METROLOGY – IN SHORT

3RD EDITION

"METROLOGY – IN SHORT" 3RD EDITION

July 2008

COVER

Photo of Great Belt east bridge, Denmark. Each of the east bridge's 55 prefabricated 48-metre, 500-ton bridge sections were measured in detail in order to adjust the four hangers which carry the section, to ensure the correct tension. The measured, and expected, deviations from the theoretical measurements required a hanger adjustment of ± 30 mm. The adjustment of each hanger pin was determined to an accuracy of ± 1 mm. A wide network of contractors and subcontractors from 10 European countries were involved in building the bridge 1988 - 1997. Reliable and verified measurements were essential in this huge and complex collaboration.

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SUMMARY

The main purpose of "Metrology – in short" 3rd edition is to increase awareness of metrology and to establish a common metrological frame of reference. It is meant to provide users of metrology with a transparent and handy tool to obtain metrological information.

Today's global economy depends on reliable measurements and tests, which are trusted and accepted internationally. They should not create technical barriers to trade and a precondition for this is a widely utilised and robust metrological infrastructure.

The content of this handbook is a description of scientific, industrial and legal metrology. The technical subject fields of metrology and metrological units are described. The international metrology infrastructure is detailed, including the regional metrology organisations such as EURAMET. A list of metrological terms is collected primarily from internationally recognised standards. References are given to institutions, organisations and laboratories by reference to their website homepages.

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FOREWORD

It is with pleasure that we present this 3rd edition of the easy-to-use handbook "©Metrology – in short". It is meant to provide users of metrology and the general public with a simple yet comprehensive reference source on the subject. It targets those who are not familiar with the topic and who require an introduction, as well as those who are involved in metrology at various levels but who want to know more about the subject or simply gain specific information. It is our hope that "Metrology – in short" will make it easier to understand and work with the technical and organisational aspects of metrology. The 1st edition of the handbook, published in 1998, proved to be a very successful and widely used publication throughout the metrology world, as did the 2nd edition published in 2004. This 3rd edition aims to build on this success by providing a broader scope of information to a wider target audience.

The main purpose of "Metrology – in short" is to increase awareness of metrology and to establish a common metrological understanding and frame of reference both in Europe, and between Europe and other regions throughout the world. This is particularly important with the increased emphasis on the equivalence of measurement and testing services for quality of life, environmental protection and trade and in particular where technical barriers to trade are caused by metrological impediments.

Since metrology evolves in line with scientific and technological advances it is necessary to update and enhance "Metrology – in short" to take account of this evolution. Consequently the content of this 3rd edition has been broadened and updated to address developments in the CIPM Mutual Recognition Arrangement (MRA) and regional metrology, including the establishment of the legal entity EURAMET e.V. in January 2007 as the new European Regional Metrology Organisation. It also contains more information about measurements in chemistry and biology and provides some specific examples of how developments in metrology have impacted the wider world.

I hope that this new edition will prove to be even more popular and widely used than the first two editions and thereby contribute to a common metrological frame of reference worldwide, which will ultimately promote trade between the different regions in the world and improved quality of life for its citizens.

Michael Kühne
EURAMET Chairman
June 2008

1. INTRODUCTION

1.1 MANKIND MEASURES

The death penalty faced those who forgot or neglected their duty to calibrate the standard unit of length at each full moon. Such was the peril courted by the royal site architects responsible for building the temples and pyramids of the Pharaohs in ancient Egypt, 3000 years BC. The first royal cubit was defined as the length of the forearm from elbow to tip of the extended middle finger of the ruling Pharaoh, plus the width of his hand. The original measurement was transferred to and carved in black granite. The workers at the building sites were given copies in granite or wood and it was the responsibility of the architects to maintain them.

Even though we feel ourselves to be a long way from this starting point, both in distance and in time, people have placed great emphasis on correct measurements ever since. Closer to our time, in 1799 in Paris, the Metric System was created by the deposition of two platinum standards representing the metre and the kilogram – the forerunner of the present International System of Units – the SI system.

In the Europe of today we measure and weigh at a cost equivalent to 6% of our combined GNP, so metrology has become a natural and vital part of our everyday life: Coffee and planks of wood are both bought by weight or size; water, electricity and heat are metered, and that affects our private economies. Bathroom scales affect our humour – as do police speed traps and the possible financial consequences. The quantity of active substances in medicine, blood sample measurements, and the effect of the surgeon's laser must also be precise if patients' health is not to be jeopardised. We find it almost impossible to describe anything without referring to weights and measures: Hours of sunshine, chest measurements, alcohol percentages, weights of letters, room temperatures, tyre pressures ... and so on. Just for fun, try holding a conversation without using words that refer to weights or measures.

Then there is commerce, trade and regulation that are just as dependent on weights and measures. The pilot carefully observes his altitude, course, fuel consumption and speed, the food inspectorate measures bacteria content, maritime authorities measure buoyancy, companies purchase raw materials by weights and measures, and specify their products using the same units. Processes are regulated and alarms are set off because of measurements. Systematic measurement with known degrees of uncertainty is one of the foundations of industrial quality control and, generally speaking, in most modern industries the costs bound up in taking measurements constitute 10-15% of production costs. Good measurements can however significantly increase the value, effectiveness and quality of a product.

Finally, science is completely dependent on measurement. Geologists measure shock waves when the gigantic forces behind earthquakes make themselves felt, astronomers patiently measure the dim light from distant stars in order to determine their age, atomic physicists wave their hands in the air when by making measurements in millionths of a second they are able at last to confirm the presence of an almost infinitesimally small particle. The availability of measuring equipment and the ability to use it effectively are essential if scientists are to be able to objectively document the results they achieve. The science of measurement – metrology – is probably the oldest science in the world and knowledge of how it is applied is a fundamental necessity in practically all science-based professions!

Measurement requires common knowledge

Metrology presents a seemingly calm surface covering depths of knowledge that are familiar only to a few, but which most make use of – confident that they are sharing a common perception of what is meant by expressions such as metre, kilogram, litre, watt, etc. Confidence is vital in enabling metrology to link human activities together across geographic and professional boundaries. This confidence becomes enhanced with the increased use of network co-operation, common units of measurement and common measuring procedures, as well as the recognition, accreditation and mutual testing of measuring standards and laboratories in different countries. Mankind has thousands of years of experience confirming that life really does become easier when people co-operate on metrology.

Metrology is the science of measurement

Metrology covers three main activities:

1. The *definition* of internationally accepted units of measurement, e.g. the metre.

2. The *realisation* of units of measurement by scientific methods, e.g. the realisation of a metre through the use of lasers.

3. The establishment of *traceability* chains by determining and documenting the value and accuracy of a measurement and disseminating that knowledge, e.g. the documented relationship between the micrometer screw in a precision engineering workshop and a primary laboratory for optical length metrology.

Metrology develops ...

Metrology is essential in scientific research, and scientific research forms the basis of the development of metrology itself. Science pushes forward the frontiers of the possible all the time and fundamental metrology follows the metrological aspects of these new discoveries. This means ever better metrological tools enabling researchers to continue their discoveries – and only those fields of metrology that do develop can continue to be a partner for industry and research.

Correspondingly, scientific, industrial and legal metrology must also develop in order to keep pace with the needs of industry and society – and remain relevant and useful.

It is the intention to continuously develop "Metrology – in short". The best way of developing a tool is of course to collect the experience of those who use it and the publishers would therefore be grateful for comments, be they criticism or praise. Mail to either of the authors will be appreciated.

1.2 CATEGORIES OF METROLOGY

Metrology is separated into three categories with different levels of complexity and accuracy:

1. *Scientific metrology* deals with the organisation and development of measurement standards and with their maintenance (highest level).

2. *Industrial metrology* has to ensure the adequate functioning of measurement instruments used in industry, in production and testing processes, for ensuring quality of life for citizens and for academic research.

3. *Legal metrology* is concerned with measurements where these influence the transparency of economic transactions, particularly where there is a requirement for legal verification of the measuring instrument.

Fundamental metrology has no international definition, but it generally signifies the highest level of accuracy within a given field. Fundamental metrology may therefore be described as the top level branch of scientific metrology.

1.3 NATIONAL EDITIONS OF METROLOGY – IN SHORT

"Metrology – in short" has been issued in a number of national or regional editions, each adapted to and describing metrology in specific countries, following the same handbook-concept. The English editions are the international editions.

By 2008 the following editions were available:

Albanian: Metrologjia – shkurt
Published 2006, contact metrology@san.com.al

Czech: Metrologie v kostce
Published 2002 in 2 000 copies, contact jtesar@cmi.cz

Croatian: Metrologija ukratko
Published 2000 in an electronic version.

Danish: Metrologi – kort og godt
First edition published 1998 in 1 000 copies, contact pho@dfm.dtu.dk
Second edition published 1999 in 2 000 copies, contact pho@dfm.dtu.dk

English: Metrology – in short (international edition)
1st edition published 2000 in 10 000 copies, contact pho@dfm.dtu.dk
2nd edition published 2003 in 10 000 copies
3rd edition published 2008 in 8 000 copies and in an electronic version.
Contact pho@dfm.dtu.dk or fiona.redgrave@npl.co.uk

Finnish: Metrology – in short
First edition published 2001 in 5 000 copies, contact mikes@mikes.fi
Second edition published 2002, contact mikes@mikes.fi

Indonesian: Metrologi – sebuah pengantar
Published 2005, contact probo@kim.libi.go.id

Icelandic: Agrip af Mælifrædi
Published 2006, contact postur@neytendastofa.is

Japanese: Japanese characters
Published 2005

Lebanese: ABC-guide Metrology (Both in English and Arabic language)
Published 2007 in 1500 copies

Lithuanian: Metrologija trumpai
First edition published 2000 in 100 copies, contact rimvydas.zilinskas@ktu.lt
Second edition published 2004 in 2 000 copies, contact vz@lvmt.lt

MEDA region: Metrology – in short, MEDA version
Published 2007 in 1200 copies

MEDA region: Métrologie – en bref, édition MEDA
Published 2007 in 1200 copies

Portuguese: Metrologia – em sintese
Published 2001 in 2 500 copies, contact ipq@mail.ipq.pt

Turkish: Kisaca Metroloji – ikinci baski
Published 2006

2. METROLOGY

2.1 INDUSTRIAL AND SCIENTIFIC METROLOGY

Industrial and scientific metrology are two of the three categories of metrology as described in chapter 1.2.

Metrological activities, calibration, testing and measurements are valuable inputs to ensure the quality of many industrial and quality of life related activities and processes. This includes the need to demonstrate traceability, which is becoming just as important as the measurement itself. *Recognition* of metrological *competence* at each level of the *traceability* chain can be established through mutual recognition agreements or arrangements, for example the CIPM MRA and ILAC MRA, and through accreditation and peer review.

2.1.1 SUBJECT FIELDS

Scientific metrology is divided into 9 technical subject fields by BIPM: Acoustics, amount of substance, electricity and magnetism, ionising radiation and radioactivity, length, mass, photometry and radiometry, thermometry, time and frequency.

Within EURAMET there are three additional subject fields: flow, interdisciplinary metrology and quality.

There is no formal international definition of the subfields.

Table 1: Subject fields, subfields and important measurement standards. Only technical subject fields are included.

SUBJECT FIELD	SUBFIELD	IMPORTANT MEASUREMENT STANDARDS
MASS AND RELATED QUANTITIES	Mass measurement	Mass standards, standard balances, mass comparators
	Force and pressure	Load cells, dead-weight testers, force, moment and torque converters, pressure balances with oil/gas-lubricated piston cylinder assemblies, force-testing machines, capacitance manometers, ionisation gauges
	Volume and density Viscosity	Glass areometers, laboratory glassware, vibration densimeters, glass capillary viscometers, rotation viscometers,

SUBJECT FIELD	SUBFIELD	IMPORTANT MEASUREMENT STANDARDS
ELECTRICITY AND MAGNETISM	DC electricity	Cryogenic current comparators, Josephson effect and Quantum Hall effect, Zener diode references, potentiometric methods, comparator bridges
	AC electricity	AC/DC converters, standard capacitors, air capacitors, standard inductances, compensators, wattmeters
	HF electricity	Thermal converters, calorimeters, bolometers
	High current and high voltage	Measurement transformers of current and voltage, reference high voltage sources
LENGTH	Wavelengths and interferometry	Stabilized lasers, interferometers, laser interferometric measurement systems, interferometric comparators
	Dimensional metrology	Gauge blocks, line scales, step gauges, setting rings, plugs, high masters, dial gauges, measuring microscopes, optical flat standards, coordinate measuring machines, laser scan micrometers, depth micrometers, geodetic length measuring tools
	Angular measurements	Autocollimators, rotary tables, angle gauges, polygons, levels
	Form	Straightness, flatness, parallelism, squares, roundness standards, cylinder standards
	Surface Quality	Step height and groove standards, roughness standards, roughness measurement equipment
TIME AND FREQUENCY	Time measurement	Caesium atomic clock, time interval equipment
	Frequency	Atomic clock and fountain, quartz oscillators, lasers, electronic counters and synthesisers, optical combs
THERMOMETRY	Temperature measurement by contact	Gas thermometers, ITS 90 fixed points, resistance thermometers, thermocouples
	Non-contact temperature measurement	High-temperature black bodies, cryogenic radiometers, pyrometers, Si photodiodes
	Humidity	Mirror dew point meters or electronic hygrometers, double pressure/temperature humidity generators

SUBJECT FIELD	SUBFIELD	IMPORTANT MEASUREMENT STANDARDS
THERMOMETRY	Absorbed dose – Medical products	Calorimeters, Ionisation chambers
	Radiation protection	Ionisation chambers, reference radiation beams/fields, proportional and other counters, TEPC, Bonner neutron spectrometers
	Radioactivity	Well-type ionising chambers, certified radioactivity sources, gamma and alpha spectroscopy, 4 Π detectors
PHOTOMETRY AND RADIOMETRY	Optical radiometry	Cryogenic radiometer, optical detectors, stabilised laser reference sources, reference materials
	Photometry	Visible region detectors, Si photodiodes, quantum efficiency detectors
	Colorimetry	Spectrophotometer
	Optical fibres	Reference materials
FLOW	Gas flow (volume)	Bell provers, rotary gas meters, turbine gas meters, transfer meter with critical nozzles
	Flow of liquids (volume, mass and energy)	Volume standards, Coriolis mass-related standards, level meters, inductive flow meters, ultrasound flow meters
	Anemometry	Anemometers
ACOUSTICS, ULTRASOUND AND VIBRATION	Acoustical measurements in gases	Standard microphones, piston phones, condenser microphones, sound calibrators
	Accelerometry	Accelerometers, force transducers, vibrators, laser interferometer
	Acoustical measurements in liquids	Hydrophones
	Ultrasound	Ultrasonic power meters, radiation force balance

SUBJECT FIELD	SUBFIELD	IMPORTANT MEASUREMENT STANDARDS
CHEMISTRY	Environmental chemistry Clinical chemistry	Certified reference materials, mass spectrometers, chromatographs, gravimetric standards
	Materials chemistry	Pure materials, certified reference materials
	Food chemistry, Biochemistry, Micro biology	Certified reference materials
	pH measurement	Certified reference materials, standard electrodes

2.1.2 MEASUREMENT STANDARDS

A measurement standard or etalon, is a material measure, measuring instrument, reference material or measuring system intended to define, realise, conserve or reproduce a unit or one or more values of a quantity to serve as a reference.

