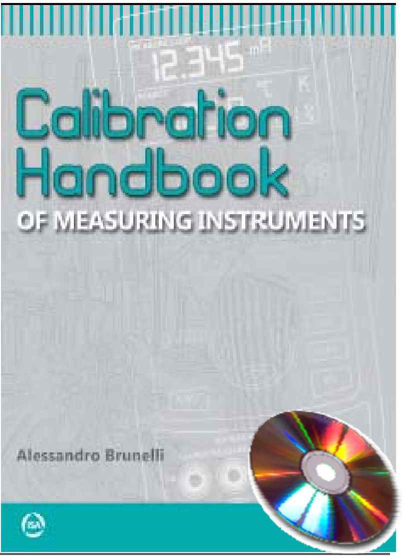
Need for traceability, uncertainty and calibration of measuring instruments in the industrial, environmental and welfare fields: *A reference handbook*



Professor

Alessandro Brunelli

Measures in Industrial and Environmental

These measures are governed by the following International Standards:

- **ISO 9001 that requires:**
  - **When monitoring or measurement is used to verify the compliance of products and services with requirements, the organization must determine and make available the resources necessary to ensure valid and reliable results (<u>measures</u>).**
- **ISO 14001 that requires:**
  - **The organization must establish, implement and maintain one or more procedures <u>to regularly monitor and measure</u> the main characteristics of its activities and operations that may have significant environmental impact.**!

Measures in Welfare Applications

These measures are governed by European and International Standards:

- **For the Health in Pharmaceutical Products:**
  - **For the sterilization of pharmaceutical products, working processes are required at least at 121 ° C +/- 1 ° C:**

    If operating at -2 °C, 25% of the bacterial flora does not die!
- **For the Well-Being of the Human People:**
  - **For the measurement of human fever, thermometers with a correct indication of :**

    + 0.10 ° C / - 0.15 ° C are required!

✓ **So in these application it is critical the measurement of the temperature that requires correct traceability and accuracy!!!**

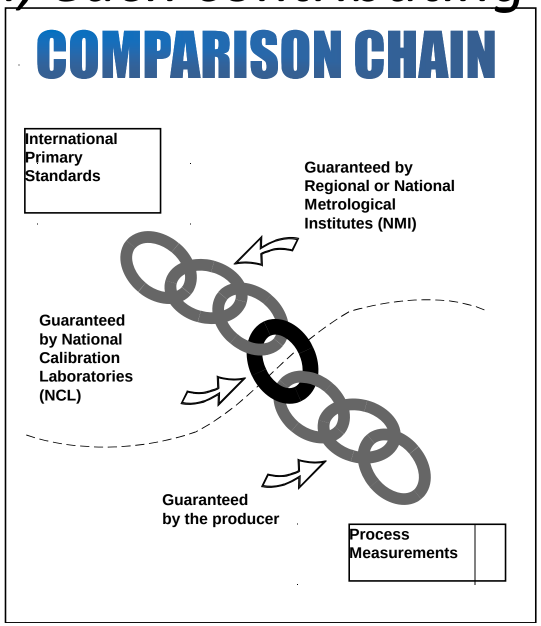
Why of the need of Traceability?

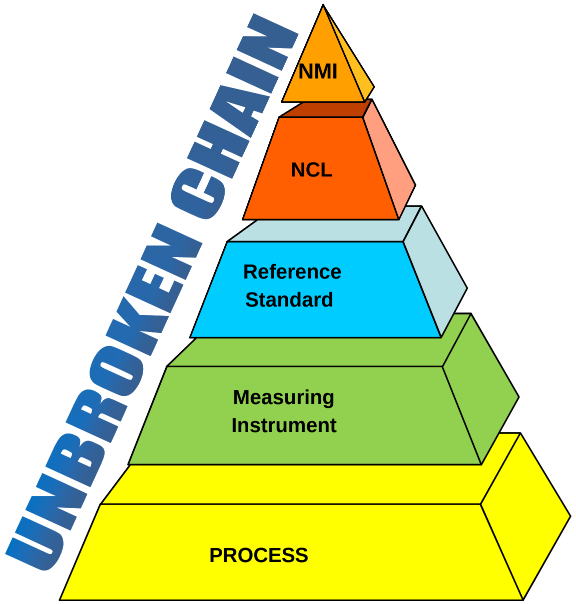
- **A measurement without traceability and uncertainty** is not comparable and therefore can not be compared in the global market!

- **A product, process or service must always be checked** with suitable equipment calibrated and confirmed metrologically at regular intervals!

What is the Traceability

- **The metrological traceability of measurements according to ISO-*VIM* *means:***
  - *"Property of a measurement results whereby the result can be related to a reference through a documented unbroken chain of calibration, each contributing to the measurement uncertainty"*





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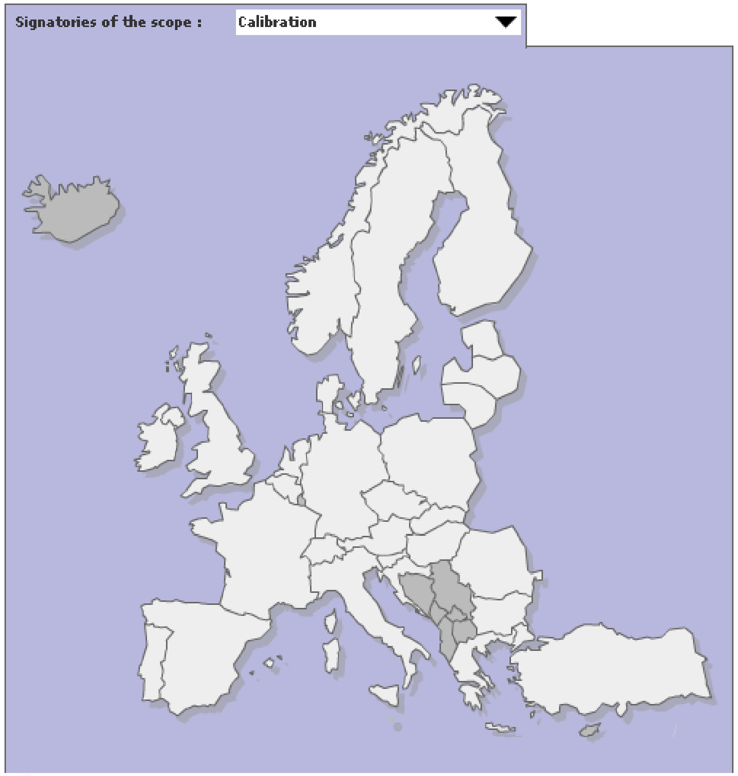
Traceability in Europe and in the World

- **National Calibration Laboratory in Europe**

Calibration
BMWFJ (Austria)
BELAC (Belgium)
BAS (Bulgaria)
CAI (Czech Republic)
DANAK (Denmark)
EAK (Estonia)
FINAS (Finland)
COFRAC (France)
DAkkS (Germany)
ESYD (Greece)
NAT (Hungary)
INAB (Ireland)
ISRAC (ISRAËL)
ACCREDIA (Italy)
LATAK (Latvia)
LA (Lithuania)
RVA (Netherlands)
NA (Norway)
PCA (Poland)
IPAC (Portugal)
HAA (Republic of Croatia)
RENAR (Romania)
SNAS (Slovakia)
SA (Slovenia)
ENAC (Spain)
SWEDAC (Sweden)
SAS (Switzerland)
TUNAC (TUNISIA)
TURKAK (Turkey)
UKAS (United Kingdom)



- **International Calibration System (ILAC)**

EA	Europe Accreditation
APAC	Asian Accreditation
ARAC	Arab Accreditation
IAAC	American Accreditation
SADC	South Africa Accreditat.

