

Digitalization of on-site characterization of climatic chambers

ARTICLE INFO

Keywords:

Climatic chambers
On-site
Calibration
Remote
Digitalization
Metrology

ABSTRACT

The implementation of a software tool applied to the characterization of climatic chambers is presented and discussed. INTA took part in the design and development of the algorithms for the automatic identification of stabilization periods of physical parameters measured based on defined acceptance criteria and the application of mathematical and statistical analysis for the interpretation of the results obtained.

The new operational procedure implemented at INTA is presented as an innovation in the service offered by the laboratory to its clients, allowing them to improve the efficiency of their production processes. It enables the remote calibration of climatic chambers and other thermal facilities of the Institute in different locations in Spain, without the need to move calibration technicians, resulting in increased efficiency in the use of human resources and cost savings.

1. Introduction

Following the integration of various research bodies and technological centres of the Ministry of Defence, INTA now operates three main technological campuses near Madrid, four main test centres in León, Lugo, Huelva and Cádiz, along with a test hangar at Granada Airport. Additionally, it has a space station in Maspalomas, Gran Canaria, and manages international space stations located in Spanish territory, belonging to NASA and ESA, as shown in Fig. 1.

The Metrology and Calibration Centre of INTA (CM&C) takes on the challenge of meeting the Institute's metrology and calibration needs comprehensively, providing metrology and measurement engineering services across INTA's new configuration. It is responsible for the comprehensive management of the calibration plan of the measurement and test equipment throughout INTA. It is accredited by the Spanish national accreditation body (ENAC) for conducting calibrations listed in the accreditation scope [1] in accordance with the ISO/IEC 17025 standard [2]. The scope includes calibration and measurement capabilities (CMC) of the accreditation technical annex, on-site characterization of climatic chambers and other isothermal media and thermal installations. These are not strictly calibratable instruments as such. Their purpose is to provide a homogeneous environment for testing or calibrating temperature and/or humidity measuring instruments by comparison. They serve as an auxiliary means, somewhat comparable to the environmental conditions of a laboratory and their effect on a calibrated instrument.

This homogeneity can be characterized by studying the uniformity and stability of the medium during the measurement process. These values will depend on the thermo-physical properties of the medium under measurement conditions, mainly thermal conductivity, viscosity, and the heat exchange and control method used.

Stability (of temperature/humidity) is the temporal variation of the measured temperature in a defined zone over a period of time suitable

for the use of the isothermal medium, taking into account the time constant of the standards, instruments, and load characteristics. It is quantified by obtaining the standard deviation of the readings of the standards.

Uniformity (of temperature/humidity) is the semi-range of the maximum difference between the average temperature/humidity values measured by any of the standards during the calibration process, located in the defined volume of the isothermal medium.

These properties have a clear dependence on temperature and humidity, so it is necessary to carry out the characterization of the medium throughout its range of use and under its actual conditions, including the load.

The characterization is performed on-site according to the procedures established by the Laboratory [3,4] and in accordance with the applicable ENAC technical note [5]. It requires the use of a temperature recording system with at least nine platinum resistance sensors and a dew point hygrometer. Likewise, various auxiliary materials are required for the execution of the work.

In the conventional execution of these calibrations, the laboratory technicians travel to the customer premises and data is analysed manually and is limited by the functionality of the tools used (spreadsheets and databases included in office software packages and custom software that technicians have adapted over several years). This requires a significant specialized human resources that increases costs and makes it difficult to meet the delivery deadlines required by the client (internal or external). This inevitably leads to a delay between the execution of the technical measurement work, prior to analysis and delivery of the calibration certificate of test report to the client. This delay often reaches up to 20 times the time dedicated to the test or calibration. For example, in the case of the characterization of an aeronautical thermal installation with uniformity test, carried out in a day, it takes an average of four weeks to deliver the report.

This is not only due to the time required for analysis and report

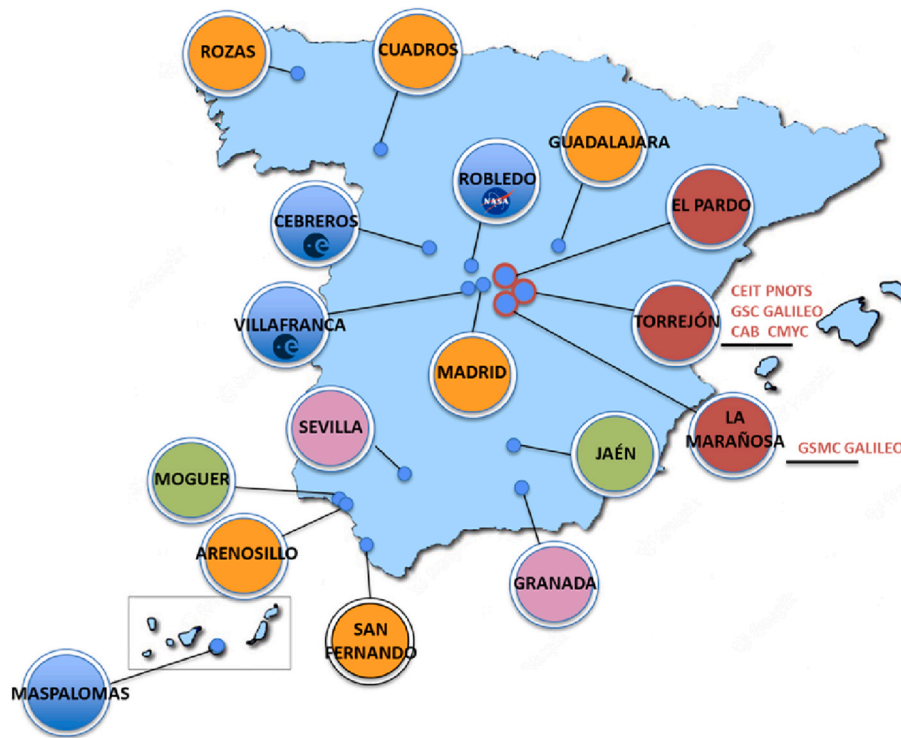


Fig. 1. INTA after integration.