Example The metre is *defined* as the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second. The metre is *realised* at the primary level in terms of the wavelength from an iodine-stabilised helium-neon laser. On sub-levels, material measures like gauge blocks are used, and traceability is ensured by using optical interferometry to determine the length of the gauge blocks with *reference* to the above-mentioned laser light wavelength.

The different levels of measurement standard are shown in Figure 1. Metrology fields, subfields and important measurement standards are shown in Table 1 in chapter 2.1.1. There is no international listing of all measurement standards.

The definitions of the different measurement standards are given in the Glossary in chapter 6.

2.1.3 CERTIFIED REFERENCE MATERIALS

A certified reference material (CRM) is a reference material, where one or more of its property values are certified by a procedure that establishes traceability to a realisation of the unit, in which the property values are expressed. Each certified value is accompanied by an uncertainty at a stated level of confidence. The term standard reference material

(SRM) is also used in some parts of the world and is synonymous with a CRM.

CRMs are generally prepared in batches. The property values are determined within stated uncertainty limits by measurements on samples representative of the whole batch.

2.1.4 TRACEABILITY & CALIBRATION

Traceability to the SI

A traceability chain, see Figure 1, is an unbroken chain of comparisons, all having stated uncertainties. This ensures that a measurement result or the value of a standard is related to references at the higher levels, ending at the primary standard.

In chemistry and biology traceability is often obtained by using CRMs and reference procedures, see chapter 2.1.3 and 2.1.6.

An end user may obtain traceability to the highest international level either directly from a National Metrology Institute or from a secondary calibration laboratory, usually an accredited laboratory. As a result of various mutual recognition arrangements, internationally recognised traceability may be obtained from laboratories outside the user's own country.

Calibration

A basic tool in ensuring the traceability of a measurement is the calibration of a measuring instrument, measuring system or reference material. Calibration determines the performance characteristics of an instrument, system or reference material. It is usually achieved by means of a direct comparison against measurement standards or certified reference materials. A calibration certificate is issued and, in most cases, a sticker is provided for the instrument.

Four main reasons for having an instrument calibrated:

1. To establish and demonstrate traceability.
2. To ensure readings from the instrument are consistent with other measurements.
3. To determine the accuracy of the instrument readings.
4. To establish the reliability of the instrument i.e. that it can be trusted.

2.1.5 METROLOGY IN CHEMISTRY

Metrology has developed from physical measurements and emphasizes results traceable to defined reference standards, normally the International System of Units (SI), with fully analysed uncertainty budgets based on the GUM [6]. The situation with respect to chemical measurements is more complex since chemical measurements often do not take place under such controlled and defined conditions, see Table 2.

Table 2: Comparison between metrology in physics and chemistry

METROLOGY IN PHYSICS AND CHEMISTRY	Physics	Chemistry
Measurement	Comparing a quantity: e.g. temperature	Comparing a quantity: e.g. DDT in milk
Units	m, s, K	mol/kg, mg/kg
Influenced by..	Often relies on direct measurements	Various factors affects the quality of the measurement results
Main impact	Equipment calibration	Chemical treatment (e.g. extraction, digestion); reference materials used; ... and equipment calibration
Depends on..	To a large extent sample independent	Strongly sample dependent
Example	Length of a table	Concentration of Pb in: seawater; soils, blood etc.

Often the primary objective of chemical measurements is to determine the amount of components of interest, not the total composition of the sample. Total composition will therefore almost always remain unknown and hence the total environment under which the measurements take place cannot be defined and controlled.

Many chemical measurements are traceable to a standard or to reference methods. In other instances measurements can be considered to be traceable to a (certified) reference material, either in the form of a pure substance or of a matrix reference material, in which the concentration of the analyte has been certified. The degree to which reference materials provide a universal reference (and specifically traceable to the SI) depends on the quality of the link to values obtained by reference measurements or via links to values carried by reference standards.

pH

pH is a measure of the degree of acidity or alkalinity of an aqueous solution, which is determined by number of available hydrogen ions, i.e. the activity (effective concentration) of hydrogen ions. pH is an important concept because many chemical processes and most biological processes depend critically on the degree of acidity at the site of the reaction. Biological processes take place in environments spanning at least twelve orders of magnitude of hydrogen ion activity, but each specific process is usually dependent on an environment within only a few degrees of hydrogen ion activity.

2.1.6 REFERENCE PROCEDURES

Reference procedures or methods can be *defined* as procedures of

- testing, measurement or analysis,

thoroughly characterised and proven to be under control, intended for

- quality assessment of other procedures for comparable tasks, or
- characterisation of reference materials including reference objects, or
- determination of reference values.

The uncertainty of the results of a reference procedure must be adequately estimated and appropriate for the intended use.

According to this definition reference procedures can be used to

- validate other measurement or test procedures, which are used for a similar task, and to determine their uncertainty.
- determine reference values of the properties of materials, which can be compiled in handbooks or databases, or reference values which are embodied by a reference material or reference object.

Figure 1: The traceability chain

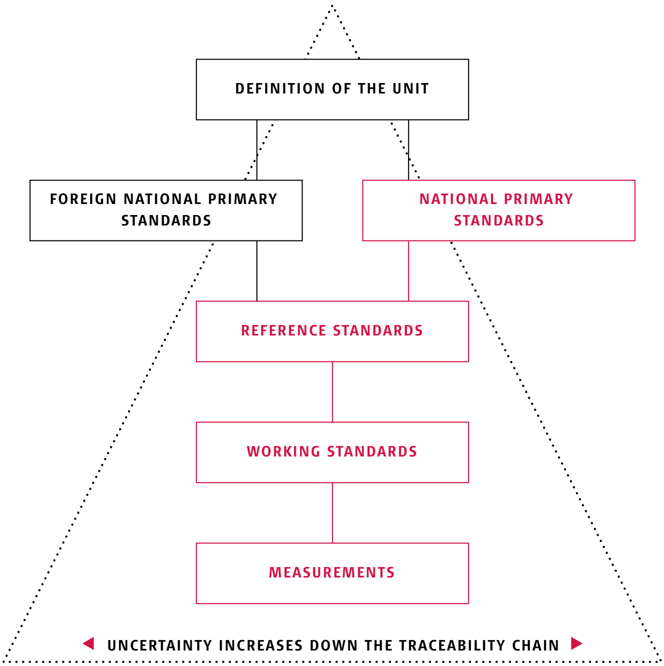
BIPM
(Bureau International des Poids et Mesures)

National metrology institutes or designated national institutes

Calibration laboratories, often accredited

Industry, academia, regulators, hospitals

End users



The national metrological infrastructure

2.1.7 UNCERTAINTY

Uncertainty is a quantitative measure of the quality of a measurement result, enabling the measurement results to be compared with other results, references, specifications or standards.

All measurements are subject to error, in that the result of a measurement differs from the true value of the measurand. Given time and resources, most sources of measurement error can be identified, and measurement errors can be quantified and corrected for, for instance through calibration. There is, however, seldom time or resources to determine and correct completely for these measurement errors.

Measurement uncertainty can be determined in different ways. A widely used and accepted method, e.g. accepted by the accreditation bodies, is the ISO recommended *GUM method*, described in the "Guide to the expression of uncertainty in measurement" [6]. The main points of the GUM method and its underlying philosophy are tabulated below.

Example A measurement result is reported in a certificate on the form

$$Y = y \pm U$$

where the uncertainty U is given with no more than **two** significant digits and y is correspondingly rounded to the same number of digits, in this example seven digits.

A resistance measured on a resistance meter with a reading of 1.000 052 7 Ω where the resistance meter, according to the manufacturer's specifications, has an uncertainty of 0.081 mΩ, the result stated on the certificate is

$$R = (1.000\ 053 \pm 0.000\ 0\underline{\mathbf{81}})\ \Omega$$

Coverage factor k = 2

The uncertainty quoted in the measurement result is usually an *expanded uncertainty*, calculated by multiplying the combined standard uncertainty by a numerical *coverage factor*, often k = 2 which generally corresponds to an interval of approximately 95% level of confidence.

The GUM uncertainty philosophy

1) **A measurement quantity** *X*, whose value is not known exactly, is considered as a stochastic variable with a probability function.
2) The **result** *x* of measurement is an estimate of the expectation value $E(X)$.
3) The **standard uncertainty** $u(x)$ is equal to the square root of an estimate of the variance $V(X)$.
4) **Type A evaluation**
   Expectation and variance are estimated by statistical processing of repeated measurements.
5) **Type B evaluation**
   Expectation and variance are estimated by other methods. The most commonly used method is to assume a probability distribution e.g. a rectangular distribution, based on experience or other information.

The GUM method

based on the GUM philosophy

1) **Identify all important components of measurement uncertainty**
   There are many sources that can contribute to the measurement uncertainty. Apply a model of the actual measurement process to identify the sources. *Use measurement quantities* in a mathematical model.
2) **Calculate the standard uncertainty of each component of measurement uncertainty**
   Each component of measurement uncertainty is expressed in terms of the *standard uncertainty* determined from either a *type A* or *type B* evaluation.
3) **Calculate the combined uncertainty**
   The principle:
   The combined uncertainty is calculated by combining the individual uncertainty components according to the law of propagation of uncertainty.
   In practice:
   - For a sum or a difference of components, the combined uncertainty is calculated as the square root of a sum of the squared standard uncertainties of the components.
   - For a product or a quotient of components, the same "sum/difference" rule applies for the relative standard uncertainties of the components.
4) **Calculate the expanded uncertainty**
   Multiply the combined uncertainty with the coverage factor k.
5) **State the measurement result on the form**

$$Y = y \pm U$$

2.1.8 TESTING

Testing is the determination of the characteristics of a product, a process or a service, according to certain procedures, methodologies or requirements.

The aim of testing may be to check whether a product fulfils specifications such as safety requirements or characteristics relevant for commerce and trade. Testing is carried out widely, covers a range of fields, takes place at different levels and at different requirements of accuracy. Testing is carried out by laboratories, which may be first-, second- or third-party laboratories. First-party laboratories are those of the producer, second-party laboratories are those of the customer, whilst third-party laboratories are independent from both the producer and the customer.

Metrology delivers the basis for the comparability of test results, e.g. by defining the units of measurement and by providing traceability and associated uncertainty of the measurement results.

2.2 LEGAL METROLOGY

Legal metrology is the third category of metrology, see chapter 1.2. Legal metrology originated from the need to ensure fair trade, specifically in the area of weights and measures. Legal metrology is primarily concerned with measuring instruments which are themselves legally controlled, and the main objective of legal metrology is to assure citizens of correct measurement results when used in official and commercial transactions.

OIML is the *International Organisation of Legal Metrology*, see chapter 3.1.8.

There are also many other areas of legislation, outside legal metrology, where measurements are required to assess conformance with regulations or legislation e.g. aviation, healthcare, construction products, environmental and pollution control.

2.2.1 Legislation for measuring instruments

People using measurement results in the application field of legal metrology are not required to be metrological experts and the government takes responsibility for the credibility of such measurements. Legally controlled instruments should guarantee correct measurement results:

- under working conditions
- throughout the whole period of use
- within given permissible errors.

Therefore requirements are laid down in national or regional legislation for legal metrology measuring instruments and measurement and testing methods including pre-packaged products.

2.2.2 EU LEGISLATION FOR MEASURING INSTRUMENTS

EU controlled measuring instruments

In Europe, harmonisation of legally controlled measuring instruments is currently based on Directive 71/316/EEC, which contains horizontal requirements for all categories of measuring instruments, as well as in other specific directives covering individual categories of measuring instruments and which have been published since 1971. Member states subject to these directives were not obliged to repeal existing national legislation. Measuring instruments, which have been granted an *EC type approval* (not all instruments) and an *EC initial verification*, can be placed on the market and used in all member states without further tests or type approvals.

For historical reasons the scope of legal metrology is not the same in all countries. With the coming into force of the Non-automatic Weighing Instruments (NAWI) Directive on 1 January 1993 and the Measuring Instruments Directive (MID) on 30 October 2006 many of the existing directives related to measuring instruments have been repealed.

EU Non-automatic Weighing Instruments (NAWI) Directive

The NAWI Directive 90/384/EEC (as amended by Directive 93/68/EEC) removes technical barriers to trade, thus creating a 'single' market and regulating the usage of instruments from shop scales to industrial weighbridges for commercial, legal and medical purposes.

EU Measuring Instruments Directive (MID)

The Measuring Instruments Directive 2004/22/EC continues this process of removing technical barriers to trade thus regulating the marketing and usage of the following measuring instruments:

MI-001	water meters
MI-002	gas meters
MI-003	electrical energy meters and measurement transformers
MI-004	heat meters
MI-005	measuring systems for liquids other than water
MI-006	automatic weighing instruments
MI-007	taximeters
MI-008	material measures

MI-009 dimensional measuring systems
MI-010 exhaust gas analysers

Member states have the option to decide which of the instrument types they wish to regulate. Existing national regulations, subject to transitional provisions, cease to apply to new instruments.

Electronic instruments were not included in the existing directives but are covered by NAWI Directive and the MID.

2.2.3 EU ENFORCEMENT OF MEASURING INSTRUMENT LEGISLATION

Legal control

Preventive measures are taken before marketing of the instruments, i.e. many of the instruments have to be type-approved and all have to be verified. Manufacturers are granted *type approval* by a competent body authorised by the member country once that type of instrument meets all associated legal requirements. With serially manufactured measuring instruments, *verification* ensures that each instrument conforms to type and fulfils all requirements laid down in the approval procedure.

Market surveillance is an *inspection type measure* to establish whether instruments placed on the market meet the legal requirements. For instruments in use, inspections or periodic *re-verifications* are carried out to ensure that measuring instruments continue to comply with legal requirements. The standards used for such inspections and tests must be traceable to national or international standards. The binding legal control of measuring instruments included in the Directives is left to each member state. Re-verifications, inspections and verification validity periods have not been harmonised and are consequently laid down by member states on the basis of their own national legislation. Member states may lay down legal requirements for measuring instruments which are not listed in the NAWI Directive or MID.

The modules for the various phases of *conformity assessment* found in NAWI and the MID correspond to those in Directive 93/465/EEC which apply to all *technical harmonisation directives.*

Enforcement responsibilities

Directives define:

- *The producer's responsibility:* The product must comply with the requirements in the directives.
- *The government's responsibility:* Non-conforming products must not be placed on the market or put into use.

The producer's responsibility

With the NAWI Directive and the MID the manufacturer is responsible for affixing the CE marking and the supplementary metrology marking on the product along with the number of the Notified Body guaranteeing the validity of the conformity assessment process. The affixing of the marks is a declaration that the product is in conformity with the requirements of the directives. Both NAWI and the MID are mandatory directives.