- **National Metrological Institutes in Europe and in North America**

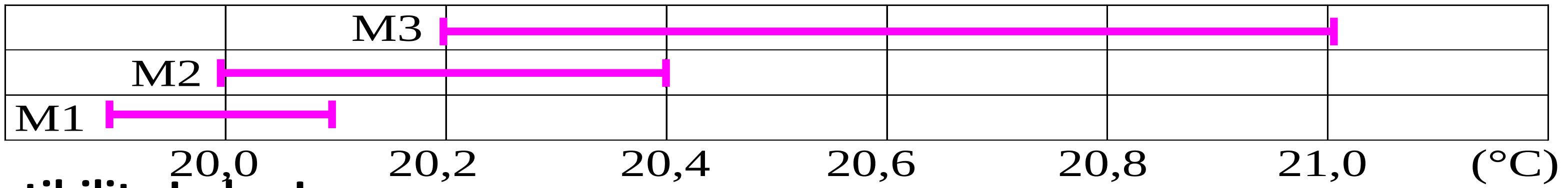
NATION	INSTITUTE	DESCRIPTION
France	LNE	Laboratoire national de métrologie et d'essai
Belgium	SMD	FPS Economy, Safety, Metrology Division
Germany	PTB	Physikalisch Technische Bundesanstalt
Italy	INRIM	Istituto Nazionale di RIcerca Metrologica
Netherland	VSL	Dutch Metrology Institute
Spain	CEM	Centro Español de Metrología
Switzerland	METAS	Federal Institute of Metrology METAS
United Kingdom	NPL	National Physical Laboratory
USA (America)	NIST	National Institute of Standards and Technology

What is the Compatibility

- **The metrological compatibility of measurements according to ISO-*VIM means:***
  - *“Property of a set of measurement results for a specified measurand, such that the absolute value of the difference of any pair of measured quantity values from two different measurement results is smaller than some chosen multiple (usually 1) of the standard measurement uncertainty of that difference”*

➢ **Example:**

- M1 = 20,0 ± 0,1 °C
- M2 = 20,2 ± 0,2 °C
- M3 = 20,6 ± 0,4 °C



❑ **Applying the Compatibility Index Ic:**

Ic = [|M1 – M2| / (U1+U2)] ≤ 1

where M1 and M2 are the measurement values, U1 and U2 the relative associated measurement uncertainties.

✓ **Results:**

- M1 and M2 are compatibles : Ic = |20,0 – 20,2| / (0,1 + 0,2) = 0,2 / 0,3 = 0,66
- M2 and M3 are compatibles : Ic = |20,2 – 20,6| / (0,2 + 0,4) = 0,4 / 0,6 = 0,66
- M1 and M3 are NOT compatibles : Ic = |20,0 – 20,6| / (0,1 + 0,4) = 0,6 / 0,5 = 1,20

What is the Uncertainty

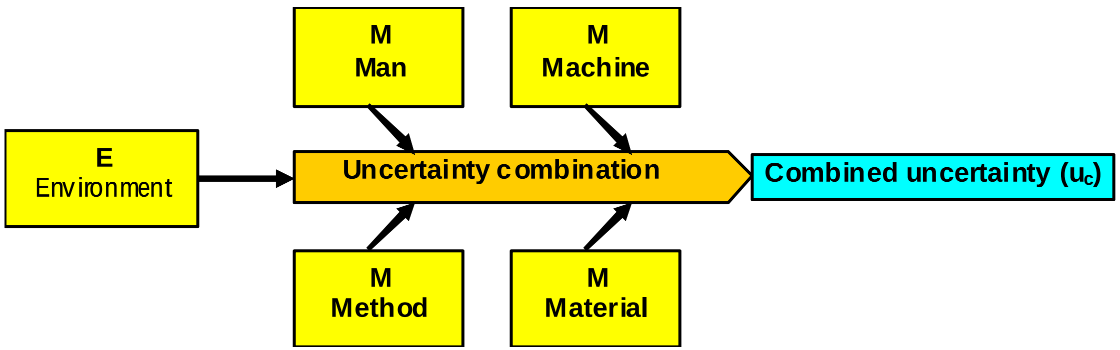
- **The measurement uncertainty according to ISO-VIM (International Vocabulary Metrology: ISO Guide 99) means:**
  - *“Non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used” (with 4 explanatory notes).*
- **While, the measurement uncertainty according to ISO-GUM (Guide for Uncertainty Measurement: ISO Guide 98-3) means:**
  - *“Parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand“ (with a 95% confidence level).*

Sources of Uncertainty

- **Generally, the combined standard uncertainty u_c** of a measurement process, depends on the following 5 factors, also known by the acronym E & 4M (see Figure):

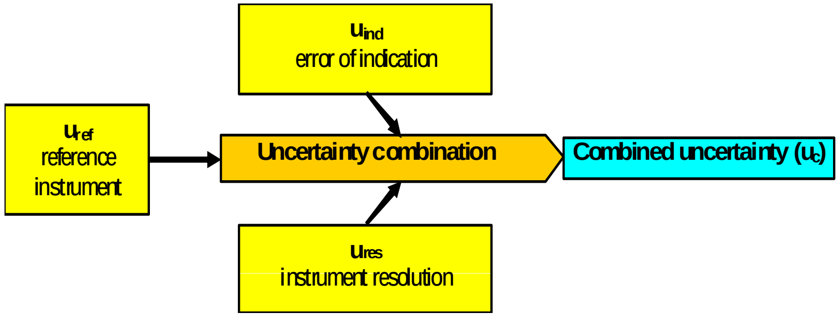
  Environment & Man – Machine – Method – Material

  - Changes in environmental conditions of measurement : Environment : u_{env}
  - Uncertainty due to the skill of the operator : Man : u_{man}
  - Uncertainty of measurement instrumentation : Machine : u_{mac}
  - Uncertainty due to measurement method : Method : u_{met}
  - Incomplete sampling of measurand : Material : u_{mat}



Possibility to Reduce the Sources?