Instrument details			
Instrument ID	Serial number	Customer Instrument ID	Tag No
CC-ACS-01	CC01	CC01	External instrument Id
Family		Brand	Product Model
CAMARAS CLIMATICAS TEMPERATURA Y HUMEDAD		ANGELANTONI CLIMATIC SYSTEMS (ACS)	CH2000 CW
Type	Common Descriptor	On Site Use	Sensor/Class type
Device	CÁMARA CLIMÁTICA	NO	
Description		Indication	Channel Num
Description of the instrument or product model			2
Remarks		Calibration Entity	
Observations on the instrument		INTA	
		Internal Structure	
		Laboratorio de Temperatura y Humedad	
		Business Line	
		select line	
		Certificate Label Template	
		CERT ENAC	

Fig. 2. Calibration of a climatic chamber – item details.

preparation, but also because the specialized technician must continue to carry out measurements without being able to pause for analysis, evaluation, and preparation of the final results report. A bottleneck occurs, delaying the completion of the service due to the backlog of pending data analysis and results. This is also not resolved by increasing the specialized technician staff, not only because it is not cost-effective, but also because, with the variability of calibration and test procedures, not all necessary technical competencies can be covered for the measurement evaluation.

Usually the laboratory organises the on-site calibration work sequentially at several customers in defined geographical region and performs the analysis of the data upon return to the permanent laboratory. It is not uncommon to discover that some of the measurements are unsatisfactory and part of the work has to be repeated.

The current version ISO/IEC 17025 [2] places emphasis on the use of information technologies as a means to ensure compliance with the requirements of the standard. This was a trigger to embark on the digital transformation of the CM&C. The following section describes the

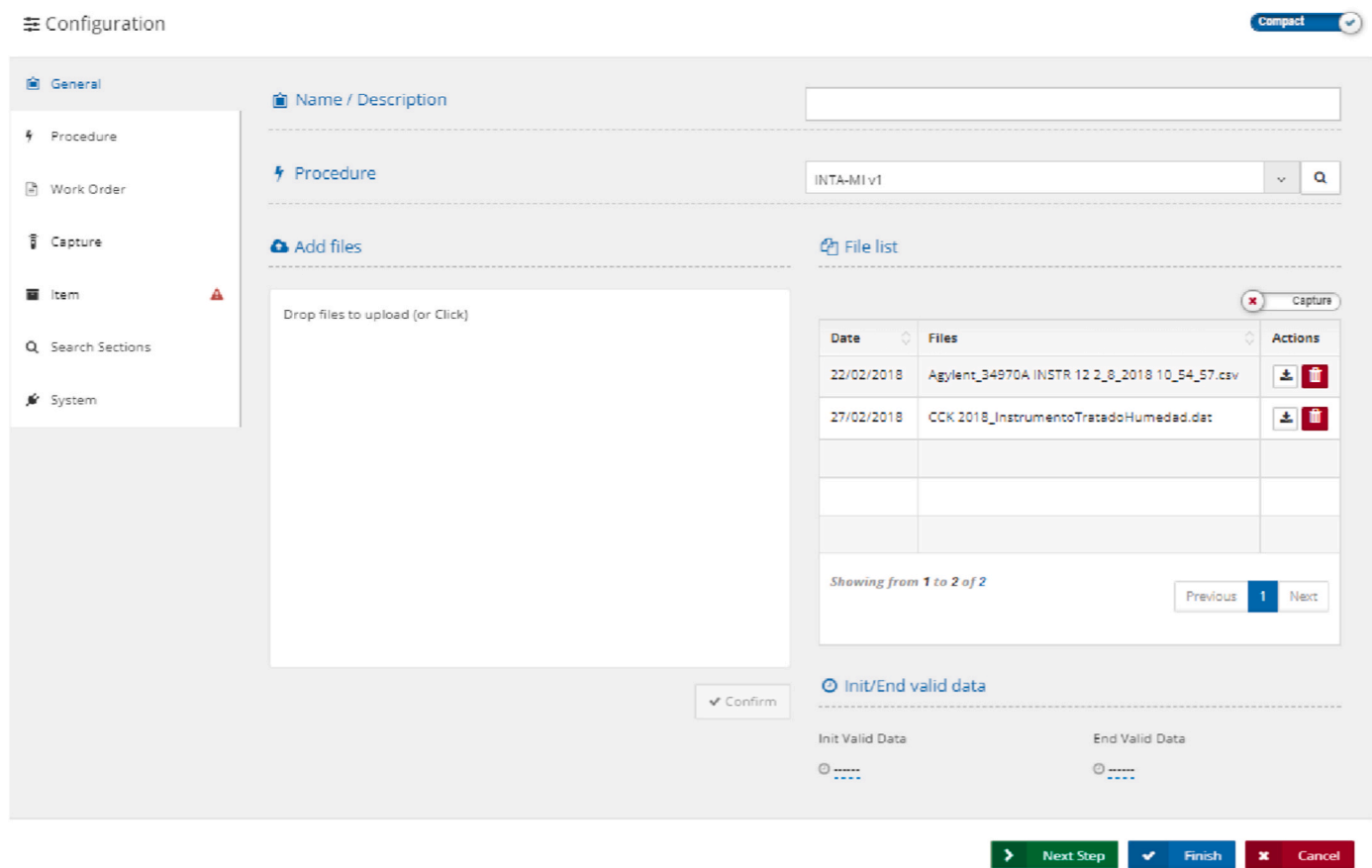


Fig. 3. Calibration of a climatic chamber - Settings.