Packers and importers of pre-packaged products must ensure that their packages have been packed so as to ensure compliance with the three packers' rules. In order to do so, packers are free to use whatever quantity control and checking procedures they wish, provided they are sufficiently rigorous to ensure compliance with the rules. Compliance with the three rules may, where necessary, be determined by appropriate tests, including the reference test which is conducted by local authority trading standards officers. The Pre-packaging Directive is a non mandatory directive.

The government's responsibility

The government is obliged to prevent measuring instruments that are subject to legal metrological control and that do not comply with applicable provisions of the directives, from being placed on the market and/or put into use. For example, the government shall in certain circumstances ensure that a measuring instrument with inappropriately fixed markings is withdrawn from the market.

The government shall ensure, that pre-packaged products, which are marked with an **"e"** or an inverted epsilon, conform to the requirements of the relevant directives.

The government fulfils its Directive obligations through market surveillance. To conduct market surveillance the government utilises local authority weights and measures inspectors and other persons to

- survey the market
- note any non-conforming products
- inform the owner or producer of the product about the non-conformance
- report to the government about non-conforming products.

2.2.4 MEASUREMENT AND TESTING IN LEGISLATION

The world economy and the quality of our everyday life depend on reliable measurements and tests which are trusted and accepted internationally and which do not form a barrier to trade. In addition to those regulations requiring legally verified instruments, many regulated areas require measurements and testing to assess compliance, either with the regulations or mandated documentary standards e.g. aviation, car safety testing, healthcare, environmental and pollution control and the safety of children's toys. Data quality, measurements and testing are therefore an important part of many regulations.

Regulatory guide to best measurement practice

Measurement may be required at any stage during the regulatory process. Good regulations require an appropriate approach to measurement/testing when

- establishing the rationale for legislation
- writing the legislation or regulation and establishing the technical limits
- undertaking market surveillance.

A guide has been developed by a collaboration of European NMIs to assist those considering measurement issues in the regulatory process. The information is presented below in a summary form.

Rational for the regulation

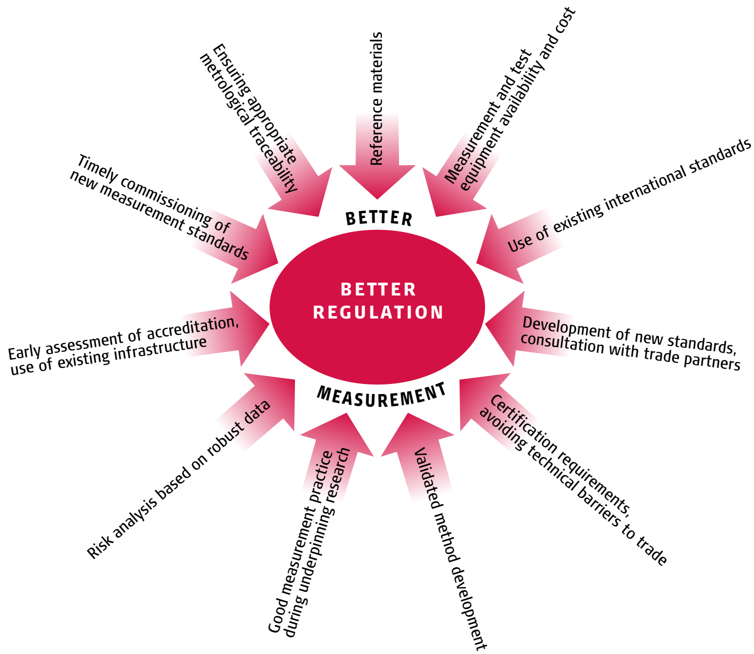
- Identification of the drivers
- Collection and collation of existing data
- Commissioning of R&D to support the rationale

Development of the regulation

- Assessment of the current state of play
- Setting of robust technical limits
- Commissioning of R&D to establish solutions
- Establishing the level of detail to be prescribed

Market surveillance

- Cost effective measurement & testing
- Feedback
- Adapting to new technology



There are at least 9 important measurement topics which may need to be addressed at each stage:

1. Which parameters will need be measured?
2. How to make best use of existing metrological infrastructure.
3. Ensuring appropriate measurement traceability, traceable to the SI (where possible) through an unbroken, auditable chain of measurements.
4. Are appropriate methods and procedures available for all tests and calibrations?
5. Can technical limits be established from risk analysis based on robust data – do the existing data support the rationale, are new or additional data required?
6. How to make best use of existing international standards – supplemented with additional requirements if necessary.
7. What is the likely measurement uncertainty – how does it compare to the technical limits, what is the impact on the ability to assess compliance?
8. Sampling of data – will it be random or selective, is there a scientific basis for requirements related to frequency, what is the impact of timing, seasonal or geographical variations?
9. Is suitable measurement technology available for the relevant parameters?

3. METROLOGICAL ORGANISATION

3.1 INTERNATIONAL INFRASTRUCTURE

3.1.1 THE METRE CONVENTION

In the middle of the 19th century the need for a universal decimal metric system became very apparent, particularly during the first universal industrial exhibitions. In 1875, a diplomatic conference on the metre took place in Paris where 17 governments signed the diplomatic treaty "the Metre Convention". The signatories decided to create and finance a permanent scientific institute: the "Bureau International des Poids et Mesures" **BIPM.** The Metre Convention was slightly modified in 1921.

Representatives of the governments of the member states meet every fourth year for the "Conférence Générale des Poids et Mesures" **CGPM.** The CGPM discusses and examines the work performed by national metrology institutes and the BIPM, and makes recommendations on new fundamental metrological determinations and all major issues of concern to the BIPM.

The Metre Convention had 51 member states in 2008, and 27 states and economies which were associates of the CGPM, with the right to send an observer to the CGPM.

CGPM elects up to 18 representatives to the "Comité International des Poids et Mesures" **CIPM,** which meets annually. The CIPM supervises BIPM on behalf of the CGPM and co-operates with other international metrology organisations. CIPM undertakes preparatory work for technical decisions to be made by the CGPM. The CIPM is supported by 10 consultative committees. The president of each of the consultative committees is usually a member of the CIPM. The other members of the consultative committees are representatives of the national metrology institutes (see chapter 3.1.3) and other experts.

A number of Joint Committees of the BIPM and other international organisations have been created for particular tasks:

- JCDCMAS Joint Committee on coordination of assistance to Developing Countries in Metrology, Accreditation and Standardization.
- JCGM Joint Committee for Guides in Metrology.
- JCRB Joint Committee of the Regional Metrology Organisations and the BIPM.
- JCTLM Joint Committee on Traceability in Laboratory Medicine.

Figure 2: The Metre Convention organisation

THE METRE CONVENTION
International convention established in 1875 with 51 member states in 2008.

CGPM CONFÉRENCE GÉNÉRALE DES POIDS ET MESURES
Committee with representatives from the Metre Convention member states. First conference held in 1889 and meets every 4th year. Approves and updates the SI-system with results from fundamental metrological research.

CIPM COMITÉ INTERNATIONALE DES POIDS ET MESURES
Committee with up to 18 representatives from CGPM. Supervises BIPM and supplies chairmen for the Consultative Committees. Co-operates with other international metrological organisations.

- CEN*
- IEC*
- ISO*
- Others

BIPM BUREAU INTERNATIONAL DES POIDS ET MESURES
International research in physical units and standards. Administration of interlaboratory comparisons of the national metrology institutes and designated laboratories.

CONSULTATIVE COMMITTEES

CCAUV	CC for Acoustics, Ultrasound and Vibrations
CCEM	CC for Electricity and Magnetism
CCL	CC for Length
CCM	CC for Mass and related quantities
CCPR	CC for Photometry and Radiometry
CCQM	CC for Amount of Substance
CCRI	CC for Ionising Radiation
CCT	CC for Thermometry
CCTF	CC for Time and Frequency
CCU	CC for Units

*) Glossary page 69

3.1.2 CIPM MUTUAL RECOGNITION ARRANGEMENT

The CIPM Mutual Recognition Arrangement, **CIPM MRA**, is an agreement between national metrology institutes (NMIs, see chapter 3.1.3). It was signed in 1999, slightly revised on some technical points in 2003, and has two parts. One part relates to the establishment of the degree of equivalence of national measurement standards, whilst the second part concerns the mutual recognition of calibration and measurement certificates issued by participating institutes. Only one NMI per country can sign the CIPM MRA, but other institutes that hold recognised national standards in that country may also be designated and participate in the CIPM MRA through the signatory NMI. Such institutes are generally referred to as ***designated institutes*** (DIs). An NMI can choose to join only part one or both parts of the CIPM MRA. NMIs of associate states of the Metre Convention can join the CIPM MRA only through their Regional Metrology Organisation. International and intergovernmental organisations designated by the CIPM may also join the CIPM MRA. The CIPM MRA does not extend nor replace any part of the Metre Convention and is a technical arrangement between the directors of the NMIs, not a diplomatic treaty.

The objectives of the CIPM MRA are:
- to establish the degree of equivalence of national measurement standards maintained by NMIs;
- to provide for the mutual recognition of calibration and measurement certificates issued by NMIs;
- thereby to provide governments and other parties with a secure technical foundation for wider agreements related to international trade, commerce and regulatory affairs.

These objectives are reached through the following process:
- peer review of the declared Calibration and Measurement Capabilities (CMCs) of the participating NMIs and designated institutes (DIs)
- credible participation by NMIs and DIs in international comparisons of measurement standards (key comparisons or supplementary comparisons)
- peer review of the quality systems and demonstration of competence by the participating NMIs and DIs

The outcomes of the above processes are statements of the measurement capabilities (CMCs) of each NMI and designated institute and the results of the comparisons published in a database maintained by the BIPM and publicly available on the Web.

NMI directors sign the MRA with the approval of the appropriate authorities in their own country and thereby:
- accept the process specified in the CIPM MRA for establishing the database;
- recognise the results of key and supplementary comparisons as stated in the database
- recognise the calibration and measurement capabilities of other participating NMIs and DIs as stated in the database

An NMI's participation in the CIPM MRA enables national accreditation bodies and others to be assured of the international credibility and acceptance of the measurements the NMI disseminates. It therefore also provides the basis for the international recognition of the measurements made by accredited testing and calibration laboratories, provided that these laboratories can demonstrate competent traceability of their measurements to a participating NMI or DI.

Signing of the CIPM MRA engages the signatory NMIs but not necessarily any other agency in their country. The responsibility for calibrations and measurements made by an NMI rests wholly with the NMI undertaking the measurements, the CIPM MRA does not extend the responsibility for those measurement to any other NMI.

The CIPM MRA is coordinated by BIPM and the consultative committees, the Regional Metrology Organisations and BIPM are responsible for carrying out the process described above, and the Joint Committee of the Regional Metrology Organisations and the BIPM is responsible for analysing and approving entries into the database. In 2008 the CIPM MRA had been signed by the representatives of 73 institutes from 45 member states, 26 associates of the CGPM, and 2 international organisations and covered a further 117 institutes designated by the signatory bodies. Currently around 90% of world trade in merchandise exports is between CIPM MRA participant nations.

BIPM Key comparison database
The BIPM Key comparison database KCDB consists of four parts, which are considered appendices to the CIPM MRA:

Appendix A: List of participating NMIs and designated institutes
Appendix B: Results of key and supplementary comparisons
Appendix C: Calibration and measurement capabilities (CMCs) of the NMIs and designated institutes
Appendix D: List of key comparisons

In 2008 620 key and 179 supplementary comparisons were registered in the database. The number of registered CMCs was 20 000, all of which have undergone a process of peer evaluation by NMI experts under the supervision of the Regional Metrology Organisations and coordinated internationally by the JCRB.

3.1.3 NATIONAL METROLOGY INSTITUTES
A National Metrology Institute, NMI is an institute designated by national decision to develop and maintain national measurement standards for one or more quantities.

An NMI represents the country internationally in relation to the national metrology institutes of other countries, in relation to the Regional Metrology Organisations and to the BIPM. The NMIs are the backbone of the international metrology organisation shown in Figure 2.

A list of NMIs and designated institutes is available via the BIPM website and the Regional Metrology Organisations, e.g. in Europe the NMIs and designated institutes that are associates of EURAMET can be found on the EURAMET website.

Many NMIs undertake primary realisations of the metrological base units and derived units at the highest achievable international level, whilst some NMIs realise some units using secondary standards which are traceable to other NMIs.

In addition to the activities described above, NMIs typically are responsible for:

- dissemination of the SI units to accredited laboratories, industry, academia, regulators etc
- research in metrology and the development of new and improved measurement standards (primary or secondary) and measurement methods
- participating in comparisons at the highest international level
- maintaining an general overview of the national calibration/traceability hierarchy (the National Measurement System).

3.1.4 DESIGNATED INSTITUTES

The NMI or its national government, as appropriate, may appoint other institutes in the country to hold specific national standards, and these laboratories are often referred to as 'Designated Institutes', particularly if they participate in the CIPM MRA activities. Some countries operate a centralised metrology organisation with one NMI. Other countries operate a decentralised organisation with a lead NMI and a multiplicity of designated institutes, which may or may not have the status of an NMI within their country depending on their national remit.

Designated laboratories are nominated in accordance with the metrological plan of action for the different subject fields and in accordance with the metrological policy of the country. As the importance of metrology in non-traditional areas such as chemistry, medicine and food increases, fewer countries have an NMI that covers all subject fields and hence the number of designated institutes is currently growing.

3.1.5 ACCREDITED LABORATORIES

Accreditation is a third-party recognition of a laboratory's technical competence, quality system and impartiality.

Public as well as private laboratories can be accredited. Accreditation is voluntary, but a number of international, European and national authorities assure the quality of testing and calibration laboratories within their area of competence by requiring an accreditation by an accreditation body. In some countries, for example, accreditation is required for laboratories working in the food sector or for the calibration of weights used in retail stores.

Accreditation is granted on the basis of laboratory assessment and regular surveillance. Accreditation is generally based on regional and international standards, e.g. ISO/IEC 17025 "General requirements for the competence of testing and calibration laboratories", and technical specifications and guidelines relevant for the individual laboratory.

The intention is that tests and calibrations from accredited laboratories in one member country shall be accepted by the authorities and industry in all other member countries. Therefore, accreditation bodies have internationally and regionally agreed multilateral agreements in order to recognize and promote the equivalence of each other's systems and of certificates and test reports issued by the organisations accredited.

3.1.6 REGIONAL METROLOGY ORGANISATIONS

The collaboration of NMIs at a regional level is coordinated by Regional Metrology Organisations, see Figure 3. The focus of the activities of an RMO depends on the specific needs of the region, but generally it includes:

- coordination of comparisons of national measurement standards and other activities of the CIPM MRA
- cooperation in metrology research and development
- facilitating traceability to primary realisations of the SI
- cooperation in developing metrological infrastructure of the member countries
- joint training and consultation
- sharing of technical capabilities and facilities

Within the CIPM MRA the RMOs play a crucial role, as it is their responsibility to carry out the review process as described in 3.1.2 and to report the results of their RMO to the Joint Committee of Regional Bodies (JCRB).

