CCM Key Comparisons on Gas Pressure

CCM.P-K2.2020, (25 – 350) kPa, Absolute Mode

CCM.P-K1.b.2020, (25 – 350) kPa, Gauge Mode,

CCM.P-K1.c.2020, (0.7 – 7) MPa, Gauge Mode

Technical Protocol

Pilot laboratory: Centro Nacional de Metrología (CENAM), Mexico
Co-pilot laboratory: Physikalisch-Technische Bundesanstalt (PTB), Germany

1. Introduction

At the meeting of the CCM Working Group Pressure and Vacuum held in Pereira, Colombia BIPM on 11 May 2017, it was decided to carry out new key comparisons (KCs) of gas pressure standards in the ranges of (25 – 350) kPa of absolute, (25 – 350) kPa of gauge and (0.7 – 7) MPa of gauge pressure. Previous CCM KCs in these pressure ranges and modes, CCM.P-K2, CCM.P-K1.b and CCM.P-K1.c, were carried out in 1998-2001, 1995-1997 and 1997-1998, respectively, and needed renewal. CENAM, Mexico, suggested providing a transfer standard (TS) for the new KCs and was approved to pilot the KCs. Later, PTB, Germany was agreed to co-pilot the KCs.

This Technical Protocol specifies the procedures to be followed in the comparisons and has been prepared in accordance with guidelines "Measurement comparisons in the CIPM MRA", CIPM MRA-D-05, Version 1.6 of March 2016.

2. Participants

The group of participants – National Metrology Institutes (NMIs) was defined to have representatives from the following Regional Metrology Organisations (RMOs):

AFRIMETS – NIS (Egypt)
APMP – KRISS (Korea), NMIJ (Japan)
COOMET – VNIIM (Russia) PTB (Germany)
EURAMET – LNE (France), METAS (Switzerland)
SIM – NIST (USA), CENAM (Mexico).

The NMIs along with their contact persons and addresses for the delivery of the transfer standard are listed in Table 1.

Table 1. List of participating NMIs

NMI, contact person(s), e-mail(s), phone(s)	Delivery address
CENAM Jorge C. Torres-Guzman jtorres@cenam.mx Jesus Aranzolo jaranzol@cenam.mx +52-442-211-0572	CENAM Centro Nacional de Metrología Carretera a los Cues km 4.5 El Marques Queretaro C. P.: 76241 MEXICO
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PTB Wladimir Sabuga wladimir.sabuga@ptb.de +49-531-592-3230	PTB Working Group "Pressure" 3.33 Bundesallee 100 38116 Braunschweig GERMANY

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NIS Alaaeldin A. Eltawil - 00201000305355 , eltaweel38@yahoo.com Shaker Gelany - 00201010304830 - shaker9595@yahoo.com Ahmed Salama - 00201000145359, ahmeddosoki@yahoo.com	National Institute of Standards (NIS) - Tersa St., El-Haram, ElGiza P.O. 136 Giza code: 12211 EGYPT
VNIIM Irina Sadkovskaya, siv@vniim.ru, Roman Teteruk r.a.teteruk@vniim.ru +7-812-575-06-14	D.I. Mendeleyev Institute for Metrology Moskovsky pr. 19 190005 St. Petersburg RUSSIA
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LNE Pierre Otal, pierre.otal@lne.fr, Djilali Bentouati djilali.bentouati@lne.fr +33-1-40-43-39-63, +33-1-40-43-37-36	LNE Pressure and Vacuum Section 25 avenue Albert Bartholomé 75015 Paris FRANCE

3. Time table

The measurements with the transfer standards will be performed in accordance with the schedule given in Table 2.

Table 2. Time table of TS circulation

Month.Year	NMI
8-9.2020	CENAM, initial study
10-11.2020	NIST
2-3.2021	PTB
4-5.2021	KRISS
6-7.2021	NMIJ
8-9.2021	CENAM, middle study, ATA carnet issue
10-11.2021	NIS
12.2021-1.2022	VNIIM
2-3.2022	METAS
4-5.2022	LNE
6-7.2022	PTB, stability check
8-9.2022	CENAM, final study

Each time slot in the table covers the time of measurement and the time of the transportation to the next NMI. This means that TS should arrive each NMI before the beginning of the respective time slot. Each participant is requested to keep strictly to this schedule and to send TS to the next laboratory as soon as the measurements are finished and not later than 2 weeks before the beginning of the time slot of the subsequent laboratory.

Sending TS, the laboratory has to inform the pilot and co-pilot laboratories as well as the addressee about the TS departure.

The receipt should be confirmed to the pilot and co-pilot laboratories as well as to the sender.

In the case of any delay or circumstances which will lead to a delay, the participant shall inform the pilot and co-pilot laboratories as well as the destination laboratory about the problem.

4. Transportation

Each participant is responsible for the transportation of TS to the next participant according to the circulation scheme. The transport way should be chosen by the participant to deliver TS to the next participant safely and in time. All TS parts should be carefully packed using original packing materials and containers. Completeness of all components is to be checked before departure and after arrival of TS.

