Methodology and Analysis of the ILCs Provided by INRIM from 2016 to 2018

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ABSTRACT

To assess the technical competence of calibration laboratories National accreditation bodies (NABs) take into account the results of national and/or international Proficiencies testing (PTs) including the Inter-laboratory comparisons (ILCs). As the Italian NAB stopped acting as PT-provider since 2015 due to the result of a peer assessment by the European co-operation for Accreditation (EA), the National Institute of Metrological Research (INRIM) reorganized itself and reoriented part of its activity to become a ILCs provider, thus supporting the calibration laboratories. This paper describes how INRIM has been organized as ILCs Provider to guarantee the accreditation activity continuation and gives information about the main typologies of the provided ILCs and details on the analysis of the ILCs results in different metrological areas. From 2016 to 2018, INRIM provided 114 ILCs, in the areas of Acoustics Ultrasonic and Vibration (AUV), electricity and magnetism (EM), length (L), mass (M) and thermometry (T), involving 138 laboratories, for which 375 ILC Reports were issued.

Keywords: Inter-laboratory comparison, PT-provider, measurement protocol, ILC report, measurement uncertainty.

1. Introduction

The technical surveillance of calibration laboratories accredited according to [1] is important for the competitiveness of modern countries. In an effective technical surveillance, the execution of inter-laboratory comparisons (ILCs) is of great importance. In an ILC, the measurements of a surveyed laboratory are compared with the measurements of a reference laboratory to establish if they are compatible. ILCs are therefore useful to establish the competence of secondary laboratories, operators skill, equipment suitability and the correctness of the dissemination process from national standards, normally maintained at the National Measurement Institutes (NMIs) [2–7]. With ILCs, it can be verified the measurements compatibility among different laboratories or of different measurement methods. It is also possible to establish the equivalence of national standards among NMIs [8]. NMIs and secondary laboratories are at the top of the measurement system of each modern industrialized country. Each step of this chain must be under control to assure that final products are reliable. This control can be made also by means of ILCs that therefore are a strategic mean to assure the reliability of measurement systems supporting the high-tech industry.

2. The Italian framework

According to [9], the Italian NAB ACCREDIA, as signatory of the multilateral EA agreement[1], must demonstrate to evaluate in an accreditation process, the laboratories technical competence, also through their satisfactory participation in national and/or international ILCs. In the past, the Calibration Service in Italy (SIT) first, and after ACCREDIA, to finalize the accreditation applications of laboratories, provided itself ILCs, with the Italian NMIs technical support. EA[2] assessment in 2015 considered this practice "non-compliant", thus, since that year ACCREDIA ceased this activity. In 2015, were active 172 accredited laboratories in 267 measurement sectors [10], although a ILCs provider was not available. To compensate this lack and to guarantee the continuity of the accreditation assessments, INRIM, and in particular, the Technical Service for Accreditation of Laboratories Department (STALT) organized itself as ILCs provider. Since then, INRIM organizes ILCs in accordance to [11] and it is accepted by ACCREDIA as ILC provider being a NMI signatory of the

[1]The EA Multilateral Agreement (EA MLA) is a signed agreement between the EA Full Members whereby the signatories recognise and accept the equivalence of the accreditation systems operated by the signing members, and also the reliability of the conformity assessment results provided by conformity assessment bodies accredited by the signing members.

[2] The European co-operation for Accreditation (EA) is the Association of the national accreditation bodies providing accreditation, for bodies performing different types of conformity assessments: Calibration, testing (including medical), inspection, quality certification of environmental management system, products/services and persons.

CIPM-MRA arrangement[3]. Therefore, INRIM has been included in the list of the EA LC Working Group on ILC for calibrations (EA LC WG ILC Calibration).

2.1 Traceability assurance for ILCs

Usually, secondary Laboratories send their standards to INRIM (or to other NMIs) for periodical calibration. In this way, traceability chains from national standards till to final users, are established. For example, Fig. 1 and 2 show typical traceability chains from INRIM to secondary electrical and thermal calibration laboratories. In the scheme of Fig. 1 a high precision digital multimeter (DMM) belonging to an accredited electrical laboratory, is periodically calibrated at INRIM. Anyway, the traceability of the reference measurements of the ILCs provided by INRIM is guaranteed by the Italian law 11 August 1991, no. 273 "Establishment of the national calibration system" and it is in accordance with the document ILAC-P10: 2013 par.2, point 1) and with the CMCs included in the CIPM MRA, (www.kcdb.bipm.org). Italy has a total of 404 CMCs divided as follows: 115 for Electricity and Magnetism (EM), 100 for Temperature (T), 63 for Mass (M), 43 for Length (L), 42 for Acoustics Ultrasonic and Vibration (AUV), 20 for Photometry and Radiometry (PR), 12, 9 for Time and Frequency (TF) and 9 for Chemistry and Biology (QM).

