the field by the authority itself or by the laboratories that maintain and service the measuring systems.

This paper was presented at the 2003 ATI (Associazione Termotecnica Italiana - Italian Thermotechnics Engineers' Association) Symposium.

1 Introduction

Accurate measurement of the mass and volume flowrate of liquids is a widespread and key requirement in many sectors such as the provisioning and distribution of water, the production and trade of hydrocarbons, and the various needs of the chemical, petrochemical and energy industries. The quantities and flowrates of the liquid have to be measured both for commercial purposes, and also to ensure the correct operation of production and distribution plants for raw materials.

Despite the existence of various different methods for measuring the flowrate, the meters currently used for the fiscal measurement of liquids other than water are volumetric meters (positive displacement flowmeters). These instruments, which have been in existence since the end of the nineteenth century, have witnessed further development over recent years when various modern design technologies were introduced. Besides, the development of electronic technology has led to the introduction of instruments equipped with microprocessors which are capable of displaying the measurement results directly expressed in the reference condition, without the need for further calculations or corrections.

A positive displacement volumetric meter continuously splits the measured flow into segments of known volume, momentarily isolating these from the input (upstream) flow and subsequently returning them to the output (downstream) flow, counting the total number. The measured volume can be directly visualized or, eventually, transmitted to a distant monitoring station. This setup can be subdivided into four essential components:

- a cover or external case (single or double), with fortified flanges for connection to the distribution network;
- a measurement element (see Fig. 1);
- a system for transmitting the calculation (mechanical gearings or electromagnetic couplings);
- a calculation unit (mechanical or electronic).

The metrological characteristics of traditional volumetric meters are summarized in Table 1.

The oil products distribution industry and the activity of fiscal checking of commercialized hydrocarbon volumes require the use of suitable volumetric meters that are type approved or certified by the competent national legal metrology authority. The tolerance requirements of these measuring systems are normally checked by the local legal metrology authorities by means of suitable test facilities, including suitable capacity measures whose requirements are defined by the appropriate legal provisions (see Table 2).

This paper deals briefly with such standards, and also Italian legislation and OIML Recommendations relative to meters for liquids other than water; it discusses capacity measures utilized in the initial and periodic verifications of such meters. Specific procedures for the management of the calibration of the capacity measures, and for the methods of error and uncertainty calculations, are proposed and analyzed.

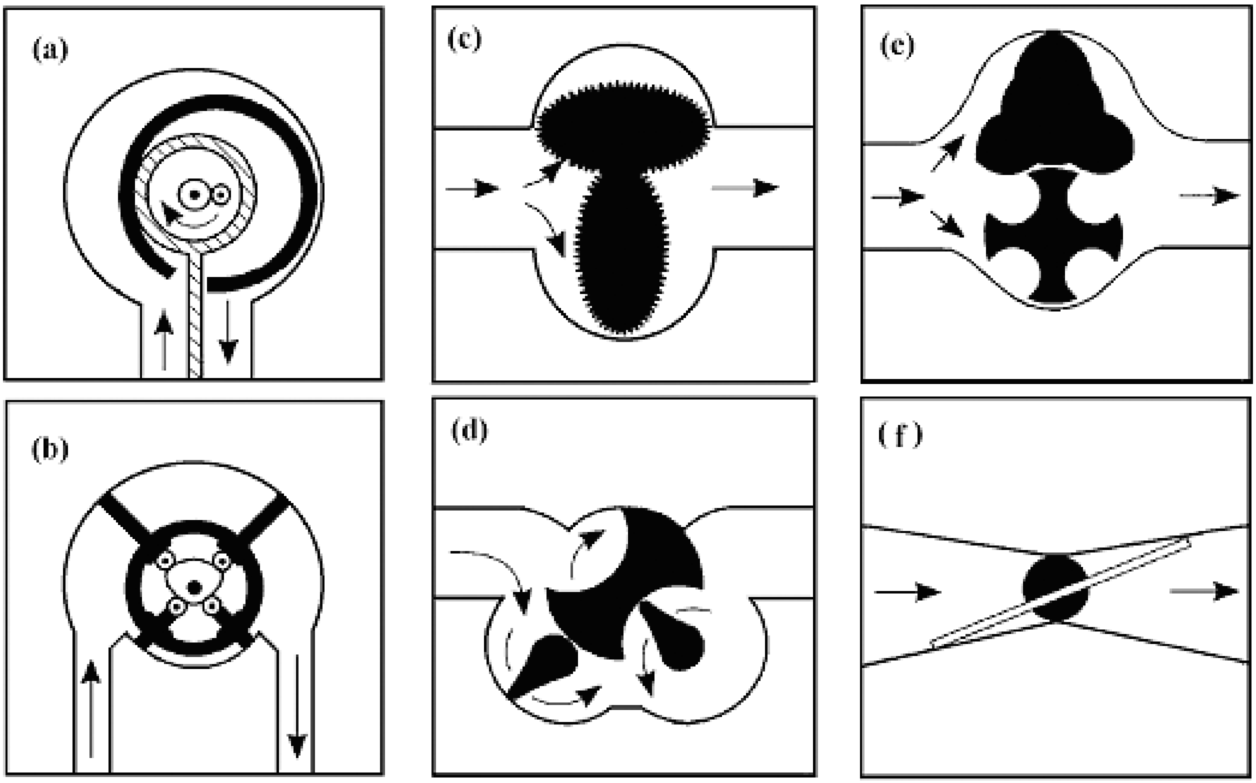

Fig. 1 The most common elements to measure liquids other than water:
a) with rotary piston, b) with shovels, c) with lobes, d) with tri-rotor, e) with bi-rotor, f) with nutating disc.

Table 1 Metrological characteristics inherent in meters for measuring liquids other than water

Advantages	Limits
• Wide measurement range • Better reliability and precision • Negligible effects of installation • Guarantee against fraud • Resistance to corrosion • Low sensibility to temperature and pressure variations	• Different drawings for different viscosity of the fluid (different calibration curves for different fluids) • Correction of the density of the fluid is needed • Sensibility to impurities and to gas bubbles in the liquid (a filter and a gas eliminating device are needed) • Large pressure losses • Typical stability of each measuring system according to the parts which are in motion • Non linear characteristic varying with the flowrate (can be made linear with electronic heads)

Table 2 List of Directives relevant to meters for measuring liquids other than water and to standard capacity measures

Directive	Approved	Object
R.D. no. 7088/1890	23 August 1890	Testo Unico delle leggi sui pesi e sulle misure
R.D. no. 226/1902	12 June 1902	Regolamento per la Fabbricazione dei Pesi e delle Misure per Pesare e per Misurare
R.D. no. 242/1909	31 January 1909	Regolamento sul servizio metrico
DPR no 1215/58	12 November 1958	Modificazioni e aggiunte al Regolamento per la fabbricazione dei pesi, delle misure a degli strumenti per pesare e misurare (R.D. no. 226/1902)
Law no. 33/67	31 January 1967	Ammissione alla verificazione metrica delle misure per oli minerali in genere ed altri liquidi della capacità di 5,10, 20, 25, 50 e 100 kL
71/319/CEE	26 July 1971	Riavvicinamento delle legislazioni degli Stati membri relative ai contatori di liquidi diversi dall'acqua
71/348/CEE	12 October 1971	Riavvicinamento delle legislazioni degli Stati membri relative ai dispositivi accessori per contatori di liquidi diversi dall'acqua
77/313/CEE	5 April 1977	Riavvicinamento delle legislazioni degli Stati membri in materia di complessi di misurazione per liquidi diversi dall'acqua
DPR no.736/82	12 August 1982	Implementation of Directive CEE 319
DPR no.737/82	12 August 1982	Implementation of Directive CEE 348
DPR no.856/82	23 August 1982	Implementation of Directive CEE 313
Law 236/91	29 August 1991	Modifica alle disposizioni del Testo Unico dei pesi e misure
DM 179/2000	28 August 2000	Nuove disposizioni su verifica prima
DM 182/2000	28 August 2000	Nuove disposizioni su verifica periodica

2 Initial and periodic verification of meters for measuring liquids other than water

Current Italian standards impose that all fuel meters (and therefore not all meters for measuring liquids other than water) used in commercial transactions must be subject to two verification tests: (i) the "initial verification" is carried out by the manufacturer or by the Legal Metrology Authorities (the *CCIAA*'s) and in an on-site situation before the meter is put on the market and (ii) "periodic verification" takes place, subsequently, in the field to verify the maintenance of the metrological characteristics.

2.1 Initial verification

Initial verification is obligatory for instruments before their sale or use in trade, and results in the apposition of a material seal (the first, a coat of arms, stating the number identifying the verification office, and the second stating the number identifying the inspector that performed the tests).

In Italy, the obligation to verify and render measuring instruments subject to legal control was introduced with the *"Testo unico delle leggi sui pesi e sulle misure"*, integrated, subsequently in 1902, by the *"Regolamento per la fabbricazione dei pesi e delle misure per pesare e per misurare"* and, in the last 30 years, modified by the European Directives acknowledged by a special D.P.R. (see Table 2). The Italian law 236/91, which modifies the *"Testo unico delle leggi sui pesi e sulle misure"*, allows instrument manufacturers to verify and legalize their own instruments in an autonomous manner. This possibility was confirmed when the Minister for Industry issued a special rule in the *Decree of 28 March 2000, no. 179*, putting into effect the above-mentioned law and laying down specifications for initial verification in accordance with principles guaranteeing the quality of production instruments in accordance with procedures for ensuring metrological conformity. It is important to note that, for the first time, the concept of mutual recognition was introduced in an Italian Legal Metrology Decree.

In Table 3 the maximum permissible errors (MPE) given in the standards for the verification of meters for measuring liquids other than water (for volumes over 2 L) are given. The MPEs allowed in Italy and in the European Union for the verification of fuel meters are equal to 0.3 % reference volume (R.V.) for the meter, and to 0.5 % R.V. for the whole measurement system.

Table 3 Maximum permissible errors for the verification of meters for measuring liquids other than water, for volumes not less than 2 L [1]

	Accuracy class				
	0.3	**0.5**	**1.0**	**1.5**	**2.5**
A (*)	0.3 %	0.5 %	1.0 %	1.5 %	2.5 %
B (*)	0,2 %	0.3 %	0.5 %	1.0 %	1.5 %

(*): **Line A:** Complete measuring systems for type approval, initial verification and subsequent verification. This applies to all liquids under all operating conditions (temperature and pressure), and for all flowrates for which the system is intended to be approved or has been approved.
Line B: Meter and volume indicator, for type approval and initial verification. This applies to all liquids, under all operating conditions (temperature and pressure), and for all flowrates for which the system is intended to be approved.

2.2 Periodic verification

With regard to periodic verification, the EU standards leave to the Member States the option to execute the appropriate controls to verify the metrological characteristics and to fix their criteria and periodicity. In some European States, these controls do not have a fixed periodicity; in others, instruments used notably in consumer trade have be inspected for example annually. In Italy, periodic verification was modified and integrated by Decree no. 182 (28 March 2000), which introduced substantial innovations in comparison with the previous standards, establishing a two-yearly verification periodicity for fuel dispenser systems and four-yearly for measurement systems for liquids other than fuel and water. The possibility to delegate, under certain conditions and pre-established formalities, periodic verifications to laboratories accredited by the Chamber of Commerce and operating in conformity to UN CEI EN ISO/IEC 17025 [2], is a further innovative element. Such delegation is surely an important aspect in legal metrology in Italy, because controls on the operation of instruments have always been the exclusive competence of the legal inspectors (whose work and powers have recently been transferred to the Chamber of Commerce).

The MPEs on periodic verification are equal to those on initial verification, unlike other types of instruments whose MPE is generally fixed as being equal to twice that on initial verification [1].

3 Problems in calibrating volumetric standards (standard capacity measures)

The calibration of a volumetric standard basically consists in determining the volume (or the correction with respect to the nominal volume) of the standard's internal volume, as well as in evaluating the uncertainty on such a volume. Theoretically, in order that the data drawn by the calibration operations may have maximum correspondence with the future use of the instrument, the same calibration is performed under real operating conditions, i.e. within the operating temperature range, and using the same test liquid. In practice, because of the variability of the fuels used and the procedural complexity in calibrating using toxic and/or inflammable fluids, water has always been used as the test fluid.

Since the MPE of fuel measuring systems on periodic verification is within 0.3 %, such verifications can be carried out only with volumetric standards having an uncertainty lower than 1/3 of the MPE, i.e. lower than 0.1 % R.V. Such characteristics can be obtained only with primary facilities, or by performing the verification with volumetric standards prescribed by national legislation (Law no. 33/67) and OIML R 120 with an MPE lower than 0.04 % R.V. and 0.05 % R.V. [3], respectively.

However, to obtain the above low level uncertainties it is necessary to:

i) Periodically verify the volumetric standards, setting a precise hierarchy that guarantees their traceability to national standards; and
ii) Use suitable procedures for the calibration, for the error calculation and for the test uncertainty level definition.

The standard volumetric calibration uncertainty is an often neglected, but unfortunately rather binding factor. In Italy, unless one directly refers to the Italian National Measurement Institute (MPI G. Colonnetti), calibration of volumetric standards from 10 L to 2000 L and from 2000 L to 25000 L is possible only with an uncertainty of 0.03 % R.V. and 0.035 % R.V. respectively (with a coverage factor k = 2). These uncertainties, which are only slightly lower than the MPE, certainly make the realization of an internal standard hierarchy, beginning from a single capacity, critical, because of the inevitable increase in the calibration uncertainty.

The geometric, gravimetric [4] and volumetric (or comparative) methods [5] are those that are currently used for standard capacity measure calibration. The first, based on the geometric measurement of the internal capacity dimensions, is used only for large and geometrically regular containers (e.g. gasometers). The gravimetric method is based on weighing the pure water apparent mass (with known density) necessary to fill (to empty) the capacity standard up to a reference level marked on it. This method is generally used in the laboratory to measure small or average capacities and is certainly the most accurate one. Finally the volumetric method, used for cisterns, reservoirs and capacities, is based on the comparison of the volume readings of a fluid (generally de-ionized water) decanted from the standard to the capacity under test, or vice versa. In this paper the authors exclusively refer to the gravimetric and volumetric methods.

3.1 The gravimetric method

The gravimetric method consists, as mentioned above, in the measurement of the filling liquid mass; to do this the use of water with laboratory quality degree (type III or IV), with conductivity not above $1 \cdot 10^{-4}$ S/m and free from dissolved gas and heavy metals, is sufficient. The measurement of the mass is carried out in air and is corrected considering both the buoyancy force and the effects produced by the variations in the reference temperature. Figure 2a shows a flow chart related to the gravimetric calibration procedure.

Environmental test conditions are, generally, equal to 20 °C (with a maximum oscillation of 2 °C and a maximum time variation of 1 °C/h) and to 50 ± 10 % R.H., although the tests can also be carried out at different temperatures and relative humidity (between 15–30 °C and 35–65 % R.H.) [6]. However, it must be underlined that the reference condition t_0 is different for each liquid tested, in particular for oil and alcohol based products where the temperature is set to 15 °C.

The mass measurement in air is generally carried out with the *double simple substitution method,* with the aim of minimizing the non-linearity and drift effects of the electronic balance used. The net water mass measurement in air (corrected for the buoyancy force) is given by the equation:

$$\rho_w V_{T0}\left[1+\beta_T\left(t_T-t_0\right)\right]\cdot\left(1-\frac{\rho_a}{\rho_w}\right)=\left(m_F-m_E\right)\cdot\left(1-\frac{\rho_a}{\rho_m}\right) \qquad (1)$$

from which, considering the relationship between the real and the conventional mass:

$$\left(m_F-m_E\right)-\left(m_{FC}-m_{EC}\right)\left[\frac{\left(1-\frac{\rho_{as}}{\rho_{mas}}\right)}{\left(1-\frac{\rho_{as}}{\rho_m}\right)}\right]=0.99985\cdot\frac{\left(m_{FC}-m_{EC}\right)}{\left(1-\frac{\rho_{as}}{\rho_m}\right)} \qquad (2)$$

Combining equations (1) and (2) the volume V_0 can be obtained as:

$$V_{T0}=\frac{0.99985}{\left(\rho_w-\rho_a\right)}\cdot\frac{\left(m_{FC}-m_{EC}\right)}{\left[1+\beta_T\left(t_T-t_0\right)\right]}\cdot\frac{\left(1-\frac{\rho_a}{\rho_m}\right)}{\left(1-\frac{\rho_{as}}{\rho_m}\right)} \qquad (3)$$

Equation (3), in the particular case $\rho_a = \rho_{as}$, can be simplified as:

$$V_{T0}=\frac{0.99985}{\left(\rho_w-\rho_{aS}\right)}\cdot\frac{\left(m_{FC}-m_{EC}\right)}{\left[1+\beta_T\left(t_T-t_0\right)\right]} \qquad (4)$$

To evaluate the V_{T0} uncertainty, equation (3) can be approximated to:

$$V_{T0}=0.99985\cdot\frac{\left(m_{FC}-m_{EC}\right)}{\left(\rho_w-\rho_a\right)}\left[1-\frac{\rho_a-\rho_{aS}}{\rho_m}-\beta_T\left(t_T-t_0\right)\right] \qquad (5)$$

Equation (5) is the functional relationship used for the standard capacity volume evaluation.

Equation (5) presents the advantage of easily identifying the most important calibration uncertainty contributions, which can be summarized in the uncertainties in:

- the measurement of the conventional net mass $u(\Delta m)$;
- the density of the water $u(\rho_w)$, of the air $u(\rho_a)$ and of the mass $u(\rho_m)$;
- the capacity cubic expansion coefficient $u(\beta_T)$;
- the temperature measurement $u(t)$;
- the calibration procedure (preparation, dissolved air, etc.) $u(p)$ (this can be considered as negligible in good laboratory practice).