- **In practical calibrations of measuring instruments performed in laboratories under controlled** environmental conditions and with qualified operating personnel, the 5 factors of uncertainty referred to above can essentially be reduced to 3 factors (see Figure):
  - Uncertainty due to the reference instrument (or standard) used : u_{ref}
  - Uncertainty due to the error of indication of the instrument in calibration : u_{ind}
  - Uncertainty due to the resolution of the instrument in calibration : u_{res}



- So, in practical applications, the combined standard uncertainty u_c corresponds to the square root of a sum of the 3 individual standard uncertainty squares influencing the measurement process:

$$u_c = \sqrt{{u_{ref}}^2 + {u_{ind}}^2 + {u_{res}}^2}$$

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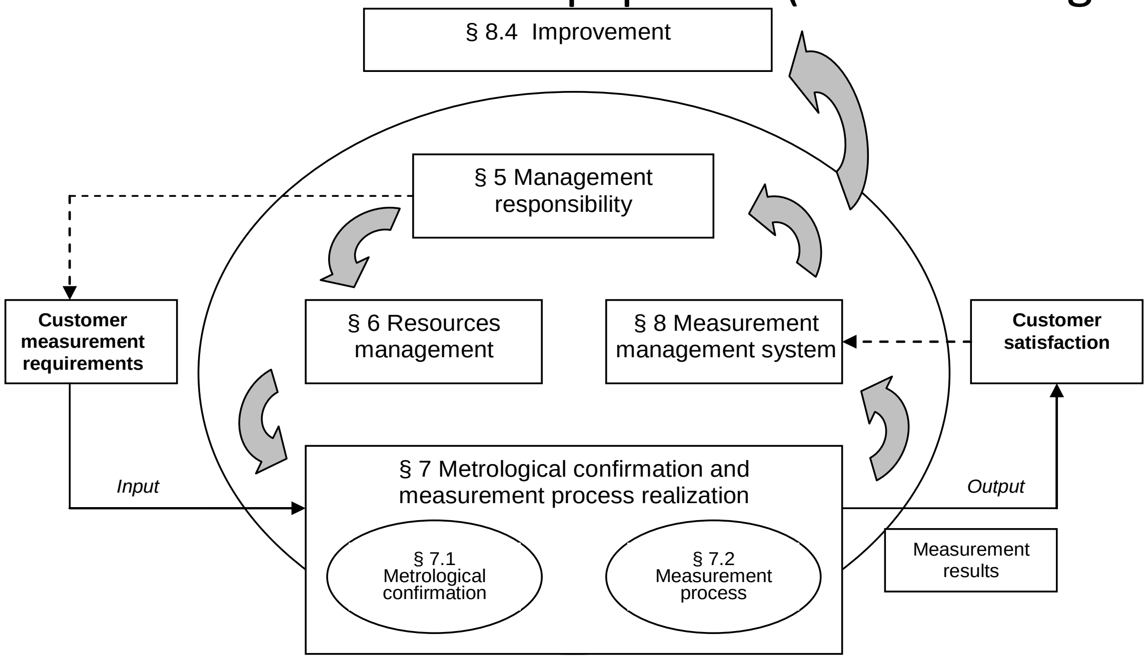
Why Calibrated the Measuring Instruments

- **The control of measuring instruments, namely:**
  - measuring equipment in the Quality Management System ISO 9001
  - surveillance equipment in the Environmental Management System ISO 14001
- **provide, where necessary to ensure valid results, that measuring instruments are:**
  - calibrated and verified at specified intervals or prior to use, against measurement standards traceable to international or national measurement standards; where no such standards exist, they must be registered with the criteria used for calibration or verification;
  - adjusted or regulated again, when necessary;
- **therefore, all management systems provide the initial calibration and any periodic** “ metrological confirmation" (according to ISO 10012 Measurement Mgt System) of the measuring instruments to validate the various measurement processes to ensure proper traceability of measurements to the International System (SI).

Measurement Management System

- **The Measurement Management System (MMS)** provides a similar process-oriented approach to the principles laid down by ISO 9001, with the objective to manage the risk that measuring equipment and measurement processes could produce incorrect results affecting the quality of the organization's product, using methods ranging from initial and periodic verification of the equipment (i.e. Metrological Confirmation).



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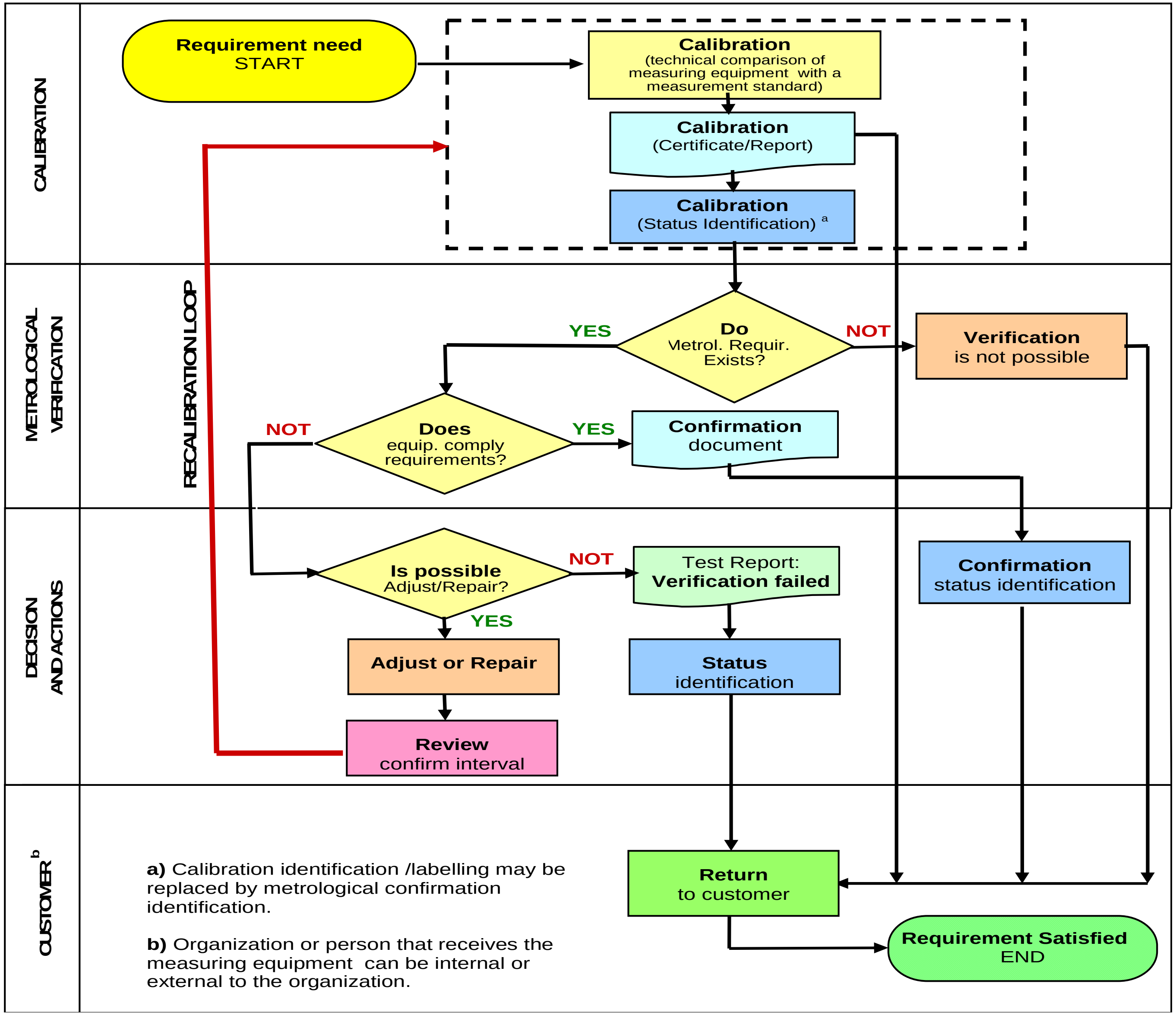
Measurement Management Paths

- **The Metrological Confirmation can be designed, executed and implemented** to ensure that the metrological characteristics of the measuring equipment satisfy the metrological requirements for the measurement process.
  - *Metrological confirmation comprises measuring equipment calibration and verification!*
- ***It can be carried out according to the table shown below according to the flow chart*** *shown in the next figure:*

