# Final Report
# CCM Key Comparison CCM.P-K6
# Pressure (10 kPa to 120 kPa) Gauge Mode

Ian Severn[1], Li Yanhua[2], Archie Miiller[3], Anil Agarwal[4], Jos Verbeek[5], Michael Jescheck[6], Christian Wüthrich[7]

## Abstract
The results are presented of key comparison CCM.P-K6 that covered the pressure range 10 kPa to 120 kPa in gauge mode. Seven national measurement institutes participated in the comparison, which used a piston-cylinder assembly of 335 mm$^2$ nominal effective area as a transfer standard. All the participants' results were equivalent to the reference value within the quoted uncertainties and all participants' results were in good agreement with all other participants' results.

[1] National Physical Laboratory, Hampton Road, Teddington, Middlesex, TW11 0LW, United Kingdom
[2] National Institute of Metrology, 18 Bei San Huan Dong Lu, 100013 Beijing, China
[3] National Institute of Standards and Technology, 100 Bureau Drive, Stop 8364, Gaithersburg, MD 20899-8364, United States of America
[4] National Research Council of Canada, Montreal Road, K1A OR6 Ottawa, Canada
[5] Netherlands Meetinstituut – Van Swinden Laboratorium, Thijsseweg 11, P.O. Box 654,NL-2600 AR, Delft, Netherlands
[6] Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany
[7] 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, gauge 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 absolute mode using the same equipment, CCM.P-K2, 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 metrology organizations – EUROMET, APMP and SIM. The Istituto di Metrologia "G Colonnetti" (CNR-IMGC) withdrew results from this comparison because of problems in the method of gauge mode with their standard at the time of the measurements. Table 1 shows the remaining participants.

| Laboratory | Country | Region |
|---|---|---|
| National Institute of Metrology (NIM) | China | APMP |
| National Institute of Standards and Technology (NIST) | USA | SIM |
| National Physical Laboratory (NPL) | United Kingdom | EUROMET |
| National Research Council (NRC). | Canada | SIM |
| Netherlands Meetinstituut – Van Swinden Laboratorium (NMi-VSL) | Netherlands | EUROMET |
| Physikalisch-Technische Bundesanstalt (PTB) | Germany | EUROMET |
| Swiss Federal Office of Metrology and Accreditation (METAS) | Switzerland | EUROMET |

**Table 1 Participants**

Most participants in the comparison use mercury manometers as their primary standards, determining the height of the mercury columns with either laser or ultrasonic interferometry, and the other participants used dimensioned piston-cylinders. 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 $1.0 \times 10^3$ Pa to $1.1 \times 10^5$ 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 NMi-VSL piston-cylinder

The NMi-VSL standard used is a commercially available piston-cylinder unit consisting of a tungsten carbide cylinder and a ceramic piston. Its nominal effective area is 980 $mm^2$ and its nominal sensitivity is 10 kPa/kg. The base of the pressure balance has sensors for measuring the air temperature, air pressure, humidity and the temperature of the piston-cylinder unit. There is also a system, in the base of the pressure balance, for rotating the piston automatically and measuring its rotation speed and position. The nominal diameter of the piston is 35 mm and the radial clearance between the piston and the cylinder wall is approximately 0.5 μm.

### 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 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.

## 2.5 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.

## 2.6 NIM piston-cylinder

The NIM standard used for the comparison is a commercially made controlled-clearance piston-cylinder that, for the comparison, was used as a simple gas operated device. It has a nominal diameter of 50 mm and an operating range of 3.5 kPa to175 kPa.

## 2.7 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 the 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 not as good as anticipated, 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-K6 was organized in conjunction with CCM.P-K2 - the absolute mode Key Comparison covering the same range and using the same transfer standard package (with the exception of a capacitance 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) | 18 May 1998 | 26 May 1998 |
| NMi-VSL | 17 August 1998 | 2 September 1998 |
| METAS | 20 November 1998 | 4 December 1998 |
| PTB | 22 February 1999 | 26 March 1999 |
| NPL2 (Monitoring – mid-point) | 18 May 1999 | 26 May 1999 |
| NIST | 22 September 1999 | 11 October 1999 |
| NIM | 9 November 1999 | 22 December 1999 |
| NPL 3 ('Participation' measurements) | 29 August 2000 | 5 September 2000 |
| NPL 4 (Monitoring - final) | 26 February 2001 | 9 March 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:

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

where

$p_o$ 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

$\alpha$ is the coefficient of thermal expansion of the piston-cylinder

$t_c$ is the temperature of the piston-cylinder

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

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

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

$\rho'_a$ is taken to be 1.2 kg.m$^{-3}$

$\rho_a$ is the density of the gas in the bell-jar

$\rho_S$ is taken to be 8000 kg.m$^{-3}$

$\rho_M$ 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 9.1x10$^{-6}$ °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 or 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 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 shows 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 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.