3.1.7 ILAC

The *International Laboratory Accreditation Cooperation*, ILAC, is an international co-operation between the various laboratory accreditation schemes throughout the world. ILAC started as a conference in 1977 and became a formal cooperation in 1996. In 2000 36 ILAC members signed the *ILAC Mutual Recognition Arrangement* and by 2008 the numbers of members of the ILAC MRA had risen to 60. Through the evaluation of the participating accreditation bodies, the international acceptance of test data and the elimination of technical barriers to trade as recommended and in support of the World Trade Organisation Technical Barriers to Trade agreement is enhanced.

ILAC is the world's principal international forum for the development of laboratory accreditation practices and procedures. ILAC promotes laboratory accreditation as a trade facilitation tool together with the recognition of competent calibration and test facilities around the globe. As part of its global approach, ILAC also provides advice and assistance to countries that are in the process of developing their own laboratory accreditation systems. These developing countries are able to participate in ILAC as Affiliates, and thus can access the resources of ILAC's more established members.

3.1.8 OIML

The *International Organisation of Legal Metrology*, OIML, is an intergovernmental treaty organisation established in 1955 on the basis of a convention, which was modified in 1968. The purpose of OIML is to promote the global harmonisation of legal metrology procedures. In 2008 OIML had 59 member countries and 57 corresponding member countries that joined the OIML as observers.

The OIML has since its establishment developed a worldwide technical structure that provides its members with metrological guidelines for the elaboration of national and regional requirements concerning the manufacture and use of measuring instruments for legal metrology applications. The OIML issues international recommendations that provide members with an internationally agreed basis for the establishment of national legislation on various categories of measuring instruments.

The main elements of the International Recommendations are:

- scope, application and terminology
- metrological requirements
- technical requirements
- methods and equipment for testing and verifying conformity to requirements
- test report format

OIML draft recommendations and documents are developed by technical committees or subcommittees composed of representatives from member countries. In 2008 OIML had 18 technical committees.

The OIML Certificate System, introduced in 1991, gives manufacturers the possibility of obtaining an OIML Certificate and a Test Report to indicate that a given instrument type complies with the requirements of the relevant OIML International Recommendations. Certificates are issued by OIML member states who have established one or more Issuing Authorities responsible for processing applications from manufacturers wishing to have their instrument types certified. Acceptance of these certificates by national metrology services is voluntary.

In 2005 the implementation of the OIML Mutual Acceptance Arrangement, OIML MAA, was begun. The OIML MAA is related to the OIML Type Evaluations. Within each area the aim is to sign a Declaration of Mutual Confidence. The process is in progress.

3.1.9 IUPAP

The *International Union of Pure and Applied Physics*, IUPAP, was established in 1923. In 2008 it had 48 physics communities as its members, and the work in IUPAP was organised in 20 commissions. One of these is the Commission on Standards, Units, Nomenclature, Atomic Masses and Fundamental Constants, which has as the first article of its mandate:

To promote the exchange of information and views among the members of the international scientific community in the general field of Fundamental Constants including:

a. physical measurements;
b. pure and applied metrology;
c. nomenclature and symbols for physical quantities and units;
d. encouragement of work contributing towards improved recommended values of atomic masses and fundamental physical constants and facilitation of their universal adoption.

IUPAP issues the “red book” on “Symbols, Units and Nomenclature in Physics”.

3.1.10 IUPAC

The *International Union of Pure and Applied Chemistry*, IUPAC, is an international, non-governmental body that aims to advance the worldwide aspects of the chemical sciences and to contribute to the application of chemistry to address issues involving the chemical sciences.

IUPAC, was formed in 1919. IUPAC is an association of National Adhering Organisations, numbering 50 in 2008, with a further 17 organisations as Associate National Adhering Organisations. IUPAC has 8 divisions. IUPAC is concerned with and recognised as the world authority on chemical nomenclature, terminology, standardised methods of measurement, atomic weights and many other critically evaluated data.

IUPAC publishes a series of books on chemical nomenclature in different areas of chemistry.

Figure 3: **Regional metrology organisations around the world**


COOMET
APMP
AFRIMETS

3.2 EUROPEAN INFRASTRUCTURE

The geographical coverage of the regional metrology organisations RMOs are shown on the RMO map, see Figure 3.

3.2.1 METROLOGY – EURAMET

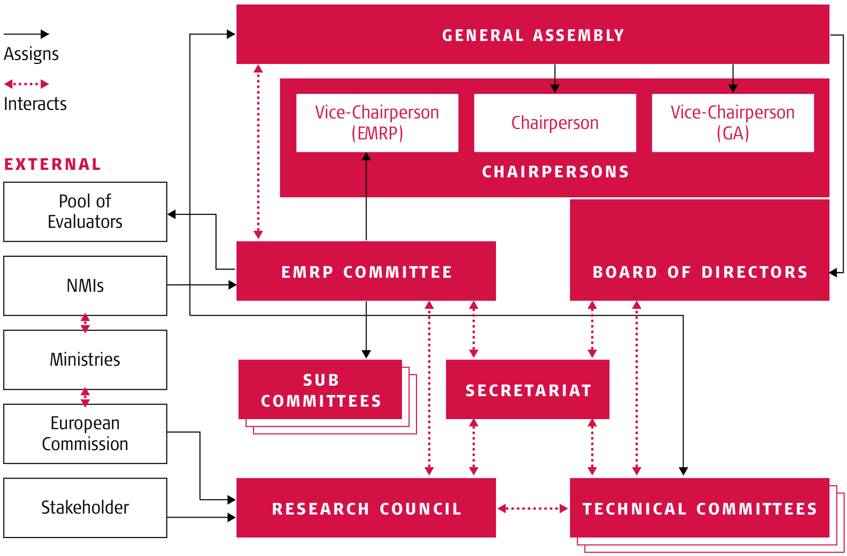
European metrology was coordinated for almost 20 years by EUROMET, the European Collaboration in Measurement Standards, a collaboration based on a Memorandum of Understanding. New challenges for European metrology, such as increasing the level of integration and coordination of metrology research and development, highlighted the need to establish a legal entity for the coordination of European metrology. In January of 2007 the *European Association of National Metrology Institutes*, EURAMET e.V., was inaugurated as a registered association of public utility under German law. On 1st July 2007 EURAMET replaced EUROMET as the European RMO.

The structure of EURAMET is shown in Figure 4. EURAMET has 12 technical committees, 10 covering the subject fields listed in Table 1, whilst the other 2 address interdisciplinary metrology and the peer review of NMI and DI quality systems under the CIPM MRA.

In 2008 EURAMET had 32 European NMI members, plus the IRMM of the European Commission and 4 applicant NMIs as associate members. Designated institutes from countries with a member NMI participate in the work of EURAMET as associates.

One aim for EURAMET is to achieve "critical mass" and greater impact via coordinated European research in metrology. This includes the analysis of common future needs in metrology, the definition of common goals and programmes and the planning and execution of joint research projects, bringing together the specialities of the participating NMIs. Under the framework of the iMERA-project (iMERA = "Implementing the Metrology European Research Area"), a European Metrology Research Programme (EMRP) was elaborated and the procedures and infrastructure within EURAMET for its implementation were developed. In 2008 a three year €64 million programme started, the first phase of the EMRP, jointly funded by the participating 20 countries and the European Commission within its ERANET Plus programme.

Figure 4: Structure of EURAMET e.V.



3.2.2 ACCREDITATION – EA

The *European Co-operation for Accreditation* (EA) is a non-profit organisation established in November 1997 and registered as an association in the Netherlands in June 2000. EA was formed as a result of the merger of the European Accreditation of Certification and the European co-operation for Accreditation of Laboratories. EA is the European network of nationally recognised accreditation bodies based in the European geographical area. EA as a region is a member of International Laboratory Accreditation Cooperation (ILAC) and International Accreditation Forum (IAF).

EA members who have successfully undergone peer evaluation may sign the appropriate multilateral agreement (EA MLA) for accreditation of

- laboratories (calibration and testing)
- inspection bodies
- certification bodies (QMS, EMS, product and services, people, EMAS verifiers)

under which they recognise and promote the equivalence of each other's systems and of certificates and reports issued by bodies accredited.

In 2008 EA had 35 full Accreditation Body members, and organisations from 27 European countries were signatories to the EA MLA.

In June 2005 EA and EUROMET signed a bilateral Memorandum of Understanding (MoU), which aimed to support continuous cooperation between the two organisations. Following the establishment of EURAMET as the European RMO a replacement MoU will be signed between EA and EURAMET. The management of the calibration specific documents has been transferred from EA to EURAMET, and in addition EURAMET provides support to EA in the field of interlaboratory comparisons related to calibration.

The metrology infrastructure in most countries consists of National Metrology Institutes NMIs, designated national laboratories and accredited laboratories. In many countries the trend is for NMIs and designated laboratories also to seek third-party assessment of their quality systems through accreditation, certification or peer assessment.

3.2.3 Legal metrology – WELMEC

The *Western European Legal Metrology Co-operation* WELMEC was established in 1990 by a Memorandum of Understanding signed by 15 member countries of the EU and 3 EFTA countries, in connection with the preparation and enforcement of the "New Approach" directives. The name of the collaboration was subsequently changed to "European Co-operation in Legal Metrology" in 1995 but remains synonymous with WELMEC. Since that time WELMEC has accepted associated membership of countries that have signed agreements with the European Union. WELMEC members are the national legal metrology authorities in the EU and EFTA member countries, whilst national legal metrology authorities in those countries that are in transition to membership of the EU are associate members. In 2008 WELMEC had 33 members and 3 associate members.

The goals of WELMEC are to

- develop mutual confidence between the legal metrology authorities in Europe
- harmonise legal metrology activities
- foster the exchange of information between all bodies concerned

The WELMEC Committee consists of delegates from the member and associate member states and observers from EURAMET, EA, OIML and other regional organisations with an interest in legal metrology. The committee meets at least once a year and is supported by a number of working groups. A small Chairman's Group advises the chairman on strategic matters.

WELMEC advises the European Commission and the Council regarding the application and further development of Directives in the field of legal metrology, for example the Measuring Instruments Directive and the Non-Automatic Weighing Instruments Directive.

3.2.4 EUROLAB

EUROLAB is the *European Federation of National Associations of Measurement, Testing and Analytical Laboratories*, covering around 2000 European laboratories. EUROLAB is a voluntary co-operation representing and promoting the views of the laboratory community technically and politically, by co-ordinating actions relating to, for example, the European Commission, European standardisation, and international matters.

EUROLAB organises workshops and symposia, and produces position papers and technical reports. Many laboratories dealing with metrology are also members of EUROLAB.

3.2.5 EURACHEM

Eurachem founded in 1989, is a *network of organisations* from 33 countries in Europe plus the European Commission, with the objective of establishing a system for the international traceability of chemical measurements and the promotion of good quality practices. Most member countries have established national Eurachem networks.

Eurachem and EURAMET cooperate with regard to the establishment of designated laboratories, the use of reference materials and traceability to the SI unit amount of substance, the mole. Technical issues are dealt with by the joint Technical Committee for Metrology in Chemistry (MetChem).

3.2.6 COOMET

COOMET, the *Euro-Asian Cooperation of National Metrological Institutions*, was founded in 1991 and is a co-operation between 17 NMIs from central and east European and central Asian countries. COOMET is the Regional Metrology Organisation for Eurasia and its members co-operate in the fields of scientific and legal metrology and calibration services.

3.3 AMERICAS INFRASTRUCTURE

3.3.1 METROLOGY – SIM

The *Inter-American Metrology System*, Sistema Interamericano de Metrologia, SIM, was formed by agreement among the national metrology organisations of the 34 member nations of the Organization of American States OAS. SIM is the Regional Metrology Organisation for the Americas under the CIPM MRA, see chapter 3.1.2.

Created to promote international, particularly inter-American, and regional cooperation in metrology, SIM is committed to the implementation of a global measurement system within the Americas, in which all users can have confidence. Working towards the establishment of a robust regional measuring system, SIM is organized in five sub-regions:

- NORAMET for North America
- CARIMET for the Caribbean
- CAMET for Central America
- ANDIMET for the Andean countries
- SURAMET for the other South American countries

SIM also covers legal metrology issues in the Americas. The objective of the Legal Metrology Working Group is the harmonisation of legal metrology requirements and activities in the Americas in consideration of OIML Recommendations and Documents.

3.3.2 ACCREDITATION – IAAC

The *InterAmerican Accreditation Cooperation* IAAC is an association of accreditation bodies and other organisations interested in conformity assessment in the Americas.

Its mission is to establish internationally recognized mutual recognition arrangements among the accreditation bodies of the Americas. It also promotes co-operation among accreditation bodies and interested parties of the Americas, aiming at the development of conformity assessment structures to achieve the improvement of products, processes and services. Both laboratory and management systems accreditation bodies may be members of IAAC. IAAC provides an extensive training programme to its members.

IAAC has 20 full members, 7 associate members and 22 stakeholder members from 22 countries. ILAC and IAF have recognized IAAC as the representative regional body for the Americas.

3.4 ASIA PACIFIC INFRASTRUCTURE

3.4.1 METROLOGY – APMP

The *Asia Pacific Metrology Programme* APMP is the RMO for the Asia-Pacific region and is engaged in the RMO responsibilities as described in chapter 3.1.3. APMP was formed in 1977 and is the oldest continuously operating regional metrological grouping in the world.

APMP established a Developing Economies Committee (DEC) helping to address the needs of NMIs from developing countries, and to oversee and coordinate associated work programmes.

3.4.2 ACCREDITATION – APLAC

The *Asia Pacific Laboratory Accreditation Cooperation* APLAC is a co-operation between organisations in the Asia Pacific region responsible for accrediting calibration, testing and inspection facilities.

Members are nationally recognized accreditation bodies and usually are owned or endorsed by their government. APLAC members assess laboratories and inspection bodies against international standards, and accredit them as competent to carry out specific tests or inspections.

APLAC was initiated in 1992 as a forum to enable accreditation bodies to share information, harmonise procedures and develop Mutual Recognition Arrangements to enable accredited test and inspection results to be recognized across national borders. APLAC has active programmes for

- information exchange between members,
- the development of technical guidance documents,
- inter-laboratory comparisons / proficiency testing,
- training of laboratory assessors and
- the development of procedures and rules for the establishment of Mutual Recognition Arrangements.

3.4.3 LEGAL METROLOGY – APLMF

The *Asia-Pacific Legal Metrology Forum* APLMF is a grouping of legal metrology authorities, whose objective is the development of legal metrology and the promotion of free and open trade in the region through the harmonisation and removal of technical or administrative barriers to trade in the field of legal metrology. As one of the regional organisations working in close liaison with the OIML, the APLMF promotes communication and interaction among the legal metrology organisations and seeks harmonisation of legal metrology in the Asia Pacific region.

APMP, APLAC and APLMF are recognized by the Asia-Pacific Economic Cooperation, APEC as Specialist Regional Bodies. Specialist Regional Bodies assist the APEC Sub-committee on Standards and Conformance to meet the objective of eliminating technical barriers to trade within the region.