3. INRIM organization for ILCs

INRIM, as Italian NMI, realizes and compares with other NMIs primary measurement standards for all SI units except for the ionizing radiations field. It carries out scientific research focused on metrology, materials science and innovative technologies. As NMI underpins the SI system, disseminates and transfers scientific results, technology and know-how to scientific, industrial and service users. Furthermore, it produces, and coordinates, even within the European Union, programs and international organizations, scientific and technological research activities, through its own facilities or in collaboration with universities and other public and private national and international entities. According to the customer needs, INRIM organizes ILCs for the physical quantities within its competence. To organize the ILCs-Provider activity, INRIM chose a unique communication channel for customers through an electronic mailbox managed by an organizing contact. This was the input/output channel for ILC management activities (requests receipt, quotations submissions, order transmissions, questions and replies, information sharing and so on). The aim has been to centralize in STALT the ILCs management and looking elsewhere, in other INRIM Departments or in other NMIs, for the reference measurements providers if not available in STALT. The technical part of the activity has been instead made by a technical contact (TC) whose task has been the management of the traveling standard, of the technical communications with the customer, the data processing and the drafting of the ILC report. A dedicated technical working group has been set up involving a member of the electrical, thermal and mechanical areas that are the metrological areas in which the largest number of secondary laboratories are accredited. This working group manages the technical aspects to operate in agreement to [11] drafting the templates of technical-economic quotation, LC protocol and ILC report which their latest revisions are available for colleagues on the relevant INRIM shared area. In the following, the steps of an ILC are summarized:

- Quotation preparation and dispatch and order receipt;
- Protocol drafting and sending;
- ILC management;
- Data processing and report issue.

3.1. Quotation editing and sending and order receipt

The information of a new ILC is given sending the technical-economic quotation. The quotation form is filled by the TC, based on the needs of accredited laboratories in the relevant area, and transmitted to customers by the INRIM communication channel. The specific supply conditions indicated in the quotation form were established by the INRIM administration while TC defines the amount. This depends on:

- The costs of INRIM calibrations;

[3] The CIPM Mutual Recognition Arrangement (CIPM MRA) is the framework through which National Metrology Institutes demonstrate the international equivalence of their measurement standards and the calibration and measurement certificates they issue. The outcomes of the Arrangement are the internationally recognized (peer-reviewed and approved) Calibration and Measurement Capabilities (CMCs) of the participating institutes.

- The shipping costs incurred by INRIM;
- Staff engagement costs to draft the protocol, to monitor the traveling standards, to draft the ILC report;
- Possible compensation costs, when a travelling standard could no longer be utilized after the ILC. Any discounts are applied during invoicing. Fig. 3 shows the process of the contract management.

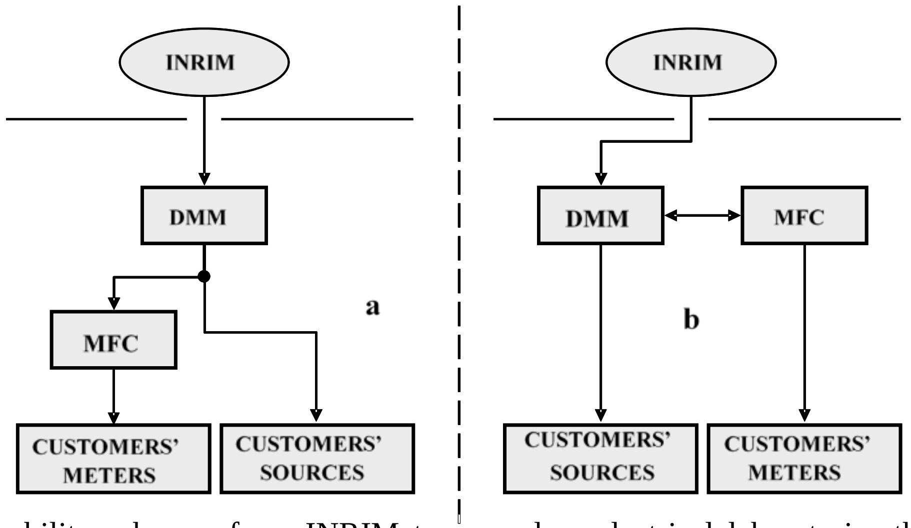

Fig. 1 Traceability schemes from INRIM to secondary electrical laboratories through a high precision DMM. In a) the DMM acts as reference standard, while in b) it acts as transfer standard.