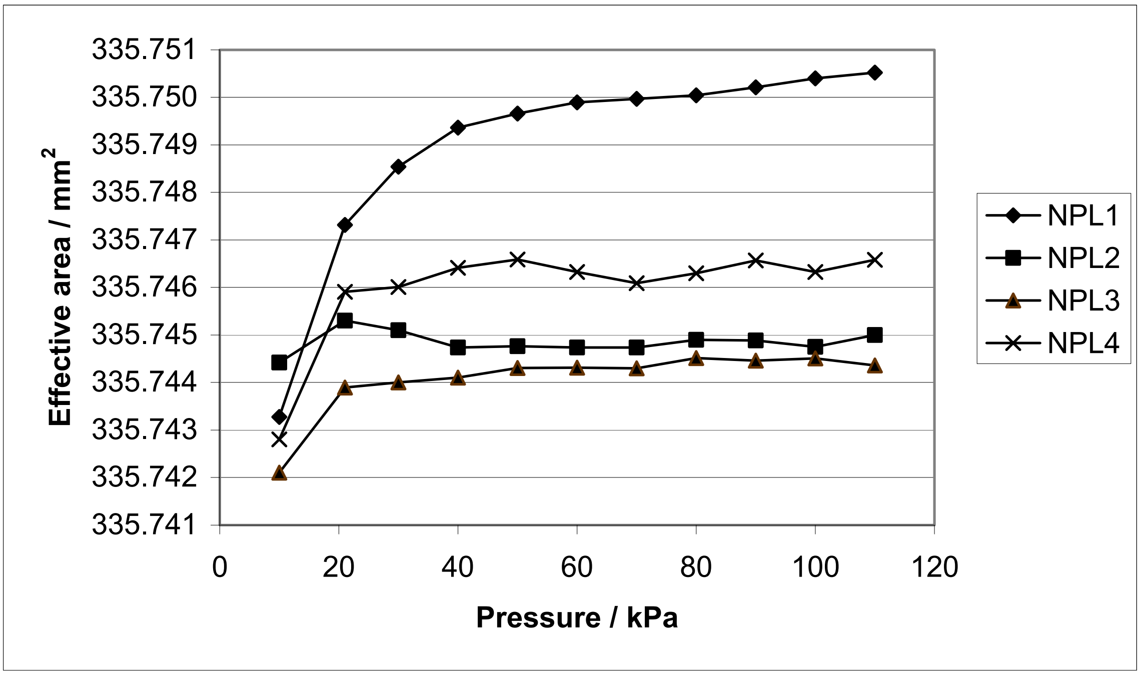


**Figure 1 Results of the four calibrations made at NPL**

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

| Pressure | Reference value | Uncertainty in reference value |
|---|---|---|
| kPa | $mm^2$ | $mm^2$ |
| 10 | 335.744 2 | 0.001 5 |
| 20 | 335.744 4 | 0.000 7 |
| 30 | 335.744 2 | 0.001 0 |
| 40 | 335.744 1 | 0.000 9 |
| 50 | 335.744 3 | 0.000 8 |
| 60 | 335.744 3 | 0.000 5 |
| 70 | 335.744 3 | 0.000 8 |
| 80 | 335.744 5 | 0.000 6 |
| 90 | 335.744 5 | 0.000 7 |
| 100 | 335.744 5 | 0.000 9 |
| 110 | 335.744 4 | 0.000 7 |
| 120 | 335.744 1 | 0.001 0 |

**Table 3 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 di = xi – xref and is given in Table 5 for each nominal pressure. The uncertainty of this deviation was calculated by using the root-sum-of-squares method[8] to combine the uncertainty of the reference value and the participant's reported uncertainty. For statistical completeness an additional uncertainty for the stability of the transfer standard could have been added to each participant's uncertainty estimate. However, given that all of the participants are equivalent with the reference value at all of the pressures it was decided that this should not be taken into account in the analysis of this comparison. The uncertainty of the deviation of each participant's result is given in Table 5, using a coverage factor of k=2.