3.5 AFRICAN INFRASTRUCTURE

3.5.1 METROLOGY – AFRIMETS

The *Intra-Africa Metrology System* AFRIMETS was established by a constituting General Assembly in July 2007, spearheaded by SADCMET (see 3.5.2) and under the auspices of the African Union's (AU) New Economic Partnership for African Development (NEPAD). In order to represent the whole continent effectively and efficiently it is built on sub-regional metrology cooperation preferably under Regional Economic Communities (such as SADC, EAC, CEMAC, ECOWAS, UEMOA) as principal members. AFRIMETS covers both scientific, industrial and legal metrology. It is expected that AFRIMETS will supersede SADCMET as the African RMO under the CIPM MRA during the latter part of 2008, in order to cover the whole of the African continent.

AFRIMETS has five sub-regional organisations as principal members:

- CEMACMET – metrology cooperation for the central African countries
- EACMET – metrology cooperation for eastern African countries
- MAGMET – the metrology cooperation for the Maghreb countries.
- SADCMET – the metrology cooperation for southern African countries, including SADCMEL for legal metrology
- SOAMET – the metrology cooperation for western African countries

Countries that are not part of a sub-regional organisation can join AFRIMETS as ordinary members. In 2008 there were 3 ordinary members.

SADC

14 countries are signatories to the **Southern African Development Community's** (SADC) treaty. SADC has the longest record in sub-regional co-operation mandated by the SADC trade protocol and the Memorandum of Understanding on Cooperation in Standardization, Quality Assurance, Accreditation and Metrology (SQAM). The SQAM programme's constituent structures SADCSTAN *(SADC Cooperation in Standardisation)*, SADCA, SADCMET and SADCMEL are pursuing the objective of removing technical barriers to trade.

3.5.2 METROLOGY – SADCMET

SADCMET is the *SADC Cooperation in Measurement Traceability* of the 14 member countries plus 5 associate members. Members are the NMIs or de facto Metrology Institutes. SADCMET has fulfilled the role of the Regional Metrology Organisation for Africa under the CIPM MRA, but covering only parts of the continent. It is planned that the recently established AFRIMETS will supersede SADCMET as an RMO under the CIPM

MRA, covering the whole of the African continent. Once AFRIMETS has taken over the role of RMO, SADCMET will continue as one of the sub-region members of AFRIMETS.

3.5.3 ACCREDITATION – SADCA

The *SADC Cooperation in Accreditation* SADCA facilitates the creation of a pool of internationally acceptable accredited laboratories and certification bodies (for personnel, products and systems, including quality and environmental management systems) in the region, and provides Member States with accreditation as a tool for the removal of TBTs in both the voluntary and regulatory areas. SADCA is tasked with defining a suitable accreditation infrastructure, enabling organisations in the SADC Member States to access accreditation services from internationally recognised National Accreditation Bodies within their countries, or to form a regional accreditation service, SADCAS.

3.5.4 LEGAL METROLOGY – SADCMEL

The *SADC Cooperation in Legal Metrology* SADCMEL facilitates the harmonisation of the national Legal Metrology regulations of the Member States and between SADC and other regional and international trading blocs. Its ordinary members are the legal metrology authorities in the SADC member states.

3.5.5 OTHER SUB-REGIONAL STRUCTURES

The **East African Community (EAC)** concluded a protocol in 2001 and an act on Standardisation, Quality Assurance, Metrology and Testing in 2006, promoting regional cooperation in metrology through the EAC Metrology Sub-Committee. Major objectives are the international recognition of measurement capabilities, capacity building and benchmarking through comparisons. Similar structures exist in the **West African Economic and Monetary Union (UEMOA),** where the West African Metrology System SOAMET and Accreditation System SOAC are promoting and coordinating the regional activities in metrology and accreditation respectively. Similar cooperation is under preparation under other African Regional Economic Communities such as ECOWAS and COMESA.

4. Measurement's impact – some examples

4.1 Natural gas

Natural gas worth billions of euros – how much?

Measuring the value of natural gas must be uniform and reliable throughout Europe in order to protect consumers and fiscal revenue
EU has 210 million consumers of natural gas, supplied from 1.4 million kilometres of pipelines. Their annual consumption is 500 billion cubic metres, worth many hundreds of billions of euros.

Gas is an expensive commodity that is traded across Europe and is subject to fiscal charges, so it is important that consumers, importing/exporting countries and tax authorities can trust that the measurements made are fair, consistent and reliable.

Payment of gas is made according to the volume and calorific value of the gas, which is determined by the composition of the gas. Gas chromatography is used to measure the composition of the gas and the measurements are complex: Measurements are made many places on the gas grid on a daily, weekly, monthly and annual basis using a gas chromatograph. Calculation of the calorific value is done automatically in the gas chromatograph according to international technical standards.

The calibration of the gas chromatograph is performed using a gas certified reference material (CRM), which is traceable to a CRM calibrated by a national metrology institute. Under the CIPM Mutual Recognition Arrangement (see chapter 3.1.2), all participating national metrology institutes and designated institutes are obliged to submit their calibration and measurement capabilities and quality systems for peer review and to participate in appropriate key comparisons (the results of CIPM worldwide comparison for natural gas is shown in Figure 6). Similarly accredited laboratories covered the ILAC Mutual Recognition Arrangements also take part in their network of comparisons. The CIPM and ILAC MRAs provide a mechanism for the international mutual recognition of calibration certificates issued by participating institutes.

These arrangements and the reviews and practical measurements and comparisons that underpin them provide confidence in those commodities traded across borders.

Figure 5: **Results from a natural gas worldwide comparison**

CCQM-K1.g, natural gas type iii
Degrees of equivalence for Methane at nominal value 824 mmol/mol

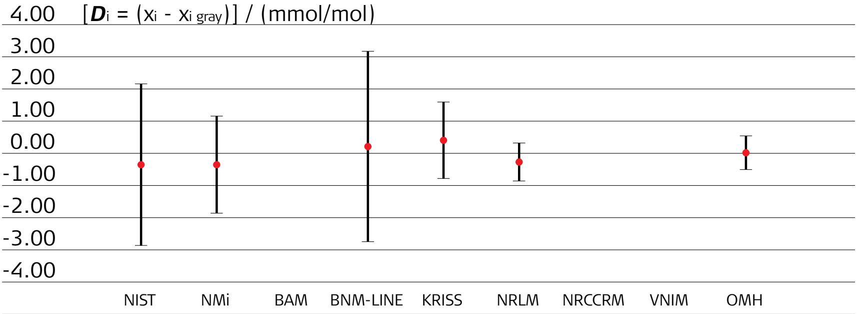


Figure 6: **European natural gas pipeline network**

Source: gte Gas Transmission Europe

4.2 KIDNEY DIALYSIS

Dialysis – accurate measurements improve quality of life and reduce healthcare costs

Fundamental research in the measurement of electrolytic conductivity has direct impact on the quality of life for dialysis patients.
The quality of life for the EU's approximately a quarter of a million dialysis patients is critically affected by their dialysis treatment, which typically lasts four to five hours two or three times every week and without which they would die. The treatment is painful for the patient and costly for the healthcare system, and the condition affects the patient's social life and ability to continue in their job. It is therefore important to make the treatment as effective as possible.

The number of patients with chronic kidney failure increases by around 7%-9% per year, which corresponds to a doubling every ten years, whilst the number of people requiring dialysis is expected to increase by around 4% per year. About 75% of Danish dialysis patients are treated by haemodialysis, where the patient's blood is pumped through a dialysis machine that removes the waste products by osmosis. The process is monitored by measuring the electrolytic conductivity of the salt solution that is also pumped through the machine to extract the waste products. The more accurately the electrolytic conductivity can be measured, the more the process can be optimised hence decreasing both the duration of the treatment but also the pain the patient experiences during dialysis.

Fundamental research in the measurement of electrolytic conductivity to improve the quality of electrolytic conductivity measurements therefore has direct impact on the quality of life for haemodialysis patients and the cost of healthcare treatment.

4.3 NANOPARTICLES

Measuring nanoparticles for health protection

The measurement of airborne nanoparticles in the environment and workplace may help improve air quality and health.
The impact on human health of airborne nanoparticles is an area of growing concern. Nanoparticles can enter the body by inhalation, ingestion or absorption through the skin and are known to cause respiratory problems. Nanoparticles are produced from both natural and man-made sources such as combustion, traffic, manufactured material, dust, soot and pollen grains. The market relating to nanotechnology is rapidly increasing, standing at around €38 billion in 2001, and expected to rise to €152 billion by 2010 with nanoparticles accounting for around 40% of this figure.

Recent studies of airborne particles suggest the damage to human genes may be related to the particle size and potentially the surface area of airborne particles, with toxicity increasing with decreasing particle size.

Three strands of research are being followed to determine the quantity of nanoparticles in the atmosphere or workplace, and their effect on human health. This research will enable future health and safety legislation, environmental regulations and the development of robust new standards that can protect human health:

1. Instrumentation that can measure nanoparticles has been around for several years, but the reliability and equivalence of measurements between different instrument types as well as their performance characteristics have yet to be established. Current metrology research is investigating the performance of different instruments as well as aiming to resolve some of the fundamental nanoparticle measurement issues. Key nanoparticle parameters under investigation include number density (concentration), particle size, surface area and composition.
2. Accurate synthesis of nanoparticles, with stable adjustable and traceable diameter and known number concentration. Such particle generators will enable the calibration of nanoparticle measuring devices, and the study of gas phase artefacts in particulate-mass (PM) concentration measurements (widely used for combustion residue analysis of engines).
3. Improved characterisation methods and understanding of human interaction with nanoparticles. This will enable nanoparticles to be toxically classified, which is an important step in establishing legalisation for nanoparticle safety.

4.4 FERTILISER

Precise measurement could save 700 000 tonnes of fertiliser each year

Precise fertiliser spreaders reduce environmental impact and improve agricultural economy.
The over-consumption of fertilisers is costly to farmers and increases environmental pollution and damage due to run-off from fields into streams, rivers and neighbouring land. This over-consumption is often unintentional and occurs due to the lack of precision of the fertiliser spreader for different fields and fertiliser types.

Innovative solutions using metrology have contributed significantly to the development of an intelligent fertiliser spreader. The solution involved the measurement of the mass of fertiliser spread on a hectare, and the development and the validation of a measurement method. Measurement of the quantity of the fertiliser flowing from the spreader is combined with the GPS position of the spreader on the field. The quantity to be spread can then be adjusted for the different fertiliser requirements at varying locations on the field. The different fertiliser needs are estimated from an annual mapping of the yield of the harvested fields in previous years.

These developments subsequently reduced the uncertainty of fertiliser spreader per hectare from 5% to 1%. This may not seem much, but if one considers that 15.6 million tonnes of commercial agricultural fertiliser were consumed by 15 EU countries during 2001, the use of the new fertiliser spreader at that time could have reduced fertiliser consumption from 15.6 million tonnes to 14.9 million tonnes – a reduction of 4.5% and a saving of several hundred million euros. The spreader has brought benefits to the farmers and society in general: The farmers earn higher profits than before and there is less damage to the environment.

4.5 HEAT METERS

Intelligent control of heat meters

An intelligent solution for heat meters could reduce costs for the hundred million people in Northern Europe – and other cold parts of the world.
EU requirements and conformity assessment procedures for heat meters are regulated by the Measuring Instruments Directive 2004/22/EC annex MI-004 (the MID), whilst the control of heat meters in use is regulated by national legislation. To measure heat consumption, a heat meter requires three measurements: the water flow, and the water temperatures at the inlet and the outlet. In order to monitor the in-service conformity of meters in Denmark, a sample of 10% of the meters are calibrated every 3rd or 6th year, depending on the previous calibration results. In Denmark, with five million inhabitants, this results in an estimated cost of €1.5 million.

By adding an extra temperature sensor and outlet flow meter, it is possible to continuously survey the temperature difference measurement and the flow measurement. These extra measurements and the continuous surveillance reduce the uncertainty of the resulting heat consumption calculation. Taken into account this more reliable heat metering, the sample of meters taken out use for conformity assessment is reduced from the previous 10% to 0.3%. The reduction is determined using an advanced probability model, ensuring the same level of reliability for heat meter control.

The reduction in conformity assessment cost for a population of 100 million, is estimated at €30 million per year. Further benefits of the intelligent solution are fewer failures due to the reinstallation of a smaller number of meters, less disruption to users and thereby better consumer protection.

4.6 FOOD SAFETY

Are shrimps safe to eat?

Understanding the measurements is important.
Two EU member states imported frozen shrimps from a third country as part of the same shipment. Before entering into the EU, the shrimps were inspected for the antibiotic residue chloramphenicol which can cause cancer and allergic reactions. After proper inspection in the entry ports of both member states, the frozen shrimps were granted entry to the first member state, whilst the second member state refused entry. The consignment of shrimps was eventually destroyed at a cost of around €1 million.

In the first member state harbour, the food inspection used Liquid Chromatography (LC) with a detection limit on 6 µg/kg. In the second member state harbour, the food inspection had the more advanced Liquid Chromatography with Mass Spectrometer (LC-MS), giving a detection limit of 0.3 µg/kg.

At that time there was no required maximum limit (RML) specified in the EU regulation 2377/90 on residue control of food, which meant that in general "Zero tolerance" was applied as the limit by inspection authorities – in practice this was taken to mean that the residue should not be detectable with the method employed. Obviously the more sensitive the detection method used, the more likely it is that the residue will be detected and conversely a low resolution instrument is not likely to detect any residues except in extreme quantities, and hence there was not an absolute scale/limit for assessment of compliance.

This illustrates that in food safety and some other areas, the metrological method and technology employed are both important and that in all cases an unambiguous maximum limit is essential to ensure effective, fair and uniform consumer protection. Measurement therefore has to be effectively addressed both for conformity assessment but also during the development of legislation.

4.7 CANCER TREATMENT

The crucial role of measurement in cancer treatment

In Europe around 25% to 33% of all citizens will suffer from cancer at some point in their life. Radiotherapy is used to treat one third of all cancer patients. The key to effective treatment is delivering the correct radiation dose to the tumour: too low a dose and the treatment is ineffective, too high a dose or inaccurately positioned radiation and the patient suffers unnecessary and unpleasant side effects. Accurate measurement of the radiation dose delivered by equipment in hospitals therefore underpins this type of treatment.

There have been significant technical advances in the equipment used to produce beams of ionising radiation for cancer treatment, so that the radiation can now be delivered in narrow multiple beams which enable the tumour to be targeted very accurately thus improving cancer treatment. However the new types of treatment machines could not be calibrated in accordance with current UK codes of practice as they are unable to produce the 10 cm x 10 cm reference beam normally required for calibration. There was therefore a need for new traceable measurement methods to characterise the output of new equipment such as helical tomotherapy machines to enable them to meet the standards expected of conventional radiotherapy equipment.

Scientists at the UK NMI have devised and validated a novel method to calibrate the output from the tomotherapy machines. Originally introduced for measuring radiation dose in industrial radiation plants, alanine dosimetry in radiotherapy achieves greater accuracy and finer spatial resolution than is possible with standard equipment. This has enabled patients and the medical profession to make use of new technology with increased confidence in the safety, reliability and effectiveness of the treatment delivered.