Applying the uncertainty propagation law [7], the combined standard uncertainty related to the test volume VTO is:

$$u_C^2=\sum_i c_i^2\cdot u^2\left(x_i\right) \qquad (6)$$

Fig. 2 Flow chart related to the gravimetric (a) volumetric (b) calibration procedure.
SC = Standard Capacity, UTC = Capacity Under Test

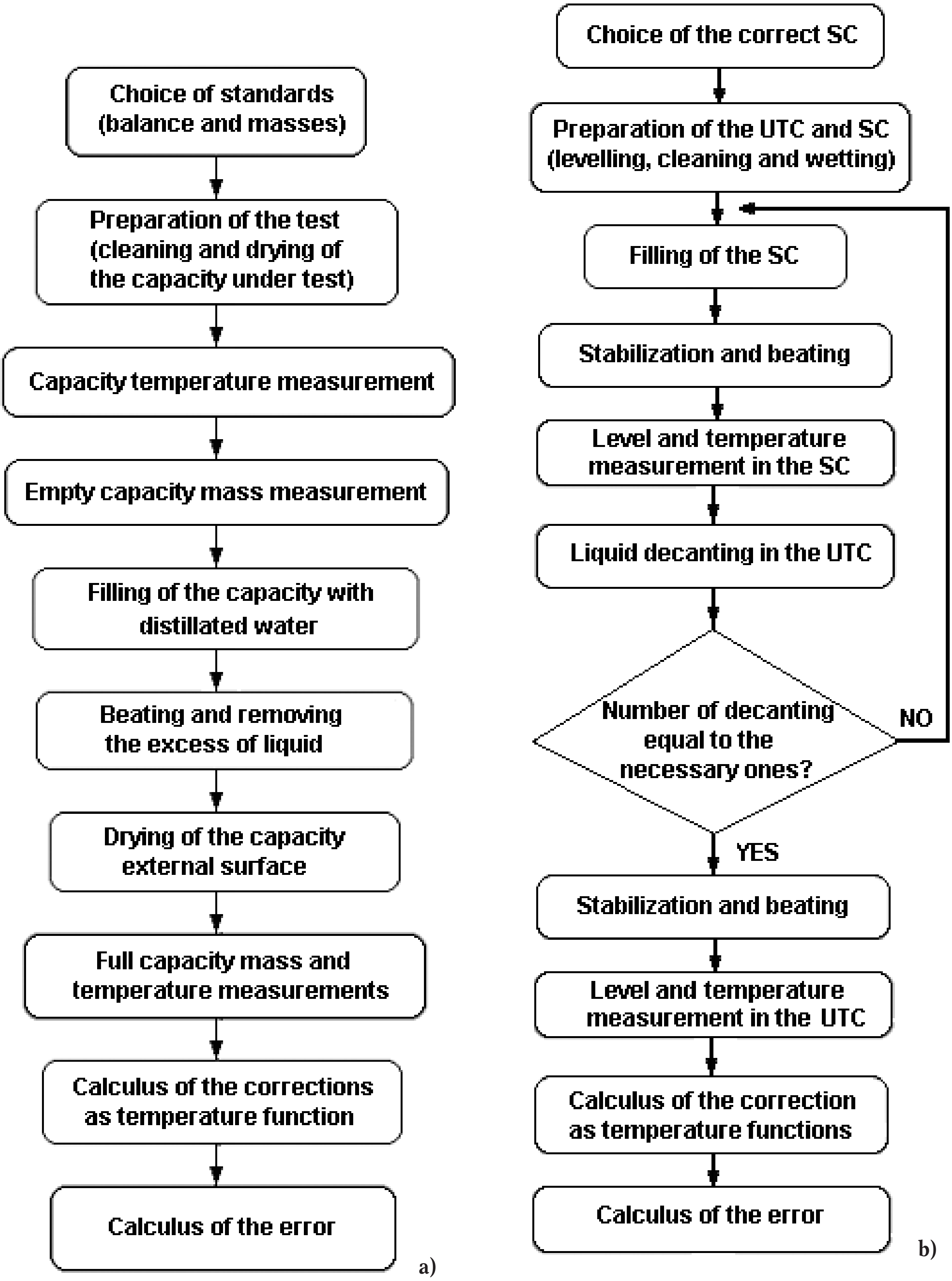

Table 4 Sensitivity coefficients in the gravimetric uncertainty evaluation method

x_i	$c_i = \partial V_{T0}/\partial x_i$	c_i (approximated values)
Δm	$\frac{0.99985}{(\rho_w-\rho_a)}\left[1-\frac{\rho_a-\rho_{aS}}{\rho_m}-\beta_T(t_T-t_0)\right]$	$\cong\frac{1}{(\rho_w-\rho_{as})}$
ρ_w	$-0.99985\cdot\frac{(m_{FC}-m_{EC})}{(\rho_w-\rho_a)^2}\left[1-\frac{\rho_a-\rho_{aS}}{\rho_m}-\beta_T(t_T-t_0)\right]$	$\cong-\frac{(m_{FC}-m_{EC})}{(\rho_w-\rho_{as})^2}$
ρ_a^*	$0.99985\cdot\frac{(m_{FC}-m_{EC})}{(\rho_w-\rho_a)^2}\left[1-\frac{\rho_w-\rho_{aS}}{\rho_m}-\beta_T(t_T-t_0)\right]$	$\cong\frac{(m_{FC}-m_{EC})}{(\rho_w-\rho_{as})^2}$
β_T	$-0.99985\cdot\frac{(m_{FC}-m_{EC})}{(\rho_w-\rho_a)}(t_T-t_0)$	$\cong-\frac{(m_{FC}-m_{EC})}{(\rho_w-\rho_{as})}(t_T-t_0)$
t_T	$-0.99985\cdot\beta_T\cdot\frac{(m_{FC}-m_{EC})}{(\rho_w-\rho_a)}$	$\cong-\beta_T\cdot\frac{(m_{FC}-m_{EC})}{(\rho_w-\rho_{as})}$
ρ_m	$0.99985\cdot\frac{(m_{FC}-m_{EC})}{(\rho_w-\rho_a)}\frac{\rho_a-\rho_{aS}}{\rho_m^2}$	$\cong 0$

whose sensitivity coefficients c_i, related to the generic size x_i, are reported in Table 4.

3.2 The volumetric or comparative method

The comparative method essentially consists in transferring a known volume of liquid (typically de-ionized water) from a capacity standard to one to be calibrated (or vice versa). Figure 2b shows the flow chart related to the comparative calibration procedure.

Typically, two different calibration procedures for transferring volume can be distinguished: a "fine" laboratory procedure and an "ordinary" on site procedure [5]. Use of one or the other is obviously a function of the accuracy objective of the calibration.

The "fine" comparative method implies carrying out the calibration activities in closed environments (preferably with controlled temperature and relative humidity), as well as the use of charts or relationships for the water (or other liquid) density determination as a function of the temperature [8-11]. The "ordinary" volumetric procedure is used for large volume standards and requires the use of average values of both the expansion coefficient of the material used, and the test liquid density.

3.2.a The "fine" comparative method

To evaluate the calibration uncertainty in the "fine" comparative method, the most general case of this method will be examined.

The basic hypothesis is that the mass of the liquid m_T transferred to the capacity measure to be calibrated is equal to the sum of the masses of liquid contained in the reference standard m_C unless other negligible substances are present, dissolved in the liquid m_i:

$$m_T + m_i = \sum m_{Ci} + m_i \quad (7)$$

From (7) we can note that in the comparative method the presence of other substances is annulled and it is therefore possible to directly refer to the pure water properties.

The volume measurement requires, necessarily, the measurement of the possible difference between the test temperature t and the reference temperature t_0 to which the reference standard has been calibrated. This difference, in fact, produces both a variation of the test standard V_{T0} and the reference standard V_{C0} volumes and a variation of the water density ρ_w expressed by:

$$m_T = \rho_{wT} V_{T0}\left[1+\beta_T(t_T-t_0)\right] = \\ = \sum m_{Ci} = \sum \rho_{wi} V_{C0}\left[1+\beta_C(t_{Ci}-t_0)\right] \quad (8)$$

Considering that in the case examined the temperature variations during the measurement are negligible (zero average value) and consequently the variations in the density of the water filling the standard ($\Sigma_i \Delta\rho_{ci} = 0$) (neglecting the infinitesimal ones of superior order), it can be assumed:

$$\rho_{wT} V_{T0}\left[1+\beta_T\left(t_T-t_0\right)\right]= \\ =V_{C0}\bar{\rho}_{wc}\sum_i\left[1+\beta_C\left(t_{Ci}-t_0\right)\right] \qquad (9)$$

Re-writing the second part of equation (9) as:

$$V_{C0}\bar{\rho}_{wC}\sum\left[1+\beta_C\left(t_{Ci}-t_0\right)\right]= \\ =N V_{C0}\bar{\rho}_{wC}\frac{\left[N+\sum_i\beta_C\left(t_{Ci}-t_0\right)\right]}{N}= \\ =N V_{C0}\rho_{wC}\left[1+\beta_C\left(\overline{t_C}-t_0\right)\right]$$

where we have $\overline{t_C}=\frac{\sum_i t_{Ci}}{N}$, then equation (8) becomes:

$$\rho_{wT} V_{T0}\left[1+\beta_T\left(t_T-t_0\right)\right]=NV_{C0}\overline{\rho_{wC}}\left[1+\beta_C\left(\overline{t_C}-t_0\right)\right] \qquad (10)$$

from which:

$$V_{T0}=NV_{C0}\frac{\overline{\rho_{wC}}}{\rho_{wT}}\frac{\left[1+\beta_C\left(\overline{t_C}-t_0\right)\right]}{\left[1+\beta_T\left(t_T-t_0\right)\right]} \qquad (11)$$

The error in the volume measurement of the test capacity is therefore [4]:

$$E=V_{TL}-V_{T0}=V_{TL}-NV_{C0}\frac{\overline{\rho_{wC}}}{\rho_{wT}}\frac{\left[1+\beta_C\left(\overline{t_C}-t_0\right)\right]}{\left[1+\beta_T\left(t_T-t_0\right)\right]} \qquad (12)$$

where V_{TL} is the volume reading on the graduated test capacity.

To evaluate the uncertainty related to the error E, equation (12) can be expanded by the Taylor series and, neglecting the infinitesimal ones of superior order (in the hypotheses $\beta_C\left(\overline{t_C}-t_0\right)<<1$ and $\beta_T(t_T-t_0)<<1$), can be approximated to:

$$E\simeq V_{TL}-NV_{C0}\frac{\bar{\rho}_{wC}}{\rho_{wT}}\left[1+\beta_C\left(\overline{t_C}-t_0\right)-\beta_T\left(t_T-t_0\right)\right] \qquad (13)$$

To eliminate the correlations between the different temperatures measured, as well as between the thermal expansion coefficients, it is possible to use the variables $\delta\beta=\beta_T-\beta_C$ and $\delta t=t_T-\overline{t_C}=\left(t_T-t_0\right)-\left(\overline{t_C}-t_0\right)$.

Substituting them in equation (13) it is straightforward to obtain:

$$E=V_{TL}-NV_{C0}\frac{\bar{\rho}_{wc}}{\rho_{wT}}\left[1-\beta_C\delta t-\delta\beta(t_T-t_0)\right] \qquad (14)$$

Equation (14) is used to evaluate the calibration error when using the "fine" comparative method, with the advantage that this method highlights the most important uncertainties associated with the calibration itself. These uncertainties can be summarized as:

- uncertainty of the reading $u(V_{TL})$ that depends, obviously, on the capacity interval scale;
- standard uncertainty $u(V_{C0})$;
- uncertainties of the water density $u(\rho_T)$ and $u(\overline{\rho}_C)$;
- uncertainties of the capacity cubic expansion coefficient $u(\delta\beta)$ and $u(\beta_C)$;
- uncertainties of the temperature differences $u(\delta t)$ and $u(t_T)$;
- uncertainty of the calibration procedure $u(p)$ (this can be ignored for good laboratory practice).

Applying the uncertainty propagation law [7], the sensitivity coefficients c_i, associated with the generic value x_i in equation (6), are given in the second column of Table 5.

3.2.b The "ordinary" comparative method

This method can be utilized to verify large capacity measures in test plants and using a traceable standard capacity with a 5–10 smaller times nominal value.

The error E associated with the measurement can be evaluated from:

$$E=V_{TL}\cdot\left[1+\beta_T\left(t_T-t_0\right)\right]\cdot\left[1+\alpha\left(t_0-t_T\right)\right]-\sum_i V_{C0}\left[1+\beta_C\left(t_i-t_0\right)\right]\cdot\left[1+\alpha\left(t_0-t_i\right)\right] \qquad (15)$$

where $\bar{\alpha}$ is the average cubic water expansion coefficient.

Equation (15) can be simplified, and neglecting the infinitesimal terms of superior order:

$$E=\left(V_{TL}-NV_{C0}\right)+N\cdot V_{C0}\cdot\left[\left(\beta_T-\bar{\alpha}\right)\left(t_T-t_0\right)-\left(\beta_C-\bar{\alpha}\right)\left(\overline{t_C}-t_0\right)\right] \qquad (16)$$

As for equation (14), the correlations between the different measured temperatures can be eliminated, using the variables $\delta t=t_T-\overline{t_C}=\left(t_T-t_0\right)-\left(\overline{t_C}-t_0\right)$ and $\delta\beta=\beta_T-B_c$; substituting them in (16) it is straightforward to obtain:

$$E=\left(V_{TL}-NV_{C0}\right)+N\cdot V_{C0}\cdot\left[\left(t_T-t_0\right)\delta\beta+\left(\beta_C-\alpha\right)\delta t\right] \qquad (17)$$

Applying the uncertainty propagation law [7], the sensitivity coefficients c_i, associated with the generic value x_i in equation (6), are given in the third column of Table 5.

Table 5 Sensitivity coefficients in the volumetric method uncertainty evaluation

x_i	$c_i = \partial E/\partial x_i$ (fine comparative method)	$c_i = \partial E/\partial x_i$ (ordinary comparative method)
V_{TL}	1	1
V_{C0}	$-N\frac{\bar{\rho}_{wc}}{\rho_{wT}}[1-\beta_C\delta t-\delta\beta(t_T-t_0)]\cong -N$	$-N\left[1-(t_T-t_0)\delta\beta-(\beta_C-\bar{\alpha})\delta t\right]$
$\bar{\rho}_{wC}$	$-\frac{NV_{C0}}{\rho_{wT}}[1-\beta_C\delta t-\delta\beta(t_T-t_0)]\cong -\frac{NV_{C0}}{\rho_T}$	---
ρ_{wT}	$NV_{C0}\frac{\bar{\rho}_{wc}}{\rho_{wT}^2}[1-\beta_C\delta t-\delta\beta(t_T-t_0)]\cong \frac{NV_{C0}}{\rho_{wT}}$	---
β_C	$NV_{C0}\frac{\bar{\rho}_{wc}}{\rho_{wT}}\delta t\cong NV_{C0}\delta t$	$N\cdot V_{C0}\delta t$
t_T	$NV_{C0}\frac{\bar{\rho}_{wc}}{\rho_{wT}}\delta\beta\cong NV_{C0}\delta\beta$	$N\cdot V_{C0}\delta\beta$
δt	$NV_{C0}\frac{\bar{\rho}_{wc}}{\rho_{wT}}\beta_C\cong NV_{C0}\beta_C$	$N\cdot V_{C0}(\beta_C-\bar{\alpha})$
$\delta\beta$	$NV_{C0}\frac{\bar{\rho}_{wc}}{\rho_{wT}}(t_T-t_0)\cong NV_{C0}(t_T-t_0)$	$N\cdot V_{C0}(t_T-t_0)$
$\bar{\alpha}$	---	$-N\cdot V_{C0}\delta t$

4 Conclusions

The methods of measurement illustrated in this paper show that:

- The gravimetric method results are on average more accurate but this method is also more expensive and complex to realize, especially in field, than the volumetric method;
- The volumetric method is effective both in the laboratory and in field tests, guaranteeing performances fit for use in the periodic verification of standard measures;
- In calculating the volume, accurate measurements of temperature and the correction of the volumes and the expansion terms of the liquid used are always necessary (besides, in the gravimetric method further correction of the buoyancy force is necessary);
- The measurement uncertainty evaluation, despite its apparent complexity, can be notably simplified through certain approximations and the elimination of the correlations between the measured values;
- A careful and rigorous calibration procedure allows a calibration uncertainty of the standard capacities to be obtained which is fit for metrological and legal uses.

Symbols used

α_T ($\bar{\alpha}$) average cubic expansion coefficient of water;

β_T (β_C) cubic expansion coefficient of the capacity measure under test;

ρ_a air density at test temperature t_T;

ρ_{aS} standard air density (1.2 kg/m^3);

ρ_{mS} weight standard density (8 000 kg/m^3);

ρ_w water density;

ρ_m weight real density;

c_i sensitivity coefficients in the standard uncertainty evaluation $u(x_i)$.

E error of the measurement of the capacity under test, equal to V_{TL} - V_{T0};

m_{FC} conventional mass of the full capacity under test (m_F real mass);

m_{EC} conventional mass of the empty capacity under test (m_E real mass);

Δm conventional net mass measurement m_{FC} - m_{EC}

m_T liquid mass transferred to the capacity in calibration (comparative method);

m_C liquid mass contained in the standard capacity (comparative method);

m_i mass of the substances dissolved in the test liquid (comparative method);

N ratio of the nominal volumes of the capacity under test and the standard capacity;

t_T temperature of the water utilized as test liquid;

u_c combined standard uncertainty associated with the error E;

$u(x_i)$ standard uncertainty associated with the generic value x_i;

V_{TL} volume reading on the capacity under test graduated scale at temperature t_T;

V_{T0} volume of the capacity under test at temperature t_0;

V_{C0} volume of the standard capacity at temperature t_0 (comparative method);

V_{nom} nominal volume of the capacity under test.