## 9. PARTICIPANTS' RESULTS AND UNCERTAINTIES

Table 4 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.

---

[8] Often called the *law of propagation of uncertainty* [2].

| | NMi | | METAS | | PTB | | NIST | | NIM | | NPL | | NRC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pressure | xi | ui/xi | xi | ui/xi | xi | ui/xi | xi | ui/xi | xi | ui/xi | xi | ui/xi | xi | ui/xi |
| 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$^{-6}$ |
| | | | | | | | | | | | | | | |
| 10 | | | 335.699 2 | 110 | 335.744 4 | 7.0 | 335.744 0 | 3.2 | 335.747 1 | 4.3 | 335.742 1 | 15 | 335.745 6 | 4.2 |
| 21 | 335.745 4 | 16 | 335.718 3 | 74 | 335.744 4 | 5.6 | 335.743 3 | 3.1 | 335.746 2 | 4.3 | 335.743 9 | 6.8 | 335.744 6 | 3.4 |
| 30 | 335.745 7 | 16 | 335.723 7 | 51 | 335.744 2 | 4.9 | 335.742 9 | 3.0 | 335.745 7 | 4.0 | 335.744 0 | 4.8 | 335.744 2 | 3.1 |
| 40 | 335.745 8 | 16 | 335.720 7 | 49 | 335.744 6 | 4.1 | 335.743 0 | 3.0 | 335.745 3 | 4.2 | 335.744 1 | 3.7 | 335.743 9 | 3.0 |
| 50 | 335.745 5 | 16 | 335.727 6 | 39 | 335.744 8 | 4.2 | 335.743 0 | 3.1 | 335.744 3 | 4.2 | 335.744 3 | 3.0 | 335.743 3 | 2.9 |
| 60 | 335.745 4 | 16 | 335.722 4 | 34 | 335.744 9 | 4.5 | 335.743 0 | 3.1 | 335.744 6 | 4.0 | 335.744 3 | 2.6 | 335.743 8 | 2.8 |
| 70 | 335.745 3 | 16 | 335.728 5 | 26 | 335.745 3 | 5.0 | 335.742 9 | 3.1 | 335.745 2 | 4.2 | 335.744 3 | 2.3 | 335.743 3 | 2.8 |
| 80 | 335.745 2 | 16 | 335.733 2 | 34 | 335.745 3 | 5.3 | 335.742 6 | 3.1 | 335.745 3 | 4.2 | 335.744 5 | 2.1 | 335.743 3 | 2.8 |
| 90 | 335.745 1 | 16 | 335.733 5 | 27 | 335.745 4 | 5.3 | 335.742 8 | 3.0 | 335.745 5 | 4.2 | 335.744 5 | 1.9 | 335.743 6 | 2.8 |
| 100 | 335.745 0 | 16 | 335.730 4 | 24 | 335.745 3 | 3.8 | 335.742 9 | 3.0 | 335.745 7 | 4.1 | 335.744 5 | 1.8 | 335.743 1 | 2.7 |
| 110 | 335.744 9 | 16 | 335.732 6 | 28 | 335.745 3 | 3.3 | 335.742 8 | 3.0 | 335.745 5 | 4.3 | 335.744 4 | 1.7 | 335.743 6 | 2.7 |
| 120 | 335.745 0 | 16 | 335.733 9 | 24 | 335.745 3 | 2.7 | 335.742 9 | 3.0 | 335.746 3 | 4.0 | | | 335.743 3 | 2.7 |

**Table 4 Participants' values and their reported relative standard uncertainties**

$x_i$ is a participant's value and $u_i$ the corresponding reported relative 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 but shows more detail in the remainder. For clarity no error bars have been included in these figures.