4.8 AIRCRAFT EMISSIONS

Improved monitoring of the heat treatment of jet engine components could lead to reduced aircraft emissions.

High-temperature metrology suffers because of a lack of reference standards above 1100 °C, leading to much higher uncertainties than can routinely be achieved at lower temperatures.

Many industrial processes and machinery operate at high temperatures. As energy efficiency becomes more important and as new manufacturing processes are introduced requiring tighter manufacturing tolerances, the need for more accurate high temperature measurements has increased. Aircraft engines work most efficiently and produce fewer emissions when they run at high temperatures, but this requires thermal treatment of their components at temperatures in excess of 1300 °C. If the treatment temperature deviates too much from the optimal temperature, it may be inadequate and a component might have to be scrapped. Treatment progress is controlled by thermocouple temperature sensors, which are calibrated using materials with known melting or freezing points, known as fixed points. The difficulty up to now has been that there were no reliable low uncertainty fixed points in the high temperature region.

A number of NMIs around the world are working together to develop and characterise a new type of reference fixed point using a material made from a mixture of a metal and graphite in a composition known as metal carbon eutectic. Utilising different materials in the fixed points it is expected that new reference fixed points up to 2500 °C could be developed. Tests at 1300 °C have already shown a reduction of the uncertainty of thermocouple temperature sensors used to track heat treatments to less than 1 °C and NMIs are now working with industry to prove the concept in an industrial thermal processing setting.

4.9 IVD DIRECTIVE

Implementing the IVD directive will lead to significant savings

The In Vitro Diagnostic Directive requires that all analyses performed in hospital laboratories and medical clinics be "traceable to a reference method or reference materials of higher order". One of the benefits of the full implementation of this directive are that analyses are not repeated unnecessarily; and this will lead to savings of healthcare costs of at least €25 per capita, or €125 million for a country of 5 million people.

The cost of redundant medical analysis is estimated to contribute 15% to 33% of the total costs of laboratory medicine. In a modern society laboratory medicine costs typically amount to 7.9% of the costs of medical treatment, with medical treatments accounting for a third of the total general health costs. General health costs are substantial for many countries, for example amounting to 8.3% of GNP for Denmark.

In the case of Denmark, implementation of the IVD Directive has led to a reduction in the number of the redundant analyses. However, when the IVD Directive came into force on 1 November 2003, the necessary metrological knowledge and capability were not available to establish traceability for even a significant fraction of the some 800 analyses that are performed within clinical chemistry. In order to set up a focussed global effort to undertake the necessary research, the CIPM established a Joint Committee for Laboratory Medicine involving all relevant parties from industry, academia, and national metrology institutes. Results of its work are now registered in a special database within the KCDB.

5. METROLOGICAL UNITS

The idea behind the metric system – a system of units based on the metre and the kilogram – arose during the French Revolution when two platinum artefact reference standards for the metre and the kilogram were constructed and deposited in the French National Archives in Paris in 1799 – later to be known as the Metre of the Archives and the Kilogram of the Archives. The French Academy of Science was commissioned by the National Assembly to design a new system of units for use throughout the world, and in 1946 the *MKSA system* (metre, kilogram, second, ampere) was accepted by the Metre Convention countries. In 1954, the MKSA was extended to include the kelvin and candela. The system then assumed the name the International System of Units, SI (Le Système International d'Unités).

The **SI system** was established in 1960 by the 11th General Conference on Weights and Measures CGPM:

> "The International System of Units, SI, is the coherent system of units adopted and recommended by the CGPM".

At the 14th CGPM in 1971 the SI was again extended by the addition of the mole as base unit for amount of substance. The SI system is now comprised of seven base units, which together with derived units make up a coherent system of units. In addition, certain other units outside the SI system are accepted for use with SI units.

The tables of units below (Table 3 to Table 9) show the following:

SI units

Table 3	SI base units
Table 4	SI derived units expressed in SI base units
Table 5	SI derived units with special names and symbols
Table 6	SI derived units whose names and symbols include SI-derived units with special names and symbols

Units outside SI

Table 7	Units accepted because they are widely used
Table 8	Units to be used within specific subject areas
Table 9	Units to be used within specific subject areas and whose values are experimentally determined

Table 3: SI base units [2]

QUANTITY	BASE UNIT	SYMBOL
length	metre	m
mass	kilogram	kg
Time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

Table 4: Examples of SI derived units expressed in SI base units [2]

DERIVED QUANTITY	DERIVED UNIT	SYMBOL
area	square metre	m^2
volume	cubic metre	m^3
speed, velocity	metre per second	$m \cdot s^{-1}$
acceleration	metre per second squared	$m \cdot s^{-2}$
angular velocity	radian per second	$rad \cdot s^{-1}$
angular acceleration	radian per second squared	$rad \cdot s^{-2}$
density	kilogram per cubic metre	$kg \cdot m^{-3}$
magnetic field intensity, (linear current density)	ampere per metre	$A \cdot m^{-1}$
current density	ampere per cubic metre	$A \cdot m^{-2}$
moment of force	newton metre	$N \cdot m$
electric field strength	volt per metre	$V \cdot m^{-1}$
permeability	henry per metre	$H \cdot m^{-1}$
permittivity	farad per metre	$F \cdot m^{-1}$
specific heat capacity	joule per kilogram kelvin	$J \cdot kg^{-1} \cdot K^{-1}$
amount-of-substance concentration	mol per cubic metre	$mol \cdot m^{-3}$
luminance	candela per square metre	$cd \cdot m^{-2}$

5.1 SI BASE UNITS

A base unit is a unit of measurement of a base quantity in a given system of quantities [4]. The definition and realisation of each SI base unit becomes modified as metrological research discovers the possibility of achieving a more precise definition and realisation of the unit.

Example: The 1889 definition of the metre was based upon the international prototype of platinum-iridium placed in Paris. In 1960 the metre was redefined as 1 650 763.73 wavelengths of a specific spectral line of krypton-86. By 1983 this definition had become inadequate and it was decided to redefine the metre as the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second, and represented by the wavelength of radiation from an iodine-stabilised helium-neon laser. These redefinitions have reduced the relative uncertainty from 10^{-7} m to 10^{-11} m.

SI base unit definitions

The metre is the length of the path travelled by light in a vacuum during a time interval of 1/299 792 458 of a second.

The kilogram is equal to the mass of the international prototype of the kilogram.

The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom.

The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.

The kelvin is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.

The mole is the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kg of carbon-12. When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

The candela is the luminous intensity in a given direction of a source that emits monochromatic radiation of frequency 540 x 10^{12} hertz and has a radiant intensity in that direction of 1/683 watts per steradian.

Table 5: SI derived units with special names and symbols [2]

DERIVED QUANTITY	SI DERIVED UNIT Special name	SYMBOL Special symbol	IN SI UNITS	IN SI BASE UNITS
plane angle	radian	rad		$m \cdot m^{-1} = 1$
solid angle	steradian	sr		$m^2 \cdot m^{-2} = 1$
frequency	hertz	Hz		s^{-1}
force	newton	N		$m \cdot kg \cdot s^{-2}$
pressure, stress	pascal	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
energy, work, quantity of heat	joule	J	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
power, radiant flux	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
electric charge, quantity of electricity	coulomb	C		$s \cdot A$
electric potential difference, electromotive force	volt	V	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
electric capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
electric resistance	ohm	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
electric conductance	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
magnetic flux	weber	Wb	$V \cdot s$	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
magnetic flux density	tesla	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
inductance	henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
Celsius temperature	degree Celsius	°C		K
luminous flux	lumen	lm	$cd \cdot sr$	$m^2 \cdot m^{-2} \cdot cd = cd$
illuminance	lux	lx	lm/m^2	$m^2 \cdot m^{-4} \cdot cd = m^{-2} \cdot cd$
activity (of a radionuclide)	becquerel	Bq		s^{-1}
absorbed dose, kerma, specific energy (imparted)	gray	Gy	J/kg	$m^2 \cdot s^{-2}$
dose equivalent	sievert	Sv	J/kg	$m^2 \cdot s^{-2}$
catalytic activity	katal	kat		$s^{-1} \cdot mol$

5.2 SI DERIVED UNITS

A derived unit is a unit of measurement of a derived quantity in a given system of quantities [4].

SI derived units are derived from the SI base units in accordance with the physical connection between the quantities.

Example: From the physical connection between
the quantity length measured in the unit m, and
the quantity time measured in the unit s,
the quantity speed measured in the unit m/s can be derived.

Derived units are expressed in base units by use of the mathematical symbols multiplication and division. Examples are given in Table 4.

The CGPM has approved special names and symbols for some derived units, as shown in Table 5.

Some base units are used in different quantities, as shown in Table 6. A derived unit can often be expressed in different combinations of 1) base units and 2) derived units with special names. In practice there is a preference for special unit names and combinations of units in order to distinguish between different quantities with the same dimension. Therefore a measuring instrument should indicate the unit as well as the quantity being measured by the instrument.

Table 6: Examples of SI derived units whose names and symbols include SI derived units with special names and symbols [2]

DERIVED QUANTITY	DERIVED UNIT	SYMBOL	IN SI BASE UNITS
dynamic viscosity	pascal second	Pa · s	$m^{-1} \cdot kg \cdot s^{-1}$
moment of force	newton metre	N · m	$m^2 \cdot kg \cdot s^{-2}$
surface tension	newton per metre	N/m	$kg \cdot s^{-2}$
angular velocity	radian per second	rad/s	$m \cdot m^{-1} \cdot s^{-1} = s^{-1}$
angular acceleration	radian per second squared	rad/s^2	$m \cdot m^{-1} \cdot s^{-2} = s^{-2}$
heat flux density, irradiance	watt per square metre	W/m^2	$kg \cdot s^{-3}$
heat capacity, entropy	joule per kelvin	J/K	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1}$
specific heat capacity, specific entropy	joule per kilogram kelvin	J/(kg·K)	$m^2 \cdot s^{-2} \cdot K^{-1}$
specific energy	joule per kilogram	J/kg	$m^2 \cdot s^{-2}$
thermal conductivity	watt per metre kelvin	W/(m·K)	$m \cdot kg \cdot s^{-3} \cdot K^{-1}$
energy density	joule per cubic metre	J/m^3	$m^{-1} \cdot kg \cdot s^{-2}$
electric field strength	volt per metre	V/m	$m \cdot kg \cdot s^{-3} \cdot A^{-1}$
electric charge density	coulomb per cubic metre	C/m^3	$m^{-3} \cdot s \cdot A$
surface charge density electric flux density, electric displacement	coulomb per square metre	C/m^2	$m^{-2} \cdot s \cdot A$
permittivity	farad per metre	F/m	$m^{-3} \cdot kg^{-1} \cdot s^4 \cdot A^2$
permeability	henry per metre	H/m	$m \cdot kg \cdot s^{-2} \cdot A^{-2}$
molar energy	joule per mole	J/mol	$m^2 \cdot kg \cdot s^{-2} \cdot mol^{-1}$
molar entropy, molar heat capacity	joule per mole kelvin	J/(mol·K)	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1} \cdot mol^{-1}$
exposure (x and g rays)	coulomb per kilogram	C/kg	$kg^{-1} \cdot s \cdot A$
absorbed dose rate	gray per second	Gy/s	$m^2 \cdot s^{-3}$
radiant intensity	watt per steradian	W/sr	$m^4 \cdot m^{-2} \cdot kg \cdot s^{-3} = m^2 \cdot kg \cdot s^{-3}$
catalytic (activity) concentration	katal per cubic metre	kat/m^3	$m^{-3} \cdot s^{-1} \cdot mol$

5.3 UNITS OUTSIDE THE SI

Table 7 gives the units outside the SI that are accepted for use together with SI units because they are widely used or because they are used within specific subject areas.

Table 8 gives examples of units outside the SI that are accepted for use within specific subject areas.

Table 9 gives units outside the SI which are accepted for use within specific subject areas and whose values are experimentally determined.

The combined uncertainty (coverage factor k=1) on the last two digits of the number is given in parenthesis.

Table 7: Units outside SI which are accepted [2]

QUANTITY	UNIT	SYMBOL	VALUE IN SI UNITS
time	minute	min	1 min = 60 s
	hour	h	1 h = 60 min = 3600 s
	day	d	1 d = 24 h
plane angle	degree	°	$1° = (\pi/180)$ rad
	minute	′	$1' = (1/60)° = ($ p/10 800) rad
	second	″	$1'' = (1/60)' =$ (p/648 000) rad
	grad	gon	1 gon = $(\pi/200)$ rad
area	hectare	ha	1 ha = 1 hm^2 = 104 m^2
volume	litre	l, L	1 l = 1 dm^3 = 10-3 m^3
mass	tonne	t	1 t = 10^3 kg

Table 8: Units outside the SI which are accepted for use within specific subject areas [2]

QUANTITY	UNIT	SYMBOL	VALUE IN SI UNITS
pressure	bar	bar	1 bar = 100 kPa = 10^5 Pa
pressure in human body fluids	millimetres of mercury	mmHg	1 mmHg ≈ 133 322 Pa
length	ångström	Å	1 Å = 0,1 nm = 10^{-10} m
distance	nautical mile	M	1 M = 1852 m
area (cross-section)	barn	b	1 b = 10^{-28} m^2
speed	knot	kn	1 kn = (1852/3600) m/s

Table 9: Units outside the SI which are accepted within specific subject areas and whose values are experimentally determined [2]

QUANTITY	UNIT	SYMBOL	DEFINITION	IN SI UNITS
energy	electron-volt	eV	1 eV is the kinetic energy of an electron passing a potential difference of 1 V in vacuum.	1 eV = 1.602 176 53 (14) · 10^{-19} J
mass	atomic mass unit	u	1 u is equal to 1/12 of the rest mass of a neutral atom of the nuclide ^{12}C in the ground state.	1 u = 1.660 538 86 (28) · 10^{-27} kg
length	astronomical unit	ua		1 ua = 1.495 978 706 91 (6) · 10^{11} m

5.4 SI PREFIXES

The CGPM has adopted and recommended a series of prefixes and prefix symbols, shown in Table 10.

Rules for correct use of prefixes:

1. Prefixes refer strictly to powers of 10 (and e.g. not powers of 2).
   Example: One kilobit represents 1000 bits not 1024 bits

2. Prefixes must be written without space in front of the symbol of the unit.
   Example: Centimetre is written as cm not c m

3. Do not use combined prefixes.
   Example: 10^{-6} kg must be written as 1 mg not 1 µkg

4. A prefix must not be written alone.
   Example: $10^9/m^3$ must not be written as G/m^3

Table 10: SI prefixes [2]

FACTOR	PREFIX NAME	SYMBOL	FACTOR	PREFIX NAME	SYMBOL
10^{1}	deca	da	10^{-1}	deci	d
10^{2}	hecto	h	10^{-2}	centi	c
10^{3}	kilo	k	10^{-3}	milli	m
10^{6}	mega	M	10^{-6}	micro	µ
10^{9}	giga	G	10^{-9}	nano	n
10^{12}	tera	T	10^{-12}	pico	p
10^{15}	peta	P	10^{-15}	femto	f
10^{18}	exa	E	10^{-18}	atto	a
10^{21}	zetta	Z	10^{-21}	zepto	z
10^{24}	yotta	Y	10^{-24}	yocto	y

5.5 WRITING OF SI UNIT NAMES AND SYMBOLS

1. Symbols are not capitalised, but the first letter of a symbol is capitalised if
   1) the name of the unit comes from a person's name or
   2) the symbol is the beginning of a sentence.
   Example: The unit kelvin is written as the symbol K.

