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Guidelines for the determination of recalibration intervals of measuring equipment

Guide pour la détermination des intervalles de réétalonnage des équipements de mesure

INTERNATIONAL LABORATORY ACCREDITATION COOPERATION

ORGANISATION INTERNATIONALE DE METROLOGIE LEGALE

INTERNATIONAL ORGANIZATION OF LEGAL METROLOGY

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Foreword (ILAC)

ILAC is the global association for the accreditation of laboratories, inspection bodies, proficiency testing providers, reference material producers and biobanks, with a membership consisting of accreditation bodies and stakeholder organisations throughout the world.

It is a representative organisation that is involved with:

- the development of accreditation practices and procedures,
- the promotion of accreditation as a trade facilitation tool,
- supporting the provision of local and national services,
- the assistance of developing accreditation systems,
- the recognition of competent testing (including medical) and calibration laboratories, inspection bodies, proficiency testing providers, reference material producers and biobanks around the world.

ILAC actively cooperates with other relevant international organisations in pursuing these aims.

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Foreword (OIML)

The International Organization of Legal Metrology (OIML) is a worldwide, intergovernmental organisation whose primary aim is to harmonise the regulations and metrological controls applied by the national metrological services, or related organisations, of its Member States.

The main categories of OIML publications are:

- **International Recommendations (OIML R),** which are model regulations that establish the metrological characteristics required of certain measuring instruments and which specify methods and equipment for checking their conformity. OIML Member States shall implement these Recommendations to the greatest possible extent;
- **International Documents (OIML D),** which are informative in nature and which are intended to harmonise and improve work in the field of legal metrology;
- **International Guides (OIML G),** which are also informative in nature and which are intended to give guidelines for the application of certain requirements to legal metrology; and
- **International Basic Publications (OIML B),** which define the operating rules of the various OIML structures and systems.

OIML Draft Recommendations, Documents and Guides are developed by Project Groups linked to Technical Committees or Subcommittees which comprise representatives from OIML Member States. Certain international and regional institutions also participate on a consultation basis. Cooperative agreements have been established between the OIML and certain institutions, such as ISO and the IEC, with the objective of avoiding contradictory requirements. Consequently, manufacturers and users of measuring instruments, test laboratories, etc. may simultaneously apply OIML publications and those of other institutions.

International Recommendations, Documents, Guides and Basic Publications are published in English (E) and translated into French (F) and are subject to periodic revision.

Additionally, the OIML participates in Joint Committees with other Institutions for the development of **Vocabularies (OIML V)** and **Joint Guides** and periodically commissions legal metrology experts to write **Expert Reports (OIML E)**. Expert Reports are intended to provide information and advice, and are written solely from the viewpoint of their author, without the involvement of a Technical Committee or Subcommittee, nor that of the CIML. Thus, they do not necessarily represent the views of the OIML.

This publication – reference ILAC-G24 / OIML D 10, Edition 2022 – was developed by the ILAC Accreditation Committee and by OIML TC 4 *Measurement standards and calibration and verification devices*. It was approved for final publication by ILAC in December 2022 and by the International Committee of Legal Metrology at its 57th meeting in October 2022 and will be submitted to the International Conference on Legal Metrology for formal sanction. This edition of D 10 supersedes the previous edition dated 2007.

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1 Introduction

1.1 This guidance Document was developed by the OIML (International Organization of Legal Metrology) and ILAC (International Laboratory Accreditation Cooperation) as a joint venture and is published as such.

1.2 It is important to point out that

a) it is the responsibility of each laboratory to choose to implement any or none of the methods described in this Document based on its individual needs and risk assessments, and

b) it is also the responsibility of each laboratory to evaluate the effectiveness of the implemented method(s). The laboratory should also take responsibility for the consequences of the choice of the method(s).