adopted approach in the case of the characterization of temperature and humidity isothermal media.

2. Development, results and discussion

2.1. Advanced characterization of climatic chambers

In November 2016, work began on a proposal from a Spanish software development company, under the Technological Development Centre (CDTI) framework co-financed by the European Regional Development Fund (ERDF), with a duration of 24 months, which culminated at the end of 2018 [6]. It started from the existing version of the Whitestone Calibry software [7], designed for managing the equipment of calibration and test laboratories, mainly intended for small and medium-sized companies offering calibration services to numerous industrial clients within a classic laboratory environment.

The most complex innovation of the project was the design and development of algorithms for the automatic identification, based on defined acceptance criteria (e.g., by sector regulations), of stabilization periods of the measured physical parameters and the application of

mathematical and statistical analysis for the interpretation of the obtained results. These algorithms take into account the correlation between physical quantities and their impact on the final result in an objective and conclusive manner.

With this tool, the Laboratory’s operation is completely changed because automatic analysis allows not only the evaluation and calculation of results but also deciding whether it is necessary to adjust the instrumentation associated with the thermal installation just at the end of the characterization. This allows the client to proceed with commissioning immediately upon completing the measurement phase, with all quality guarantees. This actually entails an innovation in the service offered to the internal client. With this approach, the certificate is generated automatically and uploaded to customer portal, once checked and signed by the qualified staff at the permanent laboratory.

One of the most demanded calibrations in the Institute and one that is difficult to assume with the available personnel is the “on-site” characterization of isothermal media, especially climatic chambers. A formula was devised that, taking advantage of the concept of functional dependence and the existence of the new software solution, would change the business model applied to on-site calibrations.

Configuration

General

Procedure

Work Order

Capture

Item

Search Sections

System

Section finding configuration

Method to search calibration points
Search sections with lowest standard deviation

Points Validation Method
Nominal

Principal standard
Inst HR Sensor (Instrument)

Stable section length type
Measures

Number of measurements of a section
121

Section change value
0.5

Parameter	Type	Use in section find procedure	Maximum standard deviation	Minimum number of measures
MPR	Standard	ON	3	4
S1	Standard	ON	3	4
S2	Standard	ON	3	4
S3	Standard	ON	3	4
S4	Standard	ON	3	4
S5	Standard	ON	3	4
S6	Standard	ON	3	4
S7	Standard	ON	3	4
S8	Standard	ON	3	4
S9	Standard	ON	3	4
Inst HR Sensor	Instrument	ON	3	4
Inst Temp Sensor	Instrument	ON	3	4

Next Step Finish Cancel

Fig. 4. Calibration of a climatic chamber - Section search.

The change consists of incorporating technicians from the unit that demands the service (client) into our quality system and qualifying them to perform the calibrations with our equipment and controlling the entire analysis and certificate issuance process from the central headquarters in Torrejón de Ardoz (Madrid), under our ENAC accreditation [1].

Two measurement systems were acquired for this purpose. They consist of an MBW 473HX dew point hygrometer and an MBW T12 temperature recorder with 12 platinum resistance sensors and the corresponding transport cases. These cases are then inserted into an aluminium chest with absorbent material and impact indicators for transportation. The equipment is periodically calibrated in our temperature and humidity laboratory, within the accredited CMC.

This equipment complements another used to date with other brands and models of hygrometer and temperature recorder belonging to the

same instrument families, which are used in the calibration of climatic chambers.

2.2. Example of characterization of a climatic chamber

To illustrate the functionality, the calibration data of a climatic chamber are analysed in the application. Fig. 2 shows the item details:

In the configuration tab, within calibration, the files of the standards and the climatic chamber are uploaded (Fig. 3). In the case of local data collection, the files provided by the data acquisition system are analysed, uploaded by the technician performing the calibration.

By clicking the next step button, the configuration of the measurement system used is obtained. In the “section search” tab, criteria for searching calibration points are defined, as shown in the following figure. The analysis of the readings of all channels has been enabled for a

