# Metrology – in short

2nd edition

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**"Metrology - in short©" 2nd edition**
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**Cover:**
Photo of Great Belt east bridge, Denmark, with light on the catwalk. 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 and the USA were involved in building the bridge between 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©" 2nd edition is to increase the 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 basic 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. Precondition for this is a widely utilised, sound metrological infrastructure.

The content of the 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 EUROMET. A list of metrological terms is collected primarily from internationally recognised standards. References are given to institutions, organisations and laboratories by reference to their homepages.

"Metrology – in short©" is commissioned by the projects METROTRADE "Metrological support to international trade" and REGMET "Improving dialogue between national metrology institutes and EU regulatory bodies" under the Competitive and Sustainable Growth (GROWTH) Programme and financed by the European Commission and the project partners.

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# Foreword

It is with pleasure that we present this 2nd 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, has proven to be a very successful and widely used publication throughout the metrology world. This 2nd 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 the 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 trade and in the context 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 2nd edition of the publication has been broadened to address the CIPM Mutual Recognition Arrangement (MRA), to contain more information on measurement uncertainty and to provide more information on the global players in measurement and testing.

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

Paul Hetherington
EUROMET Chairman
November 2003, Dublin.



# 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 established 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 more than 1% of our combined GDP with an economic return equivalent to 2-7% of GDP [4], 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 are 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.*

*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, elementary particle 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 infinitely small particle. The availability of measuring equipment and the ability to use it is essential for scientists 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 of use to many - 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, 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 considered in 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 as well as in production and testing processes.

3. *Legal metrology* is concerned with measurements where these influence the transparency of economic transactions, health and safety.

*Fundamental metrology* has no international definition, but it 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

The original international edition of "Metrology – in short©" has been issued in a number of national editions, each adapted to and describing metrology in that specific country following the same handbook-concept. The English edition is an international edition.

By 2003 the following editions are available:

**Czech: Metrologie v kostce**
First national edition issued year 2002 in 2000 copies, contact fjelinek@cmi.cz
Second national edition issued year 2003 in electronic version, contact fjelinek@cmi.cz

**Croatian: Metrologija ukratko**
Issued year 2000 in an electronic version.

**Danish: Metrologi – kort og godt**
First national edition issued year 1998 in 1000 copies, contact pho@dfm.dtu.dk
Second national edition issued year 1999 in 2000 copies, contact pho@dfm.dtu.dk

**English: Metrology – in short© (international editions)**
First international edition issued year 2000 in 10 000 copies, contact pho@dfm.dtu.dk
Second international edition issued year 2003 in 10 000 copies, contact pho@dfm.dtu.dk or fiona.redgrave@npl.co.uk

**Finnish: Metrology – in short**
First national edition issued year 2001 in 5000 copies, contact mikes@mikes.fi
Second national edition issued year 2002, contact mikes@mikes.fi

**Lithuanian: Metrologija trumpai**
First national edition issued year 2000 in 100 copies, contact rimvydas.zilinskas@ktu.lt
Second national edition will be issued year 2004, 2000 copies, contact vz@lvmt.lt

**Portuguese: Metrologia – em sintese**
Issued year 2001 in 2500 copies, contact ipq@mail.ipq.pt

and
**Korean: In the pipeline for 2004**

**Italian: In the pipeline for 2004**

It is proposed that a number of national editions of the 2nd international edition will be produced.



# 2. Metrology

## 2.1 Industrial and scientific metrology

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

Metrological activities, testing and measurements are valuable inputs to ensuring the quality of many industrial activities. This includes the need for traceability, which is becoming just as important as measurement itself. *Recognition* of metrological *competence* at each level of the *traceability* chain can be established by 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:
Mass, electricity, length, time and frequency, thermometry, ionising radiation & radioactivity, photometry and radiometry, acoustics and amount of substance.

Within EUROMET there are two additional subject fields:
Flow and interdisciplinary metrology.

There is no formal international definition of the subfields, the subfields listed in table 2.1 are those used within EUROMET.

Table 2.1 Subject fields, subfields and important measurement standards. Only the 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 |
| | Volume and density Viscosity | Glass areometers, laboratory glassware, vibration densimeters, glass capillary viscometers, rotation viscometers, viscometry scale |
| 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 |
| | Angular measurements | Autocolimators, rotary tables, angle gauges, polygons, levels |
| LENGTH | Forms | 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, (geodetic length measuring tools) |
| 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 |
| IONISING RADIATION and RADIOACTIVITY | Absorbed dose - High level industrial products | Calorimeters, calibrated high dose rate cavities, Dichromat dosimeters |
| | 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 Gamma detectors |
| PHOTOMETRY and RADIOMETRY | Optical radiometry | Cryogenic radiometer, detectors, stabilised laser reference sources, reference materials – Au fibres |
| | Photometry | Visible region detectors, Si photodiodes, quantum efficiency detectors |
| | Colorimetry | Spectrophotometer |

| SUBJECT FIELD | SUBFIELD | Important measurement standards |
|---|---|---|
| IONISING RADIATION and RADIOACTIVITY | Optical fibres | Reference materials – Au fibres |
| FLOW | Gas flow (volume) | Bell provers, rotary gas meters, turbine gas meters, transfer meter with critical nozzles |
| | Flow of water (volume, mass and energy) | Volume standards, Coriolis mass-related standards, level meters, inductive flow meters, ultrasound flow meters |
| | Flow of liquids other than water | |
| | 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 |
| AMOUNT of SUBSTANCE | Environmental chemistry | Certified reference materials, mass spectrometers, chromatographs |
| | Clinical chemistry | |
| | Materials chemistry | Pure materials, certified reference materials |
| | Food chemistry | Certified reference materials |
| | Biochemistry | |
| | Micro biology | |
| | pH measurement | |



### 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 lower-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 standards in the traceability chain are shown in figure 2.1. Metrology fields, subfields and important measurement standards are shown in table 2.1 in chapter 2.1.1. An international listing of all measurement standards does not exist.

The definitions of the different standards are given in the Vocabulary, chapter 6.

### 2.1.3 Certified Reference Materials

A certified reference material (CRM), known as a standard reference material (SRM) in the USA, 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.

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**

A traceability chain, see figure 2.1, 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 established by using CRMs and reference procedures, see chapter 2.1.3 and 2.1.5.

An end user may obtain traceability to the highest international level either directly from a National Metrology Institute or from a secondary calibration laboratory. As a result of various mutual recognition arrangements, 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 or reference material. Calibration determines the performance characteristics of an instrument or reference material. It is 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 attached to the calibrated instrument.

Three main reasons for having an instrument calibrated:

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

### 2.1.5 Reference procedures

Reference procedures 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.