From the second round sending TS abroad, an ATA Carnet will be prepared by CENAM.

A care should be taken that the ATA Carnet always accompanies TS. The ATA Carnet should be put into the outside envelope attached to the TS box. On arrival, availability of the ATA Carnet should be checked by the participating laboratory, and in a case of its absence, the pilot and co-pilot laboratories should be informed, and an enquiry for it should be started.

The indication that the instrument can be unpacked and handled only by qualified personnel should be clearly seen on the package. After arrival, TS shall be first inspected visually and deviations, if any, recorded and reported to the pilot and co-pilot laboratories.

5. Costs

Each participant bears the costs for its own measurements, any customs charges, transport costs to the next participant and the costs occurring from a loss or damage of TS within its country.

6. Transfer standard

The TS is a pressure balance model PG7601 with a mass set and two piston-cylinder assemblies (PCAs) of 10 cm^2 and 0.5 cm^2 effective area, all parts produced by DH Instruments (Fluke). The TS is provided by CENAM.

The PCAs of TS were manufactured in USA and therefore are considered sufficiently old to have stable values of their effective areas in the period of the comparison. Nevertheless, the TS stability will be checked by the pilot and co-pilot laboratories comparing the results of former calibrations with those obtained at the beginning of the comparison, at the intermediate test and at the final study.

Details of TS initial evaluation by the pilot laboratory and all relevant technical data of TS are given in Annex 1.

The list of TS components is given below:
1. Pressure balance model PG7601, serial no. 645
2. 10 cm^2 PCA, serial no. 1192
3. 0.5 cm^2 PCA, serial no. 1150
4. Mass carrying bell, serial no. 792
5. Temperature probe serial no. U626 (built in pressure balance)
6. Terminal, model PG Terminal, Part 401284, serial no. N/A
7. Power supply AC input (100-240) V, (50-60) Hz
8. Power supply cord
9. PG7601™ PISTON GAUGES, Operation and Maintenance Manual

Note: Be aware that, due to the nature of the part and difficulty to transport it, the bell jar is not included. The participant will have to perform measurements with the TS using its own bell jar.

The transfer standard is sent in one wooden box. The weight of the box, which contains 3 rigid boxes, is approximately 127 kg. The box has the following dimensions (111 × 76 × 61) cm. Inside the wooden box, there are three boxes made of thick rigid plastic, one big and 2 small. Contents of the wooden box is presented in the following table 3.

Table 3. Detailed contents of transportation wooden box

Box	Description
1 (Big) Brand: DH Instruments, Inc, Model: PG-7601, Serial: 645	1 Base pressure balance with accessories Brand: DH Instruments, Inc., Model: PG-7601, Series: 645 1 Red plug on base mounting post 1 Piston-cylinder in carrying case Brand: DHI Model: PC-7100 / 7600-10-TC Serial; 1192 1 Piston-cylinder in carrying case Brand: DHI Model: PC-7100 / 7600-200 Serial; 1150 1 Electronic terminal Brand: DHI, Model: PG-TERMINAL Part: 401264 Serial: N / A 1 Electronic Terminal Wire Part: 574 1 Power cord Part: 645 1 User Manual Reference Pressure Balance, Brand: DH Instruments, Inc, Model: PG7601 Number: 114-3 1 One Quick Clamp No Brand, No Model, No Serial. 1 One stainless steel centering ring, No Brand, No Model, No Serial. 1 90 degree tube and valve Brand: Swagelok, Model: SS-42F2 1 Plunger mounting tool - red cylinder No brand, No Model, No Serial. 1 Set of millimeter allen wrenches (8 pcs) No brand, No model, No serial. 2 Maxiflex Gloves Brand: ATG, Model: 34-874
2 (Small 1) Brand: DH Instruments, Inc, Model No, Serial: 2467 Part: 401425	1 Set of 16 auxiliary standard masses in their case Brand: DHI, Model: MS- 7001-32, Serial: 2467 (10mg:1pcs, 20mg: 2pcs, 50mg:1pcs, 100mg:1pcs, 200mg:2pcs, 500mg:1pcs, 50g:1pcs, 20g:2pcs, 10g: 1pcs, 5g: 1pcs, 2g: 2pcs, 1g: 1pcs, includes 1 plastic tweezers) 8 Standard masses, DHI Brand, Serial: 2467 (4.5Kg: 1pcs, 2Kg: 2pcs, 1Kg: 1pcs, 0.5Kg: 1pcs, 0.2Kg: 2pcs, 0.1Kg: 1pcs.) 1 Mass holder hood, No Brand, No Model Serial: 792
3 (Small 1) Brand: DH Instruments, Inc, Model No, Serial: 2467 Part: 401425	5 Standard masses Brand DHI, Serial: 2467 5 kg: 5pcs

The TS and all accompanying parts are the property of Fluke. The total cost of TS including the pressure balance, the PCAs and the mass set is approximately $111 654 USD.

7. Arrival and departure checks

When TS arrives at a participating laboratory, it should be checked by the laboratory personnel for damage and completeness of its components. The arrival check report presented in Annex 2 should be filled in and sent to the pilot and co-pilot laboratories as well as to the TS sender by e-mail.