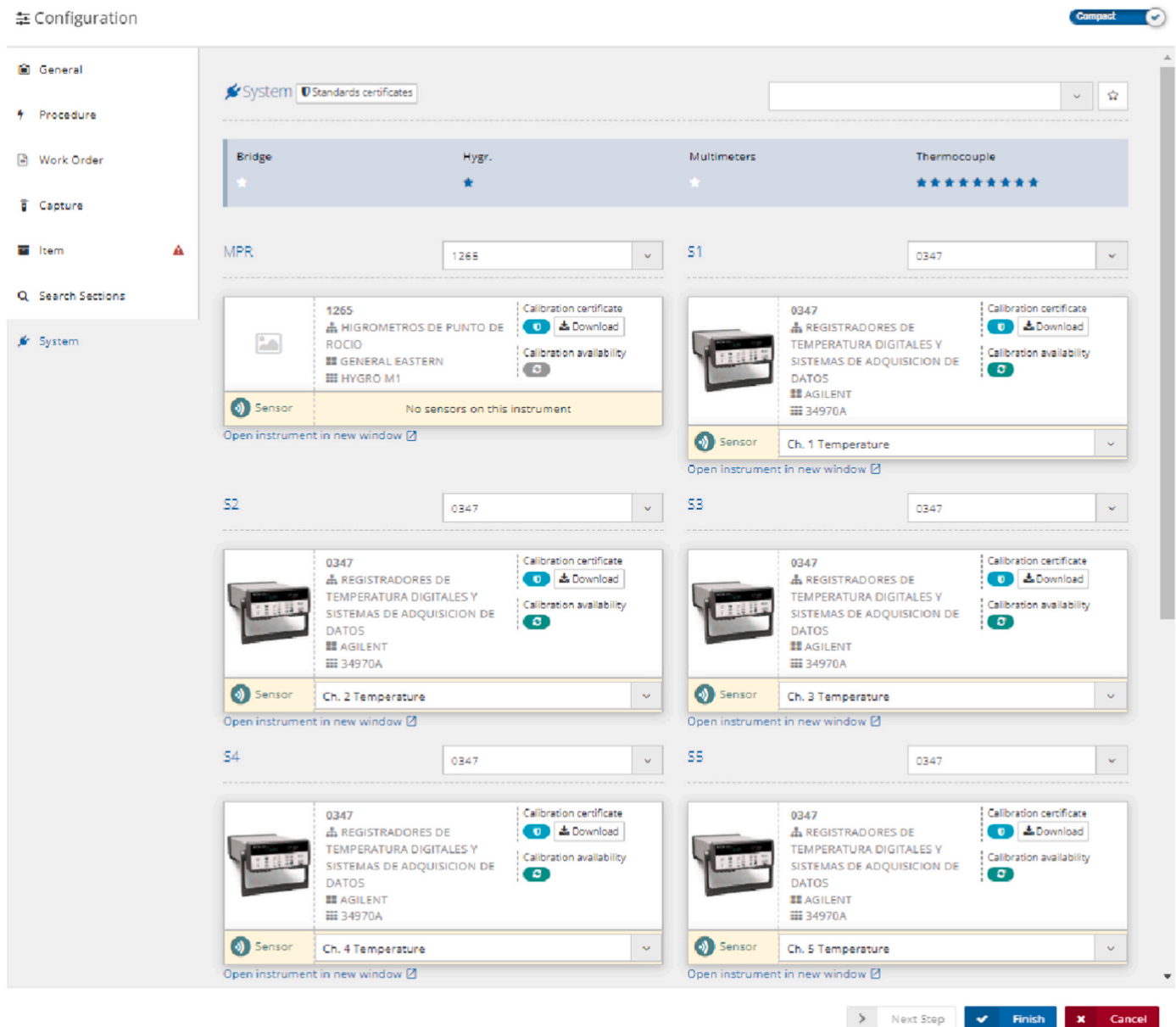


Fig. 5. Calibration of a climatic chamber - System.

total of 121 readings (Fig. 4).

In the system tab, we can see the equipment used in the calibration (Fig. 5).

In Fig. 6, we can see in the calibration tab the file data and the stable points detected with 121 readings.

With the cursor, the area of any point can be expanded, and the readings are observed in detail. The channels displayed can be added or removed simply by clicking below on the channel. Below in the same figure, Fig. 7, the expanded detail is shown.

By clicking the “play” button, all stable point calculations are

performed. These are divided in the summary section into Standards, calculations, instruments, uncertainty calculations, and correction factors, as seen in Fig. 8.

In the uncertainty calculations tab, detailed calculation for all points is shown on seven tabs for stability, uniformity, and temperature indication, dewpoint determination, relative humidity stability, uniformity and indication. Fig. 9 shows the temperature and humidity indication calculations of the second point, (90 %rh at 50 °C), as an example.

By selecting “generate draft” in the actions, a draft of the certificate that meets all ENAC requirements [5] is automatically generated. Fig. 10