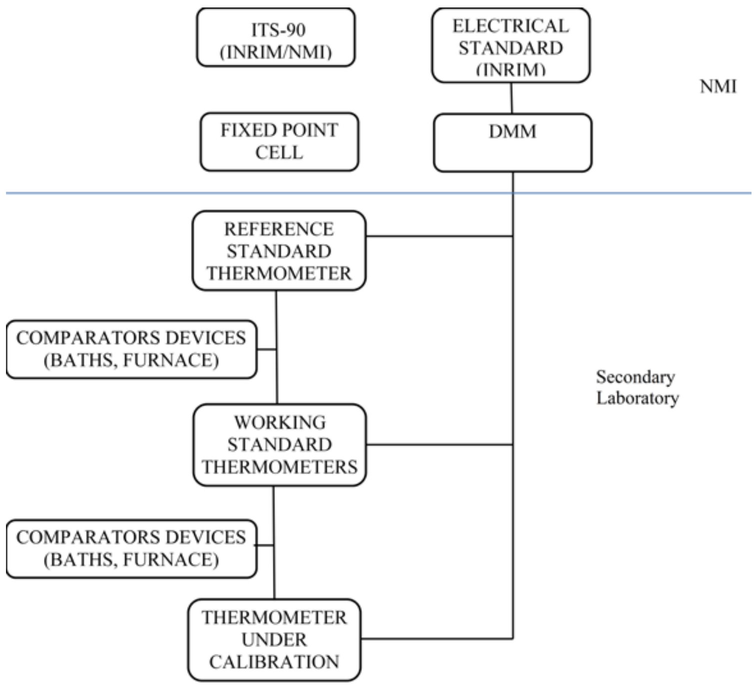

Fig. 2 Typical traceability scheme from INRIM to to secondary thermal laboratories for calibration of thermometers.

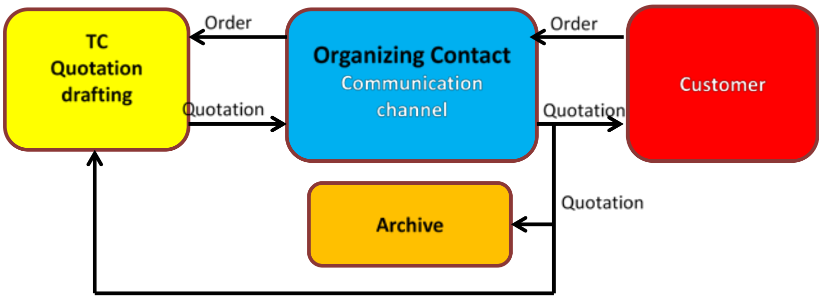

Fig. 3 Outline of the process of an ILC quotation drafting and sending and order receipt.

3.2. ILC Protocol

The ILC Protocol is the document whit technical and organizational details of the ILC including the calibrations calendar, and details of participants. It has to contain:

- Aim of the document;
- ILC provider Contacts;
- Provider of the reference measurements;
- Participant laboratories and ILC calendar;
- Travelling standards;
- Standards management;
- Execution of the activity;
- Presentation of the results;
- Used method to evaluate the results;
- Data use and confidentiality;
- References.

TC drafts the ILC protocol while a competent different and independent person carries out its review. Fig. 4 shows the issue and dispatch process of the ILC protocol.

Fig. 4 Outline of the ILC protocol issue and dispatch to participants.

3.3 ILC management

TC applies the protocol from the issue to the final report. In detail, TC:

- Contacts the customers and organizes the shipment of the traveling standards;
- Is a reference point for ILC participants;
- Manages any unforeseen events (including changes to the calendar;
- Collects the results of participants and of the reference laboratory and the related documentation as required by the protocol;
- Performs the data evaluation;
- Issues the ILC report.

4. ILC Reports

For each ILC participant an ILC report is issued to guarantee the results reservation. ILC reports have to contain:

- A summary;
- Details of the ILC Provider;
- ILC contacts;
- Details of possible subcontracting;
- The ILC scheme;
- Management of the travelling standards including any damages;

- Execution of the activity;
- Reference values;
- Results of the participating laboratories;
- Evaluation of the results;
- Comments on the results (if applicable);
- Confidentiality statement;
- References.

5 Evaluation of the ILC results

In the following, examples of results evaluation of ILCs between INRIM and secondary laboratories, are reported. Results in forms of tables/figures can instead be found in some papers listed in references [2-8].

5.1 Electrical case

The example deals with a bilateral ILC (i.e. between INRIM and one laboratory) consisting in the calibration of a multi-function electrical calibrator in the five low frequency quantities, DC and AC Voltage, DC and AC Current and DC Resistance. To establish the measurement compatibility between the INRIM and laboratory measurements, the evaluation of the results has to be carried out by determining the normalized error E_n, defined according to [11] and taking into account the case that the laboratory standards could have been calibrated by the laboratory that provided the reference measurements (INRIM). Therefore, the data have to be evaluated as follows: it should be considered, as measurand, the error of the calibrator defined in the following (1) and (2) respectively for INRIM and for the participating Laboratory:

$$E_I = \frac{(m_{I1} - s) + (m_{I2} - s)}{2s} \tag{1}$$

$$E_L = (m_L - s)/s \tag{2}$$

Where m_{I1} and m_{I2} are the INRIM measurements at the setting s, obtained before and after the measurements at the laboratory, while m_L indicates the value measured by the laboratory at the same setting s. The INRIM and Laboratory results have to be defined as:

$$E_I \pm U_I \tag{3}$$

$$E_L \pm U_L \tag{4}$$

Where U_I and U_L are their expanded uncertainties. From them, the standard uncertainties are obtained:

$$u_I \cong \frac{1}{2} U_I \text{ and } u_L \cong \frac{1}{2} U_L \tag{5}$$

The following difference for each measurement point has to be calculated:

$$y = E_L - E_I \tag{6}$$

Whose standard uncertainty is:

$$u^2(y) = [u^2(E_I) + u^2(E_L))] - -2u(E_L)u(E_I) \times r(E_L, E_I \tag{7}$$

Where $r(E_I, E_L)$ is the correlation coefficient between the INRIM and laboratory errors. Finally, the normalized error E_n is:

$$E_n = \frac{y}{U_y} \tag{8}$$

where $U_y = 2u_y$ for a 95% confidence level. The ILC result is satisfactory if $|E_n| \leq 1$, for each measurement point. Table 1 reports the results of an ILC for DC Voltage in the 100 mV range.

Table 1. ILC results in the 100 mV range in DC Voltage.

Meas. point	*Errors*			*Expanded uncertainties*			E_n
s (mV)	E_I ($\times 10^{-6}$)	E_L ($\times 10^{-6}$)	*y* ($\times 10^{-6}$)	$U(E_I)$ ($\times 10^{-6}$)	$U(E_L)$ ($\times 10^{-6}$)	$U(y)$ ($\times 10^{-6}$)	
1	–15	–340	–325	192	300	356	–0.9
–1	25	100	75	192	310	365	0.2
3	–7	–103	–97	65	100	119	–0.8
10	–3	–26	–23	23	31	39	–0.6
–10	1	9	8	23	31	39	0.2
100	0.5	0.1	–0.4	2.2	9	9	–0.0
–100	0.0	1.2	1.2	2.2	9	9	0.1

5.2 Volume case

The example deals with a multilateral ILC (i.e. between INRIM and some secondary laboratories) consisting in the calibration of a 100 ml pycnometer at 20 °C and of a 20 l standard tank at 15 °C and 20 °C (three volume measurements). The evaluation of the results of the participating laboratories has to be made determining the E_n values. In this case, it can be assumed that the INRIM and laboratories' measurements are independent. For each laboratory and for each standard, E_n has to be evaluated as follows:

$$E_n = \frac{|\Delta V|}{U(\Delta V)} \tag{9}$$

Where $\Delta V = V_{Lab} - V_{INRIM}$ and:

$$U(\Delta V) = 2\sqrt{u^2(V_{INRIM}) + u_l^2(V_{Lab})} \tag{10}$$

Table 2 reports the results for the 100 ml pycnometer for one participating laboratory.

Table 2: Evaluation of the volume comparison for the 100 ml pycnometer at 20 °C for one participating laboratory.

ΔV (ml)	$U(\Delta V)$ (ml)	E_n
–0.02	0.15	–0.8

5.3 Mass case

The example deals with a bilateral ILC consisting in the calibration of eight mass standards from 20 mg to 50 kg. To evaluate the stability of the travelling standards during the comparison, the normalized error E_n between the INRIM measurements before $m_{Xi}(I)$ and after $m_{Xi}(F)$ the laboratory measurements has to be calculated. It has to be $|E_n| \leq 1$. The following differences have to be calculated:

$$\Delta mXi = mX\text{i}(F) - mXi(I) \tag{11}$$

Whit:

$$U(\Delta m_{Xi}) = 2\sqrt{\left[\frac{U[m_{Xi}(\text{I})]}{2}\right]^2 + \left[\frac{U[m_{Xi}(\text{F})]}{2}\right]^2 - 2r_{Xi}\left[\frac{U[m_{Xi}(\text{I})]}{2}\right]\left[\frac{U[m_{Xi}(\text{F})]}{2}\right]} \tag{12}$$

Then

$$E_n(I,F) = \frac{\Delta m_{Xi}}{U(\Delta m_{Xi})} \tag{13}$$

To quantify the correlation coefficient r_{Xi} between INRIM measurements before and after for each mass standard *i* (where *i* = 1,..,8), the correlation effects have to be taken into account due to the:

- Uncertainty of the common mass standard used for the calibration;
- non-linearity of the balance;

- Operator and environment.
- The reference value is the arithmetic mean of the values measured before and after the laboratory measurements:

$$m_{Xir} = 0.5\times [m_X i(I) + m_X i(F)] \quad (14)$$

The uncertainty component due to mass instability has also to be added in the uncertainty of the reference value:

$$u_{\mathrm{instab}\,i} = \left|\Delta m_{Xi}\right| / \sqrt{12} \quad (15)$$

The expanded uncertainty of the reference value has to be evaluated taking into account the correlation coefficients r_{Xi} for all mass standards and the contribution due to the instability:

$$U(m_{Xir}) = 2\sqrt{\left[\frac{U[m_{Xi}]}{2}\right]^2 + \left[\frac{U[m_{Xi}]}{2}\right]^2 + 2\,u_{\mathrm{instab}\,i} + 2r_{Xi}\left[\frac{U[m_{Xi}]}{2}\right]\left[\frac{U[m_{Xi}]}{2}\right]} \quad (16)$$