2 Scope

2.1 The purpose of this Document is to provide guidance to laboratories on methods to determine and review the recalibration intervals of measuring equipment under their control as part of establishing the calibration program of their laboratory. This Document is also applicable to other Conformity Assessment Bodies (e.g. Inspection Bodies and Certification Bodies) and other parties (e.g. manufacturers) that utilise measuring equipment.

3 Terms and definitions

Unless otherwise stated in the following subclauses, the terminology used in this Document conforms to the VIM3 [1], ISO/IEC 17000 [12], ISO/IEC 17020 [13], ISO/IEC 17025 [3], ISO/IEC 17065 [17] and CIPM MRA-G-13 [2].

For the purpose of this Document, the definitions and abbreviations given below apply. Some of the terms in clause 3 are listed with alternative terms which are considered to have an identical definition. The text “for D 10” marks text which is not part of the definition found in the referenced documents (e.g. additional explanatory notes that specifically concern terms used in this Document).

3.1 accreditation body (ISO/IEC 17000, 4.7)

authoritative body that performs accreditation

Note: The authority of an accreditation body can be derived from government, public authorities, contracts, market acceptance, or scheme owners.

3.2 adjustment of a measuring system (VIM3, 3.11)

adjustment

set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured

Note 1: Types of adjustment of a measuring system include zero adjustment of a measuring system, offset adjustment, and span adjustment (sometimes called gain adjustment).

Note 2: Adjustment of a measuring system should not be confused with calibration, which is a prerequisite for adjustment.

Note 3: After an adjustment of a measuring system, the measuring system must usually be recalibrated.

3.3 calibration (VIM3, 2.39)

operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication

Note 1: A calibration may be expressed by a statement, calibration function, calibration diagram, calibration curve, or calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.

Note 2: Calibration should not be confused with adjustment of a measuring system, often mistakenly called "self-calibration", nor with verification of calibration.

Note 3: Often, the first step alone in the above definition is perceived as being calibration.

3.4 calibration and measurement capability (CIPM MRA-G-13)

(CMC)

calibration and measurement capability available to customers under normal conditions:

a) as published in the BIPM key comparison database (KCDB) of the CIPM MRA (International Committee for Weights and Measures Mutual Recognition Arrangement); or

b) as described in the laboratory's scope of accreditation granted by a signatory to the ILAC Arrangement

3.5 certification body (ISO/IEC 17065, 3.12)

third-party conformity assessment body operating certification schemes

Note: A certification body can be non-governmental or governmental (with or without a regulatory authority).

3.6 certified reference material (VIM3, 5.14)

CRM

reference material, accompanied by documentation issued by an authoritative body and providing one or more specified property values with associated uncertainties and traceabilities, using valid procedures

Example Human serum with assigned quantity value for the concentration of cholesterol and associated measurement uncertainty stated in an accompanying certificate, used as a calibrator or measurement trueness control material.

Note 1: 'Documentation' is given in the form of a 'certificate' (see ISO Guide 31:2000).

Note 2: Procedures for the production and certification of certified reference materials are given, e.g. in ISO Guide 34 and ISO Guide 35.

Note 3: In this definition, "uncertainty" covers both 'measurement uncertainty' and 'uncertainty associated with the value of a nominal property', such as for identity and sequence. "Traceability" covers both 'metrological traceability of a quantity value' and 'traceability of a nominal property value'.

Note 4: Specified quantity values of certified reference materials require metrological traceability with associated measurement uncertainty (Accred. Qual. Assur.:2006).

Note 5: ISO/REMCO has an analogous definition (Accred. Qual. Assur.:2006) but uses the modifiers "metrological" and "metrologically" to refer to both quantity and nominal property.

3.7 combined standard measurement uncertainty (VIM3, 2.31)

combined standard uncertainty
standard measurement uncertainty that is obtained using the individual standard measurement uncertainties associated with the input quantities in a measurement model

Note: In the case of correlations of input quantities in a measurement model, covariances must also be taken into account when calculating the combined standard measurement uncertainty; see also GUM:1995, 2.3.4.