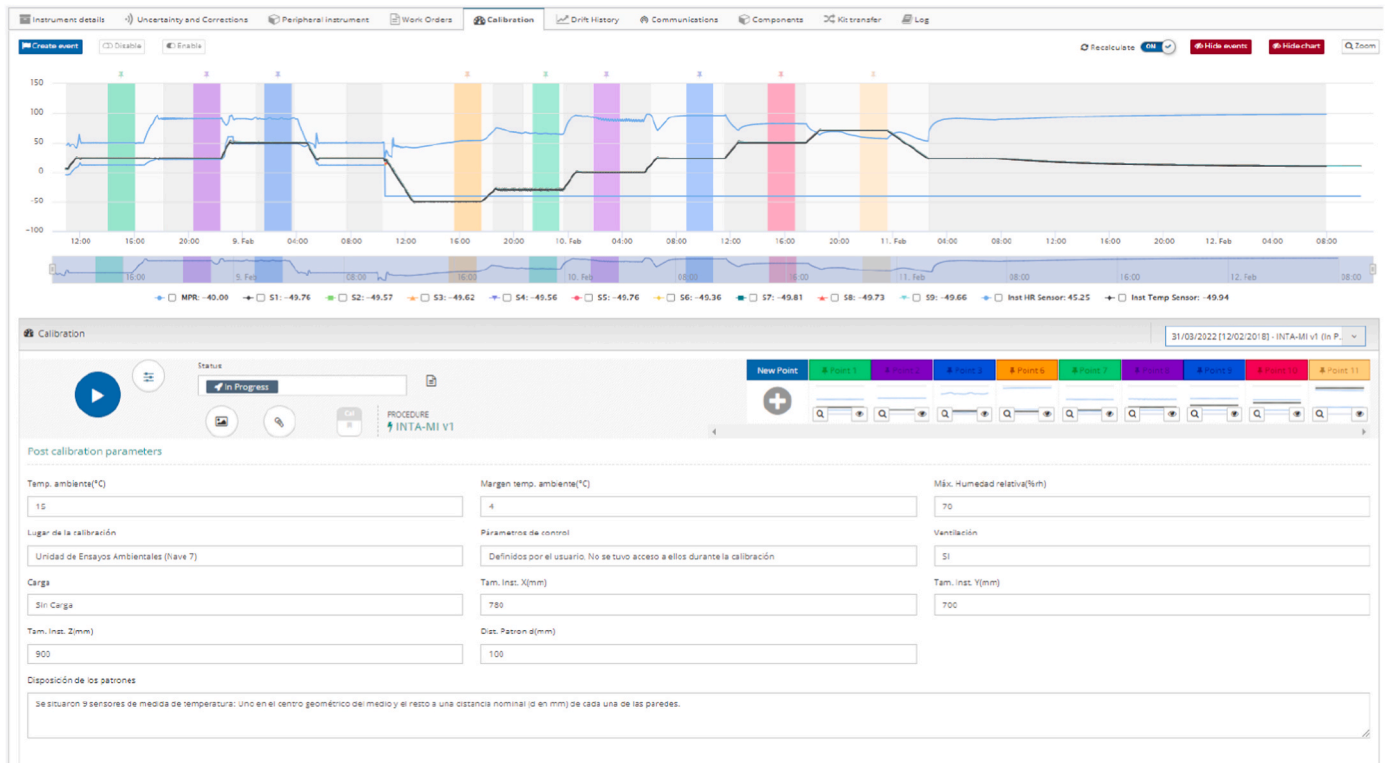


Fig. 6. Calibration of a climatic chamber - Calibration.

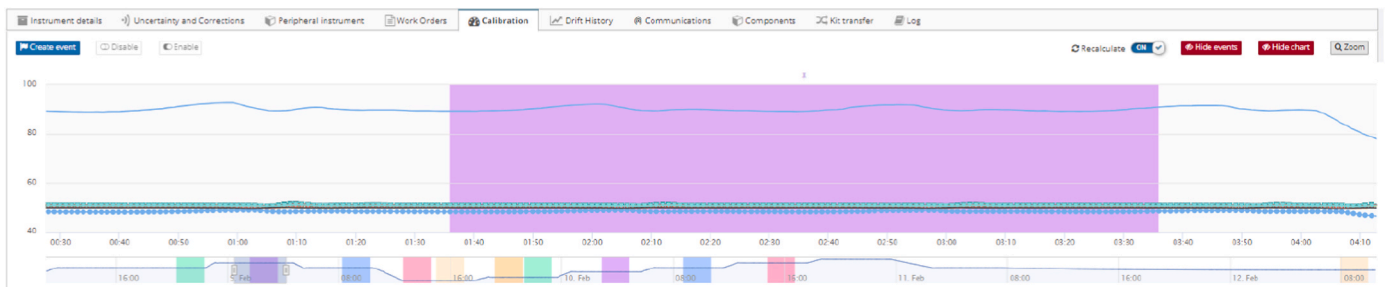


Fig. 7. Calibration of a climatic chamber - New item with enlarged detail.

reproduces the main sections of the certificate obtained in draft version with the results of the second point.

By selecting finish in the actions button, the certificate goes through the signing process and is automatically uploaded to the client portal. The system notifies the client that the certificate is available on the portal. This solves the confidentiality problem when certificates were sent by email.

3. Conclusions

An application of the digital transformation of the Metrology and

Calibration Centre of INTA has been presented. The new approach applied to the on site characterization of climatic chambers has been presented.

In the characterization of isothermal media and thermal installations, the advantages of the available functionalities are of high impact. The algorithms developed and implemented in the software solution, allow in a few seconds, represent graphically and numerically the plateaus that best meet the selection criteria. This completes the data analysis, even before dismantling the sensors from the chamber, and makes the certificate available for the signature of the technical manager immediately.