When sending TS to the next participant, it should be checked again, and the departure check report given in Annex 3 should be filled in and sent to the pilot and co-pilot laboratories as well as to the destination laboratory by e-mail.

Follow the instruction in the Operation and Maintenance Manual when preparing the pressure balance for the work or for the shipping.

For countries in the second loop, verify that the ATA Carnet accompanies the TS.

8. Preparation and conditions of measurements

The transfer standard should be handled and the PCAs mounted in the pressure balance according to the instructions given in the Operation and Maintenance Manual.

Technical data and the results of a metrological characterisation of TS by the pilot laboratory are presented in Annex 1. They should help participants to verify that the TS operates properly. In the case of any anomaly or significant deviation from the results of the pilot laboratory, it should be contacted.

Gloves should be worn when handling the PCAs, the mass carrying bell and the masses of TS.

The piston-cylinder modules containing PCAs can be installed in the pressure balance platform without being dismantled.
However, if any anomaly in TS behaviour is observed, the magnetisation of the piston and cylinder is recommended to be checked. The magnetic flow density at their surfaces should not exceed $2 \cdot 10^{-4}$ Tesla. If it is higher, the parts should be demagnetised, and the magnetisation should be checked again.

To check the tightness of TS, the piston fall rates and free rotation times shall be measured at the conditions specified in Annex 1. Wait a minimum of 10 minutes after generating the pressure in the TS measurement system prior to starting the piston fall rate measurements in order to stabilise the TS temperature. The target fall rates are given in Annex 1. If the measured fall rates are too high or the free rotation times too short compared with the specified values, measures to seal up the system or to clean the PCA, respectively, should be undertaken. The piston and cylinder can be cleaned according to the usual practice in the laboratory. Recommended procedures for cleaning PCAs are given in Annex 4.

The TS pressure balance should be operated with clean nitrogen gas as a pressure-transmitting medium. If participant's LS is other than a gas operated pressure balance, e.g. a liquid column manometer, special measures should be taken to prevent contamination of TS with liquid substances such as mercury or oil. These measures should be reflected in the laboratory report. Nevertheless, each laboratory receiving TS should check that TS is clean, and, if it is contaminated, report this in the Arrival check protocol.

The temperature of TS is measured with a platinum resistance thermometer calibrated by the pilot laboratory (see Annex 1).

The reference temperature of the comparison is 20 °C. If measurements are performed at a temperature deviating from 20 °C, the effective area of TS should be referred to 20 °C using the piston-cylinder thermal expansion coefficient given in Annex 1.

TS is recommended to be located close to the laboratory's reference standard to keep the pressure line between the two instruments as short as possible.
It is also recommended to adjust the height position of TS to minimise the height difference between the reference level of TS specified in Annex 1 and the reference level of the laboratory standard.

In the equilibrium state, the piston of TS should not deviate from its working position by more than 1 mm.

The TS electronics requires to be warmed up for at least 6 h prior to start measurements

The direction of the piston rotation is clockwise. The rotation should be initiated by hand (in absolute with the aid of the automatic) and, at the equilibrium between the reference standard and TS, should be equal to 20 rpm for both pressure modes, gauge and absolute.

The time between a pressure level change and the acquisition of the data corresponding to the equilibrium of the laboratory standard and TS should be not shorter than 5 minutes.

9. Measurement procedures

The measurand of the comparisons is the effective area (A_p) of the respective PCA at 20 °C and a specified gauge pressure (p_e) or absolute pressure (p_a).

In gauge mode, it is calculated by equation (1):

$$A_p = \frac{\sum m_i g(1 - \rho_\mathrm{a}/\rho_i)}{p_\mathrm{e}\left[1 + (\alpha_\mathrm{p} + \alpha_\mathrm{c})(t - 20\ ^\circ\mathrm{C})\right]}, \qquad (1)$$

and in absolute mode, by equation (2):

$$A_p = \frac{\sum m_i g}{(p_\mathrm{a} - p_\mathrm{res})\left[1 + (\alpha_\mathrm{p} + \alpha_\mathrm{c})(t - 20\ ^\circ\mathrm{C})\right]}, \qquad (2)$$

where

m_i – true masses of the piston, the weight carrier and the mass pieces placed on the weight carrier of TS;
ρ_i – densities of the parts with masses m_i;
ρ_a – air density;
g – local gravity acceleration;
α_p and α_c – thermal expansion coefficients of the TS piston and cylinder materials, respectively;
t – TS temperature;
p_res – residual pressure in the TS bell jar when operated in absolute mode.

Pressures p_e and p_a are those generated by the laboratory standard at the TS reference level.

Values of m_i, ρ_i and $\alpha_\mathrm{p} + \alpha_\mathrm{c}$ are provided by the pilot laboratory (Annex 1).
Values of t and p_res are to be measured by the participant using the TS thermometer's and vacuum sensor's calibration data provided by the pilot laboratory (Annex 1).
Values of ρ_a, g, p_e and p_a are to be measured by the participant.