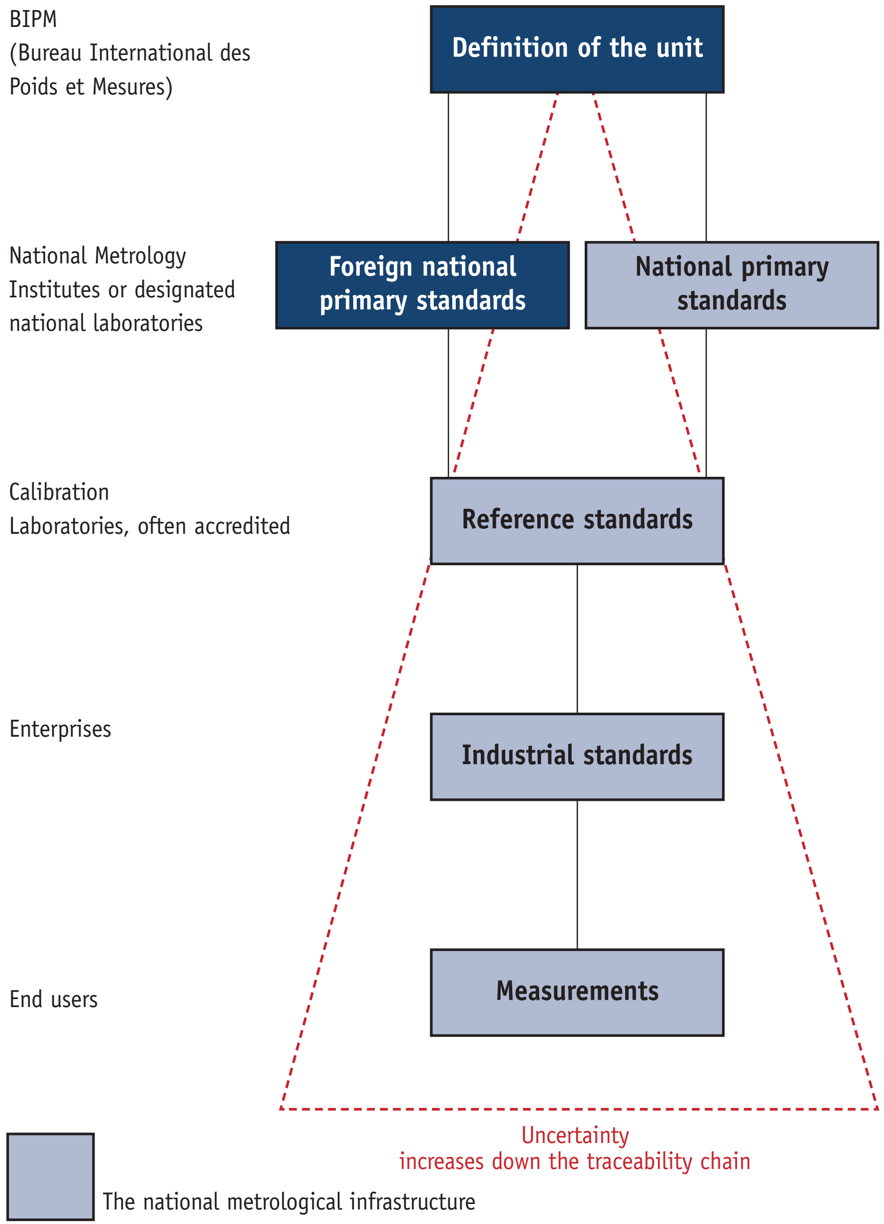
The uncertainty of the results of a reference procedure must be adequately estimated and appropriate for the intended use.

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 hand books or databases, or reference values which are embodied by a reference material or reference object.



***Figure 2.1 The traceability chain***



**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.



### 2.1.6 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 “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 in the form

$$Y = y \pm U$$

where the uncertainty U is given with no more than **<u>two</u>** 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 $\Omega$ where the resistance meter, according to the manufacturer’s specifications, has an uncertainty of 0,081 m$\Omega$, 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 corresponds to an interval of approximately 95% level of confidence.

**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 praxis:
- 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 by the coverage factor $k$.

5) **State the measurement result in the form**

$$Y = y \pm U$$



**2.1.7 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 (conformity assessment) 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. While first-party laboratories are those of the producer and second-party laboratories are the ones of the customer, third-party laboratories are independent.

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.

The main objective of legal metrology is to ensure citizens of correct measurement results when used
- in official and commercial transactions
- in labour environments, health and safety.

OIML is the *International Organisation of Legal Metrology*, see chapter 3.1.7.

There are also many other areas of legislation, outside legal metrology, where measurements are required to assess conformance with regulations e.g. aviation, 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 legislation for measuring instruments and measurement and testing methods including pre-packaged products.

All over the world, national legal requirements for measuring instruments and their use are laid down for the above-mentioned areas.

### 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 requirements for all categories of measuring instruments, as well as on other directives covering individual categories of measuring instruments and which have been published since 1971. Measuring instruments, which have been granted an EEC type approval and an EEC initial verification, can be placed on the market and used in all member countries without further tests or type approvals.

For historical reasons the scope of legal metrology is not the same in all countries. A new directive, the Measuring Instruments Directive (MID) has been developed and once it comes into force, most of the existing directives related to measuring instruments will be repealed.

**EU - Measuring Instruments Directive**

The Measuring Instruments Directive aims at the elimination of 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 |



Software used within the instruments is not included in the existing directives but will be covered by the MID.

### 2.2.3 EU - Enforcement of measuring instrument legislation

**Legal control**

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

*Market surveillance* is a *repressive measure* to reveal any illegal usage of a measuring instrument. For instruments in use, inspections or periodic *re-verifications* are prescribed to guarantee that measuring instruments comply with legal requirements. Such legal requirements, including those on usage and validity periods differ from country to country depending on the national legislation. The standards used for such inspections and tests must be traceable to national or international standards.

Consumer protection may differ in various member states and hence the requirements governing the use of instruments become the subject of national legislation. Member states may lay down legal requirements for measuring instruments which are not listed in the MID.

The *conformity assessment* procedures correspond to those in Directive 93/65/EEC on the modules to be used in all *technical harmonisation directives*.

### 2.2.4 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**
After the MID is implemented the manufacturer is responsible for affixing the CE-marking and the supplementary metrology marking on the product. By doing so, the manufacturer ensures and declares that the product is in conformity with the requirements of the directives. The Measuring Instruments Directive is a mandatory directive.

The producer of pre-packaged products has to submit his production to a quality assurance system and reference tests. A public administration or a notified body may approve the quality assurance system and a public administration or a notified body may perform the reference tests. 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.

**Market surveillance**
The government fulfils its obligations through market surveillance. To conduct market surveillance the government authorises inspectors 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.



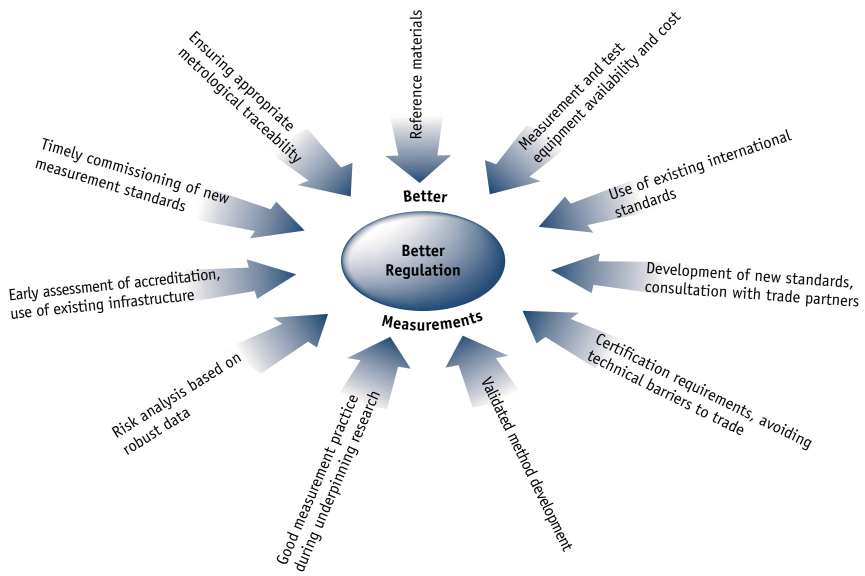
### 2.2.5 Measurement and testing in legislation
The world economy and the quality of our everyday life depend on reliable measurements and tests which are trusted and accepted internationally and which do not form a barrier to trade. In addition to those regulations requiring legally verified instruments,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

National Metrology Institutes and other organisations provide advice and guidance on measurement issues to the users.