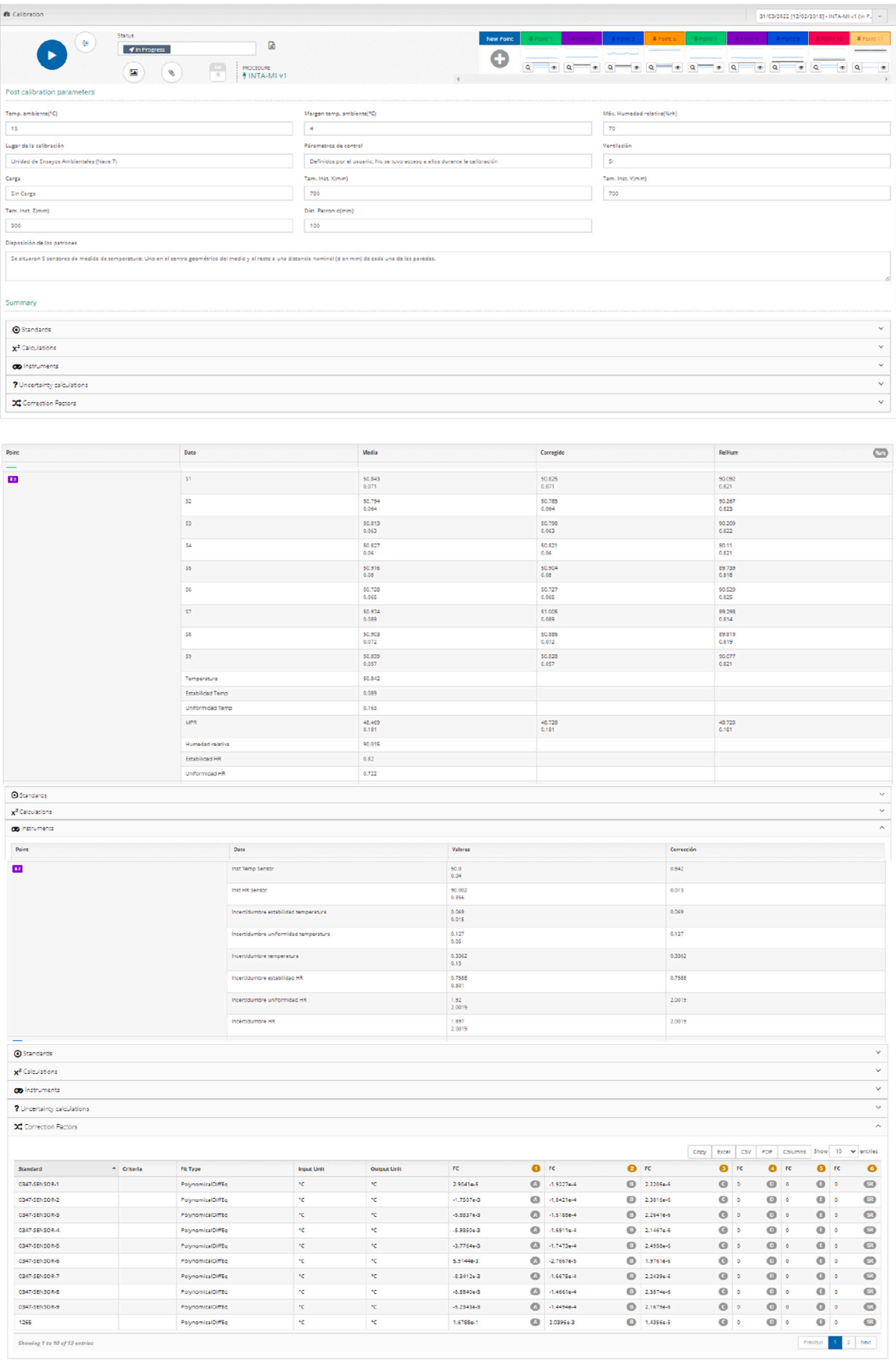


Fig. 8. Calibration of a climatic chambers - calculations.

Standards										
Calculations										
Instruments										
Uncertainty calculations										
Estabilidad Temperatura Uniformidad Temperatura Indicación Temperatura Determinación del punto de rocío Estabilidad humedad relativa Uniformidad humedad relativa Indicación humedad relativa										
Code	Type	Uncertainty component	Value	Unit	Prob Distrib	Divider	Gi	ui	vi	uif/vi
Reference determination										
A1	A	Desv. tip. Lecturas MI	0.0500	°C	N	1	1	0.0500	120	5.21e-8
B1	B	Calibración TLD	0.0200	°C	N	2	1	0.0100	1000000	1.00e-14
B2	B	Estabilidad largo plazo TLD	0.0200	°C	R	1.73	1	0.0115	1000000	1.70e-14
B3	B	Linealidad y sensib. conjunto TLD	0.0200	°C	R	1.73	1	0.0115	1000000	1.70e-14
B4	B	Efectos de radiación	0.100	°C	R	1.73	1	0.0577	1000001	1.11e-11
B5	B	Efectos de carga	0	°C	R	1.73	1	0	1000002	0
B6	B	Estabilidad temperatura	0.0894	°C	N	1	1	0.0894	1000000	6.50e-11
B7	B	Uniformidad temperatura	0.163	°C	R	1.73	1	0.0941	1000000	7.80e-11
B8	B	Determinación estabilidad	0.0686	°C	N	2.01	1	0.0341	1000000	1.35e-12
B9	B	Determinación uniformidad	0.127	°C	N	2.00	1	0.0636	1000000	1.64e-11
uc(t)		Combined uncertainty			N		0.168		1.528e+4	
U		Expanded uncertainty			N		0.3362		1.520e+4	
Calibration										
Standards										
Calculations										
Instruments										
Uncertainty calculations										
Estabilidad Temperatura Uniformidad Temperatura Indicación Temperatura Determinación del punto de rocío Estabilidad humedad relativa Uniformidad humedad relativa Indicación humedad relativa										
Code	Type	Uncertainty component	Value	Unit	Prob Distrib	Divider	Gi	ui	vi	uif/vi
Reference determination										
A1	A	Temperatura de rocío de referencia	0.0416	°C	N	2.00	4.53	0.0942	100000	7.89e-10
B1	B	Temperatura ambiente de referencia	0.936	°C	N	2.00	4.46	0.760	1000000	3.17e-7
B2	B	Función de referencia ev (numerador)	0.00101	°C	N	1	4.53	0.00459	1000000	4.45e-16
B3	B	Función de referencia ew (denominador)	0.000996	°C	N	1	4.46	0.00446	1000000	3.94e-16
B4	B	Resolución MI	0.0500	°C/h	R	1.73	1	0.0289	1000000	0.04e-13
B5	B	Lecturas MI	0.856	°C/h	R	1.73	1	0.484	1000000	5.95e-8
B6	B	Reproducibilidad instrumento	0.500	°C/h	R	1.73	1	0.289	1000000	6.94e-9
uc(t)		Combined uncertainty			N		0.949		2.109e+6	
U		Expanded uncertainty			N		1.897		2.109e+6	
Calibration										