The laboratory results m_{Xil} and uncertainties $U(m_{Xil})$ for each mass standard, have to be compared with reference values:

$$\Delta m_{Xil} = m_{Xil} - m_{Xir} \quad (17)$$

For the uncertainty evaluation, the correlation coefficient r_{Xil} between INRIM and the laboratory measurements has to be considered as:

- r_{Xil} = 0.3 if the laboratory mass standards are traceable directly to INRIM;
- r_{Xil} = 0.1 if the laboratory mass standards are traceable to an accredited laboratory traced to INRIM;
- r_{Xil} =0 if the laboratory mass standards are traceable to another NMI or to an external accredited laboratory. The expanded uncertainty is therefore $U(\Delta m_{Xil}) = 2u(\Delta m_{Xil})$ with:

$$u(\Delta m_{Xil}) = \sqrt{\left[\frac{U(m_{Xil})}{2}\right]^2 + u^2_{\mathrm{instab}\,i} + \left[\frac{U(m_{Xir})}{2}\right]^2 - 2r_{Xil}\left[\frac{U(m_{Xil})}{2}\frac{U'(m_{Xir})}{2}\right]} \quad (18)$$

$$\text{where } U'(m_{Xir}) = \sqrt{\left[\frac{U[m_{Xi}]}{2}\right]^2 + \left[\frac{U[m_{Xi}]}{2}\right]^2 + 2r_{Xi}\left[\frac{U[m_{Xi}]}{2}\right]\left[\frac{U[m_{Xi}]}{2}\right]} \quad (19)$$

is the expanded uncertainty of the reference value without the instability component. Then:

$$E_n = \frac{\Delta m_{Xil}}{U(\Delta m_{Xil})} \quad (20)$$

Table 3 shows the results of one ILC according to the previous analysis.

Table 3: Evaluation of the mass comparison for one participating laboratory.

Standard	m_{Xir} g	$U(m_{Xir})$ mg	m_{Xil} g	$U(m_{Xil})$ mg	Δm_{Xil} mg	$U(\Delta m_{Xil})$ mg	E_n
2 mg	0.002 001 9	0.000 8	0.002 003 2	0.002 0	0.0013	0.0021	0.6
100 mg	0.100 002 0	0.001 5	0.100 004 5	0.005 0	0.0025	0.0051	0.5
2 g*	2.000 006 4	0.002 4	2.000 017	0.013	0.0106	0.0130	0.8
50 g	50.000 007	0.014	50.000 011	0.033	0.0043	0.0348	0.1
200 g*	200.000 032	0.029	200.000 06	0.10	0.0281	0.1013	0.3
1 kg	1 000.000 07	0.14	1 000.000 11	0.53	0.043	0.535	0.1
10 kg	10 000.007 8	1.9	10 000.007 8	5.3	0.047	5.448	0.0
50 kg	50 000.043	16	50 000.036	75	-7.42	75.14	-0.1

5.4 Length case

The example deals with a multilateral ILC consisting in the calibration of a 22 mm diameter steel ball, a RTH hemisphere, and a 50 mm diameter Tesa ring, (Fig. 3). The measurand is the deviation from the ideal roundness of the standards, RONt, which is obtained as difference between the maximum and minimum profile radius, with reference circumference evaluated with the least squares method.

Fig. 5. Roundness standards for the ILC.

The plane where the measured profile has to placed depends on the standard:

• For the sphere, has to be parallel to the base of the support of the standard and has to be placed in correspondence with the maximum section of the standard (equator);

• For the hemisphere has to be parallel to the base of the support of the standard and has to be placed about 3 mm from the fixing ring of the standard;

• for the ring, the mid-height profile has to be considered.

Gaussian filtering has to be applied to the data, with a cut off frequency f_C = 50 UPR. The roundness error measured by INRIM with multiple orientation technique at the end of the circulation has to be considered the reference value. The analysis of the results follows the same treatment of the electrical case only considering the correlation coefficient between INRIM and laboratory measurements as 0.1.