**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 regulation and establishing the technical limits
- undertaking market surveillance.

A guide is available, see link to Regulatory guide chapter 6, developed by a collaboration of European NMIs to assist those considering measurement issues in the regulatory process. The brief condensed extract below gives an indication of the contents of the guide.

| Rational for the regulation | Development of the regulation | Market surveillance |
|---|---|---|
| Identification of the drivers | Assesment of the current state of play | Cost effective measurement & testing |
| Collection and collation of existing data | Setting of robust technical limits | Feedback |
| Commissioning of R&D to support the rationale | Commissioning of R&D to establish solutions | Adapting to new technology |
| | Establishing the level of detail to be prescribed | |




There are at least 8 important measurement topics which may need to be addressed at each stage in addition to those above:

1. Which parameters to be measured?
2. Use of existing metrological infrastructure.
3. Ensuring appropriate measurement traceability – traceable to the SI (where possible) through an unbroken, auditable chain of comparisons.
4. Are appropriate methods and procedures available for all tests and/or calibrations?
5. Technical limits established from risk analysis based on robust data – do the existing data support the rationale, are new or additional data required?
6. Use of existing international standards – supplemented with additional requirements if necessary or the development of new international standards.
7. 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?



# 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 exhibitions. In 1875, a diplomatic conference on the metre took place in Paris where 17 governments signed a treaty “the Metre Convention”. The signatories decided to create and finance a permanent, scientific institute: The “Bureau International des Poids et Mesures” **BIPM**.

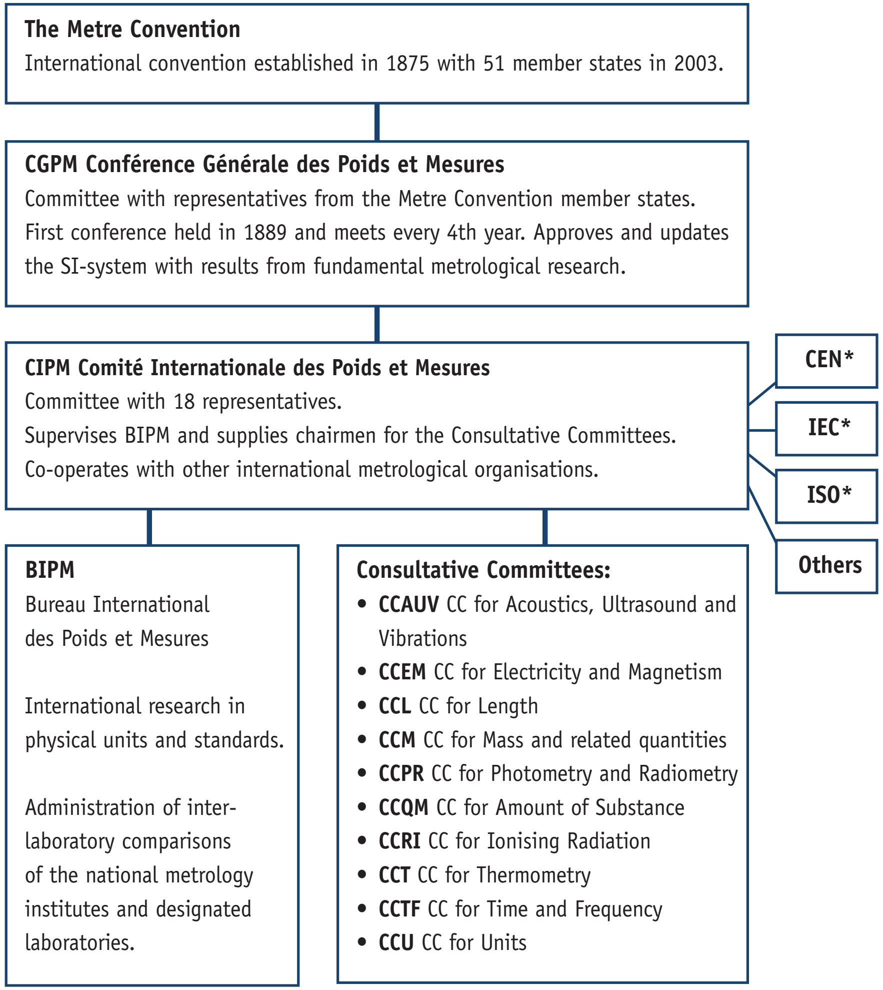
The “Conférence Générale des Poids et Mesures” **CGPM** discusses and examines the work performed by National Metrology Institutes and the BIPM, and makes recommendations on new fundamental metrological determinations and all major issues of concern to the BIPM.

In 2003, 51 states were members of the Metre Convention and a further 10 states were associates of the CGPM.

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,
- JCR Joint Committee of the BIPM and the International Astronomical Union,
- JCRB Joint Committee of the Regional Metrology Organisations and the BIPM,
- JCTLM Joint Committee on Traceability in Laboratory Medicine,

*Figure 3.1 The Metre Convention organisation*






### 3.1.2 CIPM Mutual Recognition Arrangement

In October 1999, the CIPM Mutual Recognition Arrangement **CIPM MRA** for national measurement standards and for calibration and measurement certificates issued by National Metrology Institutes was signed. By the end of 2003, NMIs of 44 Signatory States of the Metre Convention, 2 International organisations and 13 Associates of CGPM had signed the CIPM MRA.

The objectives of the CIPM MRA are to provide governments and other parties with a secure foundation for wider agreements related to international trade, commerce and regulatory affairs. This is achieved through two mechanisms:

- Part 1, establishing the degree of equivalence of national measurement standards maintained by the participating NMIs.
- Part 2, involving mutual recognition in the calibration and measurement certificates issued by participating NMIs.

Currently, around 90% of world trade in merchandise exports is between CIPM MRA participant nations.

Participants recognise each other's capabilities based on the following criteria:

1) Credible participation in comparisons identified by the international measurement community as of key significance for particular quantities over specified ranges.
   At present around 400 key comparisons have been designated and are being carried out by NMIs, of which about 130 have been completed.
2) Credible participation in other comparisons related to specific calibration services or that have some trade and/or economic priority for individual countries or geographical regions, the supplementary comparisons. Presently some 50 supplementary comparisons are being undertaken.
3) Declaration of each participant's calibration and measurement capabilities (CMCs), which are subject to peer review and are published on BIPM key comparison database.
4) A quality system for calibration services which is recognised to be on the level of international best practice, based on agreed criteria.

The first two of these criteria provides the technical basis for recognition under part 1 of the MRA. Compliance with both criteria 3 and 4 enables recognition under part 2 of the MRA.