NORMAL PHASES	PHASES IN CASE OF ADJUSTMENT	PHASES IN CASE OF ADJ. IMPOSS.
0. Filing equipment		
1. Requirement of calibration		
2. Equipment calibration 3. Writing of calibration document 4. Calibration identification (*) 5. There metrological requirements???		
6. Conformity with the metrological req.	6a. Adjustment or repair	6b. Adjustment impossible
7. Preparing of confirmation document	7a. Review of confirm intervals	7b. Negative verification
8. Identification confirmation status	8a. Recalibration path from 2 to 8	8b. Identification status
9. Requirement satisfied	9a. Requirement satisfied	9b. Requirement not satisfied

Measurement Management Cycle



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Decalogue of the Metrological Confirmation

1. ***Define the metrological characteristics of measuring instruments according to the use.***
2. ***Establish an effective and documented system for confirming to ensure that the risk*** that a measuring instrument produces results with unacceptable errors is reduced to minimum.
3. ***Verify and periodically review the confirmation system to ensure that the system itself* continues** to be effective and take corrective action where appropriate.
4. ***Develop procedures for all of metrological confirmation operations with a level of detail*** commensurate with the complexity of the instrument in confirmation.
5. **Record the successful metrological confirmation on file and confirmed the instrument** using the provided label.
6. **Seal the adjustment devices which can affect the performance of the instrument.**
7. **Maintain, handle and store the instrument in such a way as not affect its stability.**
8. **Refer all measures at the national or international standards consistent** with the recommendations of the General Conference of Weights and Measures (CGPM) and with the International System (SI).
9. **Calculate the measurement uncertainty taking into account all significant components** of uncertainty identified in the measurement process, including those related to environmental factors.
10. **Establish the metrological confirmation intervals of the measuring instrument at suitable intervals** (usually periodic), fixed on the basis of its stability, purpose and use.

Frequency of Calibration Intervals

To **determine the frequency of the confirmation is not always very easy because they affect a large number of factors, among which the most important are the following:**

a) the type of instrument
b) the manufacturer's recommendations
c) the obtainable trends in the documents relating to previous calibrations
d) the recording of historical information regarding maintenance and service
e) the frequency and severity of the conditions of use
f) the drift and stability trends
g) the frequency of the comparisons with other instruments, in particular with the standard
h) the frequency and the formalization for the internal calibration checks
i) the environmental conditions (temperature, humidity, vibration, etc.)
j) the uncertainty of the desired measures
k) the importance of the consequences arising from correct to assume an incorrect measured value, when the instrument is out of calibration or in failure.

Definition of Calibration Intervals

- **Therefore, given the variety of influential factors and practical case studies,** before defining the metrological confirmation intervals of measuring instruments calibration, it is always advisable to balance these two fundamental and opposing criteria:
  - **to minimize the risk that the instrument ceases to be in accordance to its metrological requirement**
  - **to minimize the cost of metrological confirmation operations.**

- **A good basis to be able to deal with this dilemma is to determine the confirmation intervals** through the so called **"technical intuition"** or comparing similar applications and experiences of the same or similar instrument, made in other companies/laboratories, taking account these factors:

**a*) the manufacturer's recommendations*
b) the frequency and severity of the use
c) the influence of the environment of use
*d) the desired measurement uncertainty***

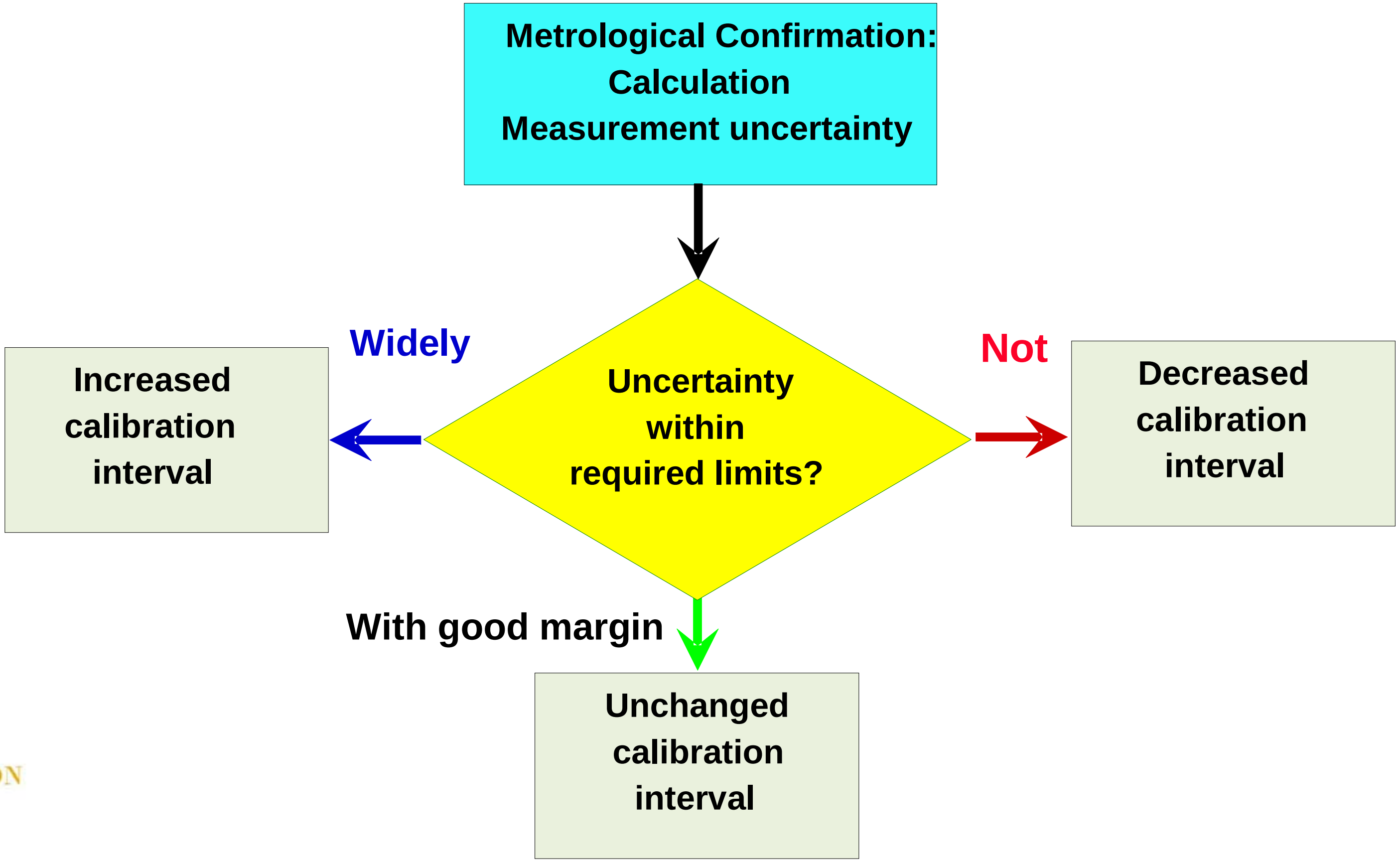
Review of Calibration Intervals

- **Once established the initial confirmation intervals, it will be necessary later to a critical review** of their confirmation or calibration intervals, for to minimize, according to the initial hypothesis, on the one hand the risks of non conformity and on the other hand, the confirmation costs.