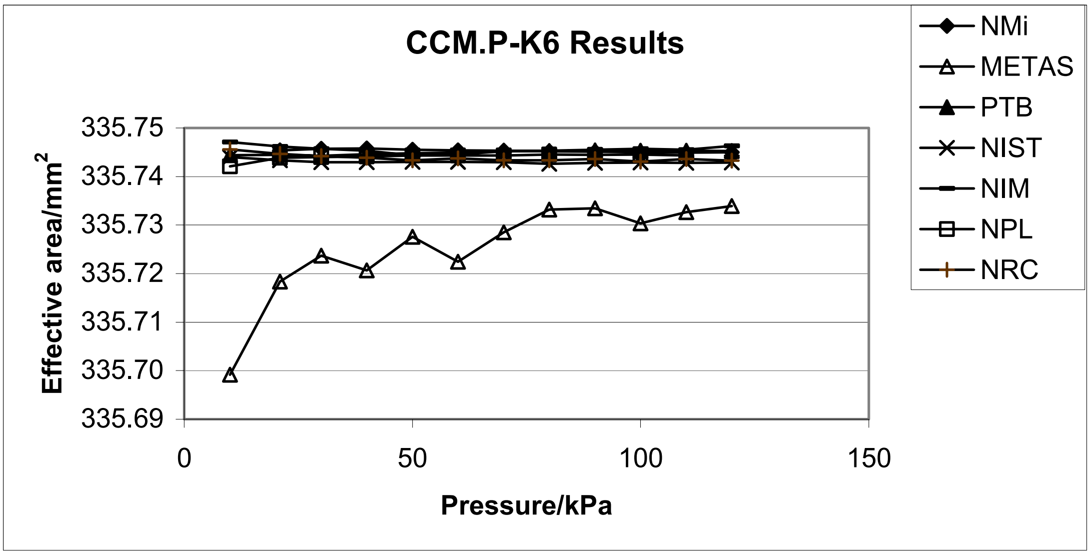


**Figure 2 Participants' results**

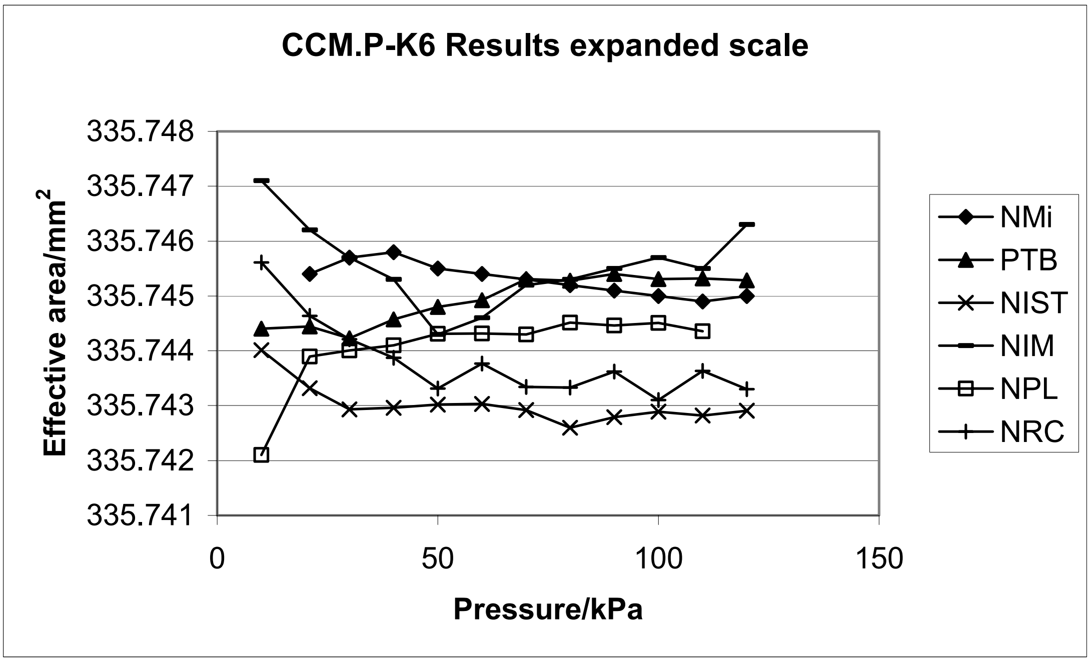


**Figure 3 Participants' results with expanded scale**

The participants' results are shown graphically at two pressures in Figure 4 and Figure 5. The error bars represent the expanded uncertainty reported by each laboratory. The solid line represents the reference value at the given pressure while the broken lines represent the uncertainty in the reference value for a coverage factor of k=2. It can therefore be seen that all participants were in agreement with the reference value within the reported uncertainties.