3.8 conformity assessment body (ISO/IEC 17000, 4.6)

body that performs conformity assessment activities, excluding accreditation

3.9 inspection body (ISO/IEC 17020, 3.5)

body that performs inspection

Note: An inspection body can be an organisation, or part of an organisation.

3.10 instrumental drift (VIM3, 4.21)

continuous or incremental change over time in indication, due to changes in metrological properties of a measuring instrument

Note: Instrumental drift is related neither to a change in a quantity being measured nor to a change of any recognised influence quantity.

3.11 laboratory (ISO/IEC 17025, 3.6)

body that performs one or more of the following activities:

- testing;
- calibration;
- sampling, associated with subsequent testing or calibration

3.12 material measure (VIM3, 3.6)

measuring instrument reproducing or supplying, in a permanent manner during its use, quantities of one or more given kinds, each with an assigned quantity value

Examples: Standard weight, volume measure (supplying one or several quantity values, with or without a quantity-value scale), standard electric resistor, line scale (ruler), gauge block, standard signal generator, certified reference material.

Note 1: The indication of a material measure is its assigned quantity value.

Note 2: A material measure can be a measurement standard.

3.13 maximum permissible measurement error (VIM3, 4.26)

maximum permissible error

limit of error

extreme value of measurement error, with respect to a known reference quantity value, permitted by specifications or regulations for a given measurement, measuring instrument, or measuring system

Note 1: Usually, the terms “maximum permissible errors” or “limits of error” are used where there are two extreme values.

Note 2: The term “tolerance” should not be used to designate ‘maximum permissible error’.

3.14 measurement result (VIM3, 2.9)

result of measurement

In the context of this Document, result is defined as:

set of quantity values being attributed to a measurand together with any other available relevant information

Note 1: A measurement result generally contains "relevant information" about the set of quantity values, such that some may be more representative of the measurand than others. This may be expressed in the form of a probability density function (PDF).

Note 2: A measurement result is generally expressed as a single measured quantity value and a measurement uncertainty. If the measurement uncertainty is considered to be negligible for some purpose, the measurement result may be expressed as a single measured quantity value. In many fields, this is the common way of expressing a measurement result.

Note 3: In the traditional literature and in the previous edition of the VIM, measurement result was defined as a value attributed to a measurand and explained to mean an indication, or an uncorrected result, or a corrected result, according to the context.

3.15 measurement standard (VIM3, 5.1)

etalon

realisation of the definition of a given quantity, with stated quantity value and associated measurement uncertainty, used as a reference

Note: For examples and notes see VIM3, 5.1.

3.16 measurement uncertainty (VIM3, 2.26)

uncertainty of measurement

uncertainty

non-negative parameter characterising the dispersion of the quantity values being attributed to a measurand, based on the information used

Note 1: Measurement uncertainty includes components arising from systematic effects, such as components associated with corrections and the assigned quantity values of measurement standards, as well as the definitional uncertainty. Sometimes estimated systematic effects are not corrected for but, instead, associated measurement uncertainty components are incorporated.

Note 2: The parameter may be, for example, a standard deviation called standard measurement uncertainty (or a specified multiple of it), or the half-width of an interval, having a stated coverage probability.

Note 3: Measurement uncertainty comprises, in general, many components. Some of these may be evaluated by Type A evaluation of measurement uncertainty from the statistical distribution of the quantity values from series of measurements and can be characterised by standard deviations. The other components, which may be evaluated by Type B evaluation of measurement uncertainty, can also be characterised by standard deviations, evaluated from probability density functions based on experience or other information.

Note 4: In general, for a given set of information, it is understood that the measurement uncertainty is associated with a stated quantity value attributed to the measurand. A modification of this value results in a modification of the associated uncertainty.

3.17 measuring equipment

equipment (including, but not limited to, measuring instruments, software, measurement standards , reference materials, reference data, reagents, consumables or auxiliary apparatus) that is required for the correct performance of laboratory activities and that can influence the results

Note 1: In the context of this Document, a measuring instrument is a component of the measuring equipment which plays an important role for measurement. Some measuring instruments can be used independently to complete a measurement process or to realise a physical quantity.