5.5 Pressure case

The example deals with a multilateral ILC consisting in the calibration of a pressure transducer with absolute method between 10 kPa and 130 kPa. To assess the stability of the travelling standard during the comparison, the pilot laboratory has to perform the calibration at least three times. Therefore, the reference value $p_{i,ref}$) is the mean value of the calibrations. Its standard uncertainty is:

$$u(p_{i,ref}) = \sqrt{u^2(e_{i,ref}) + u^2(drift)} \tag{21}$$

Where $e_{i,ref}$) is the INRIM measurement error, defined as relative difference vs. the reference applied pressure, value in the i-th measurement point and $u(e_{iref})$ is its standard uncertainty. $u(drift)$ is the standard uncertainty of the drift evaluated as:

$$u^2(drift) = max\left(\frac{\max(e_{i,j,INRIM}) - \min(e_{i,j,INRIM})}{\sqrt{12}}\right) \tag{22}$$

For each participating laboratory, the value of the measured pressure $p_{i,lab}$ for a nominal pressure value p_{ti} is:

$$p_{i,lab} = pt_i + e_{i,lab} \tag{23}$$

$$\text{where } u(p_{i,lab}) = u(e_{i,lab}) \tag{24}$$

is the standard uncertainty of the laboratory Error. The values obtained by the laboratories and the reference ones have to be defined respectively as:

$$p_{ilab} \pm U_{ilab} \quad (25)$$
$$p_{iref} \pm U_{iref} \quad (26)$$

The analysis of the results follows the same treatment of the case in par. 5.1 but considering the correlation coefficient between INRIM and laboratory measurements as in par. 5.3.

6 Management of the outcomes of the ILCs

Let's consider the example of a multilateral ILC in the field of low frequency electrical quantities (DC and AC Voltage, DC and AC Current and DC Resistance. In this kind of ILC, the allowed participants for each ILC are usually no more than ten laboratories to avoid too long times for the circulation, drift and damages to the travelling instrument (normally a high precision $8^{1/2}$ digit DMM or a top level multifunction calibrator). INRIM carries out its measurement before and after the circulation and, if necessary, in the mid-time of the circulation itself. When, during the evaluation of the results, it is observed that some measurements of one laboratory are compatible with those of INRIM, the very first thing is to ask the laboratory to check the correct transcription of their measurement results. After the evaluation of the results, INRIM provides, for each participant laboratory, an ILC report containing only its results for confidentiality reasons along with the E_n for each ILC measurement point. Each applicant or accredited laboratory, in the framework of the first accreditation or in the accreditation renewal, must show to its Accreditation body its ILC report in which all the points out of compatibility are outlined. If $|E_n| >>1$ in several points and in different quantities, the ILC result is clearly unsatisfactory and the laboratory must communicate this negative result to the Accreditation body that will interrupt the accreditation or the accreditation renewal processes. The laboratory, after suitable internal verifications and corrective actions (for example to enlarge its or the requested CMC, has to repeat the ILC to resume the accreditation or the accreditation renewal. Instead if $|E_n|>1$ in only few points of the same quantity, the laboratory can make immediate corrective actions to submit to INRIM for evaluation. If INRIM considers adequate these corrective actions can update the laboratory report indicating the suitable corrective actions proposed by the laboratory. Whit this amended report the Accreditation body can decide to carry out an additional measurement comparison only in the points where $|E_n|>1$ when the technical assessor will carry out the planned inspection visit to the laboratory itself. For other INRIM quantities, as thermal and mechanical ones, the no. of laboratories admitted to the participation to ILCs is limited to 12-15 laboratories. For thermal and mechanical ILCs, the typical way of circulation is at" flower petal" in which the travelling standard comes back to INRIM for recalibration, after the calibration at three-four laboratories, to check its integrity and stability.

7 Summary of the INRIM activity as ILCs provider from 2016 to 2018.

As the Italian accredited calibration laboratories (at the end of 2019 about 194 plus 5 Reference Materials Producers) must submit their ILCs plan to ACCREDIA on a four years' period, they usually ask to INRIM to schedule their ILCs over that period for all the quantities for which they are accredited or ask accreditation. As consequence, from 2016 to 2018, INRIM provided 114 ILCs, in the metrological areas of Acoustics Ultrasonic and Vibration (AUV), electricity and magnetism (EM), length (L), mass (M) and thermometry (T), involving 138 companies, for which 375 ILC reports were issued. Main customers are the national calibration accredited laboratories that have to demonstrate to the NAB their competence through ILC results, but also laboratories that have to validate their calibration methods or to provide evidence of their competence to customers. Occasionally also foreign customers took part in the ILCs. Table 4 shows the main typologies of the provided ILCs along with indication of the travelling standards/instruments, measurand definitions, measurement methods, physical quantities, measurement ranges and uncertainties. It is possible to observe wide uncertainty ranges as, for each physical quantity or type of travelling instrument/standard, different level of ILCs can be provided according to the requested uncertainties for participation and to the employed travelling instrument/standard. This allows to the laboratories to choose suitable ILCs to their accreditation status or improvement needs.

Table 4. Main ILCs typologies provided by INRIM from 2016 to 2018.