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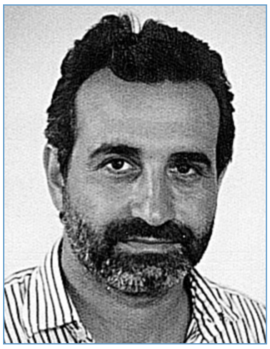

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Traceability system for breath-alcohol measurements in Germany

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Abstract

Since 1998, breath-alcohol measurements have been carried out under German traffic law, and that year saw the first type approval of an evidential breath-alcohol measuring instrument in Germany.

Over the following years breath-alcohol measurements met with considerable resistance due to drivers' fear of false positive measurement results. Now, such measurements are established for the determination of the regulatory offence of "Driving under the influence of alcohol". One of the reasons for the acceptance of this method by both drivers and the law courts is the reliability of the results, this reliability being guaranteed by the closed traceability chain from each breath-alcohol measurement to the German national breath-alcohol standard.

This paper describes the specific way in which evidential breath-alcohol measurements are made in Germany, and the traceability chain behind them.

1 Why do we measure breath-alcohol concentration?

Consumption of alcohol influences the driving capability of a person; to ascertain the degree of this influence one should employ psychological tests. For daily use, these tests are too time-consuming and expensive. As an alternative, the alcohol concentration in body fluids (breath, urine, blood, sweat) can be used to obtain a measurable quantity for drink-driving prosecutions.

As Borkenstein et al. showed in the Grand Rapids study [1] in 1964, there is a significant correlation between the alcohol concentration measured in a driver's breath and the accident risk. This study was the basis for the implementation of limits for breath-alcohol concentration in many countries all over the world. The realization of instruments fit for evidential purposes was very difficult due to three totally different scientific areas influencing evidential breath-alcohol measurements:

- Firstly there is the measurement instrumentation, which has to be capable of measuring the breath-alcohol concentration with an appropriate uncertainty.
- Secondly there is the physiology of human beings, which itself leads to various influences on a breath test.
- Thirdly there are the special requirements of the justice system - special precautions are necessary to obtain measurement results that can be used as evidence in court.

2 Legal basics of evidential breath-alcohol measurement in Germany

The advantages of measuring the breath-alcohol concentration in comparison to carrying out a blood analysis are that breath is usually always available, the measurement result is valid very shortly after, and the procedure does not cause discomfort to the subject being tested. These are the main reasons why breath-alcohol testing is used in many countries to check the influence of alcohol on drivers.

For a long time in Germany, blood analysis was the only valid method for testing alcohol content for evidential purposes. Since the 1960's, the police has been obliged to order a blood-alcohol analysis if a driver was suspected of being over the alcohol limit imposed by the traffic law. Thus after a pre-test (using a simple breath-alcohol tester) showing a non-negligible degree of alcohol content, the driver has to be taken to a doctor to take the blood sample which is then analyzed in a specialized laboratory, and the result interpreted. Blood tests are therefore time-consuming and expensive.

In 1987, the former German Health Institute (BGA) was ordered by the German government to check whether breath-alcohol measurements could be used for evidential purposes in Germany.

In 1991, the report "Evidential safety of breath-alcohol analysis" [2] was published; it concluded that breath-alcohol analysis can deliver evidential results provided that special requirements are taken into account.

Another important result was that breath-alcohol and blood-alcohol values cannot be converted into each other directly with the necessary reliable level of uncertainty. It was therefore proposed to define special limits for breath-alcohol concentration. The proposals in the report formed the basis for changing the German traffic law in 1998. Now, not only are the limits in units of blood-alcohol concentration included in the drink-driving law, but also the limits for units of breath-alcohol concentration.

In Germany, the drink-driving limits are determined in a specific way and are traced back to the understated uncertainty of forensic scientists of the 1960's. The limit is a combination of the so-called "danger limit", where the risk of having an accident reaches a certain value, and a so-called "security addition" including all the possible effects which can influence the measurement. For blood analysis, these are effects caused by sampling, by preparation of the sample and by the analysis itself.

To gain an idea of the magnitude of these limits, the value of the former legal limit was 0.8 g/kg, there was a "danger limit" of 0.65 g/kg and a "security addition" of 0.15 g/kg (note: "g/kg" is gram ethanol per kilogram blood that is "‰" or "per-mill"). Thus, if someone is over the legal limit, there is no question about a possible uncertainty of the measured value since the uncertainty is "part of the limit".

The breath-alcohol limits were determined based on the blood-alcohol limits including a "security margin". To be in line with the blood-alcohol limits, even if the legal limits change no special danger limit was proposed, but a calculation was made by means of a conversion factor and an additional security factor. Thus, the uncertainty of the measurement is also "part of the limit" for the breath-alcohol measurements.

Now, breath-alcohol measurements are mainly used for the determination of regulatory offences in Germany. Therefore, special instruments accepted for evidential measurements have to be used. If someone does not want to or is not able to give an appropriate breath sample then a blood analysis is ordered by the police. In Germany, the resulting "injury" to the body is still justified by law.

3 Requirements of evidential instruments and schedule of the measurement in Germany

The requirements of evidential breath-alcohol instruments are defined in the BGA report and in DIN 0405 [6]. They not only fulfill those of OIML R 126 [3] but go much further. The requirements include special arrangements for the instruments, for the schedule of the measurements (method and procedure of execution of measurement, etc. - see Table 2) and, last but not least, type approval and periodic verification of the instruments by verification offices.

The limits for the maximum deviation of the instruments from a reference standard during verification are based on OIML R 126. These limits (as per the verification ordinance - see Eichordnung [4]), can be found in Table 1. The limits for daily use are 1.5 times the test limits.

Table 1 Limits for the maximum deviation from a reference standard of breath-alcohol measuring instruments under test

Measured breath-alcohol concentration	Limit of deviation during tests
$c < 0.4$ mg/l	0.02 mg/l
0.4 mg/l $\le c < 1$ mg/l	$0.05 \times c$
1 mg/l $\le c \le 2$ mg/l	$0.10 \times c$
$c > 2$ mg/l	$0.20 \times c$

The requirements on instrumentation and the measurement schedule are fixed in such a way that one could attain the necessary accuracy of the results and that an intentional or unintentional manipulation is impossible. Table 2 shows the resulting requirements on evidential breath-alcohol measurements according to the BGA report.

The analysis of two breath samples (i.e. expiration time, expiration volume, breath temperature and ethanol concentration), the recalculation of the ethanol concentration according to a breath temperature of 34 °C and the comparison of all measured parameters of both samples reduce the possibility of influencing the measurements by breathing techniques to a minimum. Together with the self-control mechanism of the instrument, this ensures the integrity of the measurement.

The basic/main requirement for evidential breath-alcohol measuring instruments in Germany is the type approval and verification of the instrument by the German verification offices.

4 Realization of the traceability chain

4.1 What is the aim of traceability for breath-alcohol measurements?

One obtains results using instruments for evidential purposes that can have serious consequences for a

Table 2 Special requirements on instrumentation and measurement schedule of evidential breath-alcohol measurements according to the BGA report

What has to be secured?	Resulting requirements according to BGA
Equilibrium of alcohol in breath and blood can be assumed in the alveoli only. Thus, the analyzed sample should be end-exhaled air or "deep lung air".	Breath volume and exhaling time have to be measured. A minimum breath volume depending on age and gender should be achieved. Exhalation time has to be greater than 5 s.
Under German traffic law, "alcohol" means that only the ethanol concentration has to be determined. Other components must not influence the measurement.	During the measurement two different analytical measurands (as, for example, two different wave lengths would do for infrared analysis) have to be obtained.
Body and environmental temperature should have no influence on the measurement.	The temperature of the breath has to be measured and the measured alcohol concentration has to be recalculated for a breath temperature of 34 °C.
Mouth-alcohol or even residual alcohol in the mouth (e.g. after eating a chocolate filled with alcohol) must not influence the measurement of breath-alcohol.	The measurement should only start after a waiting time of at least 20 minutes after drinking. Following a strict protocol, two breath samples (within a time interval of 2 to 5 minutes) have to be analyzed. The resulting difference of the measured ethanol concentration must not exceed 0.02 mg/l.
Breath techniques should have no influence.	First, the flow of breath during sampling is obtained. It has to be higher than 0.1 l/s during the whole sampling. Second, the breath temperature is measured and the ethanol concentration recalculated. Third, the obtained parameters of the two breath samples (volume, time, concentration) are compared and their differences have to be within certain limits.
Substances other than ethanol (e.g. spray, sweets) in the mouth should not influence the measurement.	The measurement should only start if the subject was monitored (by the police) for 10 minutes with no ingestion.
The instrument should be valid during the whole measurement.	The instrument shall use two independent measuring systems (redundancy) and must have self-control mechanisms.

driver, which is why reliable results and low uncertainties are essential. Measurement uncertainties are not used here as is usual practice in engineering, because they are included in the "security margin" of the alcohol concentration limit. Nevertheless, they have to be determined accurately following the rules given by the GUM [5]. The determined measurement uncertainties are important for checking whether the instrument is capable of remaining within the limits given in Table 1 during the verification validity period.

It is not possible to determine a reliable result and its uncertainty if there is no traceability of the measurement to a standard with known uncertainty. So for reliable results, traceability of each evidential breath-alcohol measurement to a national standard of breath-alcohol concentration (or the SI) is essential.

Figure 1 shows the principle of how each breath-alcohol measurement carried out by the police is traced back to the national standard. The breath-alcohol measuring instruments at the police stations can only be used as evidential instruments if they are verified by the verification offices, whose verification standards are under the control of the PTB, the German National Metrology Institute. The national standard for breath-alcohol concentration is located at the PTB.

Figure 1 Principle of traceability of breath-alcohol measurements in Germany

4.2 Type approval

Before an evidential breath-alcohol measuring instrument can be used for evidential purposes it requires PTB type approval. The PTB has been involved in the process of establishing evidential breath-alcohol analysis since the outset. Together with the experts (i.e. manufacturers, users (the police), scientists and legal authorities), represented in the German standardization committee of DIN concerning breath-alcohol, it was possible to enforce the standard DIN 0405 [6] in such a way that the essential elements necessary for type approval were directly included.

Type approval includes not only the pure test of the instrument but also the specification of how the traceability chain shall be realized for each breath-alcohol measurement. This means in practice that the method used for testing the device by the local verification offices (*Eichamt*) has to be described, and what these institutes should use as their reference standard has to be specified.

To obtain type approval, three points have to be investigated:

- Is the instrument capable of measuring the breath-alcohol concentration and all additional parameters with the required accuracy according to DIN 0405?
- Are the repeatability and the reproducibility of the instrument within the given limits according to DIN 0405?
- Is it possible to check the parameters of the instrument and its measurement capability by the verification offices?

Additionally, the security level for evidential breath-alcohol analyzers is much higher than, for example, for vehicle exhaust-measuring instruments. For evidential instruments used in court, it is important to investigate whether the device can be handled in such a way that both unintentional misuse and intentional manipulation are rendered impossible.

In 1998, the first request for type approval of a breath-alcohol analyzer was received. The bases for the resulting examinations were the BGA report, DIN 0405 and OIML R 126. Some of the tests were delegated to specialized laboratories, e.g. vibration tests, software security or electromagnetic compatibility. In the PTB laboratory, attention was focused on problems concerning ethanol analysis, e.g. accuracy of the measurements, and cross-sensitivities or other influence parameters. Besides testing these parameters, techniques to intentionally manipulate the measurement results were thought up and applied to counter any possible future misuse in the field.

4.3 The German national breath-alcohol standard

To investigate the capabilities of the instrument, the German national standard for breath-alcohol concentra-

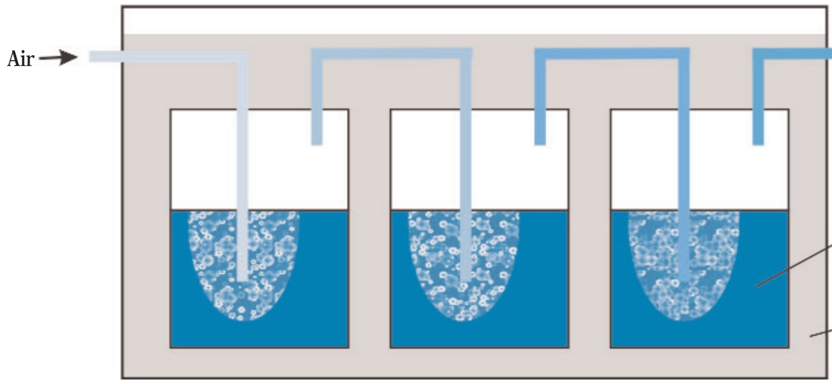

Figure 2 Principle of a bubble train described in OIML R 126

tions was used. The PTB national standard is a three-flask "bubble train" in a thermostated bath as described in OIML R 126. The flasks are filled with an ethanol-water solution of known ethanol concentration and the air flowing through is cleaned and preheated.

Figure 2 shows the bubble train in principle. The ethanol concentration of the air flowing through the flasks increases subject to the ethanol concentration of the solution and to the gas temperature. This effect is, in principle, described by Henry's law. The ethanol concentration of the solution decreases with the amount of gas flowing through and absorbing the ethanol. So, if only one flask was used the ethanol concentration in the resulting gas mixture would decrease immediately. To obtain a nearly stable system (for a limited volume) the three-flask model was designed. In the first two flasks the ethanol concentration of the gas is enriched and in the third flask the resulting concentration is reached and held stable. The volume of calibration gas that can be prepared with a stable ethanol concentration can be calculated.

The mass concentration of ethanol in the resulting gas mixture is calculated using the Dubowski equation described in OIML R 126 based on Henry's law:

$$c\_gas = c\_solution \cdot K_0 \cdot e^{A \cdot T} \qquad (1)$$

$$K_0 = 4.145 \times 10^{-2}$$

$$A = 0.06583 \text{ 1/°C}$$

with:

c_gas...	resulting ethanol concentration of the gas mixture in mg/l
c_solution...	ethanol concentration of the water-ethanol solution in g/l
K_0...	constant including the Henry coefficient for ethanol
A...	constant describing the temperature dependency
T...	Celsius temperature of the gas mixture (in °C)

The author is aware of the wide range of Henry coefficients used for the formulation of the Dubowski equation (see [7]) fixed in OIML R 126. Nevertheless, the equation is considered as internationally agreed on. That is why the included Henry coefficients with a zero uncertainty were used as, for example, similarly the extinction coefficient of ozone is used for international comparisons. Whilst this is metrologically unsatisfactory, for the moment it is an acceptable method.

Besides the Henry coefficients, the gas temperature and the ethanol concentration of the ethanol-water solution determine the ethanol concentration of the gas mixture and its uncertainty. The ethanol-water solution used is prepared and spot checked in the PTB laboratory. Its expanded relative uncertainty is ≤ 0.35 % ($k = 2$). In this value, the preparation of the solution and the impurity of the ethanol used are recognized, but not the decrease in concentration during the use in the bubble train.

The temperature of the gas is determined in the third flask, as here the final enrichment with ethanol occurs. Here, the temperature measured is the temperature of the solution, since the gas and liquid temperatures should have reached equilibrium at this stage. This means that no change in the solution temperature should be perceived by the PTB thermometer, which has a resolution of 0.01 K.

The expanded relative measurement uncertainty determined for the delivered gas concentration is smaller than 1.1 % (with $k = 2$). The determined uncertainty of the delivered gas composition was confirmed by bilateral comparisons with the Belgian Traffic Institute BIVV (IBSR) which is responsible for the calibration of breath-alcohol analyzers in Belgium.

4.4 Periodical verification by Local Verification Offices

One of the fundamental requirements for evidential breath-alcohol analyzers described by the BGA report is the periodic verification of each instrument by the local verification offices. In 1992, evidential breath-alcohol analyzers were included in the German verification regulations. The limits for the measurement uncertainties of instruments under test and in daily use are described there (see also section 3), and how often the instruments have to be verified is also laid down. As there was no information about the long-term stability of breath-alcohol analyzers, the verification period was fixed at six months.

For the verification offices, the verification of evidential breath-alcohol analyzers is unique because not only one measurand has to be checked but also the other relevant measurands such as sampling volume and gas temperature. The maximum deviation from a “known” value of those secondary measurands is specified in the BGA report and in DIN 0405, i.e. 0.3 K for the gas temperature and 15 % of the measured volume for the sampling volume.

In the German Standardization Committee for Breath-alcohol Measurement, the problem was discussed of how to obtain accurate measurements on the one hand and proper handling on the other hand. The best solution was to make a system available to the local verification offices which provides all the necessary measurands in one step.

4.5 Reference standard for the Local Verification Offices

In cooperation with the University of Applied Sciences (Gießen), Draeger Safety and the PTB, a reference standard for the local verification offices was established. The result is a compact system based on the principle of a “bubble train” (see Figure 4).

For use as a reference standard, a reference water-ethanol solution with a concentration uncertainty of ≤ 1 % traceable to national standards, a high-level calibrated thermometer capable of measuring the temperature with an uncertainty of ≤ 0.1 K, and optionally a computer are needed.

The reference standard consists of a two-flask bubble train and a calibrated flow-control and measuring system. Regularly, a certain amount of the ethanol-water solution inside the bubble train is replaced by a “fresh” solution. Thus, the wash-out effect of the solution is negligible and the concentration of the solution is held stable.