Note 2: In the context of this Document, measuring equipment may be considered as being equivalent to measuring system.

3.18 measuring instrument (VIM3, 3.1)

device used for making measurements, alone or in conjunction with one or more supplementary devices

Note 1: A measuring instrument that can be used alone is a measuring system.

Note 2: A measuring instrument may be an indicating measuring instrument or a material measure.

3.19 measuring system (VIM3, 3.2)

set of one or more measuring instruments and often other devices, including any reagent and supply, assembled and adapted to give information used to generate measured quantity values within specified intervals for quantities of specified kinds

Note: A measuring system may consist of only one measuring instrument.

3.20 reference material (VIM3, 5.13)

RM

material, sufficiently homogeneous and stable with reference to specified properties, which has been established to be fit for its intended use in measurement or in examination of nominal properties

Note: For notes see VIM3, 5.13.

3.21 reference quantity value (VIM3, 5.18)

reference value

quantity value used as a basis for comparison with values of quantities of the same kind

Note 1: A reference quantity value can be a true quantity value of a measurand, in which case it is unknown, or a conventional quantity value, in which case it is known.

Note 2: A reference quantity value with associated measurement uncertainty is usually provided with reference to

a) a material, e.g. a certified reference material,
b) a device, e.g. a stabilised laser,
c) a reference measurement procedure, or
d) a comparison of measurement standards.

4 General

4.1 An important aspect for maintaining the capability of a laboratory to produce traceable measurement results is to determine the maximum period that should be permitted between successive calibrations (recalibrations) of the measuring equipment used. Various international standards dealing with measurement activities take this aspect into account, e.g. ISO/IEC 17025 [3] and ISO 15189 [15]. In addition, this aspect is also included in international standards applicable to conformity assessment bodies and other parties operating according to e.g. ISO/IEC 17020 [13], ISO/IEC 17043 [14], ISO/IEC 17065 [17], ISO 9001 [11], ISO 17034 [16] or ISO 22870 [18].

Note: Establishing and maintaining traceability of measurement results can be done by means such as, but not limited to

- defining calibration periodicity,
- defining process control measures,
- defining intermediate checks.

4.2 The purposes of calibrating measuring equipment as a measure of maintaining metrological traceability are:

a) to provide an estimate of the deviation between a reference value and the value obtained using the measuring equipment, and the uncertainty in this deviation, at the time the measuring equipment is actually used;

b) to support the validation of the required or declared measurement uncertainty that can be achieved with the measuring equipment; and

c) to confirm whether or not there has been any alteration of the measuring equipment which could introduce doubt about the results delivered in the elapsed period.

4.3 One of the most significant decisions regarding the calibration of measuring equipment is the timing and frequency of its implementation. The frequency between calibrations is a critical issue and is influenced by many factors that need to be taken into account by the laboratory. The most important of these factors are provided in 5.1.

4.4 The calibration records may be used to determine recalibration intervals, when calibrations are provided by, but not limited to:

a) national metrology institutes and designated institutes that have been subject to appropriate peer review processes under the CIPM MRA; or

b) laboratories that have been accredited by an accreditation body which is a signatory to the ILAC (International Laboratory Accreditation Cooperation) Arrangement or to Regional Arrangements recognised by ILAC; or

c) calibration provided by national metrological institutes, designated institutes or laboratories not fulfilling conditions a) or b) and whose services are suitable for the intended use, provided that conditions a) or b) could not be met for other than economic reasons (i.e. are not available). Also refer to ILAC P10 [19].

The recommendations mentioned above do not preclude involvement of other parties, provided that sufficient evidence of metrological traceability is available.

4.5 It is acknowledged that the costs associated with performing recalibrations may be higher when increased recalibration frequencies are applied. However, these costs need to be balanced against increased measurement uncertainties or a higher risk in decreased measurement reliability which may occur with longer recalibration intervals.