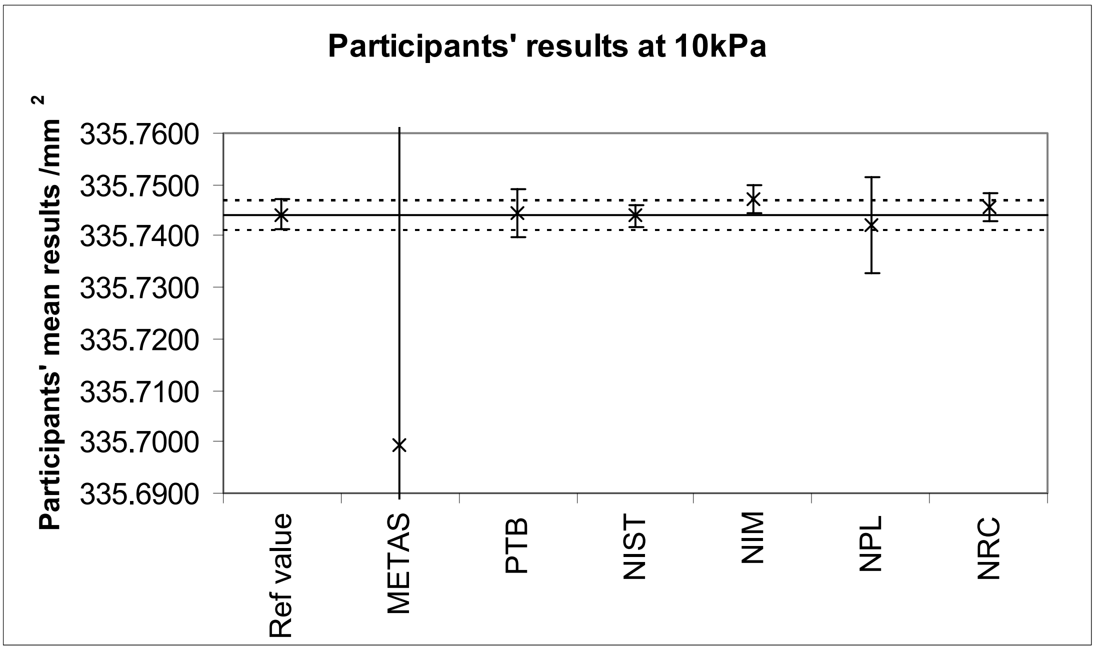


**Figure 4 Participants' results at 10 kPa**

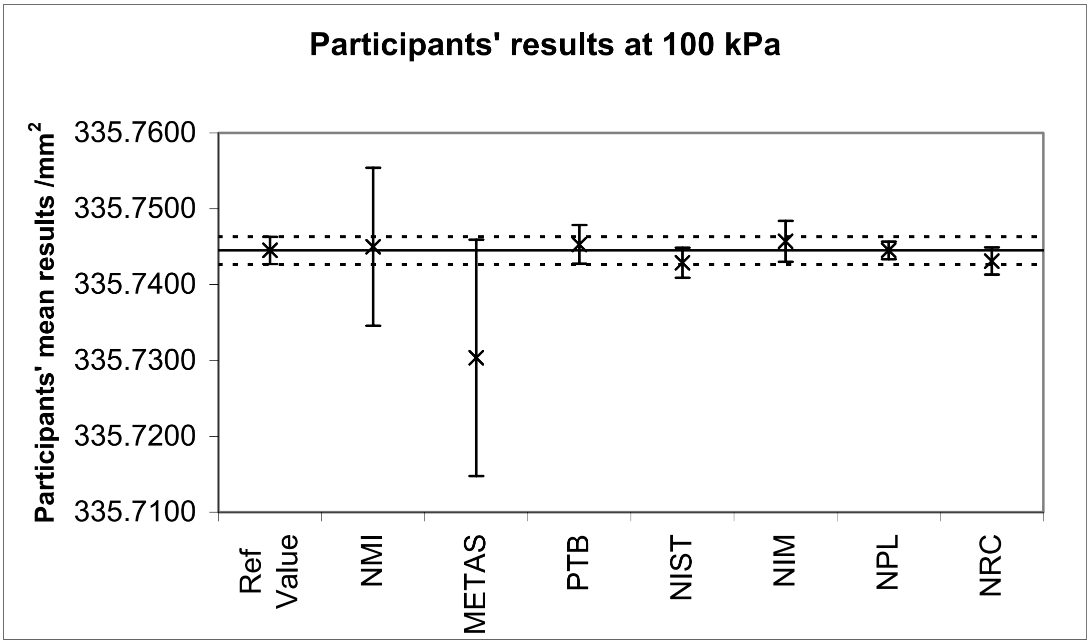


**Figure 5 Participants' results at 100 kPa**

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 Tables 6 to 17. The uncertainty of each pairwise difference was calculated by using the root-sum-of-squares method to combine the uncertainty reported by each participant. For statistical completeness an additional uncertainty term could be added to the uncertainty reported by each participant to account for the instability of the transfer standard. In this comparison this has not been done as all of the participants were shown to be equivalent without such additional uncertainty components. The expanded uncertainty (k=2) of each pairwise difference $U(d_{i,j})$ is given in Tables 6 to 17. These tables also include the deviation of a given laboratory's result from the reference value and the expanded uncertainty of this deviation as given in Table 5.

## 10. CONCLUSION

All the participants' results were equivalent to the reference value within the quoted uncertainties and all participants' results were in good agreement with all other participants' results.

Since the start of this comparison, stability problems have been seen in other devices similar to the type used as the transfer standard. At the meeting of the 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. Although all laboratories were found to be equivalent, 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

| | NMi | | METAS | | PTB | | NIST | | NIM | | NPL | | NRC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pressure | $x_i$-$x_{ref}$ | 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 | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ |
| 10 | | | -0.0451 | 0.075 | 0.0002 | 0.0056 | -0.0002 | 0.0036 | 0.0029 | 0.0041 | -0.0021 | 0.0100 | 0.0014 | 0.0041 |
| 20 | 0.0010 | 0.011 | -0.0261 | 0.050 | 0.0000 | 0.0041 | -0.0011 | 0.0026 | 0.0018 | 0.0032 | -0.0005 | 0.0048 | 0.0002 | 0.0027 |
| 30 | 0.0015 | 0.011 | -0.0205 | 0.035 | 0.0000 | 0.0038 | -0.0013 | 0.0028 | 0.0015 | 0.0033 | -0.0002 | 0.0038 | 0.0000 | 0.0029 |
| 40 | 0.0017 | 0.011 | -0.0234 | 0.033 | 0.0005 | 0.0033 | -0.0011 | 0.0027 | 0.0012 | 0.0033 | 0.0000 | 0.0030 | -0.0002 | 0.0027 |
| 50 | 0.0012 | 0.011 | -0.0167 | 0.026 | 0.0005 | 0.0032 | -0.0013 | 0.0026 | 0.0000 | 0.0032 | 0.0000 | 0.0025 | -0.0010 | 0.0025 |
| 60 | 0.0011 | 0.011 | -0.0219 | 0.023 | 0.0006 | 0.0032 | -0.0013 | 0.0023 | 0.0003 | 0.0028 | 0.0000 | 0.0020 | -0.0005 | 0.0021 |
| 70 | 0.0010 | 0.011 | -0.0158 | 0.018 | 0.0010 | 0.0037 | -0.0014 | 0.0026 | 0.0009 | 0.0032 | 0.0000 | 0.0022 | -0.0010 | 0.0024 |
| 80 | 0.0007 | 0.011 | -0.0113 | 0.023 | 0.0008 | 0.0038 | -0.0019 | 0.0024 | 0.0008 | 0.0031 | 0.0000 | 0.0019 | -0.0012 | 0.0022 |
| 90 | 0.0006 | 0.011 | -0.0110 | 0.018 | 0.0009 | 0.0039 | -0.0017 | 0.0025 | 0.0010 | 0.0031 | 0.0000 | 0.0019 | -0.0008 | 0.0024 |
| 100 | 0.0005 | 0.011 | -0.0142 | 0.016 | 0.0008 | 0.0032 | -0.0016 | 0.0027 | 0.0012 | 0.0033 | 0.0000 | 0.0022 | -0.0014 | 0.0026 |
| 110 | 0.0005 | 0.011 | -0.0117 | 0.019 | 0.0010 | 0.0027 | -0.0015 | 0.0025 | 0.0011 | 0.0032 | 0.0000 | 0.0019 | -0.0007 | 0.0024 |
| 120 | 0.0009 | 0.011 | -0.0103 | 0.016 | 0.0011 | 0.0027 | -0.0012 | 0.0028 | 0.0022 | 0.0033 | | | -0.0009 | 0.0027 |

