Final Report
CCM Key Comparison CCM.P-K2
Pressure (10 kPa to 120 kPa) Absolute Mode

Michael Perkin[1], Alain Picard[2], Michel Lecollinet[3], Kitty Fen[4], Marina Sardi[5], Archie Miiller[6], Anil Agarwal[7], Michael Jescheck[8], Christian Wüthrich[9]

Abstract
The results are presented of key comparison CCM.P-K2 that covered the pressure range 10 kPa to 120 kPa in absolute mode. Nine national measurement institutes participated in the comparison, which used a piston-cylinder assembly of 335 mm^2 nominal effective area as a transfer standard.

Whilst not all laboratories were found to be equivalent at all pressures, the larger-than –expected instabilities in the transfer standard precluded the ability to discriminate between participant's standards at a level needed to fully support the Calibration Measurement Capabilities table in the BIPM key comparison database.

[1] National Physical Laboratory, Hampton Road, Teddington, Middlesex, TW11 0LW, United Kingdom
[2] Bureau International des Poids et Mesures, Pavillon de Breteuil, 92312 Sèvres Cedex, France
[3] Institut National de Métrologie, 61 rue du Landy, 93210 La Plaine Saint-Denis, France
[4] National Measurement Institute, PO Box 264, Lindfield, (Sydney) NSW 2070, Australia
[5] Istituto Nazionale di Ricerca Metrologica, Strada delle Cacce 91, 10135 Torino, Italy
[6] National Institute of Standards and Technology, 100 Bureau Drive, Stop 8364, Gaithersburg, MD 20899-8364, United States of America
[7] National Research Council of Canada, Montreal Road, K1A OR6 Ottawa, Canada
[8] Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany
[9] Federal Office of Metrology, Lindenweg 50, CH-3003 Bern-Wabern, Switzerland

Contents

Tables

Figures

1. INTRODUCTION

At its 6th meeting, in May 1996, the Consultative Committee for Mass and Related Quantities (CCM) approved proposals made by the Pressure Working Groups that identified six Key Comparison pressure ranges, the type of transfer standards to be used, and the pilot laboratories. The objective of each comparison is to determine the degree of equivalence of the pressure measurement standards held at National Measurement Institutes (NMIs) and to test the principal measurement methods in the field [1].

One of the identified key comparisons was 10 kPa to 120 kPa, absolute mode, to be piloted by the National Physical Laboratory (NPL) using a gas-operated piston-cylinder assembly as the transfer standard. This Report details the results. An associated comparison in gauge mode using the same equipment, CCM.P-K6, also piloted by NPL took place at the same time and the results of that comparison are published in a separate report.

2. PARTICIPATING LABORATORIES AND THEIR STANDARDS

The participants in this Key Comparison included NMIs from three regional metrological organizations – EUROMET, APMP and SIM. The Netherlands Meetinstituut – Van Swinden Laboratorium (NMi-VSL) and National Institute of Metrology, China (NIM) withdrew results from the comparison because of problems with their standard or associated system. Table 1 shows the remaining participants.

Laboratory	Country	Region
Bureau International des Poids et Mesures (BIPM)		
Institut National de Métrologie (LNE-INM)	France	EUROMET
National Measurement Institute (NMIA)	Australia	APMP
Istituto Nazionale di Ricerca Metrologica (INRIM)	Italy	EUROMET
National Institute of Standards and Technology (NIST)	USA	SIM
National Physical Laboratory (NPL)	United Kingdom	EUROMET
National Research Council (NRC).	Canada	SIM
Physikalisch-Technische Bundesanstalt (PTB)	Germany	EUROMET
Swiss Federal Office of Metrology (METAS)	Switzerland	EUROMET

Table 1 Participants

All participants in the comparison use mercury manometers as their primary standards, essentially if not exclusively determining the height of the mercury columns interferometrically. Brief details of the standards are given below in the order of which they participated in the comparison.

2.1 NPL mercury manometer

The NPL manometer used in the comparison is a mercury U-tube instrument fitted with cat's-eye floats, in 110 mm diameter columns, that enable fringe counting, in monochromatic light (HeNe), in the presence of ripples on the mercury surfaces. The instrument is mounted inside a temperature-stabilised housing and is designed to operate in both absolute and gauge modes. Its operating range is from 1.0×10^3 Pa to 1.1×10^5 Pa with an uncertainty in pressure measurement of $\pm(0.3 + 5 \times 10^{-7} \times p)$ Pa at a coverage factor k=2 [2].

2.2 BIPM manobarometer

The BIPM manobarometer is a mercury U-tube instrument using a Michelson white-light interferometer to locate the mercury surfaces. The height difference of the mercury columns is compensated by an adjustable optical delay line whose displacement is measured visually on a graduated scale.

2.3 METAS mercury manometer

The METAS standard used in the comparison is a manometer in U-tube configuration where the mercury is contained in a fixed cistern, a moving cistern, and a flexible tube connecting them. A laser interferometer is used to measure the height difference between the two cisterns and two capacitive bridges measure the mercury levels in the cisterns. The instrument has a sophisticated electronic system controlled by a computer and it can be remotely operated via an IEEE STD 488 interface bus.

2.4 LNE-INM mercury manometer

The mercury manometer is built with two large diameter cells connected by a flexible tube. One cell is installed on a support that can be moved by three lead screws turning in synchronism. The rotation of the screws is controlled by remote motors, and may be operated at three different speeds.

2.5 PTB mercury manometer

The mercury manometer of PTB, used for the comparison, is a modified commercially-available dual cistern manometer. It is operated in a specially designed enclosure protecting it from variations in ambient temperature and platinum resistance thermometers provide accurate temperature information. The instrument has been equipped with a counting laser interferometer to measure the difference in height between the mercury cisterns and time-dependent, high-resolution measurements of the output signal of capacitance sensing systems are used to detect changes in the position of the mercury menisci in the cisterns.

2.6 NIST mercury manometer

The NIST standard used for the comparison is a mercury Ultrasonic Interferometer Manometer (UIM) with a full-scale range of 360 kPa. The unique feature of the UIM is that changes in height of its mercury surfaces are determined by an ultrasonic technique. A transducer at the bottom of each liquid column generates a pulse of ultrasound (near 10 MHz) that propagates vertically up the column, is reflected from the liquid-gas interface, and returns to be detected by the transducer. The change in phase of the returned signal is proportional to the length of the column. The manometer employs a "W" or three-column design to correct for possible tilt, 75 mm diameter liquid surfaces to minimize capillary effects, thermal shields to stabilize the temperature and minimize its gradients, and high-vacuum techniques to minimize leaks and pressure gradients.

2.7 NMIA mercury manometer

The NMIA standard is an interferometric mercury manometer which is still largely as described in Harrison et al Metrologia 12, 115 (1976) with a modified float in the mercury tubes. A float sits on the surface of the mercury in each arm of a U-tube manometer. The mercury of the manometer is linked to the mercury pools contained within floats and light from a HeNe laser is reflected from the surfaces of these pools. Thus the mercury surfaces are reflectors of a Michelson interferometer and pressure changes are detected reversibly as "fringes" sensed by two photomultipliers and recorded on a counter.

2.8 INRIM mercury manometer

The pressure standard of INRIM in the barometric range used in the comparison is a laser interferometer mercury manometer, designated HG-5. It operates from 100 Pa to 120 kPa, both in absolute and gauge mode. It has a glass-made U-tube with bores of 60 mm diameter placed in a temperature controlled water bath. The measurement of the differential levels of mercury menisci is made through a single-beam interferometer.

2.9 NRC mercury manometer

The NRC standard is a modified commercially available mercury manometer employing a fixed and a moveable cistern that are connected by a flexible pipe. The mercury-column height within the flexible mercury line was established by elevating the moving cistern, the displacement of which was measured using the laser interferometer. The level of mercury in each cistern was maintained constant by using a high-accuracy capacitance gauging system. To improve the temperature stability along the mercury column, the manometer was separated from the electronics panel and housed in a thermally isolated chamber. Also, a high-accuracy capacitance diaphragm gauge was used to measure the reference pressure in the moving cistern during the absolute mode operation.

3. TRANSFER STANDARD

The transfer standard used in the comparison was a Ruska 2465 piston-cylinder assembly manufactured by the Ruska Instrument Corporation and provided by BIPM. Its piston and cylinder were both made of tungsten carbide with a nominal diameter of 20 mm. The supplied package included a base, bell-jar, capacitance diaphragm gauge and control unit, weight set and thermometer, together with various connecting pieces and fittings.

Prior to starting the comparison initial calibrations were performed to assess the characteristics of the transfer standard piston-cylinder assembly. These included absolute-mode calibrations against a manobarometer at the BIPM and gauge- and absolute- mode calibrations at NPL against both a mercury manometer and a piston-cylinder. The results showed some uncharacteristic and unexpected differences in gauge- and absolute-mode performance, including a significantly pressure-dependent effective area observed only in the absolute mode, which could not readily be explained. Subsequent calibrations also showed some erratic changes in characteristics, particularly in the absolute mode, which could potentially compromise the comparison.