As a result, users in the verification offices do not need to calculate the actual ethanol concentration in the gas with respect to the gas flowing through the bubble train. To maintain the system, only the containers with new and used ethanol-water solutions have to be controlled.

The reference standard delivers an amount of water-saturated gas with a known ethanol concentration, a known temperature and a known volume flow. Therefore it allows the verification officers to check the relevant parameters of the evidential breath-alcohol analyzer in one single step (for detailed information see [8]).

Once a year, the reference standards are serviced by the manufacturer and then checked by the PTB by comparison with the national breath-alcohol standard.

5 Conclusion

In Germany there are detailed and strict requirements for the schedule and instrumentation of evidential breath-alcohol measurements.

The requirements for these instruments not only conform to OIML R 126, but go much further. The PTB is not only responsible for testing the instruments for type approval but also for the evaluation of test procedures for periodic verification of the instruments by the local verification offices.

Analogous to other measurands, a system of reference standards with traceability to the national standard was realized. Because of its special design the reference standard used by the local verification offices allows the relevant measurands of a breath-alcohol analyzer to be tested in one single step.

In this way, an effective procedure was drawn up which allows the instruments to be tested at a high metrological level with an acceptable amount of work taking reasonable time and being reasonably cost-effective. ■

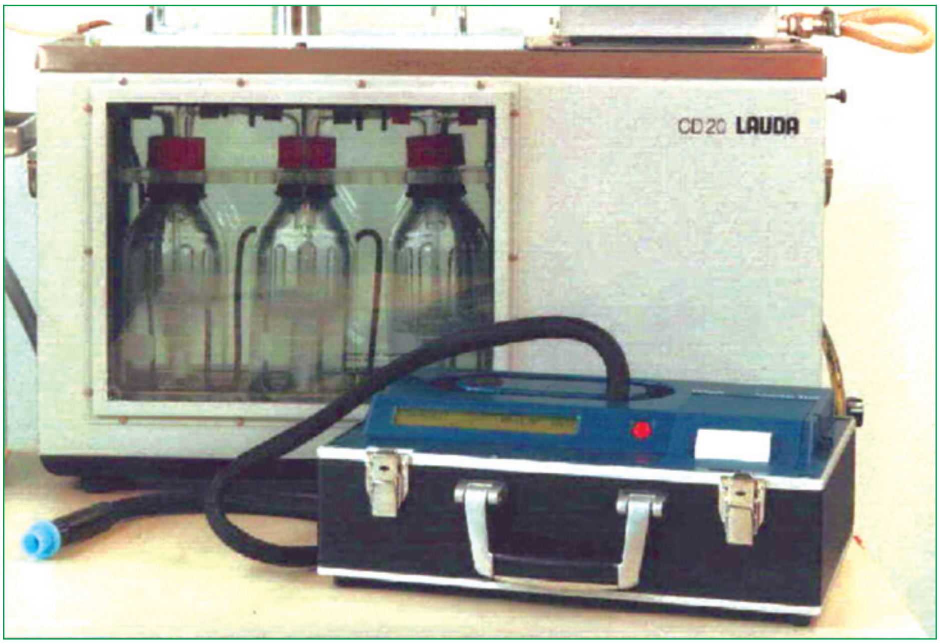

Figure 3 German national standard for breath-alcohol concentration with equipment under test

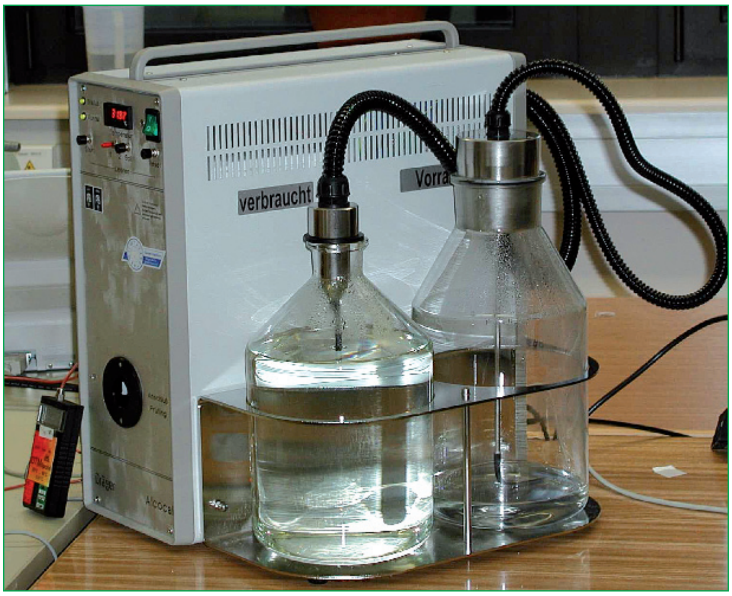

Figure 4 Reference standard for the local verification offices

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Evolution of philosophy and description of measurement (preliminary rationale for VIM3)

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Abstract

Different approaches to the philosophy and description of measurement have evolved over time, and they are still evolving. There is not always a clear demarcation between approaches, but rather a blending of concepts and terminologies from one approach to another. This sometimes causes confusion when trying to ascertain the objective of measurement in the different approaches, since the same term may be used to describe different concepts in the different approaches. Important examples include the terms "value," "true value," "error," "probability" and "uncertainty."

Constructing a single vocabulary of metrology that is able to unambiguously encompass and harmonize all of the approaches is therefore difficult, if not impossible. This paper examines the evolution of common philosophies and ways of describing measurement. Some of the differences between these approaches are highlighted, which provides a rationale for the entries and structure of the August 2006 draft of the 3rd Edition of the *International Vocabulary of Metrology – Basic and General Concepts and Associated Terms* (VIM3).

* **Disclaimer: Material discussed in this paper does not represent the current policy of the National Institute of Standards and Technology (NIST).**

1 Introduction

The concept of measurement covers a wide range of activities and purposes. Different approaches to describing and characterizing measurement have been developed and have evolved to address the various types and uses of measurements, and they are still evolving. Many terms have been used over time in the context of describing measurement, and the evolution of the different approaches to measurement has led to sometimes subtle, but undoubtedly different, uses of some terms.

A "vocabulary" is defined (e.g., ISO 1087-1:2000 "Terminology Work – Vocabulary – Part 1: Theory and Application") as "terminological dictionary that contains designations and definitions from one or more specific subject fields." Ideally, every term in a vocabulary should designate only one concept, in order to minimize confusion. However, because of the different concepts that are sometimes associated with the same term in the different approaches to measurement, it is virtually impossible to create a vocabulary of measurement that designates only one concept with each term in the vocabulary. This is a major difficulty that has been encountered in developing the 3rd Edition of the *International Vocabulary of Metrology – Basic and General Concepts and Associated Terms* (VIM) [1], where "metrology" is defined as "field of knowledge concerned with measurement."

This paper examines the evolution of the more common approaches to describing measurement, highlighting a few of the differences in the use of terms, and providing some of the rationale for how several of the terms are likely to be treated in the final version of VIM3.

In the text, concepts are mostly identified by their full systematic preferred terms of VIM3. In the figures, for convenience, a shortened form, also given in VIM3, is used.

2 Common Elements of Most Approaches to Measurement

There are a few fundamental concepts in most, if not all, approaches to describing measurement. Probably the most fundamental concept pertains to the kinds of things that can be measured, i.e. quantities. Another fundamental concept is the means used to express the magnitude of that which has been measured (in terms of values). Just as fundamental is the concept of measurement itself. The following definitions are taken from the August 2006 draft of the VIM3:

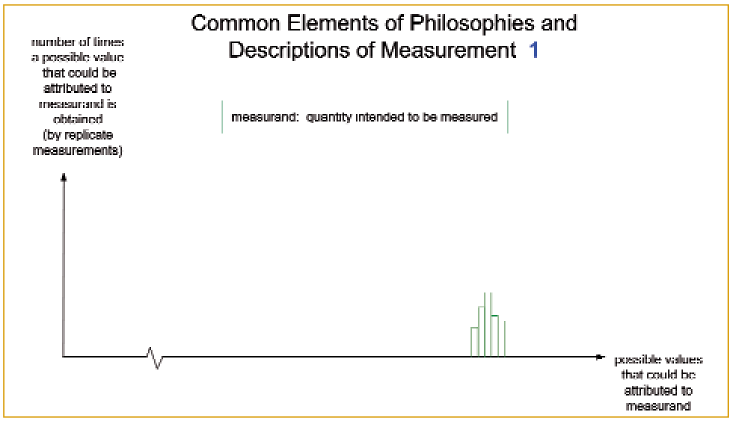

Figure 1 Common elements of philosophies and descriptions of measurement 1

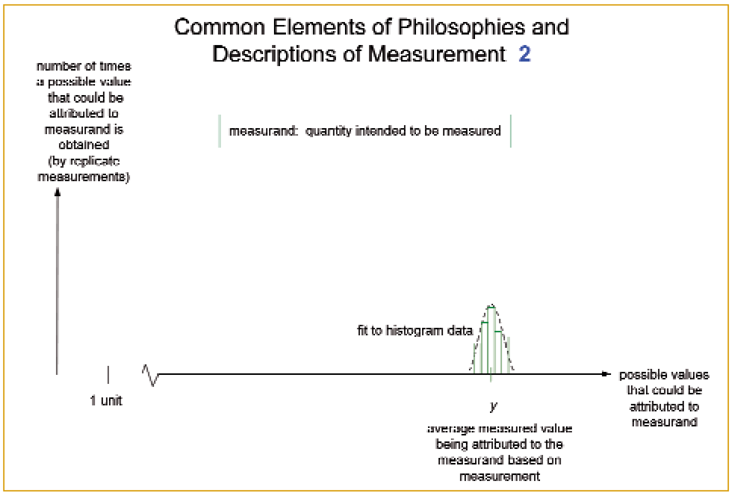

Figure 2 Common elements of philosophies and descriptions of measurement 2

- *Quantity* is "property of a phenomenon, body, or substance, to which a number can be assigned with respect to a reference" (which allows comparison with other quantities of the same kind).
- *Quantity value* (value of a quantity) is "number and reference together expressing magnitude of a quantity."
- *Measurement* is "process of experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity."

In VIM3 the concept *measurand* is defined as "quantity intended to be measured." This concept has 'evolved' from the definition in the *International Vocabulary of Basic and General Terms in Metrology*, 2nd Edition [2], VIM2, which is "particular quantity subject to measurement," that could be different from the quantity intended to be measured. The distinction must be kept in mind when considering the objective of measurement in the different approaches; this will be discussed further later on.

Figure 1 demonstrates some simple common elements of all approaches to describing measurement. The rectangular box gives the VIM3 definition of "measurand," and the horizontal scale represents the entire set of values that could possibly be attributed to that type of measurand. Note that there is no measurement unit associated with the horizontal line, because the quantity is an *ordinal quantity*, which is "quantity, defined by a conventional measurement procedure, for which a total ordering relation, according to magnitude, with other quantities of the same kind is defined, but for which no algebraic operations among those quantities are defined." Due to the latter characteristic, an average of a set of replicate measurements, illustrated schematically by a histogram, has no meaning.

For those quantities where there are meaningful algebraic operations among the quantities, a *measurement unit* can be defined as "scalar quantity, defined and adopted by convention, with which any other quantity of the same kind can be compared to express the ratio of the two quantities as a number." This is indicated in Fig. 2, where the measurement unit is the reference to be associated with the numerical value in the measured quantity value. The concept of measurement unit is common to all approaches to describing measurement (for other than ordinal quantities). The bell curve in Fig. 2 illustrates a 'Gaussian' fit to the histogram data. The curve is dashed to indicate that replicate measurements are not always performed in a measurement (that is, sometimes only a single measurement is performed), as will be elaborated below in the discussion of the International Electrotechnical Commission (IEC) Approach.

The two main approaches to describing measurement that will be discussed in this paper are sometimes called the 'classical' approach and the 'uncertainty' approach. Within each of these approaches are sub-approaches. While the two main approaches are given discrete names, there has in actuality been an evolution of these approaches that makes it difficult to ascribe certain concepts to one approach or another. This evolution of concepts is discussed below. Also, since probability and statistics usually play an important role in most aspects of measurement evaluation, both the 'frequentist' and 'Bayesian' theories of inference, as used in measurement, will be discussed as appropriate.

3 Classical Approach to Measurement

It is generally accepted that the key distinguishing premise of the classical approach to measurement is that, for a specified measurand, there exists a unique value, called the true value, that is consistent with the definition of the measurand. This is shown schematically in Fig. 3, where it is indicated that, in the general case, the value being attributed to the measurand based on measurement is different from the true value. This difference could be due to a variety of reasons, including mistakes in formulating the measurement model (such as not taking into consideration all significant factors and influences), and blunders in carrying out the measurement procedure.

Another premise of the classical approach is that it is possible to determine the true value of a measurand through measurement, at least in principle, if a 'perfect' measurement were performed. The objective of measurement in the classical approach is then usually considered to be to determine an estimate for the true value of the measurand as 'closely' as possible, or at least as closely as necessary, both by eliminating or correcting for all (known) systematic errors and mistakes, and by performing enough repeated measurements to adequately minimize errors due to random causes.

In the classical approach it is recognized that it is not possible to perform a 'perfect' measurement and so there will remain errors, both systematic and random, in the value ultimately being attributed to the measurand based on measurement. This value, frequently referred to as the 'measurement result' or sometimes the 'final measurement result' in the classical approach, and in other approaches as well, is often obtained as the average measured value, as illustrated in Fig. 4. Figure 4 also illustrates the concept of an individual measurement error, defined in the classical approach as the difference between an individual measurement result and the true value. The individual measurement result ('individual measured value,' denoted by y_i in Fig. 4) is illustrated with respect to the bell-curve, which is now solid to indicate that multiple individual measurements are being considered. Also indicated in Fig. 4 are "systematic error," defined as the difference between the unknown mean of the uncorrected measurement results and the true value, and "random error," defined as the difference between an individual measurement result and the unknown mean of the uncorrected measurement results. Note that the "mean of the uncorrected measurement results" here is meant to be that of a distribution of relative frequencies of measurement results obtained by repeating an experiment infinitely often, always under the same conditions. Thus, in reality, the mean cannot be known exactly. This is illustrated schematically in Fig. 5, where two systematic errors are shown, the lower one (systematic error$_b$) with respect to the average of the histogram data, and the upper one (systematic error$_a$) with respect to the mean of the theoretical frequency distribution for an 'infinite' set of data. The bell curve of the theoretical frequency distribution is dashed to indicate that it is not knowable. The systematic error$_a$ line is also dashed to indicate that its length cannot be known, since the mean of the

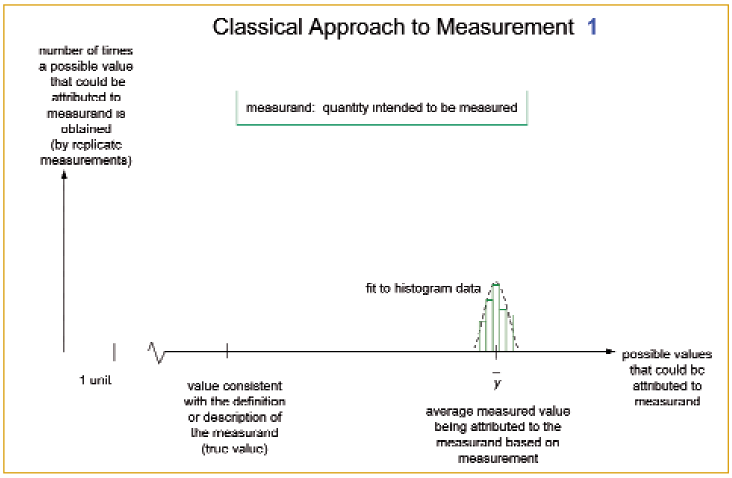

Figure 3 Classical approach to measurement 1

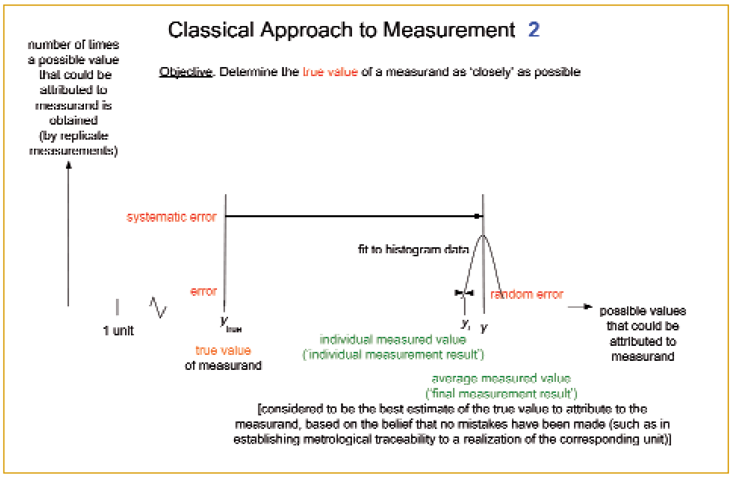

Figure 4 Classical approach to measurement 2

theoretical frequency distribution cannot be known. The question of whether or not the length of the systematic measurement error$_b$ line can be known, as well as the lengths of the three 'error lines' in Fig. 4, will be discussed next.