2. Symbols must remain unchanged in the plural – no "s" is added.

3. Symbols are never followed by full stops unless at the end of a sentence.

4. Units combined by the multiplication of several units must be written with a raised dot or a space.
   Example: $\mathrm{N \cdot m}$ or $\mathrm{N\ m}$

5. Units combined by the division of one unit with another must be written with a slash or a negative exponent.
   Example: $\mathrm{m/s}$ or $\mathrm{m \cdot s^{-1}}$

6. Combined units must only include one slash. The use of parenthesis or negative exponents for complex combinations is permitted.

Example:	$\mathrm{m/s^2}$	or $\mathrm{m \cdot s^{-2}}$	but not	$\mathrm{m/s/s}$
Example:	$\mathrm{m \cdot kg/(s^3 \cdot A)}$	or $\mathrm{m \cdot kg \cdot s^{-3} \cdot A^{-1}}$	but neither	$\mathrm{m \cdot kg/s^3/A}$
			nor	$\mathrm{m \cdot kg/s^3 \cdot A}$

7. Symbols must be separated from the numerical value they follow by a space.
   Example: 5 kg not 5kg

8. Unit symbols and unit names should not be mixed.

Numerical notation

1. A space should be left between groups of 3 digits on either the right or left-hand side of the decimal place (15 739.012 53). In four-digit numbers the space may be omitted. Commas should not be used as thousand separators.

2. Mathematical operations should only be applied to unit symbols (kg/m3) and not unit names (kilogram/cubic metre).

3. It should be clear to which unit symbol a numerical value belongs and which mathematical operation applies to the value of a quantity:
   Examples: 35 cm x 48 cm not 35 x 48 cm 100 g ±2 g not 100 ±2g

6. GLOSSARY

[x] refers to reference no. [x] in chapter 8.

Accredited laboratory Laboratory with 3rd party approval of the laboratory's technical competence, the quality assurance system it uses, and its impartiality. See chapter 3.1.5.
Accuracy class Class of measuring instruments that meet stated metrological requirements intended to keep errors within specified limits under specified conditions. [4]
Accuracy of a measuring instrument The ability of a measuring instrument to give responses close to a true value. [4]
Accuracy of measurement Closeness of the agreement between measured quantity value and the true quantity value of the measurand. [5]
Adjustment of a measuring instrument Process carried out on a measuring system so that it provides prescribed indications corresponding to the given values of the quantity to be measure. [4]
AFRIMETS Intra-Africa Metrology System, see chapter 3.5.1.
APEC Asia-Pacific Economic Cooperation.
APLAC Asia Pacific Laboratory Accreditation Cooperation, see chapter 3.4.2.
APLMF Asia Pacific Legal Metrology Forum, see chapter 3.4.3.
APMP Asia Pacific Metrology Programme, see chapter 3.4.1.
Artefact An object fashioned by human hand. Examples of artefacts made for taking measurements are a weight and a measuring rod.

Base quantity Quantity in a conventionally chosen subset of a given system of quantities, where no subset quantity can be expressed in terms of others. [4]
Base unit Measurement unit that is adopted by convention for a base quantity. [4]
BEV Bundesamt für Eich- und Vermessungswesen, the national metrology institute of Austria.
BIM Bulgarian Institute for Metrology, the national metrology institute of Bulgaria.
BIPM Bureau International des Poids et Mesures, see chapter 3.1.1.
BIPM key comparison database (also referred to as KCDB) see chapter 3.1.2.
BOM Bureau of Metrology, the national metrology institute of FYR Macedonia.

Calibration certificate Result(s) of a calibration can be registered in a document sometimes called a calibration certificate or a calibration report. [5]
Calibration history, measuring equipment Complete registration of the results from the calibration of a piece of measuring equipment, or measuring artefact, over a long period of time, to enable the evaluation of the long-term stability of the measuring

instrument, artefact or the measuring system.

Calibration interval Time interval between two consecutive calibrations of a measuring instrument.

Calibration report Result(s) of a calibration can be registered in a document sometimes called a calibration certificate or a calibration report. [5]

Calibration Set of operations that establish, under specified conditions, the relationship between the quantity values with measurement uncertainties provided by measurement standards or certified reference materials and corresponding indications with the associated measurement uncertainties of the measurement instrument, measuring system or reference material under test. [4]

CCAUV Consultative Committee for Acoustics, Ultrasound and Vibrations. Established 1998.

CCEM Consultative Committee for Electricity and Magnetism. Established 1927.

CCL Consultative Committee for Length. Established 1952.

CCM Consultative Committee for Mass and related quantities. Established 1980.

CCPR Consultative Committee for Photometry and Radiometry. Established 1933.

CCQM Consultative Committee for Amount of Substance. Established 1993.

CCRI Consultative Committee for Ionising Radiation. Established 1958.

CCT Consultative Committee for Thermometry. Established 1937.

CCTF Consultative Committee for Time and Frequency. Established 1956.

CCU Consultative Committee for Units. Established 1964.

CEM Centro Español de Metrología, the national metrology institute of Spain.

CE-mark See chapter 2.2.3.

CEN Comité Européene de Normalisation, the European standardisation organisation.

CGPM Conférence Générale des Poids et Mesures. First held in 1889, meets every 4th year. See chapter 3.1.1.

CIPM Comité International des Poids et Mesures. See chapter 3.1.1.

CIPM MRA see Mutual Recognition Arrangement, CIPM.

CMC Calibration and Measurement Capabilities, see chapter 3.1.2.

CMI Czech Metrology Institute, the national metrology institute of the Czech Republic.

Compound standard A set of similar material measures or measuring instruments that, through their combined use, constitutes one standard called a compound standard.

Conformity assessment An activity that provides demonstration that specified requirements relating to a product, process, system, person or body are fulfilled, i.e. testing, inspection, certification of products, personnel and management systems.

Conventional value of a quantity Quantity value attributed by agreement to a quantity for a given purpose, for example the "standard acceleration due to free fall". [4]

Correction factor Factor by which the uncorrected measuring result is multiplied to compensate for a systematic error. [5]

Correction value Value which added algebraically to the uncorrected result of a measurement compensates for a systematic error. [5]

Coverage factor A number greater than 1 by which the combined standard measurement uncertainty is multiplied to obtain an expanded measurement uncertainty, see chapter 2.1.7.

CRM Certified Reference Material. Reference material accompanied by a certificate issued by an authoritative body which provides one or more specified property values with associated uncertainties and demonstrated traceability established using valid procedures. [4]

Dead band Maximum interval through which the value of the quantity being measured may be changed in both directions without producing a detectable change in the corresponding indication of the measuring instrument. [4]

Derived quantity Quantity, in a system of quantities, defined in terms of the base quantities of that system. See chapter 5.2. [4]

Derived unit The measurement unit for a derived quantity. See chapter 5.2. [4]

Designated institute An institute designated by its NMI or its national government to hold specific national standards, and which usually participates in the CIPM MRA see chapter 3.1.4.

Detector A device or substance that indicates the presence of a phenomenon, body or substance when a threshold value is exceeded, without necessarily providing a value of an associated quantity e.g. litmus paper. [4]

Deviation Quantity value minus its reference value. [5]

DFM Danish Fundamental Metrology, the national metrology institute of Denmark.

Drift Continuous or incremental change in indication over time due to changes in the metrological properties of a measuring instrument, measuring system or reference material. [4]

DMDM Directorate of Measures and Precious Metals, the national metrology institute of Serbia.

DPM General Directorate of Metrology, the national metrology institute of Albania.

DZM State Office for Metrology, the national metrology institute of Croatia.

EA European co-operation for Accreditation, formed by the amalgamation of EAL (European Co-operation for Accreditation of Laboratories) and EAC (European Accreditation of Certification) in November 1997. See chapter 3.2.2.

EAC See EA.

EAL See EA.

EC initial verification See chapter 2.2.2.

EC type approval See chapter 2.2.2.
EIM Hellenic Institute of Metrology, the national metrology institute of Greece.
e-mark See chapter2.2.3.
EPTIS European Proficiency Testing Information System, see link in chapter 7.
Error (for a measuring instrument), maximum permissible Extreme values for a measurement error with respect to a known reference quantity value permitted by specifications, regulations, etc. for a given measurement, measuring instrument or measurement system. [4]
Error, systematic Component of measurement error that for repeated measurements remains constant or varies in a predicable manner. [4]
Eurachem See chapter3.2.5.
EURAMET European Association of National Metrology Institutes. See chapter 3.2.1.
EUROLAB Voluntary co-operation between testing and calibration laboratories in Europe. See chapter 3.2.4.

Fundamental Metrology See Metrology, fundamental.

General Conference on weights and measures See CGPM.
GLP Good Laboratory Practice. Accrediting bodies approve laboratories in accordance with the GLP rules of OECD.
GUM Central Office of Measures, the national metrology institute of Poland.
GUM Guide to the Expression of Uncertainty in Measurement. Published by BIPM, IEC, IFCC (International Federation of Clinical Chemistry), ILAC, ISO, IUPAC, IUPAP and OIML. [6]
GUM method see chapter 2.1.7.

Henri Tudor CRP Henri Tudor, the national metrology institute of Luxembourg.
History, measuring equipment See calibration history.

IEC International Electrotechnical Commission.
ILAC International Laboratory Accreditation Cooperation, see chapter 3.1.7.
IMBiH Institute of Metrology of Bosnia and Herzegovina, the national metrology institute of Bosnia and Herzegovina.
Indication (of a measuring instrument) Quantity value provided by a measuring instrument or measuring system. [4]
Influence quantity A quantity that in a direct measurement does not affect the quantity that is actually measured (the measurand) but does affect the relationship between the indication and the measurement result. [4]
INM National Institute of Metrology, the national metrology institute of Romania.

INRIM Istituto Nazionale di Ricerca Metrologica, the national metrology institute of Italy.
Instrument constant Coefficient by which the direct indication of a measuring instrument must be multiplied to give the indicated value of the measurand or be used to calculate the value of the measurand. [5]
International measurement standard Measurement standard recognised by signatories to an international agreement and intended to serve worldwide e.g. the international prototype of the kilogram. [4]
IPQ Instituto Português da Qualidade, the national metrology institute of Portugal.
IRMM Institute for Reference Materials and Measurements, an institute of the Joint Research Centre of the European Commission.
ISO International Organisation for Standardisation.
IUPAC The International Union of Pure and Applied Chemistry, see chapter 3.1.10.
IUPAP The International Union of Pure and Applied Physics, see chapter 3.1.9.

Joint Committees of the BIPM, see chapter 3.1.1.
JV Justervesenet, the Norwegian Metrology Service, the national metrology institute of Norway.

KCDB BIPM Key comparison database, see chapter 3.1.2.

Legal metrology See Metrology, legal.
LNE Laboratoire national de métrologie et d'essais, the national metrology institute of France.
LNMC State Agency Latvian National Metrology Centre, the national metrology institute of Latvia.

Maintenance of a measurement standard Set of measures necessary to preserve the metrological characteristics of a measurement standard within stated limits. [4]
Market surveillance An approach used to ensure compliance with legislation, see chapter 2.2.3.
Material measure Device intended to reproduce or supply, in a permanent manner during its use, one or more known quantity value e.g. a standard weight, a volume measure, a gauge block, or a certified reference material. [4]
Maximum permissible error (of a measuring instrument) Extreme values for a measurement error with respect to a known reference quantity value permitted by specifications, regulations, etc. for a given measurement, measuring instrument or measurement system. [4]

MBM Montenegrin Bureau of Metrology, the national metrology institute of Montenegro.

Measurand The quantity which is subject to measurement. [4]

Measure, material see material measure [4]

Measurement Process of experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity. Set of operations for the purpose of determining the value of a quantity. [4]

Measurement error Measured quantity value minus a reference quantity value. [4]

Measurement error, absolute When it is necessary to distinguish "error" from "relative error" the former is sometimes called "absolute error of measurement". [5]

Measurement procedure Detailed description of a measurement according to one or more measurement principles and to a given measurement method, based on a measurement model and including any calculation to obtain a measurement result. [4]

Measurement result Set of quantity values being attributed to a measurand together with any other available relevant information. [4]

Measurement standard, etalon Realisation of the definition of a given quantity, with stated quantity value and associated measurement uncertainty, used as a reference. The realisation may be provided by a material measure, measuring instrument, reference material or measuring system. [4]

Measurement standard, international Measurement standard recognised by signatories to an international agreement and intended to serve worldwide e.g. the international prototype of the kilogram. [4]

Measurement standard, maintenance Set of operations necessary to preserve the metrological properties of a measurement standard within stated limits. [4]

Measurement standard, national Measurement standard recognized by national authority to serve in a state or economy as the basis for assigning quantity values to other measurement standards for the kind of quantity concerned. [4]

Measurement unit Real 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. [4]

Measuring chain Series of elements of a measuring system constituting a single path of the signal from a sensor to an output element. [4]

Measuring instrument Device intended to be used to make measurements, alone or in conjunction with one or more supplementary devices. [4]

Measuring range Set of values of measurands for which the error of a measuring instrument is intended to lie within specified limits. [5]

Measuring system Set of one or more measuring instruments and often other devices, including any reagent and supply, assembled and adapted to give information used to generate measured quantity values within specified intervals for quantities of specified kinds. [4]

Measuring unit, off-system Unit of measurement that does not belong to a given system of units. [4]

MEDA MEsures D'Accompagnement – Accompanying Measures.

MEDA countries: Algeria, Cyprus, Egypt, Jordan, Israel, Lebanon, Malta, Morocco, Palestinian Authority, Syria, Tunisia and Turkey.

METAS Federal Office of Metrology, the national metrology institute of Switzerland.

Method of measurement Generic description of a logical organisation of operations used in a measurement. [4]

Metre Convention International diplomatic treaty established in 1875 for the purpose of ensuring a globally uniform system of measuring units. In 2008 there were 51 member nations. See chapter 3.1.1.

Metric system A measuring system based on the metre and kilogram and other base units. Subsequently developed into the SI system. See chapter 4.

Metrological subject field Metrology is divided into 11 subject fields. See chapter 2.1.1.

Metrology From the Greek word "metron" = measurement. The science of measurement and its application. [4]. See chapter 1.1.

Metrology, fundamental There is no international definition of the expression "fundamental metrology" but this expression is used to refer to the most accurate level of measurement within a given discipline. See chapter 1.2.

Metrology, industrial Ensures appropriate function of the measuring instruments used in industry as well as in production and testing processes.