A replacement piston-cylinder was potentially available but not in a timescale that would allow adequate evaluation before the scheduled start of the comparison. Later NPL calibrations of the piston-cylinder, however, produced considerably better results, perhaps indicating that the instrument had benefited from a ‘running-in’ period. Therefore, after discussions between NPL and BIPM, a decision was made to start the comparison with this transfer standard.

Unfortunately, repeated measurements made during the comparison showed that reproducibility of the instrument was poorer than hoped, and indeed poorer than needed to support participants' subsequently declared Calibration Measurement Capabilities in Appendix C of the BIPM Key Comparison Database [3].

4. ORGANIZATION OF THE KEY COMPARISON AND CHRONOLOGY

The CCM Key Comparison P-K2 was organized in conjunction with CCM.P-K6 - the gauge mode Key Comparison covering the same range and using the same transfer standard package (with the exception of the capacitance manometer diaphragm gauge used to measure reference pressures in the absolute mode). Periodically through the comparison the transfer standard was returned to NPL in order to monitor its performance. The chronology of the calibrations carried out by the participants is shown in Table 2, which shows the start and end dates of the period during which calibration data was taken.

Participant	Calibration Start Date	Calibration End Date
NPL 1 (Monitoring - initial)	13 March 1998	16 April 1998
BIPM	26 June 1998	9 July 1998
METAS	20 November 1998	4 December 1998
LNE-INM	25 January 1999	1 February 1999
PTB	22 February 1999	26 March 1999
NPL2 (Monitoring – mid-point)	22 April 1999	27 April 1999
NIST	7 September 1999	17 September 1999
NMIA	18 February 2000	21 March 2000
NPL 3 ('Participation' measurements)	7 August 2000	18 August 2000
INRIM	24 January 2001	26 January 2001
NPL 4 (Monitoring - final)	20 February 2001	22 February 2001
NRC	16 July 2001	25 September 2001

Table 2 Chronology of measurements

5. GENERAL CALIBRATION PROCEDURE

The general procedure for the Key Comparison required that each laboratory calculate the effective area of the transfer standard, using nitrogen as the pressure medium, at the following nominal pressures: 10.0 kPa, 21.1 kPa, 29.9 kPa, 40.1 kPa, 50.3 kPa, 59.7 kPa, 69.9 kPa, 80.1 kPa, 89.8 kPa, 100.0 kPa, 109.3 kPa and 120.4 kPa. These pressures were chosen to be evenly spread throughout the range of the comparison, within the limitations imposed by the supplied weight set.

The procedure required that each participant carry out a calibration in an ascending, and then descending sequence of pressures. At each calibration pressure, one reading was taken with the cylinder rotating clockwise and one with the cylinder rotating counter-clockwise. The whole procedure was then repeated, giving a total of eight effective area measurements at each calibration pressure.

6. CALCULATION

For each measurement, the effective area of the piston-cylinder at 20 ˚C was calculated, using the following equation:

$$A_p = \frac{g \sum M}{(p - p_0)\left[1 + \alpha \ (t_c - 20)\right]}$$

where

p_0 is the bell-jar pressure at the time of the measurement

p is the pressure measured by the participant's standard at the transfer standard reference point

A_p is the calculated effective area at the pressure p

g is the local acceleration due to gravity

α is the coefficient of thermal expansion of the piston-cylinder

t_C is the temperature of the piston-cylinder

M is the mass of the ringweights and piston corrected for variations in density using the following equation:

$$M = M' \times \left[1 + \rho'_{\mathrm{a}} \left(\frac{1}{\rho_M} - \frac{1}{\rho_S}\right)\right] \times \left(1 - \frac{\rho_a}{\rho_M}\right)$$

where

M is the mass of the component, corrected for buoyancy of gas in the bell jar

M' is the conventional mass of the component at the time of its weighing

ρ'_a is taken to be 1.2 kg.m^{-3}

ρ_a is the density of the gas in the bell-jar (taken to be zero in the absolute mode)

ρ_S is taken to be 8 000 kg.m^{-3}

ρ_M is the density of the component.

The densities and conventional masses of the components were provided in the comparison protocol. The thermal expansion of the piston-cylinder was taken to be 9.1×10^{-6} °C^{-1} and calibration data were provided for the thermometer used to measure the piston-cylinder temperature.

7. MONITORING BY THE PILOT LABORATORY

For stability-monitoring purposes, NPL took three sets of measurements during the comparison – one at the beginning, one approximately half way through and one close to the end. (The final NPL monitoring measurements were taken before participation by NRC, Canada, because of the need for NPL to complete its measurements in time to dismantle its manometer before the scheduled move to a new building.) NPL took a separate set of measurements to submit as its ‘own’ results. Thus during the comparison NPL took four sets of measurements; in this document they are identified as follows:

Measurement purpose	**Identifier**
Initial monitoring of transfer standard	NPL1
Mid-point monitoring of transfer standard	NPL2
NPL’s ‘own’ measurements	NPL3
Final monitoring of transfer standard	NPL4

The set of results that NPL should use as its ‘own’ were not identified prior to the comparison (a deficiency in the protocol) but were discussed with the participants at the CCM Medium pressure Working Group meeting in May 2002. This involved a choice between results NPL2 and NPL3 as it was felt that, since NPL1 and NPL4 were made at the start and end of the comparison respectively, they should be monitoring measurements. NPL3 was randomly chosen from the two sets of results. It is worth noting that if NPL1 or NPL4 had been selected as NPL's own results it would have been non-equivalent with the reference values over part of the pressure range under test.

Figure 1 and Table 3 show all four sets of data taken by NPL during the comparison and they illustrate considerable non-temporal instability. The difference between NPL1 and NPL2 results shows that, at maximum pressure, the transfer standard's effective area had changed by around 15 parts per million – far greater than expected or appropriate. Thus by the mid-point of the comparison it was clear that the transfer standard's instability would reduce the comparison's usefulness and consideration was given to terminating it. However, given the effort already made by four participants, the time needed to obtain and evaluate a replacement piston-cylinder, and appreciating that the results would have some temporary value, it was decided to continue with the comparison.

The transfer standard stability problem was discussed by the participants at the CCM meeting in Paris in May 2002. From the preliminary analysis it was decided that the reports should be written and submitted for inclusion in the BIPM databases.

Nominal Pressure kPa	**NPL1** Eff area mm^2	**NPL2** Eff area mm^2	**NPL3** Eff area mm^2	**NPL4** Eff area mm^2	**Mean** Eff area mm^2	Standard Deviation mm^2
10	335.747 4	335.748 1	335.746 3	335.745 8	335.746 9	0.001 1
21	335.748 7	335.747 7	335.747 5	335.748 7	335.748 1	0.000 6
30	335.748 8	335.747 7	335.747 2	335.748 8	335.748 1	0.000 8
40	335.748 2	335.747 4	335.746 5	335.748 1	335.747 6	0.000 8
50	335.748 2	335.747 0	335.746 5	335.748 0	335.747 4	0.000 8
60	335.748 2	335.746 6	335.746 5	335.749 5	335.747 7	0.001 4
70	335.749 5	335.746 4	335.746 1	335.747 4	335.747 4	0.001 5
80	335.749 5	335.745 7	335.745 9	335.747 2	335.747 1	0.001 8
90	335.749 5	335.745 6	335.745 8	335.747 4	335.747 1	0.001 8
100	335.750 5	335.745 7	335.745 7	335.747 2	335.747 2	0.002 3
109	335.751 1	335.745 9	335.745 6	335.748 6	335.747 8	0.002 6