ILC Instrument/standard	*Measurand*	*Measurement method*	*Quantity*	*Measurement ranges*	*U* [4]
8.5 digits multimeter (DMM)	Relative difference vs. the standard applied value	Comparison with laboratory standards	DC Voltage AC Voltage DC Current AC Current DC Resist	100 m V ÷ 1000 V 1 mV÷1000V 0.04÷10^2 kHz 1 mA÷ 1 A 100 µA÷1.9A 0.04÷5 kHz 10 Ω ÷ 10 MΩ	($\times 10^{-6}$) 1.1 ÷ 33.5 27.8÷ 2009 5.0÷ 344 32÷ 7609 1.3 ÷ 541
Multifunction Calibrator (MFC)	Relative difference vs. the standard measured value		DC Voltage AC Voltage DC Current AC Current DC Resist.	1 mV ÷ 1000 V 1mV÷1000V 40Hz÷1 MHz 10 µA÷ 1.9 A 100 µA÷1.9 A 0.04÷5 kHz 10 Ω ÷ 100 MΩ	0.6 ÷ 1050 50 ÷ 3008 2.5 ÷ 72.6 19.6 ÷ 310 1.1 ÷ 50
Meter + power sensor in 3.5 mm connection.	Power Ratio: traveling sensor and on standard sensor.		RF Power	1 mW (10 MHz÷26.5 GHz).	($\times 10^{-4}$) 4.0 ÷ 300
Attenuators and mismatched loads.	Attenuation attenuator input/output. Refl. coeff. Attenuator input/output		RF Attenuation and Reflection Coefficient	100 kHz, 1 MHz, 10 MHz, 50 MHz, 1 GHz, 4 GHz, 6 GHz, 8 GHz, 10 GHz, 12 GHz, 15 GHz, 18 GHz.	0.03 dB÷0.09 dB ($\times 10^{-2}$) 0.4 ÷ 3.2
Wattmeters, Power/ Energy meters, Energy counters, Power sources.	Relative difference vs. applied value	Dummy load method	Single-Three-Phase AC Power and Energy	30 V÷750 V 10 mA ÷ 120A power factor: - 0.1 ÷ 1 Freq.: 47 Hz ÷ 53 Hz.	($\times 10^{-5}$) 5.0 ÷ 430
Standard resistors	DC Resistance value		DC Resistance	1 Ω ÷ 1 TΩ	($\times 10^{-6}$) 0.1 ÷ 1000
Zener diode-based standard	DC Voltage value		DC Voltage	1.018 V, 10 V	0.5 ÷ 5
IPRT and thermocouples liquid in glass thermometers	Error vs reference temperature		Temperature	-196 °C ÷ 1530 °C	0.01 °C ÷ 2.5 °C
Thermo-hygrometers			Air temperature Relative humidity	5 °C ÷ 70 °C 10 %rh ÷ 90 %rh	0.06 °C 0.6 %rh ÷ 2.9 %rh
Temperature/humidity chambers	Error vs ref. temp./relative humidity in centre space			70 °C ÷ 180 °C 10 % rh ÷ 90 % rh	0.06 °C ÷0.52 °C 0.15 %rh ÷2.30 %rh
External cylinder (plug) Internal cylinder (ring)	Diameter	Comparison with laboratory standards	Length	25 mm and 100 mm (ring) 28 mm and 150 mm (plug)	0.1 µm+ $0.5\times 10^{-6} L$ [5]÷0.3 µm + $2\times 10^{-6} L$
Internal cylinder Sphere Hemisphere	Error vs nominal roundness			Standard diameter < 200 mm Roundness error < 400 µm	(0.007 ÷0.11) µm

[4] For each measurement range, the uncertainties (95 % confidence level) of the provided ILCs span from the lowest value (normally declared by INRIM) to the highest one declared by the participant laboratory with the worst uncertainty and likely in different measuring points and in different ILCs.
[5] *L* is the nominal length.

Pressure balances in - liquid medium - gas medium	Pressure Value/Relative difference vs. standard applied value		Pressure	10 MPa ÷ 100 MPa 1.4 kPa ÷ 8 MPa	290 Pa ÷ 2810 Pa 0.68 Pa ÷ 225 Pa
Absolute pressure transducer in gas medium	Pressure Value/Relative difference vs. the standard applied value		Pressure	0.2 MPa ÷ 7.5 MPa	0.7 Pa ÷ 180.5 Pa
Pressure gauge in - in gas - in liquid				0.5 MPa ÷ 100 Mpa 10 MPa ÷ 100 MPa	100 Pa ÷ 2830 Pa 290 Pa÷8.2 kPa
Mass flow controller	Mass flow value	Gravimetrc. volumetric or comparison vs master meter Comparison with standardsCompa rison Comparison	Gas Flow	100 SCMM[6] ÷ 5×10^4 SCCM	0.1 % ÷0.5%
Water meter	Liquid flow value	Comparison with standardsn	Fluid flow Volume (liquid)	D[7] =25 mm 250 l/h[8] ÷14000 *l*/h D =150 mm 30000 l/h ÷ 5×10^5 *l*/h	(0.1÷ 0.3) % (0.2 ÷0.5) %
Mass Standards	Mass value	Comparison with laboratory standards Gravimetric or volumetric method	Mass	1 mg ÷ 500 kg	0.7 µg÷1 g
Balance NAWI	Error vs reference mass			1 mg ÷ 500 kg	1 µg ÷6.5 g
Balance AWI				1 mg ÷ 60 kg	(50÷300)mg
Standard tanks	Volume value	Comparison	Volume	(0.01 ÷ 200) l	$5\times10^{-5}\div1\times10^{-4}$