9.1. Measurements within CCM.P-K2.2020, (25 – 350) kPa, absolute mode

The measurements shall be performed using the 10 cm^2 PCA of TS. They shall include five cycles each with nominal pressures generated in the following order (25, 50, 100, 150, 200, 250, 300, 350, 350, 300, 250, 200, 150, 100, 50, 25) kPa.

The pressure points of (250, 300, 350) kPa are optional if they lie beyond the LS operation range.

The TS piston must be loaded by the masses provided with TS in the following combinations:

Nominal pressure / kPa	Load
25	piston, weight carrier, 200 g, 500 g, 1 kg
50	piston, weight carrier, 200 g, 2 kg (1), 2 kg (2)
100	piston, weight carrier, 200 g, 500 g, 2 kg (1, 2), 4.5 kg
150	piston, weight carrier, 200 g, 500 g, 2 kg (1), 2 kg (2), 4.5 kg, 5 kg (1)
200	piston, weight carrier, 200 g, 500 g, 2 kg (1), 2 kg (2), 4.5 kg, 5 kg (1, 2)
250	piston, weight carrier, 200 g, 500 g, 2 kg (1), 2 kg (2), 4.5 kg, 5 kg (1, 2, 3)
300	piston, weight carrier, 200 g, 500 g, 2 kg (1), 2 kg (2), 4.5 kg, 5 kg (1, 2, 3, 4)
350	piston, weight carrier, 200 g, 500 g, 2 kg (1), 2 kg (2), 4.5 kg, 5 kg (1, 2, 3, 4, 5)

No additional mass must be put on the TS piston. Pressure equilibrium between the TS and LS should be achieved by adjustment of the LS pressure.

9.2. Measurements within CCM.P-K1.b.2020, (25 – 350) kPa, gauge mode

The measurements shall be performed using the 10 cm^2 PCA of TS. They shall include five cycles each with nominal pressures generated in the following order (25, 50, 100, 150, 200, 250, 300, 350, 350, 300, 250, 200, 150, 100, 50, 25) kPa.

The mass combinations to generate these pressures are the same as in absolute mode specified in section 9.1

9.3. Measurements within CCM.P-K1.c.2020, (0.7 – 7) MPa, gauge mode

The measurements shall be performed using the 0.5 cm^2 PCA of TS. They shall include five cycles each with nominal pressures generated in the following order (0.7, 1, 2, 3, 4, 5, 6, 7, 7, 6, 5, 4, 3, 2, 1, 0.7) MPa.

The TS piston must be loaded by the masses provided with TS in the following combinations:

Nominal pressure / MPa	Load
0.7	piston, weight carrier, 2 kg (1), 1 kg
1	piston, weight carrier, 4.5 kg
2	piston, weight carrier, 4.5 kg, 5 kg (1)
3	piston, weight carrier, 4.5 kg, 5 kg (1, 2)
4	piston, weight carrier, 4.5 kg, 5 kg (1, 2, 3)
5	piston, weight carrier, 4.5 kg, 5 kg (1, 2, 3, 4)
6	piston, weight carrier, 4.5 kg, 5 kg (1, 2, 3, 4, 5)
7	piston, weight carrier, 4.5 kg, 5 kg (1, 2, 3, 4, 5), 2 kg (1, 2), 1 kg

In all measurements specified in 9.1, 9.2 and 9.3, the TS piston must be loaded only by the masses provided with TS in the combinations specified above. No additional mass must be put on the TS piston. Pressure equilibrium between the TS and LS should be achieved by adjustment of the LS pressure.

9. Report of results

Each participant should provide the pilot and co-pilot laboratories with the data of its own pressure standards, used in each of comparisons CCM.P-K2.2020, CCM.P-K1.b.2020 and CCM.P-K1.c.2020, filling in Table 5.1 or Table 5.2 given in Annex 5, as well as with any additional information, if useful.

It should be reported how TS was connected to LS and how their pressure equilibrium was achieved and controlled. When LS was operated with another pressure-transmitting medium than used in TS, details of separating the two different fluids should be reported.

Results of measurements in 5 individual cycles and a summary of the 5 cycles should be reported using forms given in:
Annex 6, Tables 6.1 and 6.2 for CCM.P-K2.2020,
Annex 7, Tables 7.1 and 7.2 for CCM.P-K1.b.2020,
Annex 8, Tables 8.1 and 8.2 for CCM.P-K1.c.2020.

In addition, a list of main uncertainty sources and their contributions to $u(A_p)$ for minimum and maximum pressure of each comparison, CM.P-K2.2020, CCM.P-K1.b.2020 and CCM.P-K1.c.2020, must be reported.

Each participant should report whether equations (1) and (2) or alternative equations were used for A_p calculation.

Equations for calculating p_e and p_a should be given.

Any additional information which, in opinion of the participating laboratory, is important for the interpretation of the comparison results is welcome.

Reports with the results of the measurements should be prepared as a WORD file with the tables from Annexes 6, 7 and 8 being additionally provided in an EXCEL file. The reports should be sent to the pilot and co-pilot laboratories by e-mail to

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within two months after finishing the measurements.