Table 3 Results of the four calibrations made at NPL

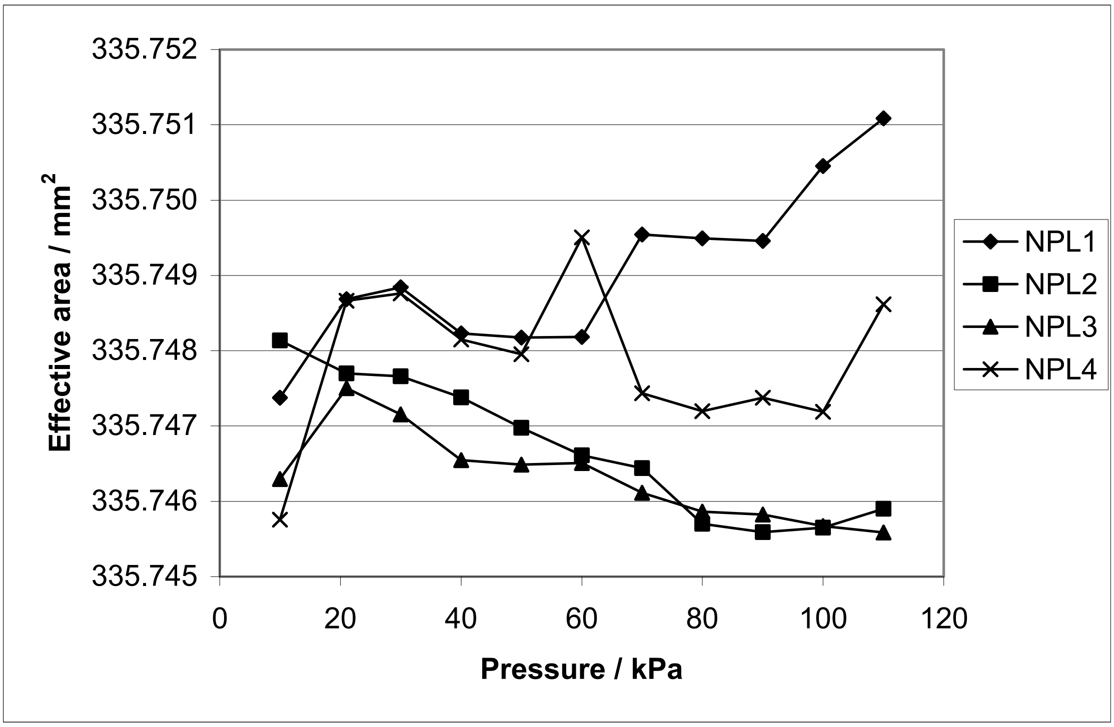

Figure 1 Results of the four calibrations made at NPL

8. ANALYSIS OF THE RESULTS

The results were analysed in two ways – firstly by the method of weighted means and secondly by calculating the median at each pressure to use as reference values.

The second analysis, using the median values as the reference values, was chosen because of its insensitivity to the wide spread of the participants results as well as the variation in uncertainties and the instability of the transfer standard. An additional component of uncertainty for the instability in the monitoring measurements was not included as this is reflected in the larger uncertainty of the median. It is this method of analysis that is shown in this report.

A confidential presentation of the results and the preliminary analysis was presented to the participants at the CCM meeting in Paris in May 2002 and the use of median values as reference values was agreed.

The uncertainty in the median has been calculated using the method of Müller [4]. This calculation is based on taking the median of absolute deviations from the median of the results contributing to the reference value, multiplying by 1.858 (derived in [4]) and dividing the answer by the square root of one less than the number of results.

$$s = \frac{1.858}{\sqrt{n-1}} \times MAD \qquad (1)$$

where s is the uncertainty

n is the number of participants contributing to the reference value

MAD is the median of absolute deviations from the median.

Table 4 shows the reference value at each nominal pressure together with the corresponding uncertainty, at a coverage factor of k=1.

Nominal Pressure	Reference value	Uncertainty in reference value
kPa	mm^2	mm^2
10	335.744 4	0.000 9
21	335.744 8	0.001 7
30	335.745 5	0.001 0
40	335.744 2	0.000 8
50	335.744 0	0.000 8
60	335.745 1	0.000 9
70	335.745 3	0.000 5
80	335.744 6	0.000 9
90	335.744 8	0.000 9
100	335.745 1	0.000 7
109	335.744 3	0.001 0
121	335.743 2	0.001 6

Table 4 Reference values and corresponding uncertainties

The degree of equivalence of a participant's standard is defined in the Mutual Recognition Arrangement or MRA [1] by two terms: its deviation from the key comparison reference value, and the uncertainty of this deviation. The deviation of each participant's result from the reference value was calculated at each nominal pressure as $d_i = x_i - x_{ref}$ and is given in Table 6 for each nominal pressure. The uncertainty of this deviation was calculated by using the root-sum-of-squares method[10] to combine the uncertainty of the reference value and the participant's reported uncertainty.

An additional uncertainty must also be included to take account of the instability of the transfer standard. This was taken to be the standard deviation of the four NPL calibrations shown in Table 3. NPL did not take measurements at 120 kPa and therefore it was not possible to calculate a value for the standard deviation at this pressure. Therefore a value of 0.002 5 mm^2 has been used for the uncertainty due to the instability of the transfer standard at this pressure, calculated from a linear fit through the data at the other pressures.

The uncertainty of the deviation of each participant's result, including the calculated uncertainty due to the instability of the transfer standard, is given in Table 6, using a coverage factor of k=2.

9. PARTICIPANTS' RESULTS AND UNCERTAINTIES

Table 5 shows the calculated value of effective area obtained by each participant at each nominal pressure and the associated combined standard uncertainty reported by the participant. Each quoted value is the mean from the eight measurements made by each participant.

[10] Often called the *law of propagation of uncertainty* [2]

Nominal	BIPM		METAS		LNE-INM		PTB		NIST		NMIA		NPL		INRIM		NRC	
Pressure	x_i	u_i/x_i	x_i	u_i/x_i	x_i	u_i/x_i	x_i	u_i/x_i	x_i	u_i/x_i	x_i	u_i/x_i	x_i	u_i/x_i	x_i	u_i/x_i	x_i	u_i/x_i
kPa	mm^2	$/10^{-6}$	mm^2	$/10^{-6}$	mm^2	$/10^{-6}$	mm^2	$/10^{-6}$	mm^2	$/10^{-6}$	mm^2	$/10^{-6}$	mm^2	$/10^{-6}$	mm^2	$/10^{-6}$	mm^2	$/10^{-6}$
10	335.726 6	12	335.731 8	204	335.751 0	8.2	335.745 1	8.8	335.744 4	3.7	335.743 0	17	335.746 3	16	335.744 1	12	335.744 8	4.2
21	335.740 6	6.4	335.721 4	82	335.749 5	5.2	335.745 4	4.7	335.744 3	3.2	335.744 7	11	335.747 5	7.4	335.747 5	6.7	335.744 8	3.3
30	335.744 8	4.7	335.728 9	65	335.747 1	4.2	335.745 5	4.1	335.743 3	3.0	335.746 1	7.5	335.747 2	5.4	335.746 7	4.8	335.743 7	3.1
40	335.743 5	4.4	335.724 1	44	335.745 5	3.8	335.745 3	3.8	335.742 9	3.0	335.746 4	7.5	335.746 5	4.1	335.744 2	4.6	335.743 3	3.0
50	335.743 4	3.8	335.725 7	33	335.744 0	3.8	335.745 8	3.8	335.742 7	3.0	335.745 2	5.7	335.746 5	3.3	335.745 9	3.9	335.743 8	2.9
60	335.745 1	3.3	335.718 7	37	335.745 3	7.8	335.746 1	3.9	335.742 7	3.0	335.746 3	4.8	335.746 5	2.9	335.743 4	3.4	335.743 2	2.8
70	335.745 3	2.9	335.724 8	30	335.744 7	11	335.746 2	3.9	335.742 9	2.9	335.746 9	5.1	335.746 1	2.5	335.745 9	3.5	335.743 1	2.8
80	335.744 6	3.0	335.729 3	23	335.743 1	4.3	335.746 0	3.8	335.742 9	2.9	335.746 3	5.1	335.745 9	2.2	335.744 9	2.8	335.743 0	2.8
90	335.744 8	2.8	335.731 9	23	335.742 4	5.8	335.746 1	3.8	335.742 6	2.9	335.746 2	3.9	335.745 8	2.1	335.745 2	2.4	335.743 2	2.7
100	335.745 8	2.5	335.731 0	23	335.742 2	4.2	335.745 9	3.5	335.742 8	2.9	335.746 2	4.5	335.745 7	1.9	335.745 1	2.4	335.743 3	2.7
109			335.729 0	26			335.745 7	3.2	335.742 5	3.0	335.746 0	3.3	335.745 6	1.8	335.744 3	2.5	335.743 4	2.7
121			335.731 3	23			335.745 7	3.1	335.742 7	3.0					335.745 1	2.2	335.743 2	2.7

Table 5 Participants' values and their reported standard uncertainties

x_i is a participant's value and u_i the corresponding reported standard uncertainty.

The results showing the effective area values determined by each participant are presented graphically; Figure 2 shows all participants' results, whilst Figure 3 has a shifted and expanded scale that excludes one set of results and the 10 kPa values of two other sets of results but shows more detail in the remainder. For clarity no error bars have been included in these figures.