Consequently, 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 also provides 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.

**BIPM Key comparison database**

The BIPM key comparison database **KCDB** contains the results of key and supplementary comparisons together with the lists of peer-reviewed and approved Calibration and Measurement Capabilities (CMCs) of the NMIs. In 2003, there were approximately 13 500 individual CMCs published in the BIPM key comparison database, all of which have undergone a process of peer evaluation by NMI experts under the supervision of the Regional Metrology Organisations. This is coordinated internationally by the Joint Committee of the Regional Metrology Organisations and BIPM **JCRB**. See link in chapter 6.

### 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.

Some countries operate a centralised metrology organisation with one NMI. The NMI may devolve the maintenance of specific standards to certain laboratories without these having the status of a NMI. Other countries operate a decentralised organisation with a multiplicity of institutes, all having the status of a NMI.

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 on the figure in chapter 3.1.1.

A list of NMIs is available via the Regional Metrology Organisations, e.g. in Europe the NMIs can be found in the EUROMET Directory.

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



Many NMIs undertake internationally recognised research within specific sub-fields and maintain and further develop the unit concerned by maintaining and further developing primary standards. NMIs also participate in comparisons at the highest international level.

### 3.1.4 Designated national laboratories

Designated laboratories in most countries are nominated by the NMI in accordance with the metrological plan of action for the different subject fields and in accordance with the metrological policy of the country.

Designated laboratories in Europe are given in the EUROMET Directory, see the link in chapter 6.

### 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 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.

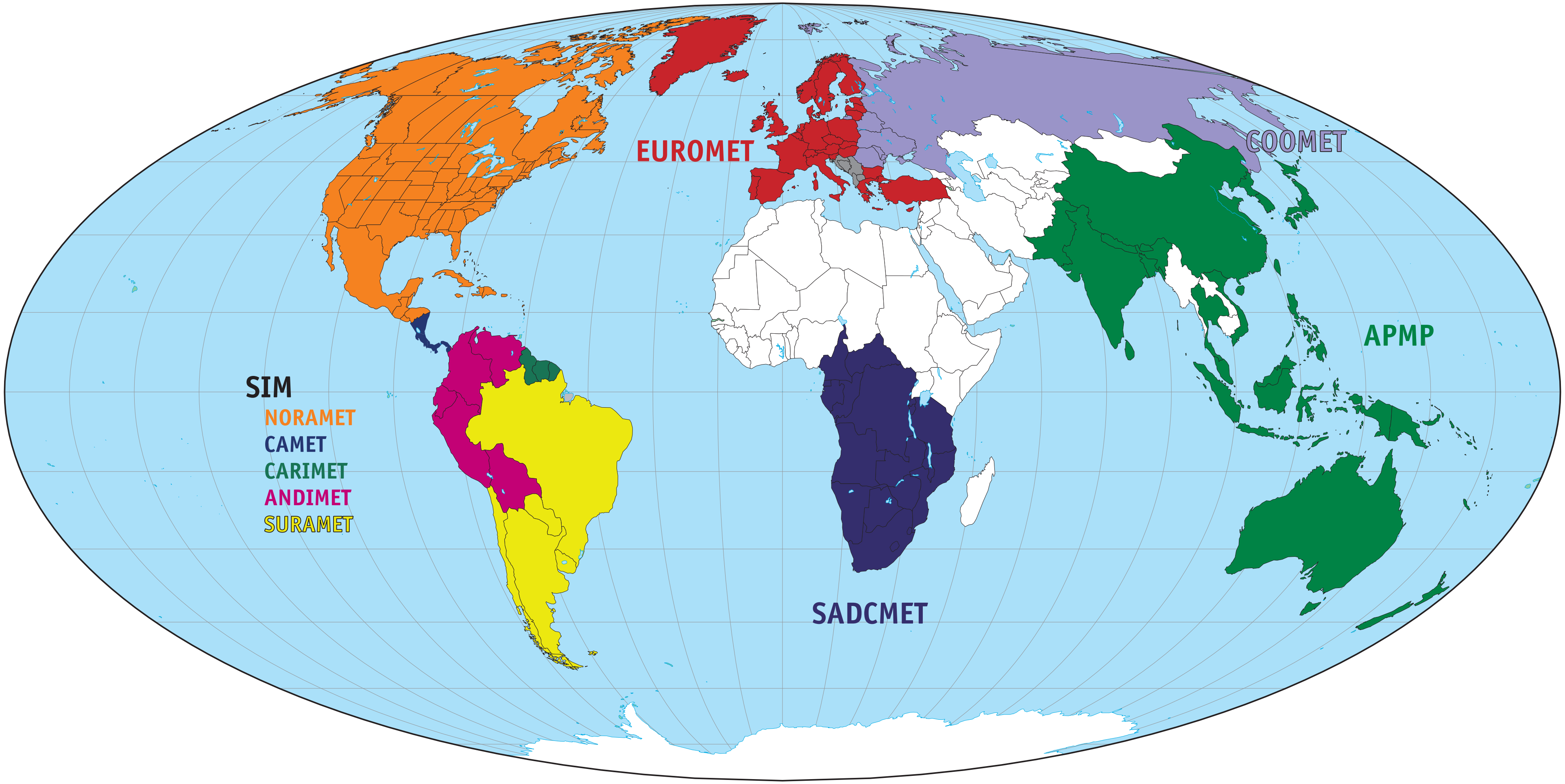
Accreditation is granted on the basis of laboratory assessment and regular surveillance. Accreditation is generally based on regional and international standards, e.g. ISO/IEC 17025 "General requirements for the competence of testing and calibration laboratories", and technical specifications and guidelines 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 recognise and promote the equivalence of each other's systems and of certificates and test reports issued by the organisations accredited.

### 3.1.6 ILAC

The *International Laboratory Accreditation Cooperation* ILAC is an international cooperation between the various laboratory accreditation schemes operated throughout the world.

# Regional Metrology Organisations



Founded twenty years ago, ILAC was formalised as a cooperation in 1996. In 2000, ILAC members signed the *ILAC Mutual Recognition Arrangement*, which further enhanced 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. ILAC was incorporated in January 2003.

Hence 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.

**3.1.7 OIML**

The *International Organisation of Legal Metrology* OIML was established in 1955 on the basis of a convention in order to promote the global harmonisation of legal metrology procedures. OIML is an intergovernmental treaty organisation with 58 member countries, which participate in technical activities, and 51 corresponding member countries that join the OIML as observers.

OIML collaborates with the Metre Convention and BIPM on the international harmonisation of legal metrology. OIML liaises with more than 100 international and regional institutions concerning activities in metrology, standardisation and related fields.

A worldwide technical structure provides 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 develops model regulations, and issues international recommendations that provide members with an internationally agreed basis for the establishment of national legislation on various categories of measuring instruments. The technical requirements in the European Measuring Instruments Directive are to a large extent equivalent to the International Recommendations of OIML.



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 sub-committees composed of representatives from member countries. Certain international and regional institutions also participate on a consultative basis. Co-operation agreements are established between the OIML and institutions such as ISO and IEC with the objective of avoiding conflicting requirements. Consequently, manufacturers and users of measuring instrument test laboratories may simultaneously use publications of the OIML and those of other institutions.

The *OIML Certificate System* 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. These certificates are the subject of voluntary acceptance by national metrology services.