ANNEX 1. Technical data of the transfer standard

The transfer standard (TS), manufactured by DH Instruments (Fluke), comprises a base PG-7601, two piston-cylinder assemblies (PCAs) of 10 cm^2 and 0.5 cm^2 and a mass set. The TS components with their designations and properties are listed below.

Table 1.1. TS components

Base	
Type	PG-7601
Part number	N/A
Serial number	645
Mass set	
Serial number	2467
Density	7 890 kg/m^3 ; U = 1.75 kg/m^3
Mass carrying bell	
Serial number	792
True mass	0.300 002 5 kg; U = 2.5 x 10^{-6} kg
Density	4 893 kg/m^3 ; U = 97.84 kg/m^3
Thermometer	Temperature Sensor / Base
Type	Minco / DH Instruments
Serial number	U 626 / 645
Vacuum sensor	Vacuum Sensor / Base
Type	Granville-Phillips / DH Instruments
Serial number	371 /645

PCAs properties are given in the following Tables 1.2 and 1.3.

Table 1.2. Characteristics of the 10 cm² PCA

Type	PC-7100/7600-10-TC
Serial number	1192
Maximum pressure	350
Piston materials	tungsten carbide
Piston true mass and its uncertainty (*k* = 2) (kg)	0.500003 kg, $U = 15 \cdot 10^{-7}$ kg
Piston mean density and its uncertainty (*k* = 2)	10 080 kg/m³, $U = 170$ kg/m³
Thermal expansion coefficient of the PCA ($\alpha_p + \alpha_c$) and its uncertainty (*k* = 2)	$9.0 \cdot 10^{-6}$ °C^{-1}, $U = 9.0 \cdot 10^{-7}$ °C^{-1}
Piston fall rates and deceleration in absolute mode at pressures, initial rotation speed 50 rpm, piston 0.2 mm above working position. Pressure (deceleration in rpm/min, piston fall rate in mm/min)	25 kPa (4.9, 0.023); 50 kPa (1.9, 0.025); 100 kPa (1.3, 0.031); 150 kPa (1.0, 0.036); 200 kPa (0.8, 0.045); 250 kPa (0.8, 0.052); 300 kPa (0.5, 0.053); 350 kPa (0.5, 0.057)
Piston fall rates and deceleration in gauge mode at pressures, initial rotation speed 55 rpm, piston 0.5 mm above working position. Pressure (deceleration in rpm/min, piston fall rate in mm/min)	25 kPa (6.5, 0.01); 50 kPa (3, 0.016); 100 kPa (1.75, 0.026); 150 kPa (1.25, 0.033); 200 kPa (1, 0.037); 250 kPa (0.75, 0.051); 300 kPa (0.75, 0.061); 350 kPa (0.75, 0.066)
Pressure reference level respective to the low piston face	32.5 mm above the bottom of piston
Piston working position above its rest position	4.5 mm
Recommended piston maximum deviations from working position, ±, in mm	0.5
Typical cross-float sensitivity and reproducibility at pressures / kPa, in mg	10 mg or 0.0001 kPa at all pressures
Typical relative experimental standard deviation of the effective area at pressures / kPa, in 10^{-6}	2.3 relative (in 25 kPa) for absolute pressure 0.64 relative (in 25 kPa) for gauge pressure
Typical temperature drift of PCA over time of 8 h, in °C	0.10 °C / h Std ; 0.13 °C / h TS; 0.09 °C / h ambient

Table 1.3. Characteristics of the 0.5 cm^2 PCA

Type	PC-7100/7600-200
Serial number	1150
Maximum pressure	7 000 kPa
Piston materials	tungsten carbide
Piston true mass and its uncertainty (*k* = 2)	0.199 998 1 kg $U = 10 \cdot 10^{-7}$
Piston mean density and its uncertainty (*k* = 2)	7 964 kg/m^3, U = 98 kg/m^3
Thermal expansion coefficient of the PCA ($\alpha_p + \alpha_c$) and its uncertainty (*k* = 2)	$9.0 \cdot 10^{-6}$ °C^{-1}, $U = 9.0 \cdot 10^{-7}$ °C^{-1}
Piston fall rates and deceleration in gauge mode at pressures, initial rotation speed 60 rpm, piston 1 mm above working position. Pressure (deceleration in rpm/min, piston fall rate in mm/min)	0.7 MPa (0.88, 0.08); 1 MPa (0.63, 0.1); 2 MPa (0.38, 0.19); 3 MPa) (0.25, 0.24); 4 MPa (0.25, 0.30); 5 MPa (0.13, 0.33); 6 MPa (0.13, 0.36); 7 MPa (0.13, 0.40)
Pressure reference level respective to the low piston face	Bottom of piston
Piston working position above its rest position	4.5 mm
Recommended piston maximum deviations from working position, ±, in mm	0.5
Typical cross-float sensitivity and reproducibility at pressures / MPa, in mg	10 mg or 0.002 kPa at all pressures
Typical relative experimental standard deviation of the effective area at pressures / MPa, in 10^{-6}	0.49 / 0.700 MPa (max)
Typical temperature drift of PCA over time of 8 h, in °C	0.05 °C / h Std ; 0.04 °C / h TS; 0.15 °C / h ambient