- **For this purpose the International Reference Standard ISO 10012, refers to the International Document OIML D 10 (also transposed as an International Document ILAC Guide G-24)** as a reference guide, which provides 5 methods for the review of confirmation intervals, while underlining that no method is ideally suitable for all instruments, but that in turn will have to be evaluated the applicability and its effectiveness:
    1) ***Automatic adjustment (or stair-case)***
    2) ***Control chart (or calendar-time)***
    3) ***Time of utilization (in use-time):***
    4) ***Tests in service (or black-box):***
    5) ***Other statistical approaches:***

Example of Calibration Intervals Review

- ***Automatic adjustment (or stair-case)***



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Example of Calibration Intervals

- ***In the absence of standard and regulations in this regard the following intervals can be considered:***

INSTRUMENT	ACCURACY	USING CONDITIONS	USING FREQUENCY	CALIBRATION FREQUENCY (MONTHS)	
				min	max
Manometers, dial	Classes 0.1÷0.5	Laboratory instruments	Weekly	6	12
	Classes 1÷4	Field instruments	Continues	12	24
Manometers, digital	Lower at 0.5 %FS	Laboratory instruments	Daily	6	12
	Higher at 0.5 %FS	Field instruments	Continues	12	24
Pressure transmitters	Lower at 0.5 %FS	Laboratory instruments	Daily	6	12
	Higher at 0.5 %FS	Field instruments	Continues	12	24
Thermometer, glass	Lower at 0.2 °C	Laboratory instruments	10÷50 times / year	6	12
	Higher at 0.2 °C	Field instruments	Daily / continues	12	24
Thermoresistances (TR)	Lower at 0.5 °C	Laboratory instruments	10÷50 times / year	6	12
	Higher at 0.5 °C	Field instruments	Continues	12	24
Thermocouples (TC)	Lower at 1.0 °C	Laboratory instruments	10÷50 times / year	6	12
	Higher at 1.0 °C	Field instruments	Continues	12	24
Thermometer, digital	Refer also to the type of probe (TR or TC)	Laboratory instruments	10÷50 times / year	6	12
		Field instruments	Daily / continues	12	24
Standard resistor		Laboratory instruments	10÷50 times / year	12	24
		Field instruments	Daily / continues	24	48
Ammeters, voltmeters wattmeters, etc.		Laboratory instruments	10÷50 times / year	6	12
		Field instruments	Daily / continues	12	24
Digital multimeters benchtop and handheld		Laboratory instruments	10÷50 times / year	6	12
		Field instruments	Daily / continues	12	24
Digital multifunction calibrators		Laboratory instruments	10÷50 times / year	6	12
		Field instruments	Daily / continues	6	12

Selection of Measuring Instrument

- **The instrument or equipment for measuring for the measurement processes designed,** should be first choice, then calibrated and then confirmed before being inserted in the measurement process, according to the requirements prescribed in the ISO 10012.

- **The initial selection must be made according to the metrological characteristics required:** usually the initial calibration can be done directly from the supplier, or externally by a qualified laboratory, or even internally at the company's laboratory, but always traceable to the International System SI.

- **In any case the measuring equipment must be specified at least the following elements:**
  - Manufacturer
  - Type and description
  - Series or serial number
  - Measuring range
  - Measuring resolution
  - Measurement accuracy
  - Measurement uncertainty
  - Functional operating conditions
  - Environmental operating conditions
  - Stability or possible eventual drift
  - Sensitivity to any influential quantities

Selection of Reference Instrument

- **Calibration of the apparatus for measurement (otherwise also called instrument)** may be made externally or internally within the organization, with reference equipment (otherwise also called standard), having a measurement uncertainty possibly at least 3 times lower the presumed uncertainty of the instrument to be calibrated.

- **The relationship between the uncertainty of measurement between the instrument** to be calibrated and reference standard (otherwise also called TUR: Test Uncertainty Ratio), should also be possibly greater than 3, but 3 could be already sufficient given the treatment of uncertainties:

➢ In fact, since the treatment of uncertainties in squaring, the individual contribution due to standard is about 1/10 compared to the contribution of any instrument errors, and therefore it increases the result of the instrument measurement uncertainty < 5%.

Relation between Instrument and Reference

- **The recommended uncertainty ratios , unless otherwise specified from technical normativ**es and/or regulation are defined in the following table:

Instrument uncertainty / Reference uncertainty	Adequacy
< 3	INSUFFICIENT
3	ACCEPTABLE
4 - 9	GOOD
10	EXCELLENT
> 10	EXCESSIVE

Definition of Instrument Conformity

For ***"Instrument Conformity"*** in metrological terms, it means:

- Conformity of an instrument, device or measuring equipment, at all the metrological requirements specified.

- The ***"Metrological Requirements Specified"*** can be essentially of two types:
  - *Measurement error*
  - *Measurement uncertainty*

  whose characteristics are periodically checking through the metrological confirmation.

- In fact, the ***"Metrological Confirmation"*** is formally defined in ISO 10012:

  "Set of operations required to ensure that measuring equipment conforms to the requirements for its intended use".

Verification of Instrument Conformity

- **The conformity assessment of measuring instruments installed in the field on production processes, to control a specified parameter, it can be implemented in three ways:**

1. **Practical method, by means of verification of the Maximum Tolerated Error (MTE):**
   without determining the actual uncertainty of measurement given normal low uncertainty influence of the measurement reference standard used.

2. **Analytical method, by means of verification of the Maximum Tolerated Uncertainty (MTU):**
   determining the actual uncertainty of measurement given the not always scarce influence of the uncertainty of the measurement reference standard used.

3. **Precautionary method, by checking the Zone Secure Conformity (ZSC):**
   determining the area of secure conformity respect the specific zone required and tolerated

1^{st} Practical Verification Conformity

- This first practical method, evaluate the conformity of the instruments in the field by checking only that the Maximum Relieved Error (MRE) during the metrological confirmation process, is less than or equal to the Maximum Tolerated Error (MTE) specified for the instrument, or:
  - **MRE ≤ MTE**
- This method is applied by default when the reference standard used for the calibration of the instrument to be verified, has an error or measurement uncertainty negligible respect that of the field instruments to be verified (typically ≤ 1/3).
- In fact if the reference standard has a lower measurement uncertainty Uref equal or maximum 1/3 of the maximum tolerated error the instrument in calibrations Uins, it is demonstrable that the total budget of the calibration uncertainty U, is equal to the square root of the squaring sum of the individual uncertainties of the instrument and the reference standard:

$$U = \sqrt{(Uins)^2 + (Uref)^2}$$

- If Uins = 1 and Uref = 1/3, result:

$$U = \sqrt{(1)^2 + (1/3)^2} = 1{,}05 \cong 1$$

  - **Therefore the uncertainty of the measuring instrument in calibration does not vary!**

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2^{nd} Analytical Verification Conformity

- This second analytical method, evaluate instead the conformity of the instruments in the field by checking that the Maximum Relieved Uncertainty (MRU) during the metrological confirmation process, is less than or equal to the Maximum Tolerated Uncertainty (MTU) specified for the measurement process , or:
  - **MRU ≤ MTU**
- This method is applied in case when the reference standard used for the calibration of the instrument to be verified, has an error or measurement uncertainty not negligible respect that of the of the instruments to be verified (typically > 1/3).