**3.1.8 IUPAP**

*The International Union of Pure and Applied Physicists* focuses on

- physical measurements
- pure and applied metrology
- nomenclature and symbols for physical quantities and units

and encourages 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”.

## 3.2 European infrastructure

The geographical coverage of the regional metrology organisations RMOs are shown on the RMO-map on page 32.

### 3.2.1 Metrology - EUROMET

EUROMET is a *collaborative forum on measurement standards*, established by a Memorandum of Understanding in 1987. It originated from the Western European Metrology Club WEMC, which was initiated by a conference on metrology in Western Europe in 1973. EUROMET is the Regional Metrology Organisation for Europe under the CIPM MRA, see chapter 3.1.2.

EUROMET is a voluntary collaboration between the national metrology institutes in the EU, EFTA and EU Accession States. The European Commission is also a member. Other European states may apply for membership based on certain published criteria.

In 2003 there were 27 members and 12 corresponding applicants and corresponding NMIs, several countries are in the process of applying for membership.

EUROMET has the following specific tasks:

- Provision of a framework for collaborative research projects and inter-laboratory comparisons between the member national metrology institutes;
- Co-ordination of major investments for metrological facilities;
- Transfer of expertise in the field of primary or national standards between the members;
- Provision of information on resources and services; and co-operation with the calibration services and legal metrology services in Europe.

### 3.2.2 Accreditation - EA

The *European Co-operation for Accreditation* EA is the organisation of accreditation bodies in Europe. In June 2000 EA was established as a legal entity according to Dutch law. The members of EA are the nationally recognised accreditation bodies of the member countries or the candidate countries, of the European Union and EFTA.

EA members who have successfully undergone peer evaluation may sign the appropriate multilateral agreement for

- certification body accreditation
- laboratory accreditation
- inspection body accreditation

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



In 2003 EA had over 30 members and associated members of which 20 accreditation bodies were signatories to the testing MLA.

The metrology infrastructure in most countries consists of National Metrology Institutes NMIs, designated national laboratories and accredited laboratories. 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 *European co-operation in legal metrology* WELMEC was established by a Memorandum of Understanding in 1990 signed by 15 member countries of the EU and 3 EFTA countries, in connection with the preparation and enforcement of the "New Approach" directives. This name was 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, which 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 2003 there were 30 member countries.

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 EUROMET, the European co-operation for Accreditation EA, the International Organisation of Legal Metrology OIML and other regional organisations with an interest in legal metrology. The committee meets at least once a year and is supported by 7 working groups. A small Chairman's Group advises the chairman on strategic matters.

WELMEC advises the European Commission and the Council regarding the development of the Measuring 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 31 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 EUROMET 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 MetChem Working Group.

### 3.2.6 COOMET

COOMET is an organisation corresponding to EUROMET with members from central and east European and Asian countries.

## 3.3 Americas infrastructure

### 3.3.1 Metrology - SIM

The Inter American Metrology System, SIM for Sistema Interamericano de Metrologia, 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 organised in five sub-regions:

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

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 *Inter American 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 recognised mutual recognition arrangements among the accreditation bodies of the Americas. It also promotes cooperation 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 program to its members.

IAAC has 14 full member counties and 5 associate member countries. ILAC and IAF have recognised 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 brings together the national metrology institutes of the region, and is aimed towards developing international recognition of the measurement capabilities of its members. APMP began in 1977 and is the oldest continually operating regional metrological grouping in the world. APMP is the Regional Metrology Organisation for the Asia-Pacific under the CIPM MRA, see chapter 3.1.2.

APMP worked closely with BIPM and other Regional Metrology Organisations to establish the global MRA and has an active intercomparison programme geared towards providing its members with access to the BIPM key comparison database, see chapter 3.1.2.

### 3.4.2 Accreditation - APLAC

The *Asia Pacific Laboratory Accreditation Cooperation* APLAC is a cooperation between organisations in the Asia Pacific region responsible for accrediting testing and inspection facilities.

Members are nationally recognised 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 recognised 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 recognised 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. The Specialist Regional Bodies cooperate with other regional and international counterparts.



## 3.5 African infrastructure

### SADC

SADC is the *Southern African Development Community* and 14 countries are signatories to the SADC Treaty. The “Memorandum of Understanding on Cooperation in Standardisation, Quality Assurance, Accreditation and Metrology in the Southern African Development Community”, the SADC SQAM Programme was signed in 2000. This Memorandum of Understanding established the SADC SQAM Programme and its constituent regional structures SADCA, SADCMET, SADCMEL, SADCSTAN and SQAMEG with the goal of removing Technical Barriers to Trade.

### 3.5.1 Metrology - SADCMET

The *SADC Cooperation in Measurement Traceability* SADCMET was established in 2000. Presently SADCMET has 14 ordinary Members, the National Metrology Institutes or de facto National Metrology Institutes of the member countries and 4 Associate Members. SADCMET is the Regional Metrology Organisation for Southern Africa under the CIPM MRA, see chapter 3.1.2.

### 3.5.2 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 access to accreditation as a tool for the removal of TBTs in both the voluntary and regulatory areas.

### 3.5.3 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.

### Standardisation - SADCSTAN

The *SADC Cooperation in Standardisation* SADCSTAN promotes the coordination of standardisation activities and services in the region, with the purpose of achieving harmonisation of standards and technical regulations, with the exception of Legal Metrology regulations.

# 4. 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 Systems 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.

**SI units**

| | |
|---|---|
| table 4.1 | SI base units |
| table 4.2 | SI derived units expressed in SI base units |
| table 4.3 | SI derived units with special names and symbols |
| table 4.4 | SI derived units whose names and symbols include SI-derived units with special names and symbols |

**Units outside SI**

| | |
|---|---|
| table 4.5 | Units accepted because they are widely used |
| table 4.6 | Units to be used within specific subject areas |
| table 4.7 | Units to be used within specific subject areas and whose values are experimentally determined |

*Table 4.1 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 4.2 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 square 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 | $cd \cdot m^{-2}$ |



## 4.1 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 realised e.g. in the wavelength of radiation from an iodine-stabilised helium-neon laser.
> These re-definitions have reduced the relative uncertainty from $10^{-7}$ to $10^{-11}$.

**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 x $10^{-7}$ 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 4.3 SI derived units with special names and symbols*

| **Derived quantity** | **SI derived unit** Special name | **Symbol** Special symbol | **In SI units** | **In SI base units** |
|---|---|---|---|---|
| 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 | W/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 induction, magnetic flux density | tesla | T | $Wb/m^2$ | $kg \cdot s^{-2} \cdot A^{-1}$ |
| inductance | henry | H | Wb/A | $m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$ |
| 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 | $m^2 \cdot s^{-2}$ |
| plane angle | radian | rad | | $m \cdot m^{-1} = 1$ |
| solid angle | steradian | sr | | $m^2 \cdot m^{-2} = 1$ |
| catalytic activity | katal | kat | | $s^{-1} \cdot mol$ |



## 4.2 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 4.2.

The CGPM has approved special names and symbols for some derived units, as shown in table 4.3.