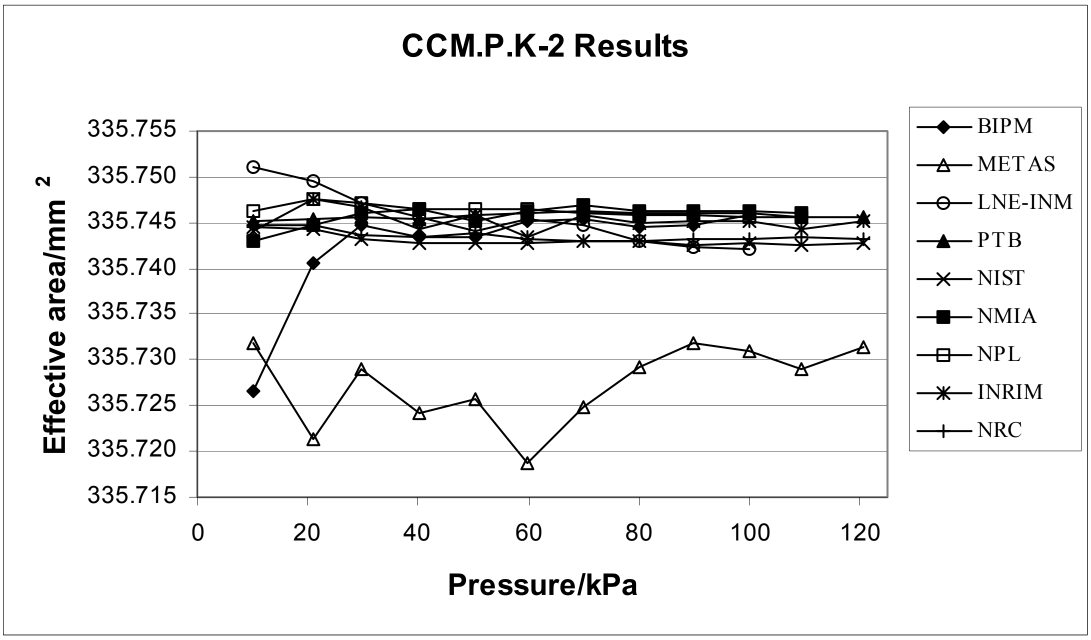

Figure 2 Participants' results

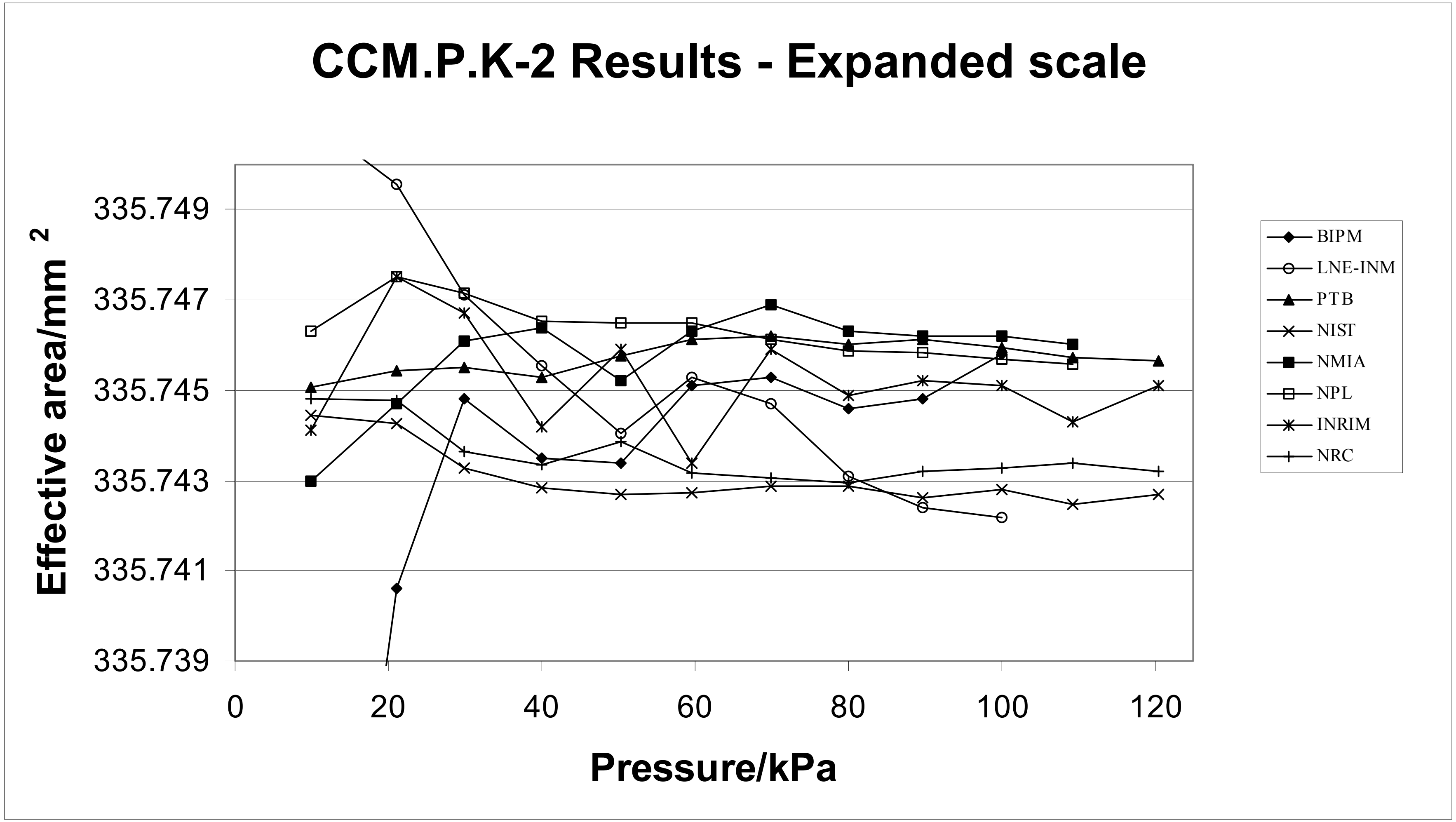

Figure 3 Participants' results with expanded scale

The deviations of the participants' results from the reference value are shown graphically at two pressures in Figure 4 and Figure 5. The error bars represent the expanded uncertainty taken from Table 6. The broken line represents zero deviation from the reference pressure at the given pressure. It can therefore be seen that seven of the participants were in agreement with the reference value within the uncertainties at 10 kPa and all were in agreement at 100 kPa.