- In this cases, the measurement relieved uncertainty resulting from the calibration or confirmation U (i.e. MRU), takes into account more than the maximum relieved error on the instrument Emax and the relative resolution error Eres, also the measurement uncertainty of the reference standard Uref, and it is given by the following formula (seen previously):

$$U = 2 \cdot \sqrt{\left(\frac{Uref}{2}\right)^2 + \left(\frac{E\max}{\sqrt{3}}\right)^2 + \left(\frac{Eres}{2.\sqrt{3}}\right)^2}$$

  - **It is better because consider also the uncertainty of the reference (standard).**

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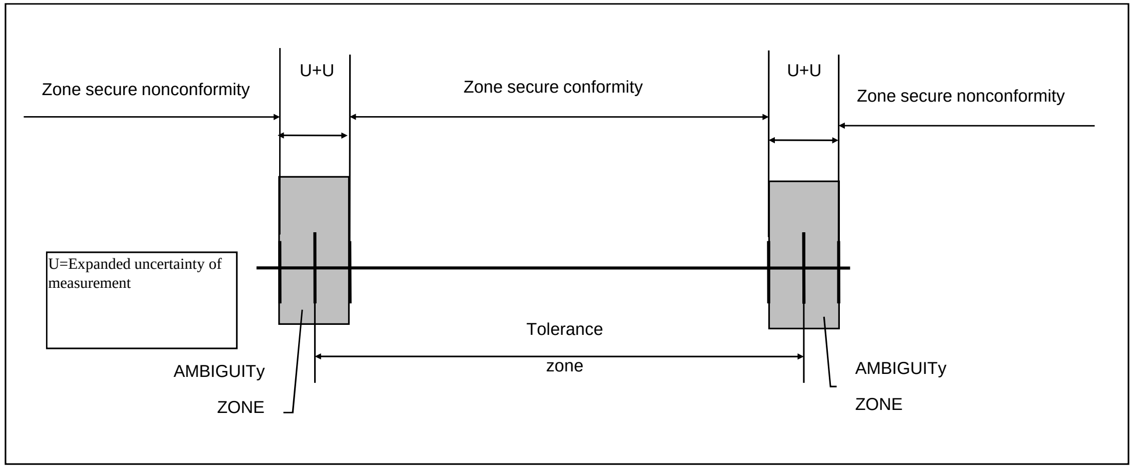
3rd Precautionary Verification Conformity

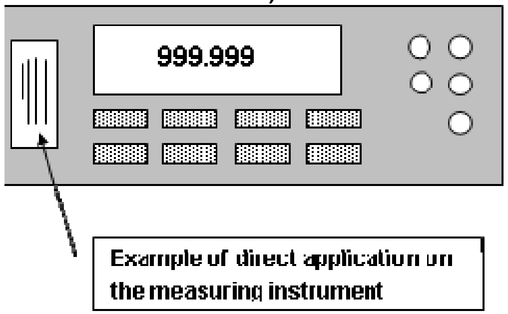
- This third method, as an alternative to the methods described above, evaluate the conformity of field instruments with the metrological requirements specified and required, always if the measurement uncertainty of the reference standard is not negligible, <u>and it is implemented according to the ISO 14253</u> which starts from the following assumptions:
  - If at project level and performing of a measurement process are defined the tolerances in the technical specifications, are easy to locate the zones of secure conformity and nonconformity as shown in Figure.



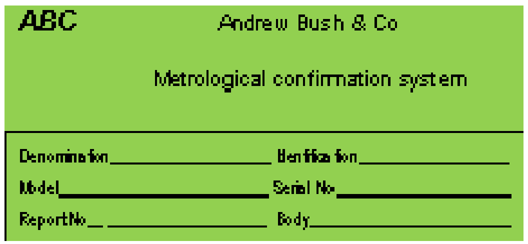
➢ **It is the best one because it does not consider the sum of the reference uncertainty U in squaring, but subtracts it from the tolerance zone and therefore the verification it is more precautionary!**

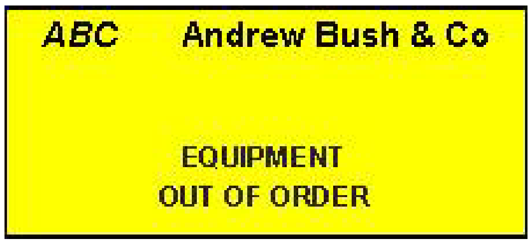
Evidence of Conformity

- Following confirmation metrology conduct and the basis used to verify the conformity of the measuring instrument, the objective evidence for the conformity of the intended use of the instrument is given from the confirmation label affixed on the instrument, or if not feasible, by means of label holder, or even on the box or instrument case.



- In case of positive metrological confirmation, the label should contain at least these items:
  - Instrument denomination and/or identification
  - Confirmation report
  - Confirmation date
  - Next confirmation date
- as shown in the left Figure, otherwise put in the instrument the negative label as shown in the right Figure.





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Calibration and Metrological Confirmation

- **The Calibration and Metrological Confirmation it must be carried out initially and then periodically** on the instruments in order to verify and maintain over time their measurement accuracy characteristics required by the production process or the monitoring service.

- **Therefore a procedure should be provided for the various types of the measuring instruments to verify** the correct measurement accuracy with the two main methods previously reported, or:

  – verifying that max relieved error (MRE) of the instrument is ≤ max tolerated error (MTE):
    generally recommended using references with uncertainty ≤ 1/3 of that of the instrument to be calibrated;

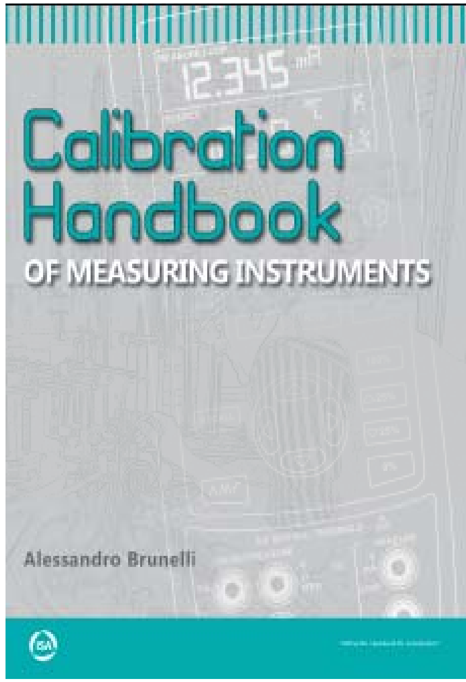
  – verifying that max relieved uncertainty (MRU) of the instrument is ≤ max tolerated uncertainty (MTU):
    particularly recommended using references with uncertainty > 1/3 of that of the instrument to be calibrated;

obviously, always in compliance with any applicable related normatives!

The Calibration Handbook

- **The book is written mainly for operators who verify and calibrate measuring** instruments used in several ambient system:
  - Quality Management Systems ISO 9001,
  - Environment Applications ISO 14001,
  - Automotive Industry ISO 16949,
  - Aviation Industry EN 9100.

- **It is a practical consultation manual that deals with all topics useful** for ensuring and managing the measurement of industrial and environmental processes in quality.



Handbook Arguments

- The Handbook describes the general concepts for managing measurement equipment according to ISO 10012, concerning the management system of instruments and measurements:
  - The instrument's suitability to perform accurate measurements and control the drift to maintain the quality of the measurement process.
  - The criteria and procedures for accepting, managing, and verifying the calibration of the main industrial measuring instruments.
  - The provisions of law and regulations for production, European marking CE of metrological instruments used in commercial transaction and for their periodic verification.