ILC Instrument/standard	*Quantity*	*Measurement Method*	*Characteristic and uncertainties*
Sound calibrators	Sound pressure level	According to IEC 60942:2003*	Sound pressure level: U 0.09 dB Frequency: *U* = 0.01 % Distortion: *U* = 0.20 %.
Sound level meters	Sound pressure level	According to IEC 61672-3:2006*	Self-generated noise with capacitive adapter: *U*=1.1 dB Frequency weighting with acoustic signals: 0.23 dB<*U* 0.62dB Frequency weighting with electrical signals: *U* = 0.15 dB Frequency and time weightings at 1 kHz: *U* = 0.11 dB Level linearity in the reference range: *U* = 0.14 dB Response to wave forms: *U* = 0.12 dB Peak sound level: U = 0.12 dB Overload indicator: *U* = 0.11 dB

[6] SCMM = standard cm^3 per minute.
[7] D = Water meter diameter.
[8] l/h = liters per hour.

Those reported in Table 4 are the ILCs that routinely INRIM provided. Nevertheless, several specific ILCs on request by laboratories or other customers were also provided. The participant laboratories carried on the measurements following their approved procedures written according to the measurement methods reported in Table 4.

Table 5: ILC reports issued from 2016 to 2018, including the reports issued in the Time and Frequency area[9].

Metrological areas	**2016**	**2017**	**2018**
AUV	15	12	12
EM	17	29	9
L	15	0	18
M	52	11	52
T	37	47	49
Total	136	99	140

Fig. 4 shows the issued ILC reports divided by the metrological areas and by year.

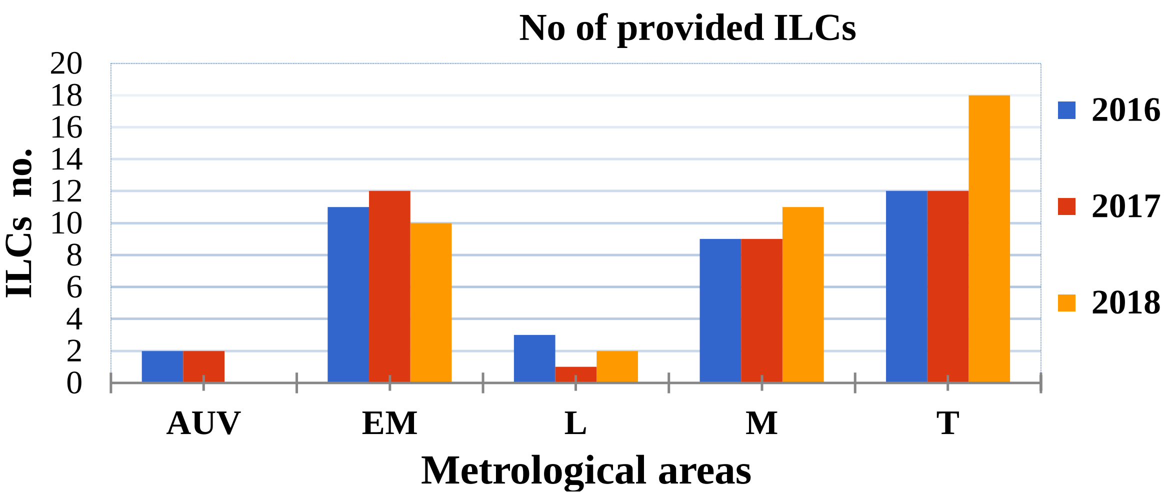

Fig. 4 Provided ILCs from 2016 to 2018.

Fig. 4 shows that the number of the provided ILCs in these three years are not decreased. Rather the number of ILCs is still slightly growing despite several accredited laboratories participated to ILCs organized by foreign NMIs or by accredited ILCs Provider.

Conclusions

After the ending of the ILCs-Provider activity by ACCREDIA, INRIM replaced ACCREDIA as independent and qualified body in the national territory, acting as ILCs provider, mainly in order to guarantee continuity of the accreditation processes and the stability of the national calibration system. The activity of ILCs Provider is made in accordance with [12]. Almost all of the ILC requests came from Italian accredited laboratories that have been managed by means of the INRIM communication channel or directly by the TCs. Future aims of this activity will be the publication on the INRIM website of the ILC program over a medium-long period and of the ILC directory in addition to that for calibration and testing activities. An analysis of the ILCs results obtained in these three years will be

[9] ILCs on Time and Frequency quantities, due to their specificity, were managed and evaluated directly by the INRIM Time and Frequency Department.

made in order to future improvements of this activity both in managing and technical aspects. A customers' satisfaction investigation could also be made to obtain useful suggestions from customers.

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