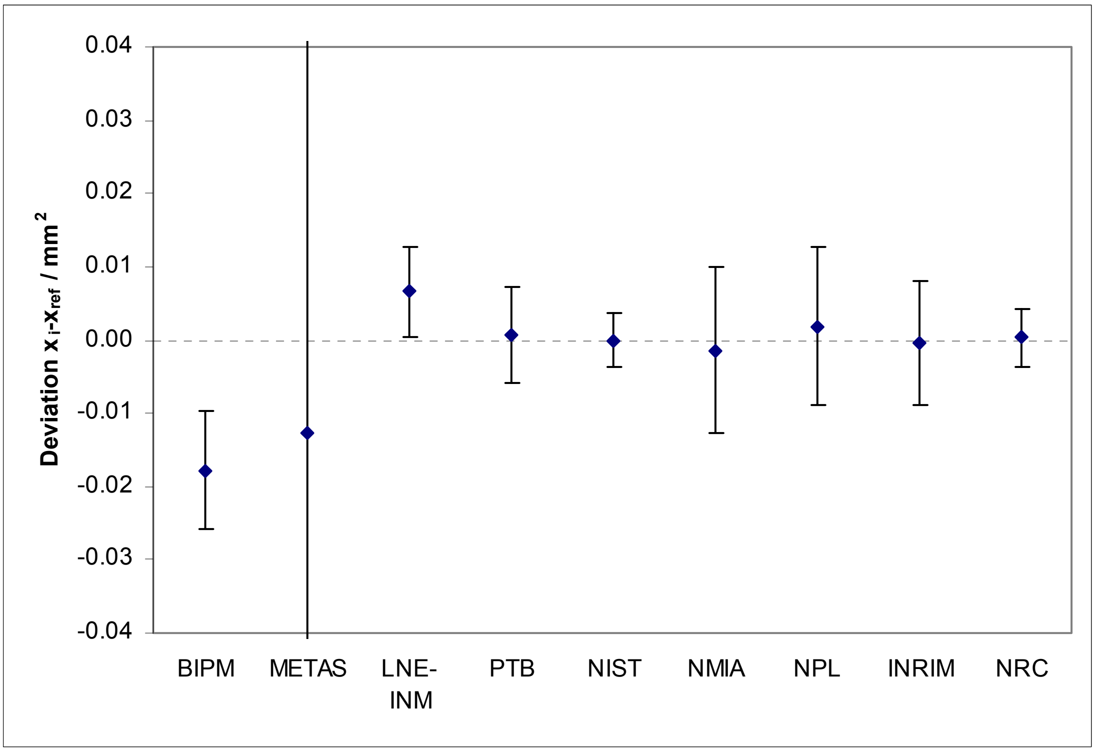

Figure 4 Participants' results at 10 kPa

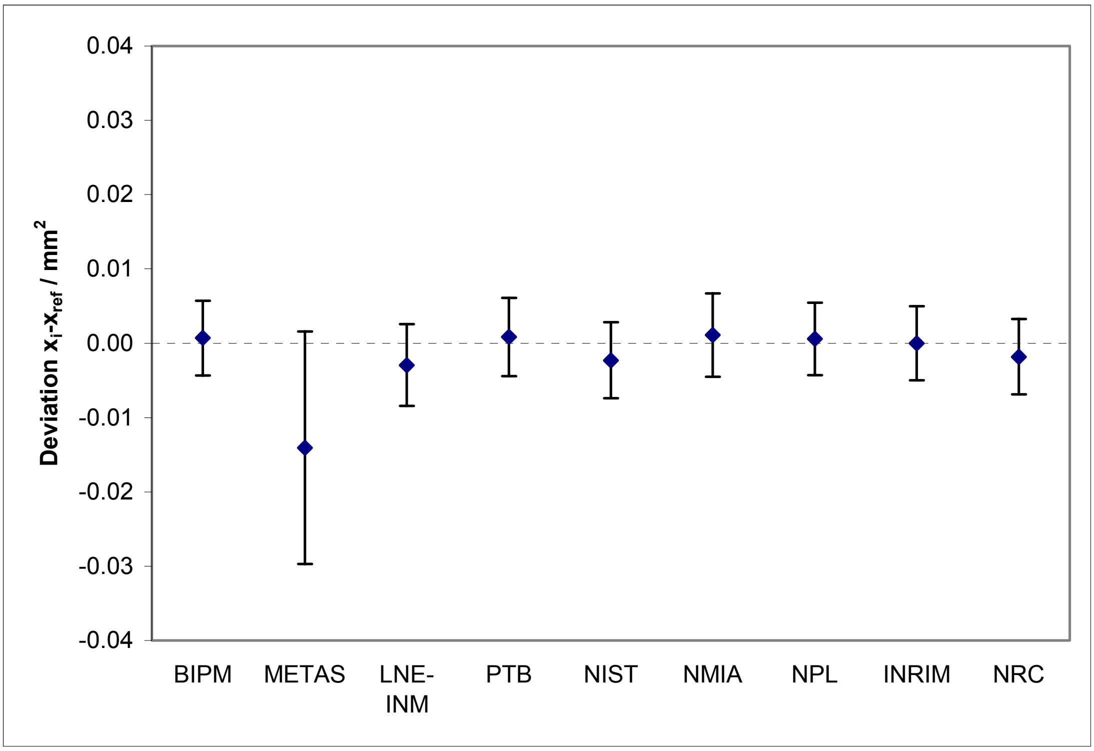

Figure 5 Participants' results at 100 kPa

The degree of equivalence between pairs of laboratories is defined in the MRA [1] by two terms: the pairwise difference in their results, and the uncertainty of this difference. The pairwise differences between individual laboratory results were calculated as $d_{i,j} = x_i - x_j$ and are given at different pressures in Table 7 to Table 18. The uncertainty of each pairwise difference was calculated by using the root-sum-of-squares method to combine the uncertainty reported by each participant and the uncertainty due to transfer standard instability, which enters twice (once for each participant's measurement). The expanded uncertainty (k=2) of each pairwise difference ($U(d_{i,j})$) is given in Table 7 to Table 18.

10. CONCLUSION

The majority of the participants measurements are in good agreement with the reference value within the associated uncertainties. Where the differences from the reference values are greater than the combined uncertainties, or the differences between pairs of laboratories measurements are larger than their combined uncertainties, the relevant uncertainty has been highlighted in the tables.

Since the start of the comparison, stability problems have been seen in other devices similar to the type used as the transfer standard. At the meeting of participants in May 2002 it was agreed that this type of standard was probably not suitable for the comparison but due to the difficulty and length of time needed to repeat the comparison the results would be published. It was also agreed that the Key Comparisons in this range would not be repeated for several years.

This key comparison determined degrees of equivalence of the participant laboratories in two ways: deviations from reference values and pairwise differences between the laboratories. Whilst not all laboratories were found to be equivalent at all pressures, the larger-than-expected instabilities in the transfer standard precluded the ability to discriminate between participant's standards at a level needed to fully support the Calibration Measurement Capabilities table in the BIPM database [3].

11. REFERENCES

[1] International Committee for Weights and Measures (CIPM), Mutual recognition of national measurement standards and of calibration and measurement certificates issued by national metrology institutes, 1999, Paris, pp.45 (see also MRA at *www.bipm.fr*).
[2] ISO, Guide to the Expression of Uncertainty in Measurement (International Organisation for Standardisation, Geneva, Switzerland, 1993).
[3] BIPM Key Comparison Database *www.bipm.fr*
[4] Müller J. W., "Possible advantages of a robust evaluation of comparisons", *J. Res. Natl. Stand. Technol.*, **105** (2000) 551-555.

12. EQUIVALENCE TABLES

Nominal Pressure	BIPM		METAS		LNE-INM		PTB		NIST		NMIA		NPL		INRIM		NRC	
	x_i-x_{ref}	U(x_i-x_{ref})	x_i-x_{ref}	U(x_i-x_{ref})	x_i-x_{ref}	U(x_i-x_{ref})	x_i-x_{ref}	U(x_i-x_{ref})	x_i-x_{ref}	U(x_i-x_{ref})	x_i-x_{ref}	U(x_i-x_{ref})	x_i-x_{ref}	U(x_i-x_{ref})	x_i-x_{ref}	U(x_i-x_{ref})	x_i-x_{ref}	U(x_i-x_{ref})
kPa	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2
10	-0.017 8	0.008 0	-0.012 6	0.137 0	0.006 6	0.006 1	0.000 6	0.006 5	0.000 0	0.003 7	-0.001 4	0.011 3	0.001 9	0.010 8	-0.000 3	0.008 5	0.000 4	0.003 9
21	-0.004 2	0.005 6	-0.023 4	0.054 8	0.004 8	0.005 0	0.000 7	0.004 8	-0.000 5	0.004 2	-0.000 1	0.007 9	0.002 7	0.006 1	0.002 7	0.005 7	0.000 0	0.004 2
30	-0.000 7	0.004 1	-0.016 6	0.043 5	0.001 6	0.003 8	0.000 0	0.003 8	-0.002 2	0.003 3	0.000 6	0.005 6	0.001 6	0.004 4	0.001 2	0.004 1	-0.001 8	0.003 3
40	-0.000 7	0.003 7	-0.020 1	0.029 4	0.001 3	0.003 4	0.001 1	0.003 4	-0.001 4	0.003 0	0.002 2	0.005 5	0.002 3	0.003 5	0.000 0	0.003 8	-0.000 9	0.003 0
50	-0.000 6	0.003 4	-0.018 4	0.022 2	0.000 0	0.003 4	0.001 7	0.003 4	-0.001 4	0.003 1	0.001 2	0.004 5	0.002 5	0.003 2	0.001 9	0.003 5	-0.000 2	0.003 0
60	0.000 0	0.004 0	-0.026 4	0.025 0	0.000 2	0.006 2	0.001 0	0.004 2	-0.002 4	0.003 9	0.001 2	0.004 6	0.001 4	0.003 8	-0.001 7	0.004 0	-0.001 9	0.003 8
70	0.000 0	0.003 8	-0.020 5	0.020 2	-0.000 6	0.007 8	0.000 9	0.004 2	-0.002 4	0.003 8	0.001 6	0.004 7	0.000 8	0.003 7	0.000 6	0.004 0	-0.002 3	0.003 8
80	0.000 0	0.004 5	-0.015 3	0.015 8	-0.001 5	0.004 9	0.001 4	0.004 7	-0.001 7	0.004 4	0.001 7	0.005 2	0.001 3	0.004 2	0.000 3	0.004 4	-0.001 6	0.004 4
90	0.000 0	0.004 4	-0.012 9	0.015 8	-0.002 4	0.005 5	0.001 3	0.004 7	-0.002 2	0.004 4	0.001 4	0.004 7	0.001 0	0.004 2	0.000 4	0.004 3	-0.001 6	0.004 4
100	0.000 7	0.005 0	-0.014 1	0.015 6	-0.002 9	0.005 5	0.000 8	0.005 3	-0.002 3	0.005 1	0.001 1	0.005 6	0.000 6	0.004 9	0.000 0	0.005 0	-0.001 8	0.005 0
109			-0.015 3	0.017 8			0.001 4	0.005 9	-0.001 8	0.005 9	0.001 7	0.005 9	0.001 3	0.005 6	0.000 0	0.005 8	-0.000 9	0.005 8
121			-0.011 9	0.016 1			0.002 4	0.006 2	-0.000 5	0.006 2					0.001 9	0.006 1	0.000 0	0.006 1

Table 6 Deviations of participants' results from reference values, and the associated uncertainties

x_i is the participant's mean value

x_{ref} is the reference value

U(x_i- x_{ref}) is the expanded uncertainty of the deviation x_i- x_{ref}

Highlighted cells show where the expanded uncertainty is less than the difference from the reference value.