3.1 Knowable Error

Two important and related questions that arise in the classical approach are, first, whether it is possible, in principle, to go about identifying and eliminating, or correcting for, all of the errors in a measurement, and, second, if so, how? One possible way of addressing these questions is to hypothesize that it is possible, at least in principle, to determine the true value by carrying out a very large number of different types of measurements of the same measurand, using different measurement procedures, measurement methods or even measurement principles, a large number of times (so that various

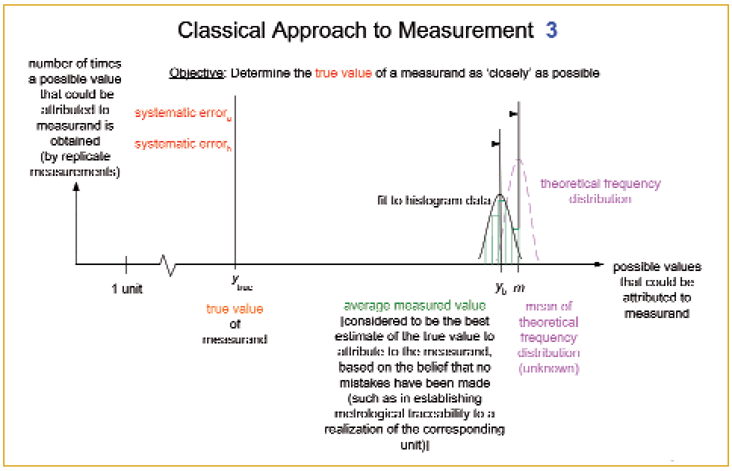

Figure 5 Classical approach to measurement 3

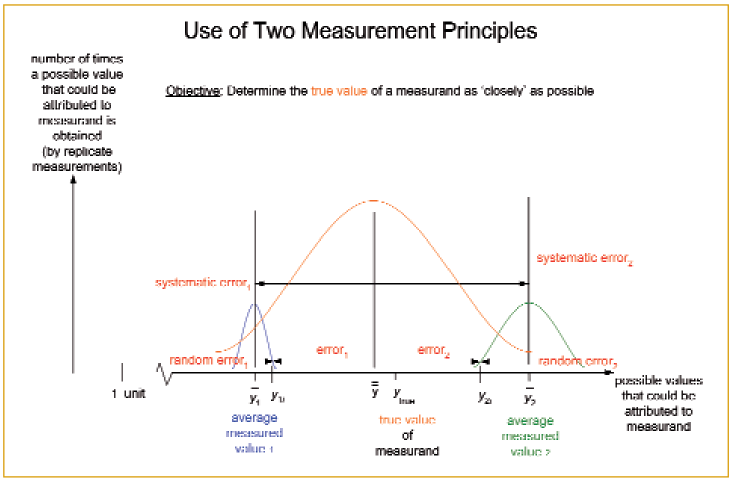

Figure 6 Use of two measurement principles

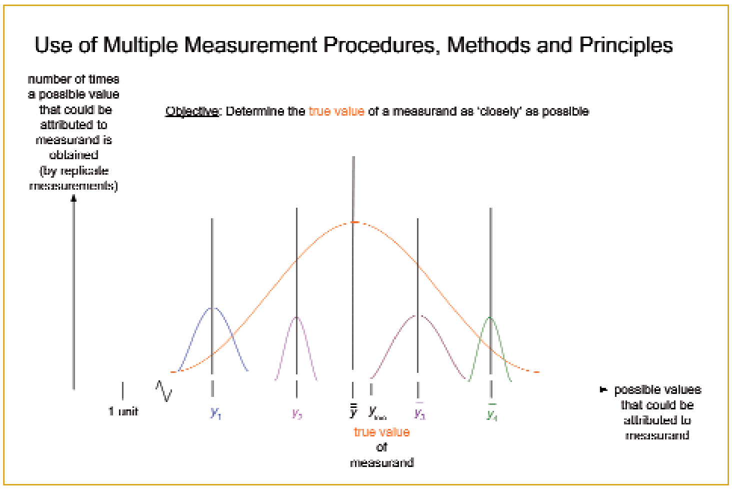

Figure 7 Use of multiple measurement procedures, methods and principles

systematic errors will 'average out'). This would require that a lot of information be obtained through measurement (which may not always be practical, even if the philosophy is sound).

Figure 6 illustrates this idea for just two different measurement principles, and Fig. 7 is meant to illustrate the advantage of using multiple measurement principles (indicated by the four different curves). Using this idea in the classical approach, a probability is usually assessed that the true value lies within a stated interval, as could be characterized by the 'width' of the large bell-shaped curve associated with the true value in both Figs. 6 and 7. Since this idea requires that an essentially infinite amount of information be obtained in order to know the true value, it is recognized that, in practice, a true value can never be known exactly using this idea. This is represented schematically in the two figures, where *y*-double-bar represents the average of the averages of the individual curves in the respective figures.

The questions then remain first, whether it is possible, in principle, in a different way, to identify and correct for all of the errors in a measurement, and, second, if so, how?

3.2 Error Analysis, Frequentist Theory in Classical Approach

One different way of trying to answer these questions is through the application of error analysis, which is based on the frequentist theory of inference as used in measurement. Error analysis is the attempt to estimate the total error using frequency-based statistics. However, the systematic error cannot be estimated in a statistical way, since it is neither observable nor behaves randomly in a measurement series under repeatability conditions. Therefore error analysis, which includes statistical and nonstatistical procedures, leads to inconsistencies in data analysis, especially in error propagation.

3.3 Bayesian Theory in Classical Approach

Another way of trying to answer these questions is to apply the Bayesian theory of inference to data analysis. Here systematic and random errors are treated on the same probabilistic basis, where probability is no longer understood as a relative frequency of the occurrence of events, but as an information-based degree of belief about the truth of a proposition, for example, about the true value. Using the Bayesian theory, it is still not possible to determine a true value unless an essentially infinite amount of information is obtained, so that it is again recognized that, in practice, a true value cannot be known.

3.4 Difficulties with the Classical Approach

So far no satisfactory way has been found to identify, let alone correct for, all of the errors in a measurement. The implications are significant, as illustrated in Fig. 8, where a hypothetical three 'known' components of systematic error are shown (usually estimated as 'worst-cases'). Since it is virtually impossible to know for sure if there is another component (say, due to a blunder, as indicated by the dashed line), the 'total' systematic error is unknown, as also indicated by a dashed line. If the total systematic error is unknown, then the true value cannot be known. If the true value is not known, then the error cannot be known (as again indicated by a dashed line). The random error, when defined with respect to the average of the histogram data, is calculable, as indicated by the solid line in Fig. 8. However, when random error is defined with respect to the mean of the theoretical frequency distribution, it also becomes unknowable, as illustrated by the dashed line for 'random error' in Fig. 9.

Systematic and random errors can therefore typically only be estimated or guessed. No generally-accepted means for combining them into an 'overall error' exists that would provide some overall indication of how well it is thought that a measurement result corresponds to the true value of the measure - and (i.e., to give some indication of how 'accurate' the measurement result is thought to be, or how 'close' the measurement result is thought to be to the true value of the measurand). The difficulty in the classical approach, of the lack of a generally-accepted, good procedure for describing the perceived 'quality' of the measurement result, is one important reason that 'modern' metrology is moving away from the philosophy and language of the classical approach. A solution to this difficulty is addressed in the uncertainty approach to measurement (as will be described shortly). There are also other reasons, but they will not be discussed here.

VIM3 Rationale: There are many measurement situations, typically of a relatively simple nature, where it is likely possible to be able to identify and correct for all of the significant systematic errors, as well as to obtain a sufficient number of replicate measurements for the purpose, such that description of the measurement result using the language and philosophy of the classical approach is a seemingly reasonable thing to do, and many people still do it. This is one of the main reasons that it was decided to keep many of the terms and concepts from the classical approach in the main body of VIM3, and not relegate them to an Annex.

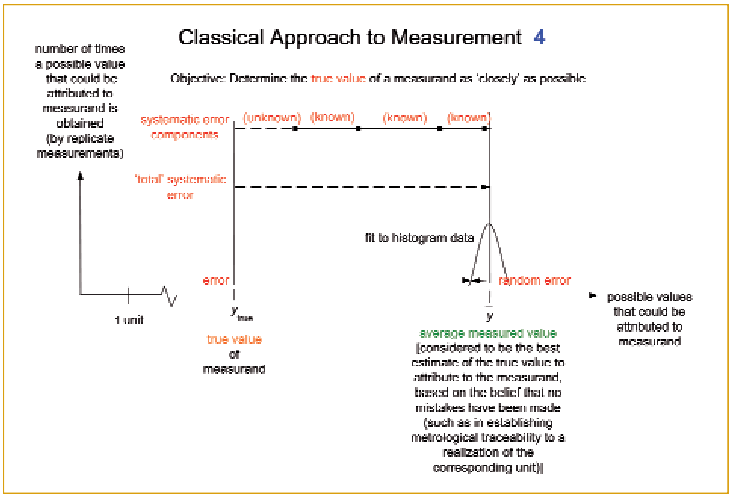

Figure 8 Classical approach to measurement 4

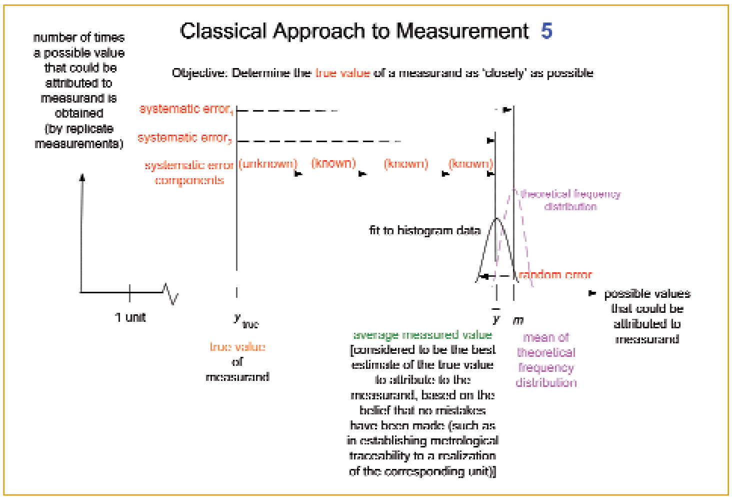

Figure 9 Classical approach to measurement 5

Another reason, as mentioned earlier and that will be elaborated further below, is that there is not always a clear demarcation between approaches. As an example, it is not clear to which measurement approach to ascribe the premise of a lack of uniqueness of a true value of a measurand.

3.5 Uniqueness of True Value

Generally, a measurand cannot be completely specified (except counts with low values), meaning that there will almost always be a set of true values that are consistent with the definition of a measurand. This is illustrated schematically in Fig. 10, where the interval of the set of true values consistent with the definition of the measurand is indicated by a pair of vertical dotted lines. The corresponding range (defined as the difference between the upper and lower limit of the interval) is shown bracketing the average measured quantity value.

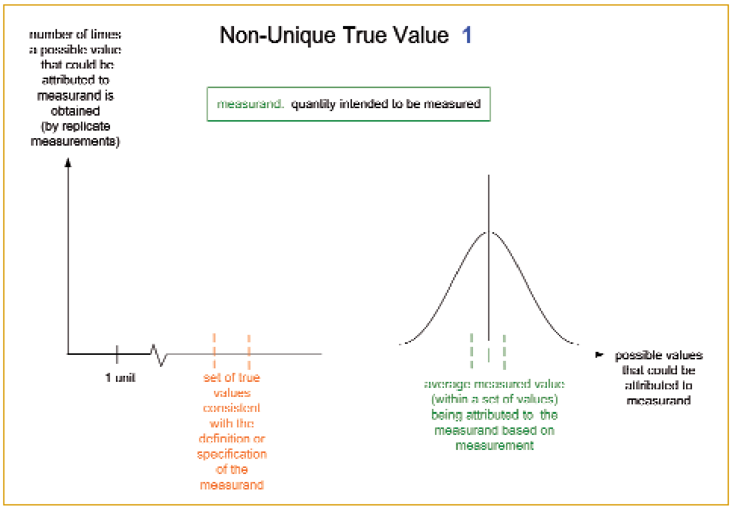

Figure 10 Non-unique true value 1

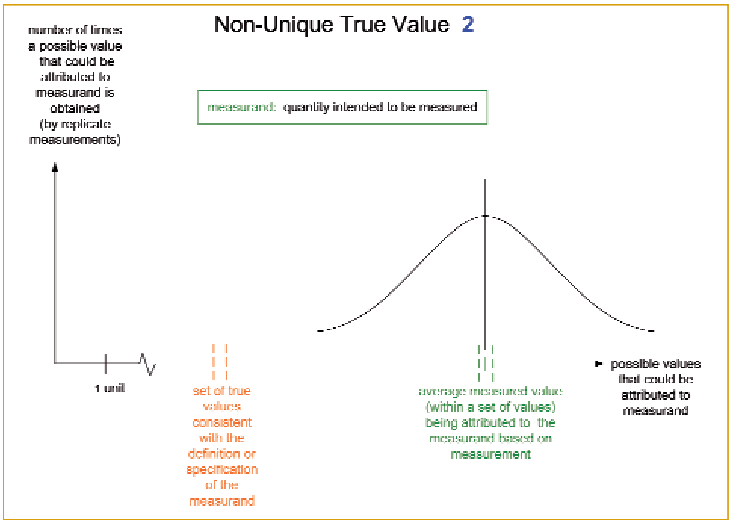

Figure 11 Non-unique true value 2

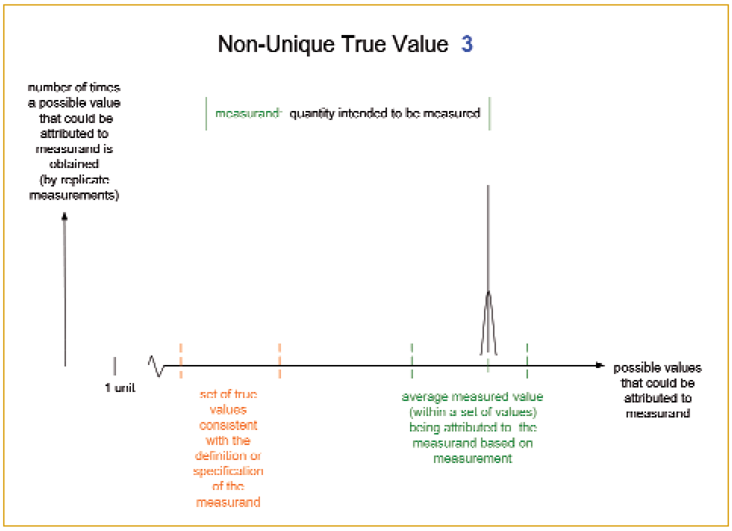

Figure 12 Non-unique true value 3

Even if an infinite series of replicate, arbitrarily precise measurements of (different samples of) the measurand were possible, there would still be a set of measured quantity values having at a minimum that same range, since any individual measurement (sample) could have any value of the set of true values consistent with the definition of the measurand. For a real measurement situation involving random errors, the range would necessarily be greater. The bell curve illustrates such a situation, where a characteristic width of the distribution (e.g., standard deviation) of the measured quantity values would lead to a range that is broader than the range of the set of true values calculated in the same way.

It is often desirable to have a measurement situation where the measurand can be progressively better defined such that the range of the set of true values becomes relatively insignificant with respect to the range of measured quantity values that can be obtained when using the (best) available measuring system, as illustrated in Fig. 11. Under these conditions, the measurand can be regarded as having an 'essentially unique' true value (i.e. 'the' true value), and the 'customary' language and mathematics of measurement can be employed.

However, this situation is not always found. Sometimes the measurand cannot, or needs not, be specified very narrowly. Alternatively, the measurement system is sometimes so precise that it is always capable of producing measured quantity values, illustrated in Fig. 12 by the curve, that are much narrower than the range of the set of true values for that measurand. Under these conditions it is necessary to think differently about the way of describing measurement, irrespective of the measurement approach. For example, in the classical approach, it would no longer be possible to talk about 'the true value' of a measurand, or 'the systematic error' associated with a measurement result, since such unique values would no longer have meaning. This measurement situation will also be addressed further in the discussion about the uncertainty approach.

Before leaving the discussion of the classical approach, it is worth noting that the classical approach is also sometimes called the 'traditional approach' or 'true value approach.' However, the latter is a misnomer, since the concept of true value is actually also used in 'modern' approaches, such as the 'uncertainty approach,' as will be discussed next.

4 Uncertainty Approach to Measurement

The concept of measurement uncertainty had its beginnings in addressing the difficulties described above with the classical approach, namely the questions of 1) whether it is possible, both in principle and in practice, to know the true value and error, 2) whether or not the true value is unique, and 3) how to combine information about random error and systematic error in a generally accepted way that gives information about the overall perceived 'quality' of the measurement. Further, if the true value, or set of true values, is not knowable in principle, then the question arises whether the concept of true value is necessary, useful or even harmful! All of these issues and perspectives will be addressed below.

While different approaches exist within the uncertainty approach, the two most prominent approaches are those put forward in the *Guide to the Expression of Uncertainty in Measurement* (GUM, 1993 and 1995) [3] and in IEC 60359 *Electrical and Electronic Measurement Equipment – Expression of Performance* [4]. IEC describes its approach as being parallel and complementary to the GUM, but uses a more operational or pragmatic philosophy, focusing primarily on single measurements made with measuring instruments. Both of these approaches, along with their impact on VIM3, will be described.

4.1 GUM Approach to Uncertainty

The GUM approach to uncertainty provides a more refined means than the classical approach for describing the perceived quality of a measurement. One of the main premises of the GUM approach is that it is possible to characterize the quality of a measurement by accounting for both random and systematic 'effects' on an equal footing, and a means for doing this is provided. Another basic premise of the GUM approach is that it is not possible to know the true value of a measurand (see GUM Section 3.3.1): "The result of a measurement after correction for recognized systematic effects is still only *an estimate* of the value of the measurand because of the uncertainty arising from random effects and from imperfect correction of the result for systematic effects." A third basic premise of the GUM approach is that it is not possible to know the error of a measurement result (see GUM 3.2.1 Note): "Error is an idealized concept and errors cannot be known exactly."