**Table 5 Differences between participants' results and 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 combined expanded uncertainty of $x_i$ and $x_{ref}$ giving an uncertainty in the difference ($x_i$- $x_{ref}$).

| | Ref value | | METAS | | PTB | | NIST | | NIM | | NPL | | NRC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $d_i$ | $U(d_i)$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ |
| | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ |
| METAS | -0.0451 | 0.075 | | | -0.0453 | 0.075 | -0.0449 | 0.075 | -0.0479 | 0.075 | -0.0429 | 0.076 | -0.0465 | 0.075 |
| PTB | 0.0002 | 0.0055 | 0.0453 | 0.075 | | | 0.0004 | 0.0051 | -0.0027 | 0.0055 | 0.0023 | 0.011 | -0.0012 | 0.0054 |
| NIST | -0.0002 | 0.0036 | 0.0449 | 0.075 | -0.0004 | 0.0051 | | | -0.0031 | 0.0035 | 0.0019 | 0.0097 | -0.0016 | 0.0035 |
| NIM | 0.0029 | 0.0041 | 0.0479 | 0.075 | 0.0027 | 0.0055 | 0.0031 | 0.0035 | | | 0.0050 | 0.0099 | 0.0015 | 0.0039 |
| NPL | -0.0021 | 0.010 | 0.0429 | 0.076 | -0.0023 | 0.011 | -0.0019 | 0.0097 | -0.0050 | 0.0099 | | | -0.0035 | 0.0099 |
| NRC | 0.0014 | 0.0040 | 0.0465 | 0.075 | 0.0012 | 0.0054 | 0.0016 | 0.0035 | -0.0015 | 0.0039 | 0.0035 | 0.0099 | | |

**Table 6 Participants' equivalence at 10 kPa**

Note NMi did not take measurements at 10 kPa

| | Ref value | | NMi | | METAS | | PTB | | NIST | | NIM | | NPL | | NRC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $d_i$ | $U(d_i)$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ |
| | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ |
| NMi | 0.0010 | 0.011 | | | 0.02705 | 0.051 | 0.0010 | 0.012 | 0.0021 | 0.011 | -0.0008 | 0.011 | 0.0015 | 0.012 | 0.0008 | 0.011 |
| METAS | -0.0261 | 0.050 | -0.0271 | 0.051 | | | -0.0261 | 0.050 | -0.0250 | 0.050 | -0.0279 | 0.050 | -0.0255 | 0.050 | -0.0263 | 0.050 |
| PTB | 0.0000 | 0.0041 | -0.0010 | 0.012 | 0.02609 | 0.050 | | | 0.0011 | 0.0043 | -0.0018 | 0.0047 | 0.0005 | 0.0059 | -0.0002 | 0.0044 |
| NIST | -0.0011 | 0.0026 | -0.0021 | 0.011 | 0.0250 | 0.050 | -0.0011 | 0.0043 | | | -0.0029 | 0.0035 | -0.0006 | 0.0050 | -0.0013 | 0.0031 |
| NIM | 0.0018 | 0.0032 | 0.0008 | 0.011 | 0.02785 | 0.050 | 0.0018 | 0.0047 | 0.0029 | 0.0035 | | | 0.0023 | 0.0054 | 0.0016 | 0.0036 |
| NPL | -0.0005 | 0.0048 | -0.0015 | 0.012 | 0.02555 | 0.050 | -0.0005 | 0.0059 | 0.0006 | 0.0050 | -0.0023 | 0.0054 | | | -0.0007 | 0.0051 |
| NRC | 0.0002 | 0.0027 | -0.0008 | 0.011 | 0.02629 | 0.050 | 0.0002 | 0.0044 | 0.0013 | 0.0031 | -0.0016 | 0.0036 | 0.0007 | 0.0051 | | |