Some base units are used in different quantities, as shown in table 4.4. 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 4.4 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 | $C/m^3$ | $m^{-3} \cdot s \cdot A$ |
| electric flux density | 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 ($\chi$ and $\gamma$ 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 | $m^4 \cdot m^{-2} \cdot kg \cdot s^{-3} = m^2 \cdot kg \cdot s^{-3}$ |
| radiance | watt per square metre steradian | $W/(m^2 \cdot sr)$ | $m^2 \cdot m^{-2} \cdot kg \cdot s^{-3} = kg \cdot s^{-3}$ |
| catalytic (activity) concentratration | katal per cubic metre | $kat/m^3$ | $m^{-3} \cdot s^{-1} \cdot mol$ |



## 4.3 Units outside the SI

Table 4.5 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 4.6 gives examples of units outside the SI that are accepted for use within specific subject areas.

Table 4.7 gives units outside the SI which are accepted for use within specific subject areas and whose values are experimentally determined.

*Table 4.5 Units outside SI which are accepted*

| 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)′ = ( $\pi$/10 800) rad |
| | second | ″ | 1″ = (1/60)″ = ($\pi$/648 000) rad |
| | nygrad | gon | 1 gon = ($\pi$/200) rad |
| volume | litre | l, L | 1 l = 1 $dm^3$ = $10^{-3}$ $m^3$ |
| mass | metric tonne | t | 1 t = $10^3$ kg |
| pressure in air, fluid | bar | bar | 1 bar = $10^5$ Pa |

*Table 4.6 Units outside the SI which are accepted for use within specific subject areas*

| Quantity | Unit | Symbol | Value in SI units |
|---|---|---|---|
| length | mile nautical | | 1 nautical mile = 1852 m |
| Speed | knot | | 1 nautical mile per hour = (1852/3600) m/s |
| Mass | carat | | 1 carat = 2 x $10^{-4}$ kg = 200 mg |
| linear density | tex | tex | 1 tex = $10^{-6}$ kg/m = 1 mg/m |
| strength of optical systems | dioptre | | 1 dioptre = 1 $m^{-1}$ |
| pressure in human body fluids | millimetres of mercury | mmHg | 1 mmHg = 133 322 Pa |
| Area | are | a | 1 a = 100 $m^2$ |
| Area | hectare | ha | 1 ha = $10^4$ $m^2$ |
| pressure | bar | bar | 1 bar = 100 kPa = $10^5$ Pa |
| length | ångström | Å | 1 Å = 0,1 nm = $10^{-10}$ m |
| Cross-section | barn | b | 1 b = $10^{-28}$ $m^2$ |

*Table 4.7 units outside the SI which are accepted within specific subject areas and whose values are experimentally determined [2]*

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

| Quantity | Unit | Symbol | Definition | In SI units |
|---|---|---|---|---|
| energy | electronvolt | eV | 1 eV is the kinetic energy of an electron passing a potential difference of 1 V in vacuum. | 1 eV = 1,602 177 33 (49) · $10^{-19}$ 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 = 1,660 540 2 (10) · $10^{-27}$ kg |
| length | astronomical unit | ua | | 1 ua = 1,495 978 706 91 (30) · $10^{11}$ m |



## 4.4 SI prefixes

The CGPM has adopted and recommended a series of prefixes and prefix symbols, shown in table 4.8.

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 4.8 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 |

## 4.5 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: $N \cdot m$ or N m

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

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

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

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 ($kg/m^3$) 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

# 5. Vocabulary

[x] refers to reference no. [x] in chapter 7.

**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 certain metrological requirements intended to keep errors within specified limits. [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 the result of a measurement and a true value of the measurand. [4]

**Adjustment of a measuring instrument** Process that brings a measuring instrument into a functional condition corresponding to the purpose for which it is used. [4]

**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.

**Basic unit** (for measurement) Unit of measurement for a basic magnitude in a given system of magnitudes. [4]

**BNM** Bureau National de Métrologie, the national metrological institute of France.

**BIPM** Bureau International des Poids et Mesures, see chapter 3.1.1.

**BIPM** key comparison database, see chapter 3.1.2.

**Calibration certificate** Result(s) of a calibration can be registered in a document sometimes called a calibration certificate or a calibration report. [4]

**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 piece of equipment or the measuring artefact.

**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. [4]

**Calibration** Set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material and the corresponding values realised by standards. [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 - Metrology in chemistry. 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 metrological institute of Spain.

**CE-mark** See chapter 2.2.3.

**CEN** Comité Europée ne de Normalisation. European standardisation organisation.

**CGPM** Conférence Générale des Poids et Mesures. Held for the first time in 1889. Meeting every 4th year. See chapter 3.1.1.

**Check standard** Working standard routinely used to ensure that measurements are made correctly. [4]

**CIPM** Comité Internationale 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 metrological institute of the Czech Republic.

**Compound standard** Set of similar material measures or measuring instruments that, through their combined use, constitutes a 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, see chapter 2.1.7.

**Conventional true value (of a quantity)** Value attributed to a particular quantity and accepted, sometimes by convention, as having an uncertainty appropriate for a given purpose. Sometimes called "assigned value", "best estimate of the value", "conventional value", or "reference value". [4]

**COOMET** Euro-Asian cooperation of national metrological institutions, see chapter 3.2.6.

**Correction factor** Factor by which the uncorrected measuring result is multiplied to compensate for a systematic error. [4]

**Correction value** Value which added algebraically to the uncorrected result of a measurement compensates for a systematic error. [4]

**Coverage factor** see chapter 2.1.6.

**CRM** See Reference material, certified.

**CSIR - NML** National Metrology Laboratory, the national metrological institute of South Africa.

**CSIRO NML** The national metrological institute of Australia. The National Measurement Laboratory NML is a National Facility within the Commonwealth Scientific and Industrial Research Organisation CSIRO.

**Dead band** Maximum interval through which a stimulus may be changed in both directions without producing a change in response of a measuring instrument. [4]

**Derived unit** (of measurement) See chapter 4.2.

**Detector** A device or substance that indicates the presence of a phenomenon without necessarily providing a value of an associated quantity. E.g. litmus paper. [4]

**Deviation** Value minus its reference value. [4]

**DFM** Dansk Institut for Fundamental Metrologi. The national metrological institute of Denmark.

**Drift** Slow change of a metrological characteristic of a measuring instrument. [4]

**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.

**EEC initial verification** See chapter 2.2.1.

**EEC type approval** See chapter 2.2.1.

**e-mark** See chapter 2.2.4.

**EOTC** The European Organisation for Conformity Assessment.

**EPTIS** European Proficiency Testing Information System, link in chapter 6.

**Error (for a measuring instrument), largest permissible** Extreme values for an error permitted by specifications, regulations, etc. for a given measuring instrument. [4]

**Error (in a measuring instrument), systematic** Systematic indication error in a measuring instrument. [4]

**Error limit (for a measuring instrument)** Extreme values for an error permitted by specifications, regulations, etc. for a given measuring instrument. [4]

**Eurachem** See chapter 3.2.5.

**EUROLAB** Voluntary co-operation between testing and calibration laboratories in Europe. See chapter 3.2.4.

**EUROMET** Co-operation between national metrological institutes in Europe and the European Commission. See chapter 3.2.1.