In the GUM approach it is explicitly recognized that it is not possible to know, for sure, how 'close' a value obtained through measurement is to the true value of a measurand (i.e., to know the error). Instead a methodology for constructing a quantity, called the standard measurement uncertainty, is established that can be used to characterize a set of values that are thought, on a probabilistic basis, to correspond to the true value, based on the information obtained from the measurement. The *objective of measurement in the GUM approach then becomes to establish a probability density function, usually Gaussian (normal) in shape, that can be used to calculate probabilities, based on the belief that no mistakes have been made, that various values obtained through measurement actually correspond to the 'essentially unique' (true) value of the measurand*. Note that the GUM does not explicitly state the objective of measurement this way, but it can be inferred through its description of standard uncertainty (see, e.g., GUM Section 6.1.2). *Another way of viewing the objective of measurement in the GUM approach is that it is to establish an interval within which the 'essentially unique' (true) value of the measurand is thought to lie, with a given probability, based on the information used from the measurement*. The modifier "true" has been put in parenthesis here as an alert that the GUM discourages use of the term (but not of the concept) "true value," and instead treats "true value" and "value" as equivalent, and thus omits the modifier "true." This, however, causes terminological difficulties that are treated in VIM3, and are discussed below.

VIM3 Rationale for *measurement uncertainty*. The concept of measurement uncertainty is defined in VIM3 as "parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used." As stated above, this important concept is introduced in the uncertainty approach to provide a quantitative means of combining information arising from both random and systematic effects (if they can be distinguished at all!) in measurement into a single parameter that can be used to characterize the dispersion of the values being attributed to a measurand, based on the information used from the measurement. The VIM3 definition is modified from the VIM2 [2] (and GUM [3]) definition because of the way that the term "measurement result" has been redefined in VIM3 (see next rationale).

VIM3 Rationale for *measurement result*. The GUM uses the VIM2 definition of "measurement result" (value attributed to a measurand, obtained by measurement), which is the same as the *estimate* mentioned above. However, it was decided by the developers of VIM3 to emphasize the importance of including measurement uncertainty in reporting the outcome of a measurement by incorporating into the definition of measurement result the notion that "a complete statement of a measurement result includes information about the uncertainty of measurement," as stated in Note 2 of the VIM2 definition of measurement result. Accordingly, measurement result is defined in VIM3 as "set of quantity values being attributed to a measurand together with any other available relevant information," which requires information not about just a single value, but also about the measurement uncertainty. The "other available relevant information," when available, pertains to being able to state probabilities.

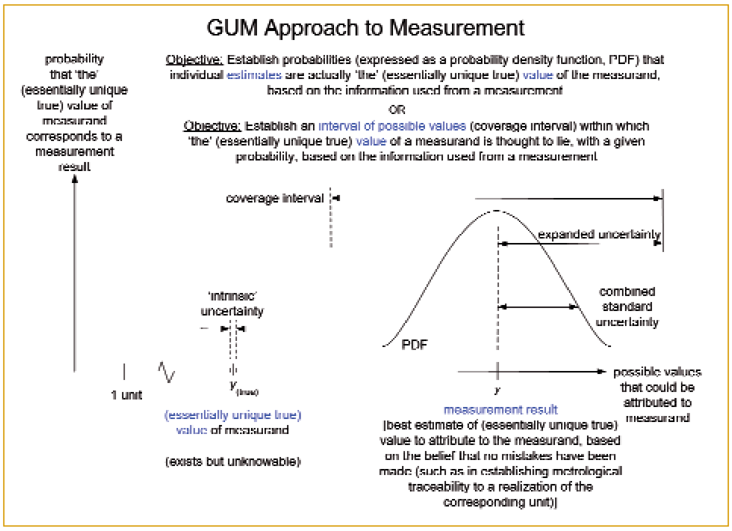

Figure 13 GUM approach to measurement

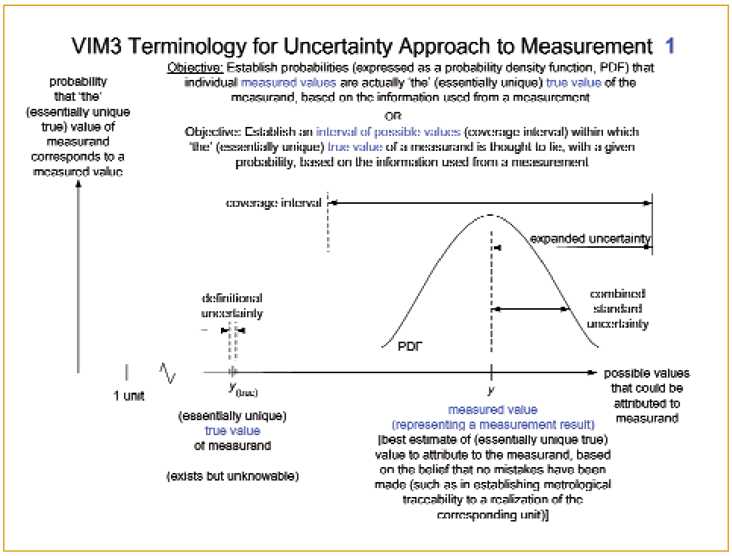

Figure 14 VIM3 terminology for uncertainty approach to measurement 1

VIM3 Rationale for *measured quantity value*. Since the term "measurement result" is defined in VIM3 in the more general sense given above, it was decided to introduce a separate concept for the individual quantity values of the set of values being attributed to the measurand based on measurement. Thus, in VIM3, "measured quantity value" is defined as "quantity value representing a measurement result."

VIM3 Rationale for *definitional uncertainty*. Another basic premise of the GUM approach is that no measurand can be completely specified, as has already been discussed earlier in the context of lack of uniqueness of a true value. In the GUM approach this premise is implemented such that there is always an 'intrinsic' uncertainty that is the minimum uncertainty with which an incompletely defined measurand can be determined (GUM Section D.3.4). Therefore, in VIM3 the term "definitional uncertainty" was coined for the concept defined by "minimum measurement uncertainty resulting from the inherently finite amount of detail in the definition of a measurand." The implication of this concept, as discussed above, is that there is no single true value for an incompletely defined measurand. However, a very important point to remember concerning the GUM approach is that it "is primarily concerned with the expression of uncertainty in the measurement of a well-defined physical quantity – the measurand – that can be characterized by an essentially unique value" (GUM Section 1.2). 'Essentially unique' means that the definitional uncertainty can be regarded as negligible when compared with the range of the interval given by the rest of the measurement uncertainty. Therefore, when using the GUM 'mathematical machinery' and language, it is important to make sure that this 'negligibility' condition applies. If it does not, then use of different approximations and language might be required. This is elaborated further below.

VIM3 Rationale for *true quantity value*. As already noted, in the GUM approach the modifier "true" in "true value" is considered to be redundant (GUM Section D.3.5), and so a "true value" is just called a "value." *It is important to recognize that this does NOT mean that the concept of true value is discouraged or ignored in the GUM*. Rather, the concept of "true quantity value," defined in VIM3 as "quantity value consistent with the definition of a quantity" has only been renamed "value," or "the value," in the GUM. This sometimes causes serious confusion, especially since the same term "value" is also frequently used in the GUM in the more general, superordinate VIM3 sense of "number and reference together expressing magnitude of a quantity." Another reason for potential confusion is that, if a true value is unknowable, then the need for the concept can be questioned (this will also be discussed later in connection with the IEC approach). However, as discussed earlier, in the GUM approach, the concept of true value is necessary for describing the objective of measurement. The concept of true value is also necessary for formulating a measurement model.

The GUM approach to measurement is illustrated schematically in Fig. 13, where the objective(s) of measurement are given at the top. Note that the vertical axis is no longer the number of times that a possible quantity value that could be attributed to a measurand is obtained by replicate measurements. Rather, the vertical axis is now the probability that individual 'estimates' of the value of a measurand actually correspond to the (essentially unique true) value of the measurand, where probability here means degree of belief under the assumption that no mistakes have occurred. The curve is now a probability density function (PDF) that is constructed on the basis of both replicate measurements (using so-called Type A evaluation) and other information obtained during measurement, such as values obtained from reference data tables and professional experience (using so-called Type B evaluation).

The combined standard uncertainty, expanded uncertainty and coverage interval are also illustrated in Fig. 13. A *coverage interval* is defined in VIM3 as "interval containing the set of true quantity values of a measurand with a stated probability, based on the information available." As indicated above, the GUM does not use the word "true" in connection with the concept of true value, and so "(essentially unique true) value" is indicated in Fig. 13. Also shown is the 'intrinsic' uncertainty associated with the fact that the (true) value is not unique (but only 'essentially unique') in the GUM Approach.

Note in Fig. 13 that the essentially unique true value is not shown to be within the coverage interval. This situation could be due to a variety of reasons, including an unidentified bias (systematic measurement error), inappropriate estimates of the values of influence quantities, or an outright blunder in conducting the measurement.

Incorporation of the terminology explained in the VIM3 rationales discussed above is illustrated schematically in Fig. 14. The objective(s) of measurement are again given at the top of Fig. 14 where the new terminology has also been incorporated. It is important to notice that nothing has changed in going from Fig. 13 to Fig. 14 other than the terminology, which is meant to emphasize that VIM3 is not intended to change the philosophy of the GUM approach, but only to clarify and possibly harmonize some of the terminology.

Figure 15 demonstrates the situation where the definitional uncertainty is not small compared to the rest of the measurement uncertainty, in which case the objective(s) of measurement are stated differently in recognition that probabilities must now be stated with respect to a set of true values, and not to an essentially unique true value. This measurement regime, and use of probability, is not treated in the GUM. However, the GUM indicates (e.g., GUM Fig. D.2) that definitional uncertainty is to be included in the calculation of measurement uncertainty.

The PDF from Fig. 14 (solid curve) is reproduced as the solid curve in Fig. 15. A broadened PDF (dashed curve) and larger coverage interval are presented in Fig. 15 in order to emphasize the necessity of now incorporating the definitional uncertainty into the probability considerations. Because of the new definition of measurand in VIM3, as "quantity intended to be measured," if it is thought (but not known) that the quantity actually being measured is different from the measurand, then, using the GUM approach, the corresponding uncertainty associated with a correction is a

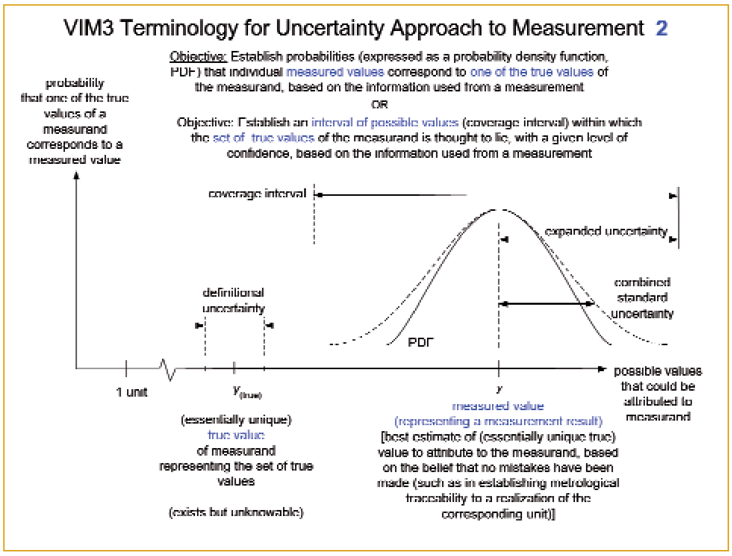

Figure 15 VIM3 terminology for uncertainty approach to measurement 2

part of the measurement uncertainty, and similar considerations concerning use of 'probability' would apply.

Since they were discussed earlier in connection with the classical approach, it is interesting to consider how the Bayesian and frequentist theories of inference relate to the GUM approach. In a sense, it can be said that the GUM approach, and in fact the uncertainty approach in general, are consequences of the Bayesian theory of describing our state of knowledge about a measurand. Using the Bayesian theory in the GUM approach, measurement can be thought to consist of incrementally improving our state of knowledge and belief about a true value based on all of the accumulated information that is available through measurement. Using the Bayesian theory, the measurement uncertainty based on probability density functions associated with a particular measurand will continually change according to additional information obtained through measurement. The frequentist theory of inference can be useful for determining certain Type A components of measurement uncertainty, but is not capable of treating most Type B components. An example of the difficulty of the frequentist theory of inference within the GUM approach is that the frequentist theory is not able to be used to assess the uncertainty of a single measured value when using a measuring instrument, such as a voltmeter. The reason is that the uncertainty here derives from 'nonstatistical' information obtained from the instrument's calibration certificate. This type of single measurement comprises a large fraction of the types of measurements routinely made daily throughout the world.

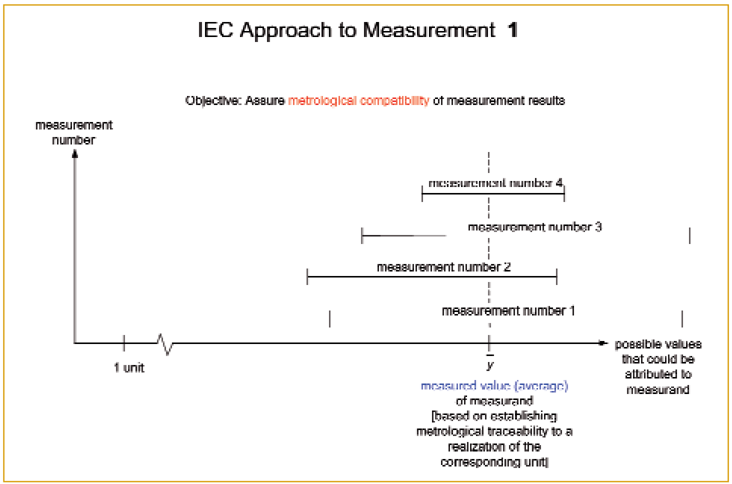

Figure 16 IEC approach to measurement 1

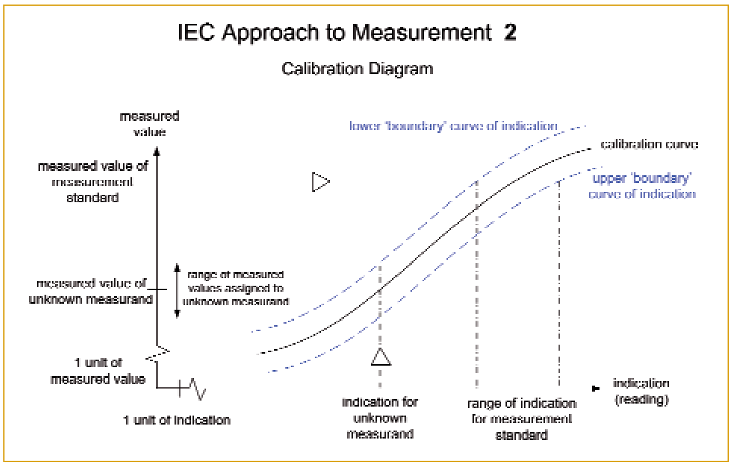

Figure 17 IEC approach to measurement 2

4.2 IEC Approach to Uncertainty

The other major approach to describing and characterizing measurement that will be discussed here is that used by the International Electrotechnical Commission (IEC), as presented primarily through their IEC 60359 *Electrical and Electronic Measurement Equipment – Expression of Performance* [4]. The IEC philosophy questions the existence, in principle, of a true value of a quantity. The objective of measurement in this view is not to determine a true value of a measurand with a given probability, but concentrates instead on *metrological compatibility of measurement results*, defined by VIM3 as "property of all pairs of measurement results for a specified measurand, such that the absolute value of the difference of the measured quantity values is smaller than some chosen multiple of the standard measurement uncertainty of that difference."

The IEC approach is based on a more operational or pragmatic philosophy than the GUM approach. Most notably, *the IEC approach treats the concept of true value as both unknowable and unnecessary, discouraging and in fact eliminating at least explicit use of the concept of true value, even in stating the objective of measurement*. In the IEC approach, as presented in the Introduction and Annex A of IEC 60359 [4], the stated objective of measurement is to obtain measurement results that are compatible with each other, within their respective measurement uncertainties. The philosophy is that, from an operational perspective, this is all that can really be done in measurement. This is illustrated schematically in Fig. 16, where the four horizontal lines represent sets of measured quantity values for four separate measurements of the same specified quantity being measured (which might be different from the measurand). From the IEC perspective, it could be argued that the concept of true quantity value is potentially harmful, since it leads to thinking about something that is not relevant.

VIM3 Rationale. As a result of this key difference in philosophy between the IEC approach and the GUM approach to the uncertainty approach, it is necessary to generalize several of the central concepts and definitions in VIM3 to accommodate both approaches whenever possible. For reasons discussed earlier, the important concept of "true quantity value" is kept in VIM3, but is not explicitly used in the context of definitions that also apply to IEC. For example, the definition of "measured quantity value" has been generalized to "quantity value representing a measurement result," instead of "quantity value representing the set of true values of a quantity..." so that true value does not need to be explicitly mentioned, but can be still be inferred for the classical and GUM approaches. Similarly, "measurement result," as mentioned above, has been defined in VIM3 as "set of quantity values being attributed to a measurand together with any other available relevant information," rather than as, e.g., "set of quantity values estimating the true values of a measurand." This wording accommodates the IEC view that a measurement result is just a set of values, with every element of the set having equal status. The probabilistic aspect of the GUM approach is left to the end of the definition as "any other available relevant information," which can be ignored for the IEC approach. A third example is definitional uncertainty, now defined in VIM3 as "minimum measurement uncertainty resulting from the inherently finite amount of detail in the definition of the measurand," rather than "parameter characterizing the estimated dispersion of the true values of a quantity...," in order to remove explicit reference to true value.