4.6 There is no universally applicable single best practice for establishing and adjusting the recalibration intervals. This has created the need for a better understanding of the recalibration

interval determination. As no single method is ideally suited for the whole range of measuring equipment, some of the simpler methods of assigning and reviewing the recalibration interval and their suitability for different types of measuring equipment are covered in this Document.

Note: The methods have been published in more detail in certain standards by reputable technical organisations (e.g. [6], [7], [8]), or in relevant scientific journals.

4.7 Methods for determining recalibration intervals developed by or adapted by the laboratory may also be used if they are appropriate and validated.

4.8 The laboratory should select the appropriate methods for determining recalibration intervals and should document those methods used. Calibration results should be collected and retained as the historical data, in order to form the basis of future decisions for recalibration intervals of the measuring equipment.

4.9 The laboratory should have an appropriate system of intermediate checks to ensure the correct functioning and calibration status of the measuring equipment used between calibrations (e.g. see ISO/IEC 17025 [3]).

4.10 The laboratory should check whether the results of external calibration and/or intermediate checks fall within predetermined limits prior to approving the measuring equipment for further use.

Note 1: For some kinds of measuring equipment, each measuring instrument or device which composes the equipment may be calibrated separately. In this case, a combined standard measurement uncertainty of the measuring equipment is calculated from the uncertainties arising from all the measuring instruments and devices.

Note 2: It may be necessary to re-evaluate calibration intervals of whole measuring equipment, or its measuring instruments and devices based on data obtained from previous calibrations.

5 Initial choice of recalibration intervals

5.1 The initial decision in determining the recalibration interval is based mainly on a risk assessment analysis and should take into account, but not limited to, the following factors:

a) measurement uncertainty required and evaluated by the laboratory;
b) type of measuring equipment and its components;
c) risk of the measuring equipment exceeding the predetermined limits (e.g. maximum permissible error), or accuracy requirements in use;
d) manufacturer’s recommendations regarding the measuring equipment (e.g. when the measurement uncertainty is required and evaluated by the laboratory based on the accuracy of the instrument);
e) tendency to wear and drift;
f) expected extent and severity of use;
g) environmental conditions (e.g. climatic conditions, vibration, ionising radiation);
h) influence of the measured quantity (e.g. high temperature effect on thermocouples) on measurement results;
i) pooled or published data about the same or similar devices;
j) frequency of comparisons with other measurement standards or measuring instruments;
k) frequency, quality and results of intermediate checks;
l) transportation arrangements of the measuring equipment and associated risks;
m) degree to which the operating staff are trained and extent to which the established procedures are implemented; and
n) legal requirements.

5.2 The decision should be made by personnel having the relevant technical competence. An estimate should be made for each piece (or a group of pieces) of measuring equipment as to the time period in which the piece(s) is (are) likely to remain within the prescribed limits (i.e. maximum permissible error, accuracy requirements) after a calibration.

6 Methods of reviewing recalibration intervals

Note: The methods described in this section may also be used to review the type and frequency of intermediate checks.

6.1 General principles

6.1.1 Once calibration has been conducted on a routine basis (based on a defined number of consecutive results), adjustment of the recalibration intervals should be possible in order to optimise the balance of risks and costs as stated in the general aspects. It will probably be found that the intervals initially selected do not give the desired optimum results due to a number of reasons, for example:

a) measuring equipment may be more or less reliable than expected;

b) the extent of usage and care in maintenance may not be as anticipated;

c) for certain measuring equipment it may be sufficient to carry out a partial calibration instead of a full calibration; and

d) the instrumental drift determined by the recalibration of the measuring equipment may show that shorter calibration intervals are required or longer calibration intervals may be possible without increasing risks, etc.