Table 1.4. Mass set, calibration by the pilot laboratory (*k* = 2)

ID	Mass / kg	*U* mass / kg	Volume / kg/m^3	*U* Volume / kg/m^3
PC high 1150	0.1999981	1.0E-06	2.51128E-05	5.023E-07
PC low 1192	0.5000030	1.5E-06	4.96035E-05	8.366E-07
Bell 792	0.3000025	2.5E-06	6.13126E-05	1.226E-06
4.5 kg	4.5000631	2.5E-06	5.69500E-04	1.100E-07
5 kg 1	5.0000361	2.5E-06	6.34190E-04	1.200E-07
5 kg 2	5.0000188	2.5E-06	6.34170E-04	1.200E-07
5 kg 3	5.0000381	2.5E-06	6.34180E-04	1.200E-07
5 kg 4	5.0000421	2.5E-06	6.34180E-04	1.200E-07
5 kg 5	5.0000476	2.5E-06	6.34170E-04	1.200E-07
2 kg 1	2.0000280	2.0E-06	2.53159E-04	4.800E-08
2 kg 2	2.0000255	2.0E-06	2.53158E-04	4.800E-08
1 kg	1.00001077	5.0E-07	1.26586E-04	2.400E-08
500 g	5.00006E-01	5.0E-08	6.32760E-05	1.200E-08
200 g 1	1.99999E-01	2.5E-08	2.53246E-05	4.800E-09
200 g 2	2.00001E-01	2.5E-08	2.53119E-05	4.800E-09
100 g	9.99994E-02	2.0E-08	1.26507E-05	2.400E-09
50 g	5.000022E-02	1.0E-07	6.313159E-06	6.313E-08
20 g	2.000070E-02	4.2E-08	2.525341E-06	2.525E-08
20 g point	2.000077E-02	4.2E-08	2.525350E-06	2.525E-08
10 g	1.000063E-02	3.0E-08	1.262706E-06	1.263E-08
5 g	5.000419E-03	2.7E-08	6.313660E-07	6.314E-09
2 g	2.000456E-03	2.0E-08	2.525828E-07	2.526E-09
2 g point	2.000771E-03	2.0E-08	2.526226E-07	2.526E-09
1 g	1.000203E-03	5.0E-09	1.262883E-07	1.263E-09
500 mg	5.000640E-04	1.4E-08	6.313939E-08	6.314E-10
200 mg	2.000520E-04	1.0E-08	2.525909E-08	2.526E-10
200 mg point	2.000490E-04	1.0E-08	2.525871E-08	2.526E-10
100 mg	1.000370E-04	8.5E-09	1.263093E-08	1.263E-10
50 mg	5.001000E-05	1.4E-08	6.314394E-09	6.317E-11
20 mg	2.001700E-05	5.0E-09	2.527399E-09	2.528E-11
20 mg point	2.002900E-05	5.0E-09	2.528914E-09	2.530E-11
10 mg	1.001900E-05	4.0E-09	1.265025E-09	1.266E-11

Table 1.5. Thermometer, Sensor N. S. U626, calibrated by the pilot laboratory in the temperature range (17 to 23) °C (*k* = 2)

Standard /°C	Instrument /°C	Error /°C	U_E /°C
17.01	17.02	0.01	0.03
20.01	20.01	0.00	0.02
23.00	22.99	-0.01	0.03

Vacuum sensor

Calibration interval: 0 Pa to 10 Pa

Error = A + B × Indication (X)

Where:
A = -0.041858876 Pa
B = -0.479922259

Uncertainty of Error U = 0.78 Pa ($k=2$)

ANNEX 2. Arrival check protocol

Laboratory name:

Arrival of TS
Date:
From:

TS is free of damage (yes/no):
if not, describe the damage

TS set is complete (yes/no):
if not, indicate the missing part from the list below

1. Pressure balance model PG7601, serial no. 645
2. 10 cm^2 PCA, serial no. 1192
3. 0.5 cm^2 PCA, serial no. 1150
4. Mass carrying bell, serial no. 792
5. Temperature probe serial no. U626 (built in pressure balance)
6. Terminal, Part 401284, serial no. N/A
7. Power supply AC input (100-240) V, (50-60) Hz
8. Power supply cord
9. PG7601™ PISTON GAUGES, Operation and Maintenance Manual

<u>Be aware that no bell jar is included.</u>

Report date:
Name of inspecting person(s):
Address, phone, e-mail, if deviating from those given in section 2 “Participants”

ANNEX 3. Departure check protocol

Laboratory name:

Departure of TS
Date:
To:

TS is free of damage (yes/no):
if not, describe the damage

TS set is complete (yes/no):
if not, indicate the missing part from the list below

1. Pressure balance model PG7601, serial no. 645
2. 10 cm^2 PCA, serial no. 1192
3. 0.5 cm^2 PCA, serial no. 1150
4. Mass carrying bell, serial no. 792
5. Temperature probe serial no. U626 (built in pressure balance)
6. Terminal, Part 401284, serial no. N/A
7. Power supply AC input (100-240) V, (50-60) Hz
8. Power supply cord
9. PG7601™ PISTON GAUGES, Operation and Maintenance Manual

Be aware that no bell jar is included

Report date:
Name of inspecting person(s):
Address, phone, e-mail, if deviating from those given in section 2 “Participants”

ANNEX 4. Instructions for cleaning the piston-cylinder

First, the piston-cylinder module must be disassembled. Follow instructions of the Operation and Maintenance Manual, section 5.3.2.1.