**Fundamental Metrology** See Metrology, fundamental.

**General conference on measures and weights** See CGPM.

**GLP** Good Laboratory Practice. Accrediting bodies approve laboratories in accordance with the GLP rules of OECD.

**GUM** Guide to the Expression of Uncertainty in Measurement. Published by BIPM, IEC, ISO, OIML and IFCC (International Federation of Clinical Chemistry), IUPAC (International Union of Pure and Applied Chemistry) and IUPAP (International Union of Pure and Applied Physics). [6]

**GUM method** see chapter 2.1.6.

**History, measuring equipment** See calibration history.

**IEC** International Electrotechnical Commission.

**ILAC** International Laboratory Accreditation Coorperation, see chapter 3.1.6.

**Indication (of a measuring instrument)** Value of a (measurable) quantity provided by a measuring instrument. [4]

**Influence quantity** Quantity that is not the measurand (quantity subject to measurement) but that affects the result of the measurement. [4]

**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. [4]

**International (measuring) standard** Standard recognised by international agreement as suitable for international use as a basis for determining the value of other standards for a given magnitude. [4]

**IPQ** Instituto Português da Qualidade, the national metrological institute of Portugal.

**IRMM** Institute for Reference Materials and Measurements, Joint Research Centre under the European Commission.

**ISO** International Organisation for Standardisation.

**IUPAP** The International Union of Pure and Applied Physicists, see chapter 3.1.8.

**JCRB** Joint Committee of the BIPM, see chapter 3.1.1.

**Justervesenet** The national metrological institute of Norway.

**Key comparison database, BIPM** see chapter 3.1.2.

**Legal metrology** See Metrology, legal.



**Maintenance of a measurement standard** Set of measures necessary to preserve the metrological characteristics of a measurement standard within appropriate limits. [4]

**Market surveillance** used to enforce legal metrology, see chapter 2.2.4.

**Material measure** Device intended to reproduce or supply, in a permanent manner during its use, one or more known values of a given quantity. e.g. a weight, a volume measure, a gauge block, or a reference material. [4]

**Maximum permissible errors (of a measuring instrument)** Extreme values of an error permitted by specifications, regulations, etc. for a given measuring instrument. [4]

**Measurand** Particular quantity subject to measurement. [4]

**Measure, material** Device intended to take a measurement, alone or in conjunction with supplementary devices. [4]

**Measurement procedure** Set of operations, described specifically, used in the performance of particular measurements according to a given method. [4]

**Measurement** Set of operations for the purpose of determining the value of a quantity. [4]

**Measurement standard**, **etalon** 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. [4]

**Measurement standard, international** Standard recognised by an international agreement to serve internationally as the basis for assigning values to other standards of the quantity concerned. [4]

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

**Measurement standard, national** Standard recognised by a national decision to serve in a country as the basis for assigning values to other standards of the quantity concerned. [4]

**Measurement unit** See Unit of measurement. A particular quantity, defined and adopted by convention, with which other quantities of the same kind are compared in order to express their magnitudes relative to that quantity. [4]

**Measuring chain** Series of elements of a measuring instrument or measuring system that constitutes the path of the measurement signal from the input to the output. [4]

**Measuring error** Result of a measurement minus a true value of the measurand. [4]

**Measuring error, absolute** When it is necessary to distinguish "error" from "relative error" the former is sometimes called "absolute error of measurement". [4]

**Measuring instrument** Device intended to be used to make measurements, alone or in conjunction with 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. [4]

**Measuring result** Value attributed to a measured measurand arrived at by measurement. [4]

**Measuring system** Complete set of measuring instruments and other equipment assembled to carry out specified measurements. [4]

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

**METAS** Swiss Federal Office of Metrology and Accreditation, the national metrological institute of Switzerland.

**Method of measurement** Logical sequence of operations, described generically, used in the performance of measurements. [4]

**Metre Convention** International convention established in 1875 for the purpose of ensuring a globally uniform system of measuring units. In 2003 there were 51 member nations. See chapter 3.1.1.

**Metric system** A measuring system based on metres and kilograms. 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.

**Metrology, fundamental** There is no international definition of the expression "fundamental metrology" but this expression stands for 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 of measurement where measured values can affect health, safety, or the transparency of financial transactions. See chapter 2.2.

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

**MID** The Measuring Instruments Directive, see chapter 2.2.1.

**MIRS** Standards and Metrology Institute of Slovenia, the national metrological institute of Slovenia.

**MKSA system** A system of measurement units based on Metres, Kilograms, Seconds and Amperes. 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.

**Mutual Recognition Arrangement, ILAC** see chapter 3.1.6.

**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** Standard recognised by a national decision to serve in a country as the basis for assigning values to other standards of the quantity concerned. [4]

**National Metrology Institute NMI** See chapter 3.1.3.

**NIST** National Institute of Standards and Technology, the national metrological institute of the USA.

**NMI** Often-used English abbreviation for the national metrological institute of a country. See chapter 3.1.3.

**NMi-VSL** Nederlands Meetinstituut - Van Swinden Laboratorium, the national metrological institute of the Netherlands.

**Nominal value** See value, nominal.

**Notified body** See chapter 2.2.4.

**NPL** National Physical Laboratory, the national metrological institute of UK.

**NRC** National Research Council, Institute for National Measurement Standards, the national metrological 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 of repressive measure) are used for market surveillance and are taken before marketing a measuring instruments, i.e. the instrument has to be type-approved and verified, see chapter 2.2.3.

**Primary laboratory** Laboratory that performs internationally adopted fundamental metrological research and which realises and maintains standards at the highest international level.

**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 magnitude being measured.

**Primary reference material** See reference material, primary.

**Primary standard** Standard that is designated or widely acknowledged as having the highest metrological qualities and whose value is accepted without reference to other standards of the same quantity [4]. See chapter 2.1.2.

**Principle of measurement** The scientific foundation of a method of measurement. [4]



**Proficiency testing schemes** See PTS.

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

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

**PTS** Proficiency testing schemes, link in chapter 6.

**Quantity (measurable)** Attribute of a phenomenon, body or substance that may be distinguished qualitatively and determined quantitatively. [4]

**Quantity derived** Quantity defined, in a system of quantities, as a function of base quantities of that system. [4]

**Quantity dimension** Expression that represents a quantity of a system of quantities as the product of powers of factors that represent the basic quantities of the system. [4]

**Realise a unit**, see chapter 2.1.2.

**Random error** Result of a measurement minus the mean that would result from an infinite number of measurements of the same measurand carried out under repeatability conditions. [4]

**Reference conditions** Conditions of use prescribed for testing the performance of a measuring instrument or for the intercomparison of results of measurements. [4]

**Reference material (CRM), certified** Reference material, accompanied by a certificate, which has one or more properties whose value is certified by a procedure that establishes traceability to the accurate realisation of the unit in which the values of the properties are expressed, and for which each certified value is accompanied by a stated uncertainty with a given level of confidence. [4], see chapter 2.1.3.

**Reference material (RM)** Material or substance one or more of whose property values are sufficiently homogenous and well established to be used for the calibration of an apparatus, the assessment of a measurement method, and for assigning values to materials. [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** In general the standard of the highest metrological quality which is accessible at a given location or in a given organisation, and from which measurements taken at the locality are derived. [4] See chapter 2.1.2.