6.1.2 Several different methods are available for reviewing the recalibration intervals. The method chosen differs according to whether

a) measuring equipment is treated individually or as groups (e.g. by the manufacturer's model or by the type),

b) the measuring equipment's performance fails to meet prescribed limits (e.g. maximum permissible error, accuracy requirements) due to drift over time or by usage,

c) the measuring equipment shows different types of instabilities,

d) the measuring equipment undergoes adjustments, and

e) data are available and the history of calibration of the measuring equipment (e.g. trend data obtained from previous calibration records, recorded history of maintenance and servicing of the measuring instrument, data from intermediate checks) can be analysed.

6.1.3 New measuring equipment should be calibrated more frequently to identify any trend in its performance characteristics which may indicate that a change to the recalibration interval may be warranted. Ongoing review of the recalibration interval and equipment performance is necessary and for this reason, fixed recalibration intervals are not recommended unless the interval has been specified in a normative document such as a reference measurement procedure, specified method or a consensus standard.

6.2 Method 1: Automatic adjustment or "staircase" (calendar-time)

6.2.1 Each time a piece of measuring equipment is calibrated on a routine basis, the subsequent recalibration interval is extended (or kept unchanged) if the deviation from the reference value is found to be within an appropriately defined percentage of the range between the maximum permissible errors. Otherwise, the recalibration interval is reduced when the deviation from the reference value is outside this percentage of the range. The maximum permissible errors may be replaced with any other set of limits as required. It is recommended that appropriate decision criteria for extension or reduction of the recalibration interval of measuring equipment are specified for typical individual cases. This "staircase" response may produce a rapid adjustment of intervals and is easily carried out without administrative effort. When the records of calibration are maintained and utilised, future issues with a group of measuring equipment become predictable because the records indicate the need for technical modifications or preventive maintenance.

6.2.2 A disadvantage of systems dealing with measuring equipment individually may be that it is difficult to keep the calibration workload smooth, relatively stable and balanced between risks and costs, and that it requires detailed advanced planning.

6.2.3 It would be inappropriate to set an extremely long recalibration interval using this method. Such a case may lead to risks associated with withdrawing large numbers of reported measurement results, or repeating a significant amount of work, and such risks may ultimately become unacceptable.

6.3 Method 2: Control chart (calendar-time)

6.3.1 Control charting is one of the most important tools of Statistical Quality Control (SQC) and is well described in various publications (e.g. [4], [5], [9]). In principle, it works as follows: Significant calibration points are chosen and the results are plotted against time. From these plots, both the dispersion of the results and the instrumental drift are calculated. The instrumental drift is the mean drift normally over one recalibration interval, although several intervals may be taken into account in the calculation for very stable measuring equipment. From these figures, the optimum interval may be calculated.

6.3.2 Considerable knowledge of the variability properties of the measuring equipment is required to use this method. A considerable variation of the recalibration intervals from those prescribed is possible, because the performance of a control chart can be calculated and in theory at least gives the efficient recalibration interval. Furthermore, the calculation of the dispersion of the results will indicate whether the manufacturer's specification limits are reasonable and the analysis of the instrumental drift found may indicate the cause of the drift.

Note: This method is not suitable for calibrations of measuring equipment without an instrumental drift. This method is suitable, for example, for a material measure with a single assigned quantity value, e.g. calibration of a gauge block or a standard resistance.

6.4 Method 3: "In-use" time

6.4.1 Method 3 is a variation of Method 1 and Method 2. The basic method remains unchanged but the recalibration interval is expressed in hours of use, rather than in calendar time, e.g. months. The measuring equipment is equipped with a device which indicates the actual "in service" time and is returned for calibration when the indication reaches a specified value. Such measuring equipment are for example thermocouples used at extreme temperatures, standard lamps of which the drift is subject to their burning time, and dead weight testers for gas pressure or length gauges (i.e. measuring equipment that may be subject to mechanical wear). The major advantage in principle of this method is that the number of calibrations performed and therefore the cost of the calibration varies directly with the length of time that the measuring equipment is used. Another advantage of this method is that an automatic timer for the hours of use of the measuring equipment may be available.