The cleaning should be performed using deionised or distilled water and soap, see Operation and Maintenance Manual, section 5.3.4. Best results have been obtained with a liquid soap that is easily soluble in water at room temperature. Some soaps have additive like titanium dioxide powder (white colour) or glycerine that are hard to remove from the surface of the piston-cylinder. Use detergents free of additives.

The piston and cylinder are first dipped in a mixture of soap and water and rubbed with soft paper to remove dust or grease. Then, they are dipped in deionised water and, after that, dried with soft paper. Special dust free paper is helpful in the last step to avoid any dust from the paper staying on the surface of the piston or cylinder.

The contamination of the piston-cylinder comes frequently from metal dust generated when the rotating piston is rubbing the polymer disc at the lower end of the free range. To avoid this, always stop the rotation of the piston while it is still in floatation. When cleaning the piston, clean also the top of the main module housing as well as the lower side of the plate mounted on the piston with alcohol.

ANNEX 5. Laboratory standards and measurement conditions

Table 5.1. Laboratory standard – pressure balance, uncertainties are standard ones (k = 1).

Manufacturer	
Measurement range in kPa	
Material of piston	
Material of cylinder	
Operation mode, free-deformation or controlled-clearance	
Zero-pressure effective area (A_0) at reference temperature in cm^2	
Relative uncertainty of A_0 in 10^{-6}	
Pressure distortion coefficient (λ) in MPa^{-1}	
Uncertainty of λ in MPa^{-1}	
Relative uncertainty of mass pieces in 10^{-6}	
Linear thermal expansion coefficient of piston (α_p) in $°C^{-1}$	
Linear thermal expansion coefficient of cylinder (α_c) in $°C^{-1}$	
Reference temperature (t_0) in °C	
Local gravity acceleration (g) in m/s^2	
Relative uncertainty of g in 10^{-6}	
Height difference between laboratory standard (LS) and TS (h), positive if LS is higher than TS, in mm	
Uncertainty of h in mm	

In addition, traceability of LS to SI units should be explained. Details of how A_0 and λ and their uncertainties were determined should be reported.

Table 5.2. Laboratory standard – liquid column manometer, uncertainties are standard ones (k = 1).

Manufacturer	
Measurement range in kPa	
Principle of liquid column height (l) measurement	
Uncertainty of l, in µm	
Liquid	
Liquid density (ρ) in kg/m^3	
Relative uncertainty of ρ in 10^{-6}	
Volumetric thermal expansion coefficient of liquid (γ) in $°C^{-1}$	
Uncertainty of γ in $°C^{-1}$	
Reference temperature (t_0) in °C	
Uncertainty of liquid temperature in mK	
Local gravity acceleration (g) in m/s^2	
Relative uncertainty of g in 10^{-6}	
Height difference between laboratory standard (LS) and TS (h), positive if LS is higher than TS, in mm	
Uncertainty of h in mm	

In addition, traceability of LS to SI units should be explained. Details of how l and ρ and their uncertainties are/were determined should be reported.

ANNEX 6. Laboratory standards and measurement conditions of CCM.P-K2.2020, (25 – 350) kPa, absolute mode

Table 6.1. CCM.P-K2.2020, (25 – 350) kPa, absolute mode - Results in individual cycles

Laboratory name :

Date (period) :

Cycle number : of 5

Meas. no.	p_{nom} / kPa	t_{LS} / °C	t_{amb} / °C	p_{res} / Pa	p / kPa	t / °C	A_p / cm^2
1	25						
2	50						
3	100						
4	150						
5	200						
6	250						
7	300						
8	350						
9	350						
10	300						
11	250						
12	200						
13	150						
14	100						
15	50						
16	25						

p_{nom} is nominal pressure,
t_{LS} is temperature of LS,
t_{amb} is temperature of ambient air,
p_{res} is residual pressure in the TS bell jar,
p is pressure generated by LS at the TS reference level,
t is temperature of TS,
A_p is effective area of TS at the reference temperature of 20 °C.

The formula to calculate p must be reported.