Another key aspect of the IEC approach is that it focuses on providing guidance for obtaining measurement uncertainty in situations where single measurements are made using measuring systems, and where the measuring system is operating not only under reference conditions, but anywhere within its rated operating conditions. The IEC approach in this regard, as described in IEC 60359 [4], is to construct a calibration diagram applicable under given operating conditions. An interpretation of the IEC calibration diagrams, using a modified terminology that is compatible with the VIM3 terminology, is illustrated in Fig. 17. The horizontal axis, called indication axis (or 'reading axis'), corresponds to the indication of a measuring system (in unit of indication'). The vertical axis, called measured value axis (or 'measurement axis'), corresponds to measured values (in 'unit of measured value') as obtained using measurement standards. The boundary curves of indication around the calibration curve are obtained during the course of calibration of the measuring system, using measurement standards, and are used to assess the range of indication for a given measurement standard. When subsequently using the measuring system for a measurand with unknown quantity value, a given indication will correspond to a measured quantity value and an assigned range of measured values, which is derived from the boundary curves of indication, as illustrated in the figure. IEC uses this range of measured values in assessing measurement uncertainty.

Returning to the fundamental IEC philosophy that the concept of true quantity value is unnecessary, and that all that really matters is that measurement results are compatible with each other, we might ask what to do when measurement results are not compatible with each other, as illustrated schematically by 'measurement number 5' in Fig. 18. In this case it is necessary to investigate whether any mistakes have been made in performing all of the measurements. If no mistakes can be found, then it is assumed that the quantity that was measured was different for some of the measurements. In this case IEC advocates to somehow 'average all of the measurements' and create an uncertainty that encompasses all of the measurement results.

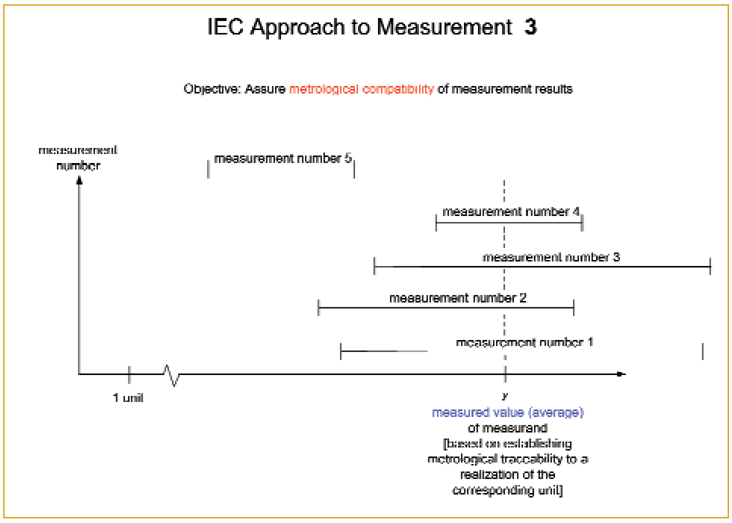

Figure 18 IEC approach to measurement 3

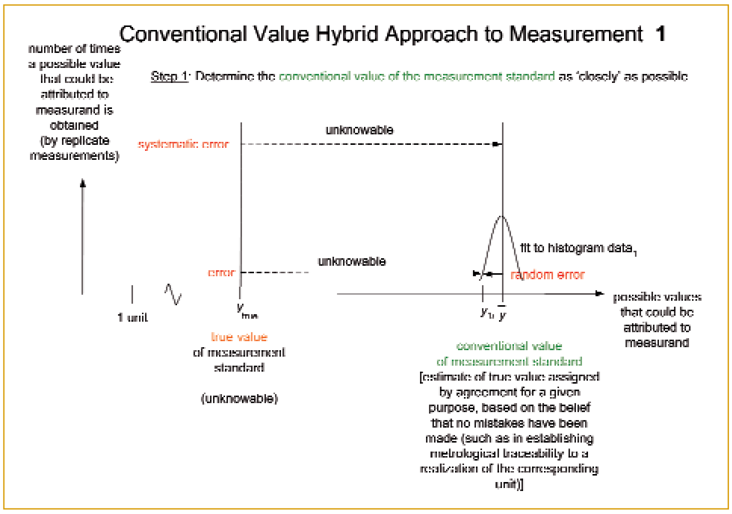

Figure 19 Conventional value hybrid approach to measurement 1

4.3 Conventional Value Hybrid Approach; Knowable Measurement Error

Before concluding, it is useful here to discuss a hybrid of the classical approach and the uncertainty approach that is frequently employed as a practical solution for handling the conceptual and terminological problems described earlier concerning the inability to know measurement error, without abandoning the concept and term, since they are still so widely used. This hybrid approach, which will be called here the 'Conventional Value Hybrid Approach,' or CVHA, is typically used in measurement situations where a decision must be made concerning whether a measured quantity conforms to a particular requirement, such as a specified machine tolerance or a legal regulation. The 'hybrid' aspect of the CVHA is that, while measurement error is used, measurement uncertainty is also taken into account.

The CVHA is a two-step approach. In the first step a measurement standard is calibrated using a 'high-level' measurement procedure and measuring system, and assigned a conventional quantity value. In the second step, a second measurement is performed on the calibrated measurement standard using a 'lower-level' measurement procedure and measuring system. Measurement error in the second step is assessed with respect to the conventional quantity value that was assigned to the measurement standard in the first step. This measurement error can be expressed as a rational quantity since it is defined with respect to the conventional quantity value, and not the true quantity value, of the measurement standard. Figures 19 and 20 schematically illustrate the two-step process of the CVHA.

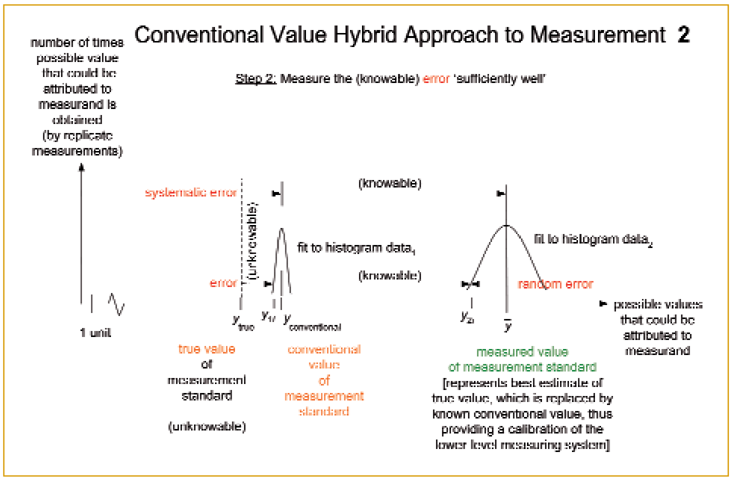

Figure 20 Conventional value hybrid approach to measurement 2

Figure 19 shows the conventional quantity value being assigned to the measurement standard, through measurement, using a 'high-level' measurement procedure and measuring system. In this first step the systematic measurement error, and hence the error, as defined with respect to the true quantity value, cannot be known, and the systematic measurement error is set to zero by convention. The curve represents a fit to a set of histogram data (subscripted '1') that are obtained when calibrating the measurement standard. Note that a measurement uncertainty associated with the conventional value can be determined, but this is not illustrated in this figure.

Figure 20 illustrates the second step of the process, where the quantity associated with the measurement standard (to which a conventional quantity value has been assigned) is now measured with a 'lower-level' measuring system. The measured quantity values obtained when using this system are denoted schematically by the "fit to histogram data_2" on the right side, and an individual measured quantity value (y_{2i}) is also indicated. Note that the measurement scale has been shifted in Fig. 20, such that the difference between the conventional quantity value and true quantity value is meant to be the same in Figs. 19 and 20, and the "fit to histogram data_1" in the two figures is also meant to be the same. Figure 20 illustrates that, typically in the CVHA, the measured quantity value using the 'lower-level' measuring system is not expected to be as "close" to the true quantity value as the conventional quantity value is and, further, the width of the "fit to histogram data_2" is not expected to be as narrow as that of the "fit to histogram data_1." More importantly in Fig. 20, however, is the illustration that systematic measurement error and error can be defined in the second step of the CVHA both with respect to true quantity value (in which case they are unknowable) and with respect to conventional quantity value (in which case they are knowable). Note that systematic measurement error here is also defined with respect to the average of the histogram data_2 and not a mean of the respective theoretical frequency distribution, as discussed earlier (Fig. 5). Figure 20 illustrates a calibration of the lower-level measuring system.

The advantage of the CVHA is that it can be used in measurement situations where the measurement uncertainty associated with the conventional quantity value is small with respect to the typical "knowable measurement error." Then it is possible to perform relatively straightforward measurements using the lower-level systems, and make equally straightforward conformity assessment decisions, without having to perform a possibly complicated measurement uncertainty analysis. This approach has been used for many years and covers many types of measurement situations where, in fact, a "knowable measurement error" is frequently treated as a measurand.

An example of the CVHA is the use of a standard weight to verify the performance of a balance. The weight is the (calibrated) measurement standard, and the balance is the lower-level measuring instrument used to obtain the measured quantity value in Fig. 20. The knowable measurement error is the difference between the indication and the conventional quantity value of the weight that is placed on the balance. This measured knowable error is then compared to a maximum permissible error (MPE) quoted in a regulation for that type of balance in order to make a decision about whether the balance conforms to the MPE requirement.

As modern measuring equipment used for even routine measurements becomes more sophisticated, it is not always possible to find a measurement standard or measuring instrument that is significantly better than the lower-level measuring system, and so the knowable measurement error is not always significantly larger than the expanded measurement uncertainty associated with the conventional quantity value of the measurement standard. Further, as the pressure increases to become more efficient in every phase of business, including that concerning measurement, there is a need to make better conformity assessment decisions. The irony is that it is then becoming increasingly important, when using the CVHA, to consider the uncertainty of the (knowable) measurement error. It therefore becomes necessary to consider whether there is less terminological and conceptual confusion by calculating the measurement uncertainty associated with the measured quantity value itself (and specifying a maximum permissible uncertainty) [5], than by estimating the knowable measurement error.

VIM3 Rationale for *measurement error*. The dual usage of the term "error", both in an unknowable sense when a measured quantity value is compared with a true quantity value, and in a knowable (calculable) sense when that same measured quantity value is compared with a conventional quantity value, is another dilemma faced in the development of VIM3, since two different concepts are being designated by the same term. The solution presented in VIM3 is to slightly re-define "measurement error" in a more general sense, as "difference of measured quantity value and reference quantity value," where the reference quantity value may or may not be the true quantity value (e.g., it could be a conventional quantity value). This new definition then encompasses both meanings of the term "error", the unknowable and the knowable "error."

VIM3 Rationale for *measurement accuracy*. A concept closely related to "measurement error" is that of "measurement accuracy," mentioned earlier, which even in the classical approach is in common use and is therefore kept in VIM3. The VIM3 definition: "<classical approach> closeness of agreement between a measured quantity value and a true quantity value of a measurand" is similar to the VIM2 definition, which also is based on true quantity value. However, since IEC does not use the concept of true quantity value, and also because a somewhat different usage of "accuracy" has developed in connection with the uncertainty approach, it was decided to include a second definition of measurement accuracy: "<uncertainty approach> closeness of agreement between measured quantity values that are being attributed to the measurand." This is a situation where a harmonized definition was not considered possible.

5 Summary

Different philosophies and approaches to measurement still exist and are in common use, most notably the classical approach and the uncertainty approach. Trying to create a vocabulary of metrology that harmonizes the language of measurement among the different approaches, and that keeps one term designating only one concept, has presented tremendous challenges in developing VIM3. While a principle used for VIM3 has been to harmonize terminology to the extent possible (e.g., "measurement error"), it has in a few cases been necessary to allow two concepts having the same term (e.g., "measurement accuracy"), or different terms for the same concept (e.g., "value"/"true quantity value"), in the different approaches. Several of the decisions and rationales have been presented.

6 Future

At the time of publication of this paper, the VIM3 has not been finalized. Once the VIM3 has passed the second international comment and review process and has been published, there are plans by the authors to develop an updated and expanded version of this paper for publication and wide distribution.

The plans for publication of VIM3 include its availability, for no charge, on the Bureau International des Poids et Mesures (BIPM) web site. Hard copies of VIM3 will be available, for a fee, from the International Organization for Standardization (ISO).

7 Acknowledgements

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8 References

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[2] "International Vocabulary of Basic and General Terms in Metrology," 2nd Edition (VIM2), *International Organization for Standardization (ISO)*, 1993.

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[5] H. Kallgren, M. Lauwaars, B. Magnusson, L. Pendrill, and P. Taylor: "Role of Measurement Uncertainty in Conformity Assessment in Legal Metrology and Trade," *Accred. Qual. Assur.*, vol. 8, pp. 541–547, 2003.

Note: In this paper, single quotes are used to denote concepts, double quotes are used to denote terms, and <> brackets are used to denote field of usage.

Editor's Note: Due to its importance and in order to reach as many members of the measurement community as possible, this article appears also in the journals *Accreditation and Quality Assurance* and *Measure* with the consent of the authors and the editors. ■

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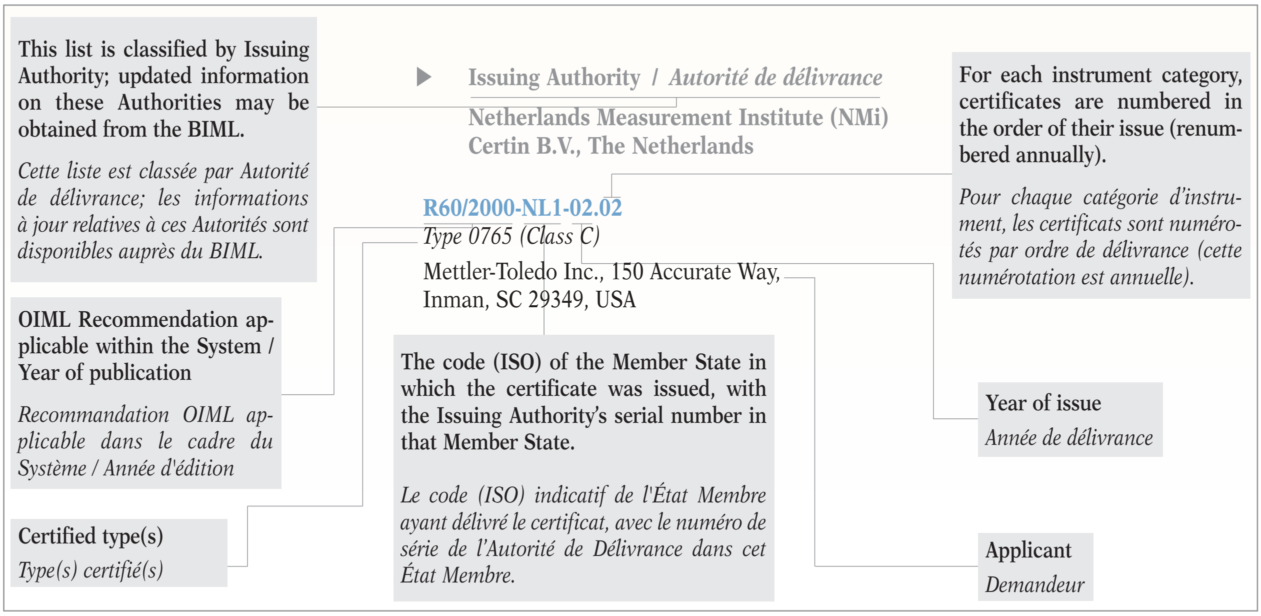

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Compteurs d'eau destinés au mesurage de l'eau potable froide

R 49 (2003)

Issuing Authority / *Autorité de délivrance*

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R049/2003-DE1-2007.01
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CATÉGORIE D'INSTRUMENT

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R 60 (2000)

Issuing Authority / *Autorité de délivrance*

Physikalisch-Technische Bundesanstalt (PTB), Germany

R060/2000-DE1-2006.01
Strain gauge shear beam load cell. Type: Z7
Hottinger Baldwin Messtechnik GmbH, Im Tiefen See 45, D-64293 Darmstadt, Germany

R060/2000-DE1-2006.03
Strain gauge compression load cell
Hottinger Baldwin Messtechnik GmbH, Im Tiefen See 45, D-64293 Darmstadt, Germany

Issuing Authority / *Autorité de délivrance*

DANAK The Danish Accreditation and Metrology Fund, Denmark

R060/2000-DK1-2006.04
Compression, strain gauge load cell. Type: BS
ESIT Electronics Ltd., Nisantepe Mahallesi, Alemdar Umraniye, TR-34775 Istanbul, Turkey

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CATÉGORIE D'INSTRUMENT

Nonautomatic weighing instruments
Instruments de pesage à fonctionnement non automatique

R 76-1 (1992), R 76-2 (1993)

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Physikalisch-Technische Bundesanstalt (PTB), Germany

R076/1992-DE1-2005.08 Rev. 1
Non-automatic electromechanical weighing instrument with or without lever works. Type: JL...-C / PL...-S
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R076/1992-DE1-2006.07
Nonautomatic, electromechanical, pricecomputing weighing instrument. Type: GLP-W...
Bizerba GmbH & Co. KG, Wilhelm-Kraut-Straße 65, D-72336 Balingen, Germany

R076/1992-DE1-2006.09
Non-automatic electromechanical baby weighing instrument. Types: M834x1, M834x1-l, M834x1-ll, M835x1, M835x1-l, M835x1-
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- The two principal international standardization organizations:

  3 The International Organization for Standardization (ISO) - member since January 1997, and
  4 The International Electrotechnical Commission (IEC) - member since January 1997;

- Three international unions:

  5 The International Union of Pure and Applied Chemistry (IUPAC) - member since January 1997,
  6 The International Union of Pure and Applied Physics (IUPAP) - member since January 1997, and
  7 The International Federation of Clinical Chemistry and Laboratory Medicine (IFCC) - member since January 1997;

- One international accreditation organization:

  8 The International Laboratory Accreditation Cooperation (ILAC) - member since December 2005.

Membership of the Joint Committee is open to metrology and measurement-related international broadly-based organizations, at the discretion of the Joint Committee.