**Reference values** Normally part of the reference conditions of an instrument. See also Values, determined.

**Relative error** Error of measurement divided by a true value of the measurand. [4]

**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. [4]

**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. [4]

**Repressive measure** (opposite of preventive measure) used in market surveillance to reveal any illegal usage of a measuring instruments, 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]

**Response** The input signal for a measuring system can be called a stimulus and the output signal can be called a response. [4]

**Result, corrected** Measuring result after correction for systematic error. [4]

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

**SADCMET** Southern African Development Community (SADC) Cooperation in Measurement Traceability. See chapter 3.5.1.

**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. [4]

**Scale spacing** Distance between two successive adjacent scale marks measured along the same line as the scale length. [4]

**SCSC** APEC Sub-committee on Standards and Conformance.

**Secondary standard** Standard whose value is assigned by comparison with a primary standard of the same quantity. [4]

**Sensor** Element in a measuring instrument or a measuring chain that is directly influenced 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 Interamricano de Metrologia, Normalización y Calidad, the Inter-American Metrology System is the regional organisation for metrology of the Americas, see chapter 3.3.1.

**SMU** Slovensky Metrologicky Ustav, the national metrological institute of the Slovak Republic.

**SP** Sveriges Provnings- och Forskningsinstitut, the national metrological institute of Sweden.

**Span** Modulus of the difference between two limits of a nominal range. [4]

**Stability** The ability of a measuring instrument to maintain constant its metrological characteristics with time. [4]

**Standard deviation, experimental** Parameters 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. [4]

**Standard** See Measuring standard.

**Standard, compound** A set of similar material measures or measuring instruments that, through their combined use, constitutes one standard called a compound standard. [4]

**Standard, transfer** Standard used as an intermediary to compare standards. [4]

**Standard Reference Material,** see Reference Material, Certified.

**Standard, travelling** Standard, sometimes specially composed, for use in making comparisons between standards at different locations. [4]

**Stimulus** The input signal for a measuring system can be called a stimulus and the output signal can be called a response. [4]

**System of measurement units** A number of basic units and derived units defined in accordance with given rules for a given system of values. [4]

**System of units** See System of measurement units.

**Systematic error** Mean that would result from an infinite number of measurements of the same measurand carried out under repeatability conditions minus a true value of the measurand. [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, resolution capability (discrimination)** Largest change in a stimulus that produces no detectable change in the response of a measuring instrument, the change in the stimulus taking place slowly and monotonically. [4]

**Traceability chain** The unbroken chain of comparisons is defined under Traceability. [4]

**Traceability** Property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties. [4]

**Transfer equipment** The description "transfer equipment" should be used when the intermediate link is not a standard. [4]

**Transfer standard** Standard used as an intermediary to compare standards. [4]

**Transparency** Ability of a measuring instrument not to alter the measurand. [4]

**Travelling standard** See Standard, travelling.



**True value (of a quantity)** The indefinite form rather than the definite form is used in connection with true value, in that there can be many values that are consistent with the definition of a particular quantity. [4]

**Third party laboratory,** see chapter 2.1.7.

**Uncertainty of measurement** Parameter, associated with the result of a measurement that characterises the dispersion of values that could reasonably be attributed to the measurand. [4] The estimation of uncertainty in accordance with GUM guidelines is usually accepted. [6]

**Uncertainty, expanded** see chapter 2.1.6.

**Unit (of measurement)** Particular quantity, defined and adopted by convention, with which other quantities of the same kind are compared in order to express their magnitudes relative to that quantity. [4] See chapter 4.

**Unit of measurement (derived) coherent** 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. [4]

**Value (of a quantity)** Magnitude of a particular quantity generally expressed as a unit of measurement multiplied by a number. [4]

**Value, nominal** Rounded or approximate value of a characteristic of a measuring instrument that provides a guide to its use. [4]

**Values, derived** Conditions for use intended to keep the metrological characteristics of a measuring instrument within specified limits. [4]

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

**WELMEC** 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. [4]

**Working standard** Standard normally used routinely to calibrate or check material measures, measuring instruments or reference materials. [4]

**WTO** World Trade Organisation.

# 6. Information on metrology – links

| Info about ... | Source | Contact |
|---|---|---|
| Accreditation in Europe<br>Accredited laboratories | **EA** European co-operation in Accreditation | Secretariat at COFRAC<br>37 rue de Lyon, FR-75012 Paris<br>www.european-accreditation.org |
| Accreditation in the Americas | **IAAC** Inter American Accreditation Cooperation | www.iaac-accreditation.org |
| Accreditation in Asia Pacific | **APLAC**<br>Asia Pacific Laboratory Accreditation Cooperation | www.ianz.govt.nz/aplac/ |
| Analytical chemistry and quality related issues in Europe | **EURACHEM** | www.eurachem.ul.pt |
| EUROMET technical projects and intercomparisons | **EUROMET** Directory | www.euromet.org |
| European Community legislation – Metrology | Official Journal of the European Communities<br>**CELEX** database | www.europa.eu.int/eurlex/en/lif/reg/en_register_133012.html |
| European national standardisation bodies | **CEN** (European Committee for Standardisation) | www.cenorm.be |
| Inter-American regional metrology organisation | **SIM** Inter-American Metrology System | www.sim-metrologia.org.br |
| International metrology organisations | **BIPM** Bureau International des Poids et Mesures | Pavillon de Breteuil,<br>F-92312 Sèvres Cedex, France<br>www.bipm.fr |
| Key comparison database | Published in "Metrologia" & **BIPM** key comparison database | www.bipm.org/kcdb |
| Legal metrology in Asia Pacific | **APLMF** Asia-Pacific Legal Metrology Forum | www.aplmf.org/index.shtml |
| Legal metrology in Europe | **WELMEC** | WELMEC Secretariat<br>www.welmec.org |



| Info about ... | Source | Contact |
|---|---|---|
| Legal metrology, international | **OIML** | secretariat at BIML, Paris<br>www.oiml.org |
| Measurement, Testing and Analytical Laboratories in Europe | **EUROlab** | www.eurolab.org |
| National Metrology Institutes | **BIPM** | www.bipm.org<br>...goto "useful links" |
| National Metrology Institutes in Africa | **SACMET** | www.satmet.org |
| National Metrology Institutes in the Americas | **SIM** | www.sim-metrologia.org.br |
| National Metrology Institutes in Asia Pacific | **APMP** Asian Pacific Metrology Programme | www.nmij.jp/apmp/ |
| National Metrology Institutes in Europe | **EUROMET** Directory | www.euromet.org |
| Proficiency testing schemes PTS regularly organised in EU | **EPTIS** European Proficiency Testing Information System | www.eptis.bam.de |
| Reference materials for chemical analysis | **IRMM**<br>COMAR database | www.irmm.jrc.be |
| Regional Metrology Organisations RMO | **BIPM** | www.bipm.org<br>...goto "useful links" |
| Regulatory guide | **RegMet** project | www.regmet.dk and<br>www.euromet.org |
| Standards | **ISO** International Organisation for Standardisation | www.iso.ch |
| TBT Technical Barriers to Trade | **EC DG Trade**<br>Market Access database | http://mkaccdb.eu.int/ |
| SI system | **BIPM** | www.bipm.fr |
| Symbols, constants etc. in physics | **IUPAP** "Red Book" | www.iupap.org/commissions |

# 7. References

The references are listed by their reference number [x]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[2] BIPM: The International System of Units, 7th edition 1998.

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

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

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

[6] ISO/IEC 17025, General requirements for the competence of testing and calibration laboratories, 1999

[7] Preben Howarth: “Metrology in short”, first edition 1999, ISBN 87-988154-0-7