Fig. 9. Calibration of a climatic chamber - Uncertainty calculation.

This reduces the delivery time from typically two weeks for analysis to a few minutes, as there are no pending tasks upon return to the laboratory that accumulate to ongoing work.

This avoids the consequences of errors that frequently occur on-site upon discovering upon return to the permanent laboratory that thermal stabilization had not been waited long enough or that one of the sensors provides dubious results, with the considerable cost savings of travel and technician hours that would have been incurred if the calibration had to be repeated at the installation. All this when using your own personnel (for external client calibrations). But the impact is even greater on the characterizations of INTA isothermal media, in which the displacement of own personnel is not required, as the work is carried out by the operator of the client unit, which frees up CMYC resources and represents a substantial economic saving for INTA, by dispensing with travel

expenses and per diems of personnel.

The acquisition of additional measurement systems has allowed simultaneous calibrations to be carried out in different locations, with total supervision by technicians in Torrejón with the same platform connected to the Institute's intranet (or accessible from any internet access, even from corporate mobile devices), which increases productivity without increasing resources.

This change in the business model has allowed for optimal service without resorting to outsourcing or subcontracting due to the inability to meet the increased demand for on-site calibration after integration.

The impact on institutional image is also significant with this new system and the positive effect on the motivation of technical staff, who no longer suffer from the quantity of pending analyses, and particularly on the technical office staff who no longer have to deal with frequent



CERTIFICADO DE CALIBRACIÓN
Calibration Certificate
Número Draft
Number
Página 1 de 14 páginas
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Ministerio de Defensa, Secretaría de Estado de la Defensa,
INSTITUTO NACIONAL DE TÉCNICA AEROSPAZIAL
Centro de Metrología y Calibración
Carretera de Ajalvir, km 4
28850 Torrejón de Ardoz, Madrid, España
Teléfono: (+34) 915 201 714 Telefax: (+34) 915 201 645



OBJETO
Item

Cámara Climática

MARCA
Mark

ANGELANTONI CLIMATIC SYSTEMS (ACS)

MODELO
Model

CH2000 CW

IDENTIFICACIÓN
Identification

CC01
Cod. Int.: CC01

SOLICITANTE
Applicant

5020 CENTRO DE METROLOGÍA Y CALIBRACIÓN
Ctra. Torrejón-Ajalvir, km. 4.5, 28850, Torrejón de Ardoz

FECHAS DE CALIBRACIÓN
Date/s of Calibration

8 de febrero de 2024 - 12 de febrero de 2024



Este certificado se expide de acuerdo con las condiciones de la acreditación concedida por ENAC que ha comprobado las capacidades de medida del laboratorio y su trazabilidad a patrones nacionales o internacionales.
ENAC es firmante del Acuerdo de Reconocimiento Mutuo (MLA) de certificados de calibración de European Cooperation for Accreditation (EA) y de International Laboratories Accreditation Cooperation (ILAC).
This certificate is issued in accordance with the conditions of accreditation granted by ENAC which has assessed the measurements capability of the laboratory and its traceability to national or international standards.
ENAC is one of the signatories of the Multilateral Agreement of the European Cooperation for Accreditation (EA) and the International Laboratories Accreditation Cooperation (ILAC).



CERTIFICADO DE CALIBRACIÓN
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Acreditación número: Nº 16/LC.10.007

RESULTADOS OBTENIDOS (Punto de Consigna: 50.0 °C / 90.0 %hr)

Ud.	VALOR DE REFERENCIA	LECTURA INSTRUMENTO	CORRECCIÓN	INCERTIDUMBRE (k=2)
°C	50,84	50	0,84	0,34
%hr	90,02	90	0,01	2

Tabla 1: Indicación

Ud.	ESTABILIDAD	INCERTIDUMBRE ESTABILIDAD	UNIFORMIDAD	INCERTIDUMBRE UNIFORMIDAD
°C	0,09	0,07	0,16	0,13
%hr	0,82	0,76	0,72	2

Tabla 2: Estabilidad y Uniformidad

	Ud.	S1	S2	S3	S4	S5	S6	S7	S8	S9
VALOR	°C	50,82	50,79	50,8	50,82	50,9	50,73	51,01	50,89	50,83
DESVIACION	°C	0,07	0,06	0,06	0,06	0,08	0,07	0,09	0,07	0,06
MÁXIMO	°C	51,11	51,05	51,06	51,07	51,23	51	51,38	51,18	51,06
MÍNIMO	°C	50,64	50,62	50,64	50,66	50,68	50,56	50,78	50,69	50,67