4. Committee Chair

The Chair of the Joint Committee shall be appointed by the Joint Committee from amongst its members for an initial term not exceeding three years, with unlimited possibility for three-year extensions of the appointment.

The Chair shall act in a neutral capacity, divesting itself from the member organization point of view.

5. Committee Secretariat

The Secretariat of the Joint Committee shall be allocated to one of the member organizations by mutual agreement of the Joint Committee.

The Secretariat is responsible for monitoring, reporting to the Joint Committee members and ensuring active progress of the work, and shall use its utmost endeavour to bring this work to an early and satisfactory conclusion. These tasks shall be carried out as far as possible by correspondence.

The Secretariat shall act in a neutral capacity, divesting itself from the member organization point of view.

If the member organization holding the Secretariat wishes to relinquish it, the member organization concerned shall inform the Chair, giving a minimum written notice of twelve months.

6. Meetings

The Joint Committee shall meet at such intervals as needs may determine, at the discretion of its Chair or at the request of a majority of its member organizations.

7. Working procedures

7.1 The Joint Committee

7.1.1 General

Each member organization shall be invited to appoint one representative to attend the meetings and to receive papers.

Each representative may be accompanied by a maximum of two experts. It is the responsibility of the representative to make sure that the views expressed by these experts reflect the views of their organization(s).

7.1.2 Secretary

The general elements of the responsibilities of the Joint Committee Secretary are Committee management and general support, membership maintenance, reporting and advising, document management, meeting management and project management in liaison with the WG Convenors.

7.1.3 Working language

The working language of the Joint Committee is English.

7.1.4 Meeting of the Joint Committee

The meetings of the Joint Committee shall be organized by the Secretariat.

Meeting dates and venues shall be fixed by the Chairman and notice thereof shall be sent to the member organizations and representatives, by the Secretariat, at least two months prior to the meeting.

The Chairman shall prepare the agenda for circulation by the Secretariat to the member representatives at least one month prior to the meeting.

Documents for a meeting shall be circulated by the Secretariat to the member representatives at least two months prior to the meeting. At the discretion of the Chairman, further documents may be accepted for discussion at the meeting.

7.1.5 Decisions of the Joint Committee

Decisions of the Joint Committee shall be by consensus*, bearing in mind the following definition:

> **consensus**: General agreement characterized by the absence of sustained opposition to substantial issues by any important part of the concerned interests and by a process that involves seeking to take into account the views of all parties concerned and to reconcile any conflicting arguments.

* Note: Consensus need not imply unanimity

Should an indicative vote be considered necessary by the Chairman, the decision shall be taken by unanimity of the member organizations and each member organization shall have one vote. Such a vote may be organized by letter ballot, if necessary.

7.1.6 Guidance documents

Guidance documents shall be approved by consensus of the member organizations. Such documents shall then be published in the name of all the member organizations and constitute recommendations of these organizations.

7.2 Working Groups (WG)

7.2.1 Setting-up

Following the circulation and review of proposals for new work, the Joint Committee may decide to establish a WG, led by a Convenor and comprising experts brought together to address specific tasks.

The WG Convenor shall be nominated by the Joint Committee at the time of the establishment of the WG, and be responsible for the management of its work programme, accountable for its productivity, and ensure membership maintenance.

The WG expert(s) shall act in their personal capacity, contributing on the basis of their own knowledge. Each member organization shall be invited to appoint a maximum of three experts to a WG.

7.2.2 Calling of meetings

Notification of a meeting shall be sent by the Convenor to the WG members and to the Secretariat, preferably at least two months in advance of the meeting.

Arrangements for meetings shall be made by the Convenor.

7.2.3 Draft documents

It is the responsibility of the Convenor of the WG, in consultation with the Secretariat and, if necessary, the Chair of the Joint Committee, to judge whether to submit a draft document for circulation at the level of the Joint Committee, either for comments or for approval.

7.2.4 Reporting

The Convenor will provide the Joint Committee Secretariat with a report[1] for circulation to the Joint Committee, detailing the progression of the WG's programme of work, including proposals regarding new work. The Joint Committee shall review and approve these proposals based on the Convenor's assessment of need. The Joint Committee may also request WGs to undertake additional specific tasks.■

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[1] Reports can be periodic, but should follow official WG meetings

RLMO NEWS

7th Meeting of COOMET TC 2 "Legal Metrology"

Chişinău, Moldova

4–5 July 2006

HARTMUT APEL,
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The members of COOMET TC 2 *Legal Metrology* met at the National Institute of Standardization and Metrology (INSM) in Chişinău, Moldova on July 4–5, 2006. A Workshop was held in the same premises on *Testing of software for measuring instruments*.

The TC 2 Meeting was attended by 20 participants from eight COOMET member countries: Belarus, Germany, Kazakhstan, Lithuania, Moldova, Russia, Slovakia and Ukraine.

The transposition of the European Measuring Instruments Directive (MID) in all EU member countries into national legislation and the direct effects on their legal metrology systems was one of the main discussion topics. Though only three members of TC 2 (Germany, Lithuania and Slovakia) belong to the European Union, other COOMET countries are interested in adopting elements or even the whole range of the MID into their national systems. Thus the MID, which came into force in the European Union on 31 October 2006, will also have consequences for almost all COOMET countries. The MID is based on the *New Approach* (NA) and the *Global Approach* and this topic played a major role throughout the meeting.

New Approach Developments in the EU

The concept of the *Global Approach* and the *New Approach* was developed in the European Community around 25 years ago. At that time it was generally assumed that a certified quality system (on the basis of the ISO 9000 series and with a focus on the production process) adopted by a manufacturer of measuring instruments would be able to replace verification procedures of authorities with the same level of consumer protection. Therefore manufactures are entitled under certain conditions to issue a *declaration of conformity* for their instruments having the same meaning and even legal consequences as an initial verification by a verification office. This assumption, though valid for those manufacturers working with a high level of responsibility, did not always materialize in a satisfactory manner.

Since more than 1800 EU Notified Bodies carry out conformity assessments in the NA area according to written standards, a wide diversity of applications and interpretations of these standards has been noted since then.

The number of non-conformities of technical products found on the market is steadily increasing, particularly due to more efficiently applied market surveillance. In a few EU member countries, proactive investigations on such products on the basis of only 11 NA Directives (out of 25 in force) showed minor and serious technical deficiencies, totaling in excess of 60 % non-conformities based on several hundred products examined.

Most EU member countries are not yet in a position to carry out expensive post-marketing conformity assessments. The European Commission is aware of these deficiencies in the current NA and has for several years been planning to revise this system and make it more practical. One key issue of this revision is supposed to be the accreditation of certifying testing laboratories of Notified Bodies - though other procedures for determining the competence of these laboratories will be admitted as well (e.g. peer assessment).

The MID determines only the essential metrological requirements, whereas functional requirements are referred to in a few mandated and voluntary standards or in normative documents, thus opening a wide field for discussions and technical interpretations about their appropriate application in legal metrology. OIML Recommendations can be determined in special cases to be such normative documents, since they are internationally well known and widely used in more than 100 countries. Therefore they are regarded as being of great assistance for the ongoing harmonization process.

The goal of COOMET TC 2 is the mutual acceptance (and even recognition) of test results, type approvals and declarations of conformity.

Revision of harmonized standards in the weighing sector

The experience gained with the Non-Automatic Weighing Instruments Directive (NAWI) 90/384/EWG, the first Directive in the area of legal metrology on the basis of the NA, has demonstrated that there is an urgent need to determine the functional requirements for all 10 types of instruments covered by the MID. The general and specific essential requirements are not sufficient to cover the functional requirements necessary to come up with a real harmonized approach in the EU. In order to work out these technical requirements, four working groups have been established within WELMEC, which correspond to all the types of instruments covered by the MID. This work is recognized to be of a permanent nature.

However, the substance of the terms *verification*, *metrological test*, and *market surveillance* are defined and practiced in the EU in a quite different way. One crucial point, still to be resolved, is the common interpretation of the essential technical requirements.

The results were presented of recent tests carried out in Germany on weighing instruments (in particular weighing platforms) which could be influenced under certain conditions by the use of analog working walky-talkies and more recently of mobile phones due to electro-magnetic interference (EMC). One of the reasons for this deficiency is the fact that the EU-mandated written standards are outdated and do not cover the widespread application of modern electronic devices. This information has already been made available to the corresponding WELMEC Working Group but should be brought to the attention of market surveillance bodies in the EU as well (via appropriate networks, still to be established) for all kinds of regional regulated measuring devices.

One of the essential preconditions for taking appropriate counter-measures will require commonly accepted updating of the standard and of newly worked out EMC testing procedures within the WELMEC Working Group. This will then have to be reflected in the manufacturer's "design approval" or the "type approval" carried out by the Notified Body, depending on the type of module the weighing instrument manufacturer chooses for his product.

New developments in software regulations

A report was presented on the 11th meeting of WELMEC Working Group 7. Guide 7.2 *Software* was adopted by the WELMEC Committee in May 2005 and can be downloaded from the WELMEC web site (www.welmec.org → "Guides"). There are still some provisional sections in the Guide as the Working Groups responsible for the various kinds of instruments have not all finished discussions on assigning risk classes to the respective measuring instruments.

One main issue of the meeting was to harmonize examinations by Notified Bodies. All WG7 members stated that they were prepared to apply the Guide with the support of a software specialist who would do this work in parallel with the regular conformity assessment.

Another important issue of the WG7 meeting was the intercomparison of software evaluation results. Six Notified Bodies of the Working Group took on the role of the examiners. The object of the evaluation was an electricity meter provided by a manufacturer, including documentation. At the end of the intercomparison the test reports were evaluated by a small WG7 subgroup which will prepare recommendations on how to improve the Guide with the aim of facilitating its application. A separate article on the performance of this intercomparison is expected to be published soon.

A report was also given on the status of the OIML 1WD on software requirements, primarily designed to provide a universal basis for other OIML Technical Committees which are developing OIML Recommendations and which want to integrate software requirements. The structure is very similar to that of OIML D 11 for electronic instruments. The main ideas of the Document are in line with WELMEC Guide 7.2.

Results of COOMET Projects

The smooth exchange of information on technical and administrative changes in the field of legal metrology in COOMET member countries is one of the most important prerequisites for harmonizing metrological regulations. The findings on test results of measurement devices is an important component for confidence building, and experience gained nationally should be more openly exchanged on a regional level particularly with the introduction of "new" evaluation elements into the legal metrology system such as software testing or compliance with EMC requirements applied to electronic devices operating under user operating conditions.

Almost all representatives reported a profound revision of their legal metrology systems, but without always being able to define the status of discussions since these are still ongoing.

The exchange of information among legal metrology authorities is of major importance and has to be carried out according to certain criteria yet to be established and on a permanent basis.

A major concern of COOMET countries is the common interpretation and application of general technical specifications. Workshops, training courses and seminars are an efficient tool for keeping up with new international developments in legal metrology.

Four workshops in Russian were organized by the PTB for COOMET member countries. Two took place on hardness and the others on pressure measurement and calibration procedures, including the calculation of uncertainties. Additionally, two workshops were held in Minsk, Belarus and in Sofia, Bulgaria on the testing of prepackages in April and October 2006. A more detailed report was published in OIML Bulletin Volume XLVII No. 2, 2006, pages 49 ff.

A further workshop took place in Chişinău, Moldova on 6–7 July 2006 called *Testing of software for measuring instruments. General approach and testing procedures according to WELMEC Guide 7.2*. The aim of all these projects is the mutual recognition of conformity assessments carried out for type approval and verification.

COOMET member countries consider workshops, training courses and seminars to be of vital importance for keeping up with new international developments in legal metrology.

Project work

Six different legal metrology projects are currently ongoing to streamline technical regulations in COOMET member countries, the objectives being:

- The harmonization of metrological rules and norms;
- The assessment of the technical competence of verification laboratories;
- Cooperation in the field of mutual acceptance of test results;
- Development of a Recommendation on measuring instrument software testing;
- Development of Recommendations on general requirements of systems for ensuring conformity of measuring instruments to the approved type; and
- Development of Recommendations for carrying out initial verification in the framework of the quality management system of a producer.

OIML Document D 1 plays an important role for a number of COOMET member countries in their efforts to remodel their legal metrology systems.

Closer cooperation beyond the geographical boundaries of Regional Metrology Organizations could be beneficial for all parties concerned. So, the results of an investigation carried out by the PTB on behalf of the Asia-Pacific Legal Metrology Forum (APLMF) on various instruments for measuring the content of moisture in rice could be of interest to other National Metrology Institutes responsible for type approval of that kind of device. Measuring the content of moisture in grain is quite common practice in a number of countries, and certain kinds of instruments can be used for measuring the content of protein at the same time. This component is economically even more important in trade than the humidity content.

Outlook

The COOMET member countries take a great interest in the work of TC 2, the outcome of whose work was reported to the COOMET Committee meeting in Braunschweig, Germany in September 2006.

In future, the exchange of information should also comprise observations on measuring devices with non-conformities, and should be realized via a database comprising classified and general information in relation to specific types of instruments. Possibly a separate project will have to be addressed on this issue which could propose a type of network for mutual information regarding the identification of measuring instruments with critical metrological non-conformities, leading to possible prosecution.

The handling of the control of prepackages is of great interest to the majority of COOMET member countries since this subject is now attracting more attention because of the liberalization of the markets. So it was suggested to establish a new SC on prepackages within the scope of TC 2 dealing with practical control issues as well as with the elaboration of legal requirements and the drafting of by-laws.

Closer cooperation between the various NMIs should comprise the area of market surveillance as far as the operating system, financing, findings and follow up measures are concerned.

The Ukraine representative declared his readiness to investigate whether the 8th COOMET TC 2 Meeting could be held in Lviv, Ukraine, during 2007. ■

The OIML is pleased to welcome the following new

CIML Members

- **Ethiopia:**
  Mr. Wondwosen Fisseha
- **Cameroon:**
  Mr Berthollet Tchami

OIML Meeting

23–26 October 2007 - Shanghai, P.R. China

42nd CIML Meeting and Associated Events

Committee Drafts

Received by the BIML, 2006.12 – 2007.02

Revision OIML R 117: Measuring systems for liquids other than water. Part 1: Metrological and technical requirements	E	DR	TC 8/SC 3	USA/DE
Newtonian viscosity standard liquids for the calibration and verification of viscometers	E	2 CD	TC 17/SC 5	RU
Revision R 85: Automatic level gauges for measuring the level of liquid in fixed storage tanks. Part 1: Metrological and technical requirements - Tests. Part 2: Metrological control and tests.	E	3 CD	TC 8/SC 1	AT
Procedure for calibration and verification of the main characteristics of thermographic instruments	E	3 CD	TC 11/SC 3	RU

Call for papers

OIML Members
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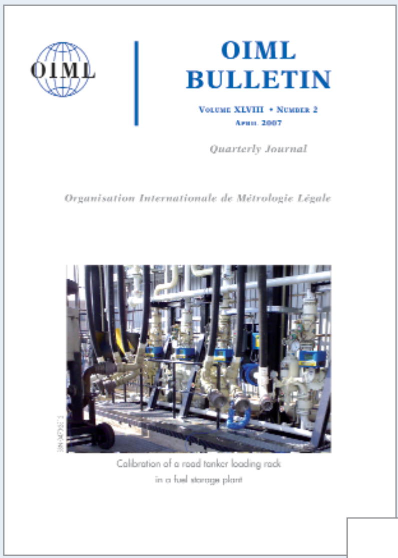
Liaison Institutions
Manufacturers' Associations
Consumers' & Users' Groups, etc.



Calibration of a road tanker loading rack in a fuel storage plant

The CIML holds its 41st Meeting in Cape Town

- Technical articles on legal metrology related subjects
- Features on metrology in your country
- Accounts of Seminars, Meetings, Conferences
- Announcements of forthcoming events, etc.

Information technology at the service of OIML Members

The **OIML Bulletin** is a forum for the publication of technical papers and diverse articles addressing metrological advances in trade, health, the environment and safety - fields in which the credibility of measurement remains a challenging priority. The Editors of the Bulletin encourage the submission of articles covering topics such as national, regional and international activities in legal metrology and related fields, evaluation procedures, accreditation and certification, and measuring techniques and instrumentation. Authors are requested to submit:

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- the paper originals of any relevant photos, illustrations, diagrams, etc.;
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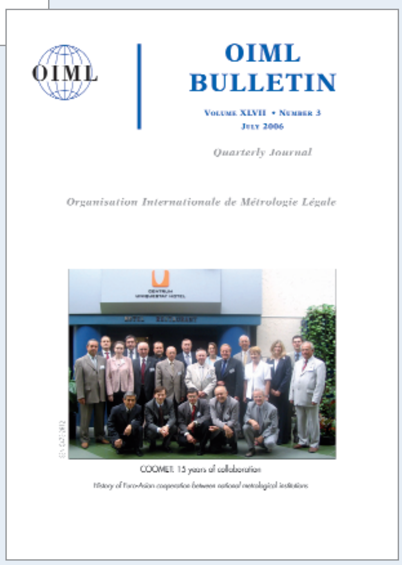

COOMET: 15 years of collaboration