Table 6.2. CCM.P-K2.2020, (25 – 350) kPa, absolute mode - Summary of all cycles

Laboratory name :

Date (period) :

p_{nom} / kPa	$\langle A_p \rangle$ / cm^2	$\sigma(A_p)/\langle A_p \rangle$ / 10^{-6}	$u(p)/p$ / 10^{-6}	$u(t)$ / °C	$u(A_p)/\langle A_p \rangle$ / 10^{-6}
25					
50					
100					
150					
200					
250					
300					
350					

$\langle A_p \rangle$ is average of the A_p values measured at the same nominal pressure,
$\sigma(A_p)/\langle A_p \rangle$ is standard deviation of the A_p mean value,
$u(p)/p$ is type B uncertainty of the pressure at the reference level of TS,
$u(t)$ is uncertainty of the TS temperature,
$u(A_p)/\langle A_p \rangle$ is combined uncertainty of the A_p mean value.

In addition, a list of main uncertainty sources and their contributions to $u(A_p)$ for pressures of 25 kPa and 350 kPa / maximum measured pressure must be presented.

All the uncertainties should be expressed as standard ones.

ANNEX 7. Laboratory standards and measurement conditions of CCM.P-K1.b.2020, (25 – 350) kPa, gauge mode

Table 7.1. CCM.P-K1.b.2020, (25 – 350) kPa, gauge mode - Results in individual cycles.

Laboratory name :

Date (period) :

Cycle number :

Average relative air humidity and its uncertainty:

Meas. no.	p_{nom} / kPa	t_{LS} / °C	t_{amb} / °C	p_{amb} / Pa	p / kPa	t / °C	A_p / cm^2
1	25						
2	50						
3	100						
4	150						
5	200						
6	250						
7	300						
8	350						
9	350						
10	300						
11	250						
12	200						
13	150						
14	100						
15	50						
16	25						

p_{nom} is nominal pressure,
t_{LS} is temperature of LS,
t_{amb} is temperature of ambient air,
p_{amb} is ambient pressure,
p is pressure generated by LS at the TS reference level,
t is temperature of TS,
A_p is effective area of TS at the reference temperature of 20 °C.

The formula to calculate p must be reported.

Table 7.2. CCM.P-K1.b.2020, (25 – 350) kPa, gauge mode - Summary of all cycles

Laboratory name :

Date (period) :

p_{nom} / kPa	$\langle A_p \rangle$ / cm^2	$\sigma(A_p)/\langle A_p \rangle$ / 10^{-6}	$u(p)/p$ / 10^{-6}	$u(t)$ / °C	$u(A_p)/\langle A_p \rangle$ / 10^{-6}
25					
50					
100					
150					
200					
250					
300					
350					

$\langle A_p \rangle$ is average of the A_p values measured at the same nominal pressure,
$\sigma(A_p)/\langle A_p \rangle$ is standard deviation of the A_p mean value,
$u(p)/p$ is type B uncertainty of the pressure at the reference level of TS,
$u(t)$ is uncertainty of the TS temperature,
$u(A_p)/\langle A_p \rangle$ is combined uncertainty of the A_p mean value.

In addition, a list of main uncertainty sources and their contributions to $u(A_p)$ for pressures of 25 kPa and 350 kPa must be presented.

All the uncertainties should be expressed as standard ones.

ANNEX 8. Laboratory standards and measurement conditions of CCM.P-K1.c.2020, (0.7 – 7) MPa, gauge mode

Table 8.1. CCM.P-K1.c.2020, (0.7 – 7) MPa, gauge mode - Results in individual cycles.

Laboratory name :

Date (period) :

Cycle number :

Average relative air humidity and its uncertainty:

Meas. no.	p_{nom} / MPa	t_{LS} / °C	t_{amb} / °C	p_{amb} / Pa	p / MPa	t / °C	A_p / cm^2
1	0.7						
2	1						
3	2						
4	3						
5	4						
6	5						
7	6						
8	7						
9	7						
10	6						
11	5						
12	4						
13	3						
14	2						
15	1						
16	0.7						

p_{nom} is nominal pressure,
t_{LS} is temperature of LS,
t_{amb} is temperature of ambient air,
p_{amb} is ambient pressure,
p is pressure generated by LS at the TS reference level,
t is temperature of TS,
A_p is effective area of TS at the reference temperature of 20 °C.

The formula to calculate p must be reported.

Table 8.2. CCM.P-K1.c.2020, (0.7 – 7) MPa, gauge mode - Summary of all cycles

Laboratory name :

Date (period) :

p_{nom} / MPa	$\langle A_p \rangle$ / cm^2	$\sigma(A_p)/\langle A_p \rangle$ / 10^{-6}	$u(p)/p$ / 10^{-6}	$u(t)$ / °C	$u(A_p)/\langle A_p \rangle$ / 10^{-6}
0.7					
1					
2					
3					
4					
5					
6					
7					

$\langle A_p \rangle$ is average of the A_p values measured at the same nominal pressure,
$\sigma(A_p)/\langle A_p \rangle$ is standard deviation of the A_p mean value,
$u(p)/p$ is type B uncertainty of the pressure at the reference level of TS,
$u(t)$ is uncertainty of the TS temperature,
$u(A_p)/\langle A_p \rangle$ is combined uncertainty of the A_p mean value.

In addition, a list of main uncertainty sources and their contributions to $u(A_p)$ for pressures of 0.7 MPa and 7 MPa must be presented.

All the uncertainties should be expressed as standard ones.