	Ud.	S1	S2	S3	S4	S5	S6	S7	S8	S9
VALOR	%hr	90,09	90,27	90,21	90,11	89,74	90,53	89,29	89,82	90,08
DESVIACION	%hr	0,82	0,82	0,82	0,82	0,82	0,83	0,81	0,82	0,82
MÁXIMO	%hr	92,26	92,39	92,31	92,22	91,91	92,54	91,48	92,07	92,17
MÍNIMO	%hr	88,53	88,79	88,75	88,7	88	89,01	87,35	88,2	88,74

Tabla 3: Valores individuales

TIEMPO DE REGISTRO	HORA INICIO	HORA FIN
120m	09/02/24 1:35	09/02/24 3:35

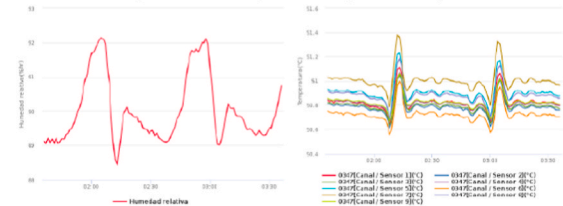


Fig. 10. Calibration of a climatic chamber - Certificate.



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CALIBRACIÓN:
La calibración se realizó in-situ en la dirección indicada en el apartado "Solicitante" en el lugar denominado Unidad de Ensayos Ambientales (Nave7)
La calibración se realizó en los siguientes puntos:

PUNTO CONSIGNA	TIEMPO MUESTREO	TIEMPO ESTABILIZACIÓN	TIEMPO DE MEDIDA
(23.0, 50.0 y 24.0)°C	1m	> 120 min	120m
(-50.0, -50.0, -30.0, -30.0, 1.0 y 10.0)°C	59s	> 120 min	120m
23.0°C	1m 1s	> 120 min	119m
50.0°C	59s	> 120 min	120m

Parámetros de control:

- Definidos por el usuario, No se tuvo acceso a ellos durante la calibración
- Ventilación: SI
- Carga: Sin Carga

Ubicación de patrones:
Se situaron 9 sensores de medida de temperatura: Uno en el centro geométrico del medio y el resto a una distancia nominal (d en mm) de cada una de las paredes.
Procedimiento utilizado: TH/PRC/7234/103/INTA
Condiciones ambientales: Temperatura (15 ± 4) °C y la Humedad Relativa <70 %hr

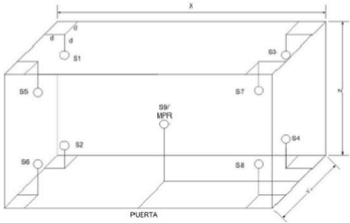
DEFINICIONES:
Estabilidad: Máxima de las desviaciones típicas, de cada uno de los patrones ubicados dentro del volumen útil, durante el tiempo de medida.
Uniformidad: Máxima diferencia entre cualquier punto y el valor medio de todos los puntos dentro del volumen útil, durante el tiempo de medida.
Valor de referencia: Valor promedio de los puntos del volumen útil, durante el tiempo de medida.

INCERTIDUMBRE:
La incertidumbre expandida de medida se ha obtenido multiplicando la incertidumbre típica de medición por el factor de cobertura k=2 que, para una distribución normal, corresponde a una probabilidad de cobertura de aproximadamente el 95%.
La incertidumbre típica de medida se ha determinado conforme al documento EA-4/02 M:2013.
Los valores e incertidumbres asignados corresponden al momento de la medida, no considerándose la estabilidad del instrumento a más largo plazo.



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DISPOSICIÓN DE PATRONES:



Sensores:

S1	0347/1
S2	0347/2
S3	0347/3
S4	0347/4
S5	0347/5
S6	0347/6
S7	0347/7
S8	0347/8
S9	0347/9
MPR	1265

Dimensiones:

X	760	mm
Y	700	mm
Z	900	mm

OBSERVACIONES:
Este certificado no podrá ser reproducido parcialmente sin la aprobación por escrito del laboratorio que lo emite.

e9

client complaints.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgments

We thank CDTI for funding the CDTI IDI-20170265 project “Development of a software application for the automation of the analysis of the calculations of the tests and measurements with metrological traceability” and the team at Whitestone Technology and INTA, whose dedication and effort made it possible to develop the software tool used in this work.

CDTI is a Business Public Entity under the Ministry of Science, Innovation and Universities that promotes innovation and technological development of Spanish companies (<https://www.cdti.es/en/about-us>).

References

- [1] ENAC accreditation 16/LC10.007. Current scope available at <https://www.enac.es>. (Last accessed 05/04/2024.).
- [2] ISO/IEC 17025:2017. General requirements for the competence of testing and calibration laboratories.
- [3] TH/PRC/7234/103/INTA Characterisation of temperature and humidity environmental chambers.
- [4] TH/PRC/7234/105/INTA On site characterisation of environmental chambers and temperature and humidity instruments.
- [5] NT - 04 Rev, 3 Characterisation of isothermal media, Spanish. Available at, <https://www.enac.es/>, 2014.
- [6] Project CDTI IDI-20170265 “Development of a software application for the automation of the analysis of the calculations of the tests and measurements with metrological traceability”.
- [7] WHITESTONE Calibry <http://calibry.com/>.

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