10 kPa	BIPM		METAS		LNE-INM		PTB		NIST		NMIA		NPL		INRIM		NRC	
	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)
	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2
BIPM			-0.005 2	0.137 2	-0.024 4	0.009 8	-0.018 5	0.010 0	-0.017 8	0.008 5	-0.016 4	0.013 7	-0.019 7	0.013 2	-0.017 5	0.011 4	-0.018 2	0.008 6
METAS	0.005 2	0.137 2			-0.019 2	0.137 1	-0.013 3	0.137 1	-0.012 6	0.137 0	-0.011 2	0.137 5	-0.014 5	0.137 4	-0.012 3	0.137 2	-0.013 0	0.137 0
LNE-INM	0.024 4	0.009 8	0.019 2	0.137 1			0.005 9	0.008 6	0.006 6	0.006 7	0.008 0	0.012 7	0.004 7	0.012 2	0.006 9	0.010 2	0.006 2	0.006 9
PTB	0.018 5	0.010 0	0.013 3	0.137 1	-0.005 9	0.008 6			0.000 6	0.007 0	0.002 1	0.012 8	-0.001 2	0.012 4	0.001 0	0.010 4	0.000 2	0.007 2
NIST	0.017 8	0.008 5	0.012 6	0.137 0	-0.006 6	0.006 7	-0.000 6	0.007 0			0.001 4	0.011 7	-0.001 9	0.011 2	0.000 3	0.008 9	-0.000 4	0.004 8
NMIA	0.016 4	0.013 7	0.011 2	0.137 5	-0.008 0	0.012 7	-0.002 1	0.012 8	-0.001 4	0.011 7			-0.003 3	0.015 5	-0.001 1	0.014 0	-0.001 8	0.011 7
NPL	0.019 7	0.013 2	0.014 5	0.137 4	-0.004 7	0.012 2	0.001 2	0.012 4	0.001 9	0.011 2	0.003 3	0.015 5			0.002 2	0.013 5	0.001 5	0.011 2
INRIM	0.017 5	0.011 4	0.012 3	0.137 2	-0.006 9	0.010 2	-0.001 0	0.010 4	-0.000 3	0.008 9	0.001 1	0.014 0	-0.002 2	0.013 5			-0.000 7	0.009 0
NRC	0.018 2	0.008 6	0.013 0	0.137 0	-0.006 2	0.006 9	-0.000 2	0.007 2	0.000 4	0.004 8	0.001 8	0.011 7	-0.001 5	0.011 2	0.000 7	0.009 0		

Table 7 Participants' equivalence at 10 kPa

20 kPa	BIPM		METAS		LNE-INM		PTB		NIST		NMIA		NPL		INRIM		NRC	
	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)
	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2
BIPM			0.019 2	0.054 9	-0.008 9	0.005 8	-0.004 8	0.005 6	-0.003 7	0.005 1	-0.004 1	0.008 4	-0.006 9	0.006 8	-0.006 9	0.006 4	-0.004 2	0.005 1
METAS	-0.019 2	0.054 9			-0.028 2	0.054 9	-0.024 1	0.054 8	-0.022 9	0.054 8	-0.023 3	0.055 2	-0.026 1	0.055 0	-0.026 1	0.054 9	-0.023 4	0.054 8
LNE-INM	0.008 9	0.005 8	0.028 2	0.054 9			0.004 1	0.005 0	0.005 3	0.004 4	0.004 8	0.008 0	0.002 0	0.006 3	0.002 0	0.005 9	0.004 8	0.004 5
PTB	0.004 8	0.005 6	0.024 1	0.054 8	-0.004 1	0.005 0			0.001 2	0.004 2	0.000 7	0.007 9	-0.002 1	0.006 1	-0.002 1	0.005 7	0.000 7	0.004 2
NIST	0.003 7	0.005 1	0.022 9	0.054 8	-0.005 3	0.004 4	-0.001 2	0.004 2			-0.000 5	0.007 5	-0.003 3	0.005 7	-0.003 2	0.005 2	-0.000 5	0.003 5
NMIA	0.004 1	0.008 4	0.023 3	0.055 2	-0.004 8	0.008 0	-0.000 7	0.007 9	0.000 5	0.007 5			-0.002 8	0.008 8	-0.002 8	0.008 5	-0.000 1	0.007 6
NPL	0.006 9	0.006 8	0.026 1	0.055 0	-0.002 0	0.006 3	0.002 1	0.006 1	0.003 3	0.005 7	0.002 8	0.008 8			0.000 0	0.006 9	0.002 7	0.005 7
INRIM	0.006 9	0.006 4	0.026 1	0.054 9	-0.002 0	0.005 9	0.002 1	0.005 7	0.003 2	0.005 2	0.002 8	0.008 5	0.000 0	0.006 9			0.002 7	0.005 3
NRC	0.004 2	0.005 1	0.023 4	0.054 8	-0.004 8	0.004 5	-0.000 7	0.004 2	0.000 5	0.003 5	0.000 1	0.007 6	-0.002 7	0.005 7	-0.002 7	0.005 3		

Table 8 Participants' equivalence at 20 kPa

30 kPa	BIPM		METAS		LNE-INM		PTB		NIST		NMIA		NPL		INRIM		NRC	
	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)
	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2
BIPM			0.015 9	0.043 6	-0.002 3	0.004 8	-0.000 7	0.004 8	0.001 5	0.004 4	-0.001 3	0.006 4	-0.002 4	0.005 3	-0.001 9	0.005 0	0.001 1	0.004 4
METAS	-0.015 9	0.043 6			-0.018 2	0.043 6	-0.016 6	0.043 6	-0.014 3	0.043 6	-0.017 2	0.043 8	-0.018 2	0.043 7	-0.017 8	0.043 6	-0.014 7	0.043 6
LNE-INM	0.002 3	0.004 8	0.018 2	0.043 6			0.001 6	0.004 6	0.003 9	0.004 2	0.001 0	0.006 2	0.000 0	0.005 1	0.000 4	0.004 8	0.003 5	0.004 2
PTB	0.000 7	0.004 8	0.016 6	0.043 6	-0.001 6	0.004 6			0.002 2	0.004 1	-0.000 6	0.006 2	-0.001 6	0.005 1	-0.001 2	0.004 8	0.001 8	0.004 1
NIST	-0.001 5	0.004 4	0.014 3	0.043 6	-0.003 9	0.004 2	-0.002 2	0.004 1			-0.002 8	0.005 9	-0.003 9	0.004 7	-0.003 4	0.004 4	-0.000 4	0.003 7
NMIA	0.001 3	0.006 4	0.017 2	0.043 8	-0.001 0	0.006 2	0.000 6	0.006 2	0.002 8	0.005 9			-0.001 1	0.006 6	-0.000 6	0.006 4	0.002 4	0.005 9
NPL	0.002 4	0.005 3	0.018 2	0.043 7	0.000 0	0.005 1	0.001 6	0.005 1	0.003 9	0.004 7	0.001 1	0.006 6			0.000 5	0.005 3	0.003 5	0.004 7
INRIM	0.001 9	0.005 0	0.017 8	0.043 6	-0.000 4	0.004 8	0.001 2	0.004 8	0.003 4	0.004 4	0.000 6	0.006 4	-0.000 5	0.005 3			0.003 0	0.004 4
NRC	-0.001 1	0.004 4	0.014 7	0.043 6	-0.003 5	0.004 2	-0.001 8	0.004 1	0.000 4	0.003 7	-0.002 4	0.005 9	-0.003 5	0.004 7	-0.003 0	0.004 4		

Table 9 Participants' equivalence at 30 kPa

40 kPa	BIPM		METAS		LNE-INM		PTB		NIST		NMIA		NPL		INRIM		NRC	
	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)
	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2
BIPM			0.019 4	0.029 5	-0.002 0	0.004 5	-0.001 8	0.004 5	0.000 7	0.004 2	-0.002 9	0.006 2	-0.003 0	0.004 6	-0.000 7	0.004 8	0.000 2	0.004 2
METAS	-0.019 4	0.029 5			-0.021 4	0.029 5	-0.021 2	0.029 5	-0.018 7	0.029 4	-0.022 3	0.029 8	-0.022 4	0.029 5	-0.020 1	0.029 5	-0.019 2	0.029 4
LNE-INM	0.002 0	0.004 5	0.021 4	0.029 5			0.000 2	0.004 2	0.002 7	0.003 9	-0.000 9	0.006 0	-0.001 0	0.004 3	0.001 3	0.004 6	0.002 2	0.003 9
PTB	0.001 8	0.004 5	0.021 2	0.029 5	-0.000 2	0.004 2			0.002 4	0.003 9	-0.001 1	0.006 0	-0.001 3	0.004 3	0.001 1	0.004 6	0.001 9	0.003 9
NIST	-0.000 7	0.004 2	0.018 7	0.029 4	-0.002 7	0.003 9	-0.002 4	0.003 9			-0.003 6	0.005 8	-0.003 7	0.004 0	-0.001 4	0.004 3	-0.000 5	0.003 6
NMIA	0.002 9	0.006 2	0.022 3	0.029 8	0.000 9	0.006 0	0.001 1	0.006 0	0.003 6	0.005 8			-0.000 1	0.006 1	0.002 2	0.006 3	0.003 1	0.005 8
NPL	0.003 0	0.004 6	0.022 4	0.029 5	0.001 0	0.004 3	0.001 3	0.004 3	0.003 7	0.004 0	0.000 1	0.006 1			0.002 3	0.004 7	0.003 2	0.004 0
INRIM	0.000 7	0.004 8	0.020 1	0.029 5	-0.001 3	0.004 6	-0.001 1	0.004 6	0.001 4	0.004 3	-0.002 2	0.006 3	-0.002 3	0.004 7			0.000 9	0.004 3
NRC	-0.000 2	0.004 2	0.019 2	0.029 4	-0.002 2	0.003 9	-0.001 9	0.003 9	0.000 5	0.003 6	-0.003 1	0.005 8	-0.003 2	0.004 0	-0.000 9	0.004 3		