Metrology, legal Ensures accuracy and reliability of measurement where measured values can affect health, safety, or the transparency of financial transactions e.g. weights and measures. See chapter 2.2.

Metrology, scientific Endeavours to organise, develop and maintain measuring standards. See chapter 1.2.

Metrosert AS Metrosert, the national metrology institute of Estonia.

MID The Measuring Instruments Directive, see chapter 2.2.2.

MIKES Centre for Metrology and Accreditation, the national metrology institute of Finland.

MIRS Metrology Institute of the Republic of Slovenia, the national metrology institute of Slovenia.

MKEH Hungarian Trade Licensing Office, the national metrology institute of Hungary.

MKSA system A system of measurement units based on the Metre, Kilogram, Second and Ampere. In 1954 the system was extended to include the Kelvin and the Candela. It was then given the name "SI system". See chapter 4.
MRA see Mutual Recognition Arrangement.
MSA Malta Standards Authority – National Metrology Services, the national metrology institute of Malta.
Mutual Recognition Arrangement, ILAC see chapter 3.1.7.
Mutual Recognition Arrangement, CIPM MRA for national measurement standards and for calibration and measurement certificates issued by NMIs, see chapter 3.1.2.

National measurement standard Measurement standard recognized by national authority to serve in a state or economy as the basis for assigning quantity values to other measurement standards for the kind of quantity concerned. [4]
National Metrology Institute NMI See chapter 3.1.3.
NEST Neytendastofa, the national metrology institute of Iceland.
NIST National Institute of Standards and Technology, the national metrology institute of the USA.
NMI Often-used English abbreviation for the national metrology institute of a country. See chapter 3.1.3.
NMIA National Measurement Institute Australia. The national metrology institute of Australia.
NMISA National Metrology Institute of South Africa, the national metrology institute of South Africa.
NMi VSL NMi Van Swinden Laboratorium B.V., the national metrology institute of the Netherlands.
NML National Metrology Laboratory, the national metrology institute of the Republic of Ireland.
Nominal value See value, nominal.
Notified body See chapter 2.2.3.
NPL National Physical Laboratory, the national metrology institute of the United Kingdom.
NRC-INMS National Research Council, Institute for National Measurement Standards. The national metrology institute of Canada.

OAS Organization of American States.
OIML Organisation Internationale de Métrologie Légale, International Organisation of Legal Metrology.

Performance testing (laboratory) Determination of the testing capability of a laboratory, by comparing tests performed between laboratories.

Preventive measures (opposite repressive measure) are used for market surveillance and are taken before measuring instrument used for a legal metrology can be placed in the market, i.e. the instrument has to be type-approved and verified, see chapter 2.2.3.

Primary method A method of the highest metrological quality which when implemented can be described and understood completely, and for which a complete uncertainty budget can be provided in SI units, the results of which can therefore be accepted without reference to a standard for the quantity being measured.

Primary reference material See reference material, primary.

Primary measurement standard A measurement standard established using a primary reference measurement procedure or created as and artefact, chosen by convention. A standard that is designated or widely acknowledged as having the highest metrological qualities and whose measurement results are determined without reference to other standards of the same quantity in the same measurement range. [4]. See chapter 2.1.2.

Principle of measurement The scientific foundation of a method of measurement. A phenomenon serving as the basis of a measurement. [4]

Proficiency testing schemes See PTS.

Prototype Artefact that defines a unit of measurement. The international prototype kilogram (1 kg weight) in Paris is today the only prototype in the SI system.

PTB Physikalisch-Technische Bundesanstalt, the national metrology institute of Germany.

PTS Proficiency testing schemes, link in chapter 7.

Quantity (measurable) Property of a phenomenon, body or substance, where the property has a magnitude that can be expressed as a number and a reference. [4]

Quantity, derived Quantity in a system of quantities defined in terms of the base quantities of that system. See chapter 5.2. [4]

Quantity dimension Expression of the dependence of a quantity on the base quantities of a system of quantities as a product of powers of factors corresponding to the base quantities, omitting any numerical factor. [4]

Quantity, kind of Aspect common to mutually comparable quantities. [4]

Quantity value Number and reference together expressing magnitude of a quantity e.g mass of a given body. [4]

Random measurement error Component of measurement error that in replicate measurements varies in an unpredictable manner. [4]

Reference conditions Operating conditions prescribed for evaluating the performance of a measuring instrument or measuring system or for comparison of measurement results. [4]

Reference material (CRM), certified Reference material accompanied by a certificate issued by an authoritative body which provides one or more specified property values with associated uncertainties and demonstrated traceability established using valid procedures. [4]

Reference material (RM) Material, sufficiently homogeneous and stable with reference to specified properties, which has been established to be fit for its intended use in measurement or in examination of nominal properties. [4]

Reference material, primary Reference material that has the highest metrological qualities and whose value is determined by the use of a primary method. [3]

Reference standard Measurement standard designated for the calibration of other measurement standards for quantities of a given kind in a given organisation or at a given location. [4] See chapter 2.1.2.

Reference value Quantity value used as a basis for comparison with values of quantities of the same kind. [4] See also Values, determined.

Relative error Error of measurement divided by a true value of the measurand. [5]

Repeatability (of a measuring instrument) The ability of a measuring instrument to give, under defined conditions of use, closely similar responses for repeated applications of the same stimulus. [5]

Repeatability (of results of measurements) Closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement. [5]

Repressive measure (opposite of preventive measure) used in market surveillance to reveal any illegal usage of a legal metrology measuring instrument, see chapter 2.2.3.

Reproducibility (of results of measurements) Closeness of agreement between the results of measurements of the same measurand carried out under changed conditions of measurement. [4]

Reproducibility condition Condition of measurement, out of a set of conditions that includes different locations, operators, measuring systems, and replicate measurements on the same or similar objects. [4]

Response The input signal for a measuring system is often referred to as a stimulus and the output signal is often referred to as a response. [5]

Result, corrected Measurement result after correction for systematic error. [5]

RMO Regional Metrology Organisation, see chapter 3.2 and the following chapters.

SADCMET Southern African Development Community (SADC) Cooperation in Measurement Traceability. See chapter 3.5.2.
Scale division Part of a scale between any two successive scale marks.
Scale range The set of values bounded by the extreme indications on an analogue measuring instrument. [5]
Scale spacing Distance between two successive adjacent scale marks measured along the same line as the scale length. [5]
SCSC APEC Sub-committee on Standards and Conformance.
Secondary standard Measurement standard established through calibration with respect to a primary measurement standard for a quantity of the same kind. [4]
Sensor Element of a measuring instrument or a measuring system that is directly affected by the measurand. [4]
SI system The international system of units, Le Système International d'Unités, continuing the formal definition of all SI basic units, approved by the General Conference on Weights and Measures. See chapter 4.
SI unit A unit in the SI system. See chapter 4.
SIM Sistema Interamericano de Metrología, the Interamerican Metrology System is the regional organisation for metrology in America, comprising the 34 member nations represented at OAS. See chapter 3.3.1.
SMD FPS Economy, DG Quality and Safety, Metrology Division, the national metrology institute of Belgium.
SMU Slovak Metrology Institute, the national metrology institute of the Slovak Republic.
SP SP Technical Research Institute of Sweden, the national metrology institute of Sweden.
Span Modulus of the difference between two limits of a nominal range. [5]
Stability Property of a measuring instrument, whereby its metrological properties remain constant in time. [4]
Standard deviation, experimental Parameter s for a series of n measurements of the same measurand, characterises the dispersion of the results and is given by the formula for standard deviation. [5]
Standard See Measurement standard.
Standard, compound A set of similar material measures or measuring instruments that, through their combined use, constitutes one standard called a compound standard.
Standard, transfer Standard used as an intermediary to compare standards. [5]
Standard, travelling Measurement standard, sometimes of special construction, intended for transport between different locations. Sometimes used comparisons of standards at different locations. [4]

Stimulus The input signal for a measuring system is often referred to as a stimulus and the output signal is often referred to as a response. [5]
System of measurement units Set of base units and derived units, together with their multiples and submultiples, defined in accordance with given rules, for a given system of quantities.. [4]
System of units See System of measurement units.
Systematic error Component of measurement error that for repeated measurements remains constant or varies in a predicable manner. [4]

TBT Technical Barrier to Trade.
Testing Technical procedure consisting of the determination of one or more characteristics of a given product, process or service, in accordance with a specified procedure. [5]
Threshold, discrimination Largest change in a value of a quantity being measured that causes no detectable change in the corresponding indication of a measuring instrument or system. [4]
Traceability chain Sequence of measurement standards and calibrations that is used to relate the measurement result to the reference. [4]
Traceability, metrological Property of a measurement whereby the result can be related to a reference through an unbroken chain of calibrations, each contributing to the measurement uncertainty. [4]
Transfer equipment The description "transfer equipment" should be used when the intermediate link is not a standard. [5]
Transfer standard or device Device used as an intermediary to compare measurement standards. [4]
Transparency Ability of a measuring instrument not to alter the measurand. [5]
Travelling standard See Standard, travelling.
True value of a quantity The quantity value consistent with the definition of a quantity. [4]

UME Ulusal Metroloji Enstitüsü, the national metrology institute of Turkey.
Uncertainty of measurement Non-negative parameter, associated with the result of a measurement that characterises the dispersion of the quantity values being attributed to the measurand, based on the information used. [4] The estimation of uncertainty in accordance with GUM guidelines is usually accepted. [6]
Uncertainty, expanded see chapter 2.1.7.
Unit of measurement Real 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. [4] See chapter 4.

Unit of measurement, derived Derived unit of measurement that can be expressed as the product of basic units in powers with the proportionality coefficient 1. [4]

Value (of a measurand), transformed Value of a measuring signal that represents a given measurand. [5]

Value, quantity Magnitude of a particular quantity generally expressed as a unit of measurement multiplied by a number. Number and reference together expressing magnitude of a quantity e.g mass of a given body. [4]

Value, nominal Rounded or approximate value of a characterising quantity of a measuring instrument or measuring system that provides guidance for its use eg a standard resistor marked with a nominal value of 100 Ω. [4]

VIM International Vocabulary of basic and general terms in Metrology. [4], [5]

VMT State Metrology Service, the national metrology institute of Lithuania.

WELMEC Western European Legal Metrology Co-operation. See chapter 3.2.3.

Working range Set of values of measurands for which the error of a measuring instrument is intended to lie within specified limits. [5]

Working standard Measurement standard that is routinely used to calibrate or verify measuring instruments or measuring systems. [4]

WTO World Trade Organisation.

7. INFORMATION ON METROLOGY – LINKS

INFO ABOUT ...	SOURCE	CONTACT
Accreditation in Europe, accredited laboratories	EA European Co-operation in Accreditation	Secretariat at COFRAC 37 rue de Lyon, FR-75012 Paris www.european-accreditation.org
Accreditation in the Americas	IAAC Inter American Accreditation Cooperation	www.iaac.org.mx
Accreditation in Asia Pacific	APLAC Asia Pacific Laboratory Accreditation Cooperation	www.aplac.org
Accreditation in Southern Africa	SADCA Southern African Development Community Accreditation	www.sadca.org
Analytical chemistry and quality related issues in Europe	Eurachem	www.eurachem.org
Certified reference materials	COMAR database	www.comar.bam.de
Documentary standards	ISO International Organisation for Standardisation	www.iso.org
EURAMET technical projects and comparisons	EURAMET	www.euramet.org
European Community legislation	EUR-lex	eur-lex.europa.eu
European national standardisation bodies	CEN European Committee for Standardisation	www.cenorm.be
International metrology organisations	BIPM Bureau International des Poids et Mesures	Pavillon de Breteuil, F-92312 Sèvres Cedex, France www.bipm.org
International Union of Pure and Applied Chemistry	IUPAC	www.iupac.org
International Union of Pure and Applied Physics	IUPAP	www.iupap.org
Key comparison database	Published in BIPM key comparison database & "Metrologia"	BIPM kcdb.bipm.org
Legal metrology in Asia Pacific	APLMF Asia-Pacific Legal Metrology Forum	www.aplmf.org

Legal metrology in Europe	WELMEC	WELMEC Secretariat United Kingdom www.welmec.org
Legal metrology, worldwide	OIML	OIML secretariat at BIML, Paris www.oiml.org
Measurement, Testing and Analytical Laboratories in Europe	EUROLAB	www.eurolab.org
National Metrology Institutes	BIPM	www.bipm.org ...goto "practical information" ...goto "useful links"
Physical and chemical constants	CODATA	physics.nist.gov/cuu/Constants
	Kaye and Laby online	www.kayelaby.npl.co.uk
Proficiency testing schemes PTS in Europe, the Americas and Australasia	EPTIS database European Proficiency Testing Information System	www.eptis.bam.de
Regional Metrology Organisations RMO	BIPM	www.bipm.org ...go to "practical information" ...go to "useful links"
Regional Metrology Organisation for the Americas	SIM Inter American Metrology System	www.sim-metrologia.org.br
Regional Metrology Organisation for Asia Pacific	APMP Asian Pacific Metrology Programme	www.apmpweb.org
Regional Metrology Organisation for Eurasia	COOMET Euro-Asian co operation of national metrological institutions	www.coomet.org
Regional Metrology Organisation for Europe	EURAMET e.V. European Association of National Metrology Institutes	www.euramet.org
Regional Metrology Organisation for Southern Africa	Southern African Development Community Cooperation in Measurement Traceability	www.sadcmet.org
Regional Metrology Organisation for Africa (future)	Intra-Africa Metrology System	www.afrimets.org
TBT Technical Barriers to Trade	EC DG Trade Market Access database	madb.europa.eu
The SI system	BIPM	www.bipm.org

8. REFERENCES

[1] Arturo Garcia Arroyo, Dr. Director of Industrial & Material Technologies, CEC DG XII: "Measurements for Europe", Measurements and Testing, June 1993, vol. 1, no.1. *(The percentage figures in chapter 1.1 refers to this reference)*

[2] BIPM: The International System of Units, 8th edition 2006.

[3] CCQM: Report of the President of the Comité Consultatif pour la Quantité de Matière, april 1995.

[4] BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP, OIML: International Vocabulary of Metrology – Basic and General Concepts and Associated Terms, 3rd edition, 2008, JCGM 200:2008, also published by ISO as ISO/IEC Guide 99-12:2007 International Vocabulary of Metrology – Basic and General Concepts and Associated

[5] BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML: International Vocabulary of Basic and General Terms in Metrology, 2nd edition 1993, ISBN 92-67-01075-1.

[6] ISO: Guide to the Expression of Uncertainty in Measurement, First edition 1995, ISBN 92-67-10188-9.

[7] ISO/IEC 17025, General requirements for the competence of testing and calibration laboratories, 2nd edition, 2005.

[8] Steen C. Martiny: Innovation og Måleteknik, 1999, ISBN 87-16-13439-7. *(The fertiliser example in chapter 4 refers to this book)*

Mankind measures

Metrology presents a seemingly calm surface covering depths of knowledge that are familiar only to a few, but which most make use of – confident that they are sharing a common perception of what is meant by expressions such as metre, kilogram, watt and second.