6.4.2 Nevertheless, this method also has the following practical disadvantages:

a) it is not suitable for measuring equipment containing passive (not requiring additional energy input source for providing output) measuring instruments (e.g. attenuators) or passive measurement standards (e.g. resistance, capacitance);

b) it is not suitable for measuring equipment known to have a drift or deteriorate when not in use (e.g. it is on the shelf) or when handled or subjected to a number of short on-off cycles;

c) the initial cost of providing and installing suitable timers for measuring the "in-service" time may be high if the time is not recorded manually. Since users may interfere with the timers, additional supervision may be required which will increase the costs; and

d) the planning of recalibration work is more difficult in comparison with the procedures of Methods 1 and 2 since is it not possible to predict the precise date on which the next calibration is required.

6.5 Method 4: In service checking, or "black box" testing

6.5.1 Method 4 is also a variation of Method 1 and Method 2, and is especially suitable when a quick/easy check of the measuring equipment or one of its components is possible. Critical parameters are checked frequently (e.g. once a day or even more often) by portable calibration gear, or preferably, by a "black box" designed specifically to check the selected parameters. If the measuring equipment is found to be outside the maximum permissible error (or any other set of limits as required) by the "black box" or portable calibration gear, it is returned for a full calibration and adjustment if necessary. Method 4 may prove to be more effective than evaluating the original measuring equipment's interval.

Note: Measuring equipment suitable for this method are for example density meters (resonance type), Pt-resistance thermometers (in combination with calendar-time methods), dosimeters (source included), or sound level meters (source included).

6.5.2 The major advantage of this method is that it provides maximum availability for the user of the measuring equipment. It is very suitable for measuring equipment which is geographically distant from the laboratory, since a complete calibration is only performed when it is known to be required. The difficulty is in deciding on the critical parameters and designing the "black box".

6.5.3 Although the method is in principle very reliable, this is slightly ambiguous, since the measuring equipment may be failing on some parameter that is not measured by the "black box". In addition, the characteristics of the "black box" itself may not remain constant, thus requiring a choice and periodic review of the recalibration interval of the black box.

6.6 Method 5: Other statistical approaches

6.6.1 Methods based on statistical analysis of individual measuring equipment or groups of measuring instruments can also be a possible approach. These methods are gaining more and more interest, especially when used in combination with adequate software tools. An example of such a software tool and its mathematical background is described by A. Lepek [10].

6.6.2 When large numbers of identical measuring equipment (i.e. groups of measuring equipment) are to be calibrated, the recalibration intervals can be reviewed with the help of statistical methods (see e.g. [8]). Detailed examples are presented for example in the publication of the National Conference of Standards Laboratories (NCSL) International - Recommended Practice RP-1 Establishment and Adjustment of Calibration Intervals [7].

6.7 Comparison of methods for reviewing recalibration intervals

6.7.1 No single method described in 6.2 to 6.6 is ideally suited for all situations, for all measuring equipment, and for all laboratories (see Table 1). The laboratory may choose the most appropriate method for each case while considering a variety of factors as discussed in 4, 5 and 6.1. There may also be additional factors that will affect the laboratory's choice of method. It should be noted that the choice of method will be affected by whether the laboratory intends to introduce a planned maintenance schedule for the equipment. It should also be noted that the method chosen will certainly affect the recalibration records that are kept.

6.7.2 For comparison of methods, see Table 1.

Table 1 - Comparison of methods of reviewing recalibration intervals

Performance	Method				
	Method 1 "staircase"	Method 2 control chart	Method 3 "in-use" time	Method 4 "black box"	Method 5 [1] other statistical approaches
Reliability	medium	high	medium	high	medium
Effort of application	low	high	medium	low	high
Work-load balanced between risks and costs	medium	medium	low	medium	low
Applicability with respect to particular devices	medium	low	high	high	low
Availability of measuring equipment	medium	medium	medium	high	medium

[1] Better grading is achieved when an appropriate software tool is used

7 Bibliography

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