Table 10 Participants' equivalence at 40 kPa

50 kPa	BIPM		METAS		LNE-INM		PTB		NIST		NMIA		NPL		INRIM		NRC	
	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)
	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2
BIPM			0.017 7	0.022 4	-0.000 6	0.004 2	-0.002 4	0.004 2	0.000 7	0.003 9	-0.001 8	0.005 1	-0.003 1	0.004 1	-0.002 5	0.004 3	-0.000 4	0.003 9
METAS	-0.017 7	0.022 4			-0.018 4	0.022 3	-0.020 1	0.022 4	-0.017 0	0.022 3	-0.019 5	0.022 5	-0.020 8	0.022 3	-0.020 2	0.022 4	-0.018 2	0.022 3
LNE-INM	0.000 6	0.004 2	0.018 4	0.022 3			-0.001 7	0.004 2	0.001 4	0.003 9	-0.001 2	0.005 1	-0.002 5	0.004 0	-0.001 9	0.004 3	0.000 2	0.003 9
PTB	0.002 4	0.004 2	0.020 1	0.022 4	0.001 7	0.004 2			0.003 1	0.003 9	0.000 6	0.005 1	-0.000 7	0.004 0	-0.000 1	0.004 3	0.001 9	0.003 9
NIST	-0.000 7	0.003 9	0.017 0	0.022 3	-0.001 4	0.003 9	-0.003 1	0.003 9			-0.002 5	0.004 8	-0.003 8	0.003 7	-0.003 2	0.004 0	-0.001 2	0.003 6
NMIA	0.001 8	0.005 1	0.019 5	0.022 5	0.001 2	0.005 1	-0.000 6	0.005 1	0.002 5	0.004 8			-0.001 3	0.004 9	-0.000 7	0.005 1	0.001 4	0.004 8
NPL	0.003 1	0.004 1	0.020 8	0.022 3	0.002 5	0.004 0	0.000 7	0.004 0	0.003 8	0.003 7	0.001 3	0.004 9			0.000 6	0.004 1	0.002 6	0.003 7
INRIM	0.002 5	0.004 3	0.020 2	0.022 4	0.001 9	0.004 3	0.000 1	0.004 3	0.003 2	0.004 0	0.000 7	0.005 1	-0.000 6	0.004 1			0.002 1	0.003 9
NRC	0.000 4	0.003 9	0.018 2	0.022 3	-0.000 2	0.003 9	-0.001 9	0.003 9	0.001 2	0.003 6	-0.001 4	0.004 8	-0.002 6	0.003 7	-0.002 1	0.003 9		

Table 11 Participants' equivalence at 50 kPa

60 kPa	BIPM		METAS		LNE-INM		PTB		NIST		NMIA		NPL		INRIM		NRC	
	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)
	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2
BIPM			0.026 4	0.025 2	-0.000 2	0.006 9	-0.001 0	0.005 3	0.002 4	0.005 0	-0.001 2	0.005 6	-0.001 4	0.005 0	0.001 7	0.005 1	0.001 9	0.005 0
METAS	-0.026 4	0.025 2			-0.026 6	0.025 6	-0.027 4	0.025 2	-0.024 0	0.025 2	-0.027 6	0.025 3	-0.027 8	0.025 2	-0.024 7	0.025 2	-0.024 4	0.025 2
LNE-INM	0.000 2	0.006 9	0.026 6	0.025 6			-0.000 8	0.007 1	0.002 6	0.006 9	-0.001 0	0.007 3	-0.001 2	0.006 8	0.001 9	0.006 9	0.002 1	0.006 8
PTB	0.001 0	0.005 3	0.027 4	0.025 2	0.000 8	0.007 1			0.003 4	0.005 2	-0.000 2	0.005 8	-0.000 4	0.005 1	0.002 7	0.005 3	0.002 9	0.005 1
NIST	-0.002 4	0.005 0	0.024 0	0.025 2	-0.002 6	0.006 9	-0.003 4	0.005 2			-0.003 6	0.005 5	-0.003 8	0.004 9	-0.000 7	0.005 0	-0.000 5	0.004 9
NMIA	0.001 2	0.005 6	0.027 6	0.025 3	0.001 0	0.007 3	0.000 2	0.005 8	0.003 6	0.005 5			-0.000 2	0.005 5	0.002 9	0.005 6	0.003 1	0.005 5
NPL	0.001 4	0.005 0	0.027 8	0.025 2	0.001 2	0.006 8	0.000 4	0.005 1	0.003 8	0.004 9	0.000 2	0.005 5			0.003 1	0.005 0	0.003 3	0.004 8
INRIM	-0.001 7	0.005 1	0.024 7	0.025 2	-0.001 9	0.006 9	-0.002 7	0.005 3	0.000 7	0.005 0	-0.002 9	0.005 6	-0.003 1	0.005 0			0.000 2	0.005 0
NRC	-0.001 9	0.005 0	0.024 4	0.025 2	-0.002 1	0.006 8	-0.002 9	0.005 1	0.000 5	0.004 9	-0.003 1	0.005 5	-0.003 3	0.004 8	-0.000 2	0.005 0		

Table 12 Participants' equivalence at 60 kPa

70 kPa	BIPM		METAS		LNE-INM		PTB		NIST		NMIA		NPL		INRIM		NRC	
	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)
	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2
BIPM			0.020 5	0.020 5	0.000 6	0.008 5	-0.000 9	0.005 5	0.002 4	0.005 2	-0.001 6	0.005 9	-0.000 8	0.005 1	-0.000 6	0.005 3	0.002 3	0.005 1
METAS	-0.020 5	0.020 5			-0.019 8	0.021 6	-0.021 3	0.020 6	-0.018 0	0.020 5	-0.022 1	0.020 7	-0.021 3	0.020 5	-0.021 1	0.020 5	-0.018 2	0.020 5
LNE-INM	-0.000 6	0.008 5	0.019 8	0.021 6			-0.001 5	0.008 7	0.001 8	0.008 5	-0.002 2	0.009 0	-0.001 4	0.008 5	-0.001 2	0.008 6	0.001 6	0.008 5
PTB	0.000 9	0.005 5	0.021 3	0.020 6	0.001 5	0.008 7			0.003 3	0.005 4	-0.000 7	0.006 1	0.000 1	0.005 4	0.000 3	0.005 6	0.003 1	0.005 4
NIST	-0.002 4	0.005 2	0.018 0	0.020 5	-0.001 8	0.008 5	-0.003 3	0.005 4			-0.004 0	0.005 9	-0.003 2	0.005 1	-0.003 0	0.005 3	-0.000 2	0.005 1
NMIA	0.001 6	0.005 9	0.022 1	0.020 7	0.002 2	0.009 0	0.000 7	0.006 1	0.004 0	0.005 9			0.000 8	0.005 8	0.001 0	0.006 0	0.003 8	0.005 8
NPL	0.000 8	0.005 1	0.021 3	0.020 5	0.001 4	0.008 5	-0.000 1	0.005 4	0.003 2	0.005 1	-0.000 8	0.005 8			0.000 2	0.005 2	0.003 1	0.005 0
INRIM	0.000 6	0.005 3	0.021 1	0.020 5	0.001 2	0.008 6	-0.000 3	0.005 6	0.003 0	0.005 3	-0.001 0	0.006 0	-0.000 2	0.005 2			0.002 9	0.005 3
NRC	-0.002 3	0.005 1	0.018 2	0.020 5	-0.001 6	0.008 5	-0.003 1	0.005 4	0.000 2	0.005 1	-0.003 8	0.005 8	-0.003 1	0.005 0	-0.002 9	0.005 3		