Handbook General Topics

- **General references for calibration:**

- ❑ **the International System of units (SI)**
- and their conversions to other units
- ❑ **the International, European and National**
- calibration Services (ILAC, EA and Others)
- ❑ **the metrological & performance requirements**
- or the measurement instruments
- ❑ **the criteria for determination the traceability**
- and for evaluation measurement uncertainty
- ❑ **the technical regulatory and legal requirements**
- relating to the mgt. instruments and measures

Handbook Specific Topics

- **Metrological verification and confirmation of instruments for the following quantities:**

  - **Physical:**
    - pressure, flow, level, temperature, humidity, mass, …

  - **Chemical:**
    - pH, conductivity, chromatography, spectrometry, …

  - **Mechanical:**
    - length, couple, force, vibration, noise, …

  - **Electrical end Electronic:**
    - current, tension, multimeters, oscilloscopes, ….

Handbook Procedure Index

- **Procedure index for calibration every measuring instrument:**

1. **Scope and purpose**
2. **Identification and classification**
3. **Normative references**
4. **Ambient conditions**
5. **Initial checks**
6. **Calibration method**
7. **Calibration verification**
8. **Calibration results**
9. **Metrological confirmation**

1.1.1 PRESSURE INDICATORS

1. SCOPE AND PURPOSE
This procedure applies to all types of pressure indicators or dial manometers with Bourdon tube or membrane and capsule, with measuring ranges between -1 and 1600 bar (or greater).

2. IDENTIFICATION AND CLASSIFICATION
The new instrument before being used in the application foreseen, must be filed in accordance with the Table in side, defining the procedures and the normative references, the required checks and results, and then confirmed metrologically for the application, including its re-calibration if necessary.

3. NORMATIVE REFERENCES
a) EN 472 (1995) :Pressure gauges – Vocabulary
b) EN 837-1-2-3 (1996) :Pressure gauges – Bourdon tube, membrane, capsule pressure gauges

4. AMBIENT CONDITIONS
a) Temperature :(20 ± 2) °C
b) Relative humidity :(50 ± 25)%
c) Atmospheric pressure :(1000 ± 25) mbar

5. INITIAL CHECKS
Before starting any operation, check that the instrument does not indicate traces of rupture, wear or alteration of parts such as measuring scale, fittings, etc.
Then install the instrument in the measuring circuit and ensure that there are no leaks and make three preload cycles on the whole verification range.

6. CALIBRATION METHOD
Calibration can be performed by comparison with standard instruments:
A) for laboratory manometers, by pressure balance with standard masses (Figure A)
B) for industrial manometers with accuracy class more than 1, with standard manometer (Figure B)
C) for industrial manometers with accuracy class less than 1, with standard calibrator (Figure C)
having in any case, a lower measurement uncertainty possibly ¼ of that of the manometer in calibration (according to the normative references).

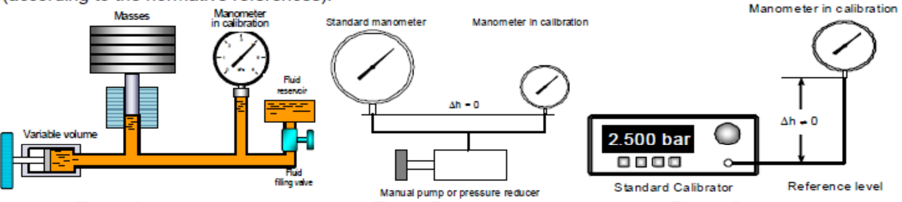


Figure A Figure B Figure C

If there is different level Δh between the intake of the standard manometer and manometer in calibration, it is necessary to correct the pressure difference ΔP between the two levels, through the relation:

$$\Delta P = \rho \cdot g \cdot \Delta h \quad \text{[Pa]}$$

ΔP = pressure differential in pascal (1 Pa = 10^{-5} bar)
ρ = density of the measurement fluid (for water ≈ 1000 kg/m^3)
g = local gravitational acceleration (or standard = 9.80665 m/s^2)
Δh = different level between the two manometers in meters

7. CALIBRATION VERIFICATION
The verification should be carried out with increasing/decreasing pressure (i.e. at least every 25% of scale):
25 - 50 - 75 - 100 - 75 - 50 - 25 - 0%
Reach every point of measurement without going over, wait for the indication of the standard and instrument in calibration are perfectly stable, then read and detect the standard and the instrument indications.

8. CALIBRATION RESULTS
Calibration results should be reported in Table in side to be first processed and then subsequently valued against the maximum tolerated error or maximum tolerated uncertainty:
- Verifying that the max relieved error (MRE) of the instrument is ≤ max tolerated error (MTE)
- Verifying that the max relieved uncertainty (MRU) of the instrument is ≤ max tolerated uncertainty (MTU)
If the check is not positive, it will be necessary to re-calibrate the instrument, then repeating the calibration verification (point 7), or downgrade or alienate the instrument.

9. METROLOGICAL CONFIRMATION
Record on the instrument card on the side the results of the metrological confirmation:
- The result of the metrological confirmation (positive, negative: declassification or alienation)
- The signature of those who made the verification and the date of the next verification
Also fill out and attach the label of positive confirmation on the instrument indicating at least the number of verification/calibration report, the instrument serial number and date of the next verification.

Procedure Example

❑ **The procedure details:**

➢ **Main reference normatives**
International, Regional or National

➢ **Main calibration methods**
in relation to the measurement uncertainty of the instrument in the calibration

➢ **The calibration verification**
cycles and measuring points

➢ **The conformity of the instrument**
evaluated according two methods:

1°: Practical method:
Max Relieved Error ≤ Max Tolerate Error

2°: Analytical method:
Max Rel. Uncertainty ≤ Max Tol. Uncertainty

Metrological Laboratory	Pressure Indicators (Pressure Gauges or Dial Manometers)		Card Number XX-PI
IDENTIFICATION AND METROLOGICAL DATA			
Instrument identification	*PI 11*	Measuring range	*0-10 bar*
Instrument classification	*Process*	Calibration range	*0-10 bar*
Instrument denomination	*Manometer*	Accuracy class	*1%*
Manufacturer	*ABC*	Measure resolution (E_{res})	*0.05 bar*
Model	*DN 100*	Max Tolerated Error (MTE)	*0.10 bar*
Serial number	*XYZ*	Max Tolerated Uncert. (MTU)	*0.15 bar*
Date of acquisition	*01.02.2010*	Reference std Uncert. (U_{ref})	*0.01 bar*
Location of installation	*Process PI 11*	Certificate number of standard	*1111*
Installation conditions	*Vertical*	Fluid Exercise / Calibration	*Air / Air*
Utilization conditions	*Eventual*	Fluid Filling	*Eventual*
APPLICABLE PROCEDURES AND NORMATIVES			
Calibration procedure	*PP-PI*	Maintenance procedure	Manufacturer spec.
Confirmation procedure	*PP-PI*	Normative reference	EN 837
REQUIRED CONTROLS			
Calibration	Confirmation	Certification	Body Control
☒ YES ☐ NOT	☒ YES ☐ NOT	☐ YES ☒ NOT	☒ *Internal* ☐ *External*
TRACEABILITY OF MEASUREMENT			
Calibration and Confirmation		Certification	
Internal traceability to reference standard PS 11		*External Traceability of Certification Body*	
INTERVAL OF METROLOGICAL CONFIRMATION			
☐ 3 months	☐ 6 months	☒ 1 year	☐ 2 years