Table 13 Participants' equivalence at 70 kPa

80 kPa	BIPM		METAS		LNE-INM		PTB		NIST		NMIA		NPL		INRIM		NRC	
	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)
	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2
BIPM			0.015 3	0.016 2	0.001 5	0.006 1	-0.001 4	0.005 9	0.001 7	0.005 7	-0.001 7	0.006 3	-0.001 3	0.005 5	-0.000 3	0.005 7	0.001 6	0.005 7
METAS	-0.015 3	0.016 2			-0.013 8	0.016 3	-0.016 7	0.016 3	-0.013 6	0.016 2	-0.017 0	0.016 4	-0.016 6	0.016 2	-0.015 6	0.016 2	-0.013 7	0.016 2
LNE-INM	-0.001 5	0.006 1	0.013 8	0.016 3			-0.002 9	0.006 3	0.000 2	0.006 1	-0.003 2	0.006 7	-0.002 8	0.005 9	-0.001 8	0.006 0	0.000 1	0.006 0
PTB	0.001 4	0.005 9	0.016 7	0.016 3	0.002 9	0.006 3			0.003 1	0.005 9	-0.000 3	0.006 5	0.000 2	0.005 7	0.001 1	0.005 8	0.003 1	0.005 8
NIST	-0.001 7	0.005 7	0.013 6	0.016 2	-0.000 2	0.006 1	-0.003 1	0.005 9			-0.003 4	0.006 3	-0.003 0	0.005 5	-0.002 0	0.005 6	-0.000 1	0.005 6
NMIA	0.001 7	0.006 3	0.017 0	0.016 4	0.003 2	0.006 7	0.000 3	0.006 5	0.003 4	0.006 3			0.000 4	0.006 2	0.001 4	0.006 3	0.003 3	0.006 3
NPL	0.001 3	0.005 5	0.016 6	0.016 2	0.002 8	0.005 9	-0.000 2	0.005 7	0.003 0	0.005 5	-0.000 4	0.006 2			0.001 0	0.005 5	0.002 9	0.005 5
INRIM	0.000 3	0.005 7	0.015 6	0.016 2	0.001 8	0.006 0	-0.001 1	0.005 8	0.002 0	0.005 6	-0.001 4	0.006 3	-0.001 0	0.005 5			0.001 9	0.005 6
NRC	-0.001 6	0.005 7	0.013 7	0.016 2	-0.000 1	0.006 0	-0.003 1	0.005 8	0.000 1	0.005 6	-0.003 3	0.006 3	-0.002 9	0.005 5	-0.001 9	0.005 6		

Table 14 Participants' equivalence at 80 kPa

90 kPa	BIPM		METAS		LNE-INM		PTB		NIST		NMIA		NPL		INRIM		NRC	
	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)
	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2
BIPM			0.012 9	0.016 2	0.002 4	0.006 6	-0.001 3	0.006 0	0.002 2	0.005 7	-0.001 4	0.006 0	-0.001 0	0.005 5	-0.000 4	0.005 6	0.001 6	0.005 7
METAS	-0.012 9	0.016 2			-0.010 5	0.016 6	-0.014 2	0.016 3	-0.010 7	0.016 2	-0.014 3	0.016 3	-0.013 9	0.016 2	-0.013 3	0.016 2	-0.011 3	0.016 2
LNE-INM	-0.002 4	0.006 6	0.010 5	0.016 6			-0.003 7	0.006 8	-0.000 2	0.006 6	-0.003 8	0.006 9	-0.003 4	0.006 5	-0.002 8	0.006 5	-0.000 8	0.006 6
PTB	0.001 3	0.006 0	0.014 2	0.016 3	0.003 7	0.006 8			0.003 5	0.006 0	-0.000 1	0.006 2	0.000 3	0.005 8	0.000 9	0.005 9	0.002 9	0.005 9
NIST	-0.002 2	0.005 7	0.010 7	0.016 2	0.000 2	0.006 6	-0.003 5	0.006 0			-0.003 6	0.006 0	-0.003 2	0.005 6	-0.002 6	0.005 6	-0.000 6	0.005 7
NMIA	0.001 4	0.006 0	0.014 3	0.016 3	0.003 8	0.006 9	0.000 1	0.006 2	0.003 6	0.006 0			0.000 4	0.005 8	0.001 0	0.005 9	0.003 0	0.006 0
NPL	0.001 0	0.005 5	0.013 9	0.016 2	0.003 4	0.006 5	-0.000 3	0.005 8	0.003 2	0.005 6	-0.000 4	0.005 8			0.000 6	0.005 5	0.002 6	0.005 5
INRIM	0.000 4	0.005 6	0.013 3	0.016 2	0.002 8	0.006 5	-0.000 9	0.005 9	0.002 6	0.005 6	-0.001 0	0.005 9	-0.000 6	0.005 5			0.002 0	0.005 6
NRC	-0.001 6	0.005 7	0.011 3	0.016 2	0.000 8	0.006 6	-0.002 9	0.005 9	0.000 6	0.005 7	-0.003 0	0.006 0	-0.002 6	0.005 5	-0.002 0	0.005 6		

Table 15 Participants' equivalence at 90 kPa

100 kPa	BIPM		METAS		LNE-INM		PTB		NIST		NMIA		NPL		INRIM		NRC	
	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)
	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2
BIPM			0.014 8	0.016 3	0.003 6	0.007 2	-0.000 1	0.007 0	0.003 0	0.006 9	-0.000 4	0.007 3	0.000 1	0.006 7	0.000 7	0.006 8	0.002 5	0.006 8
METAS	-0.014 8	0.016 3			-0.011 1	0.016 5	-0.014 9	0.016 4	-0.011 8	0.016 3	-0.015 2	0.016 5	-0.014 6	0.016 3	-0.014 1	0.016 3	-0.012 2	0.016 3
LNE-INM	-0.003 6	0.007 2	0.011 1	0.016 5			-0.003 8	0.007 4	-0.000 6	0.007 2	-0.004 0	0.007 6	-0.003 5	0.007 1	-0.002 9	0.007 2	-0.001 1	0.007 2
PTB	0.000 1	0.007 0	0.014 9	0.016 4	0.003 8	0.007 4			0.003 1	0.007 1	-0.000 3	0.007 4	0.000 3	0.006 9	0.000 8	0.007 0	0.002 7	0.007 0
NIST	-0.003 0	0.006 9	0.011 8	0.016 3	0.000 6	0.007 2	-0.003 1	0.007 1			-0.003 4	0.007 3	-0.002 9	0.006 8	-0.002 3	0.006 9	-0.000 5	0.006 9
NMIA	0.000 4	0.007 3	0.015 2	0.016 5	0.004 0	0.007 6	0.000 3	0.007 4	0.003 4	0.007 3			0.000 5	0.007 2	0.001 1	0.007 2	0.002 9	0.007 3
NPL	-0.000 1	0.006 7	0.014 6	0.016 3	0.003 5	0.007 1	-0.000 3	0.006 9	0.002 9	0.006 8	-0.000 5	0.007 2			0.000 6	0.006 7	0.002 4	0.006 7
INRIM	-0.000 7	0.006 8	0.014 1	0.016 3	0.002 9	0.007 2	-0.000 8	0.007 0	0.002 3	0.006 9	-0.001 1	0.007 2	-0.000 6	0.006 7			0.001 8	0.006 8
NRC	-0.002 5	0.006 8	0.012 2	0.016 3	0.001 1	0.007 2	-0.002 7	0.007 0	0.000 5	0.006 9	-0.002 9	0.007 3	-0.002 4	0.006 7	-0.001 8	0.006 8		

Table 16 Participants' equivalence at 100 kPa

110 kPa	METAS		PTB		NIST		NMIA		NPL		INRIM		NRC	
	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)
	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2
METAS			-0.016 7	0.018 6	-0.013 5	0.018 5	-0.017 0	0.018 6	-0.016 6	0.018 5	-0.015 3	0.018 5	-0.014 4	0.018 5
PTB	0.016 7	0.018 6			0.003 2	0.007 9	-0.000 3	0.007 9	0.000 1	0.007 7	0.001 4	0.007 8	0.002 3	0.007 8
NIST	0.013 5	0.018 5	-0.003 2	0.007 9			-0.003 5	0.007 9	-0.003 1	0.007 6	-0.001 8	0.007 7	-0.000 9	0.007 8
NMIA	0.017 0	0.018 6	0.000 3	0.007 9	0.003 5	0.007 9			0.000 4	0.007 7	0.001 7	0.007 8	0.002 6	0.007 8
NPL	0.016 6	0.018 5	-0.000 1	0.007 7	0.003 1	0.007 6	-0.000 4	0.007 7			0.001 3	0.007 6	0.002 2	0.007 6
INRIM	0.015 3	0.018 5	-0.001 4	0.007 8	0.001 8	0.007 7	-0.001 7	0.007 8	-0.001 3	0.007 6			0.000 9	0.007 7
NRC	0.014 4	0.018 5	-0.002 3	0.007 8	0.000 9	0.007 8	-0.002 6	0.007 8	-0.002 2	0.007 6	-0.000 9	0.007 7		

Table 17 Participants' equivalence at 110 kPa

Note: BIPM and LNE-INM did not take measurements at 110 kPa

120 kPa	METAS		PTB		NIST		INRIM		NRC	
	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)	di.j	U(di,j)
	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2
METAS			-0.014 3	0.016 7	-0.011 4	0.016 7	-0.013 8	0.016 7	-0.011 9	0.016 7
PTB	0.014 3	0.016 7			0.002 9	0.007 6	0.000 5	0.007 5	0.002 4	0.007 5
NIST	0.011 4	0.016 7	-0.002 9	0.007 6			-0.002 4	0.007 5	-0.000 5	0.007 5
INRIM	0.013 8	0.016 7	-0.000 5	0.007 5	0.002 4	0.007 5			0.001 9	0.007 4
NRC	0.011 9	0.016 7	-0.002 4	0.007 5	0.000 5	0.007 5	-0.001 9	0.007 4		

Table 18 Participants' equivalence at 120 kPa

Note: BIPM, LNE-INM, NMIA and NPL did not take measurements at 120 kPa