RESULTS OF CONFIRMATION

Date of Control	Body Control	Number of Report	Results of Confirmat.	Drift MRE/bar	Signature Vision	Deadline	Notes
01.06.2016	Internal	XX-PI	Positive	0.05	White	01.06.2017	

RESULTS OF LAST CONFIRMATION

Before the verification is the adjustment was made? ☐YES ☒NOT

Pressure Reference (bar)	RELIEVED VALUES Increasing (bar)	RELIEVED VALUES Decreasing (bar)	RELIEVED ERRORS Increasing (bar)	RELIEVED ERRORS Decreasing (bar)	Max Relieved Error E_{max} (bar)
0	-	0.05	-	0.05	
2	1.95	2.05	- 0.05	0.05	
4	3.95	4.05	- 0.05	0.05	0.05
6	5.95	6.05	- 0.05	0.05	
8	7.95	8.05	- 0.05	0.05	
10	9.95	-	- 0.05	-	

RESULTS OF METROLOGICAL CONFIRMATION

MRE < MTE	0.05 bar < 0.10 bar	☒YES	☐NOT
OR ALTERNATIVELY			
MRU < MTU	$MRU = 2\cdot\sqrt{\left(\frac{Uref}{2}\right)^2+\left(\frac{Emax}{\sqrt{3}}\right)^2+\left(\frac{Eres}{2\sqrt{3}}\right)^2} = 2\cdot\sqrt{\left(\frac{0.01}{2}\right)^2+\left(\frac{0.05}{1.73}\right)^2+\left(\frac{0.05}{3.46}\right)^2} = 0.06bar < 0.15bar$	☒YES	☐NOT
THE NEXT VERIFICATION MUST BE CARRIED OUT WITHIN			01.06.2017
Metrological Function	EXECUTOR SIGNATURE	RESPONSIBLE SIGNATURE	DATE 01.06.2016

Card Example

❑ ***For each family of instruments it is proposed:***

- **Calibration & metrological procedures** of the main measuring instruments
- **Collection cards and the data processing** suitable for recording and drafting the related ...
- **Calibration report & metrological confirmation** manually or automatically with the CD

Calibration cards

&

Spreadsheets

reported on CD

Handbook Spreadsheet

Metrological Laboratory	CALIBRATION REPORT Measurer of Pressure				Card Number XX - PI
IDENTIFICATION AND METROLOGICAL DATA					
Instrument identification		PI 11	Measuring range		0-10 bar
Instrument classification		Process	Calibration range		0-10 bar
Instrument denomination		Dial Manometer	Accuracy class		1%
Manufacturer		ABC	Measure resolution (Eres)		0,05
Model		DN 100	Max Tolerated Error (MTE)		0,10
Serial number		XYZ	Max Tolerated Uncert. (MTU)		0,15
Date of acquisition		01/02/10	Reference std Uncert. (Uref)		0,01
Location of installation		Process PI 11	Certif. No. of Rerefence std		1111
Installation conditions		Vertical	Fluid Exercise / Calibration		Air / Air
Supply conditions		Not Applicable	Fill fluid		Eventual
APPLICABLE PROCEDURES AND NORMATIVES					
Calibration procedure		PP-PI	Maintenance procedure		Manuf. Spec.
Confirmation procedure		PP-PI	Normative reference		EN 837
REQUIRED CONTROLS					
Calibration / Confirmation		Certification		Body Control	
YES	NOT	YES	NOT	Internal	External
TRACEABILITY OF MEASUREMENT					
Calibration & Confirmation			Certification		
Internal traceability to reference standard PS 11			External Traceability of Certification Body		
INTERVAL OF METROLOGICAL CONFIRMATION					
1 months	3months	6 months	1 year	2 years	3 years
RESULTS OF CONFIRMATION					
Date of Control	Number of Report	Result of Confirmation	Drift MRE/bar	Signature Vision	Date of Deadline
01/06/16	XX - PI	POSITIVE	0,05	White	01/06/17
RESULTS OF LAST CONFIRMATION					
Before the verification is the adjustment was made?				YES	NOT
Pressure Reference (bar)	RELIEVED VALUES Increasing (bar)	RELIEVED VALUES Decreasing (bar)	RELIEVED ERRORS Increasing (bar)	RELIEVED ERRORS Decreasing (bar)	Max Relieved Error E_{max} (bar)
0	0,00	0,05	0,00	0,05	
2	1,95	2,05	-0,05	0,05	
4	3,95	4,05	-0,05	0,05	0,05
6	5,95	6,05	-0,05	0,05	
8	7,95	8,05	-0,05	0,05	
10	9,95	9,95	-0,05	-0,05	
RESULTS OF METROLOGICAL CONFIRMATION					
MRE ≤ MTE	0,05	≤	0,10	Result	YES
OR ALTERNATIVELY					
MEASUREMENT UNCERTAINTY OF THE CALIBRATION INSTRUMENT					
MRU ≤ MTU	$MRU = 2 \cdot \sqrt{\left(\frac{U_{ref}}{2}\right)^2 + \left(\frac{E_{max}}{\sqrt{3}}\right)^2 + \left(\frac{E_{res}}{2\sqrt{3}}\right)^2}$			Result 0,06	YES
THE NEXT VERIFICATION MUST BE CARRIED OUT WITHIN					01/06/17
Metrological Function	Executor Signature		Responsible Signature		DATE 01/06/16

LEGENDA

Input data	Internal Data	Calculated Data	Elaborated Data	Confirm Method	Deadline Date

If not otherwise specified the errors and measurement uncertainties have the unit of measurement of measuring range

Practical

Spreadsheets

for the compilation

of

Calibration Reports

Handbook Information

For Information

ISA

International Society of Automation

https://www.isa.org/store/calibration-handbook-of-measuring-instruments/58061591

or

https://www.eurospanbookstore.com/calibration-handbook-of-measuring-instruments.html

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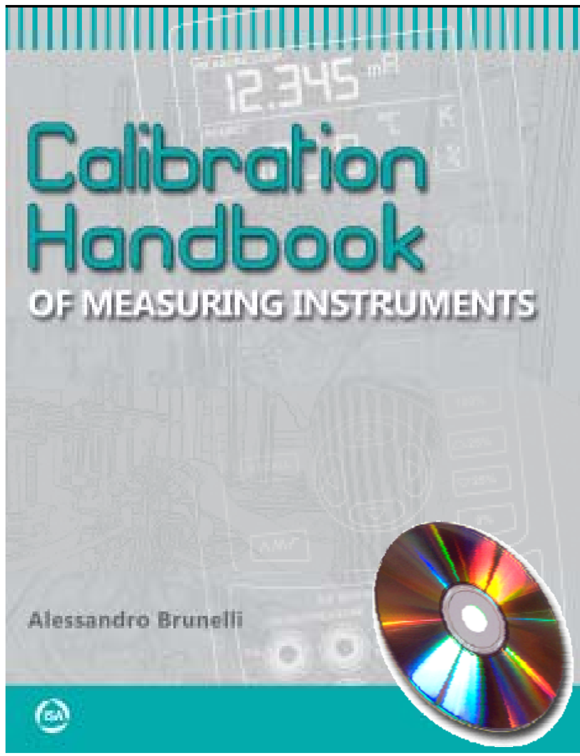

END

Thanks for Your Attention!!!