**Table 7 Participants' equivalence at 20 kPa**

| | Ref value | | NMi | | METAS | | PTB | | NIST | | NIM | | NPL | | NRC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $d_i$ | $U(d_i)$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ |
| | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ |
| NMi | 0.0015 | 0.011 | | | 0.02199 | 0.036 | 0.0015 | 0.011 | 0.0028 | 0.011 | 0.0000 | 0.011 | 0.0017 | 0.011 | 0.0015 | 0.011 |
| METAS | -0.0205 | 0.035 | -0.0220 | 0.036 | | | -0.0205 | 0.035 | -0.0192 | 0.035 | -0.0220 | 0.035 | -0.0203 | 0.035 | -0.0205 | 0.035 |
| PTB | 0.0000 | 0.0038 | -0.0015 | 0.011 | 0.02053 | 0.035 | | | 0.0013 | 0.0039 | -0.0015 | 0.0042 | 0.0002 | 0.0046 | 0.0000 | 0.0039 |
| NIST | -0.0013 | 0.0028 | -0.0028 | 0.011 | 0.0192 | 0.035 | -0.0013 | 0.0039 | | | -0.0028 | 0.0033 | -0.0011 | 0.0038 | -0.0013 | 0.0029 |
| NIM | 0.0015 | 0.0033 | 0.0000 | 0.011 | 0.02199 | 0.035 | 0.0015 | 0.0042 | 0.0028 | 0.0033 | | | 0.0017 | 0.0042 | 0.0015 | 0.0034 |
| NPL | -0.0002 | 0.0038 | -0.0017 | 0.011 | 0.0203 | 0.035 | -0.0002 | 0.0046 | 0.0011 | 0.0038 | -0.0017 | 0.0042 | | | -0.0002 | 0.0039 |
| NRC | 0.0000 | 0.0029 | -0.0015 | 0.011 | 0.02051 | 0.035 | 0.0000 | 0.0039 | 0.0013 | 0.0029 | -0.0015 | 0.0034 | 0.0002 | 0.0039 | | |

**Table 8 Participants' equivalence at 30 kPa**

| | Ref value | | NMi | | METAS | | PTB | | NIST | | NIM | | NPL | | NRC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $d_i$ | $U(d_i)$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ |
| | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ |
| NMi | 0.0017 | 0.011 | | | 0.02514 | 0.035 | 0.0012 | 0.011 | 0.0028 | 0.011 | 0.0005 | 0.011 | 0.0017 | 0.011 | 0.0019 | 0.011 |
| METAS | -0.0234 | 0.033 | -0.0251 | 0.035 | | | -0.0239 | 0.033 | -0.0223 | 0.033 | -0.0246 | 0.033 | -0.0234 | 0.033 | -0.0232 | 0.033 |
| PTB | 0.0005 | 0.0033 | -0.0012 | 0.011 | 0.02392 | 0.033 | | | 0.0016 | 0.0034 | -0.0007 | 0.0039 | 0.0005 | 0.0037 | 0.0007 | 0.0034 |
| NIST | -0.0011 | 0.0027 | -0.0028 | 0.011 | 0.0223 | 0.033 | -0.0016 | 0.0034 | | | -0.0023 | 0.0035 | -0.0011 | 0.0032 | -0.0009 | 0.0029 |
| NIM | 0.0012 | 0.0033 | -0.0005 | 0.011 | 0.02464 | 0.033 | 0.0007 | 0.0039 | 0.0023 | 0.0035 | | | 0.0012 | 0.0037 | 0.0014 | 0.0034 |
| NPL | 0.0000 | 0.0030 | -0.0017 | 0.011 | 0.02345 | 0.033 | -0.0005 | 0.0037 | 0.0011 | 0.0032 | -0.0012 | 0.0037 | | | 0.0002 | 0.0032 |
| NRC | -0.0002 | 0.0027 | -0.0019 | 0.011 | 0.02321 | 0.033 | -0.0007 | 0.0034 | 0.0009 | 0.0029 | -0.0014 | 0.0034 | -0.0002 | 0.0032 | | |

**Table 9 Participants' equivalence at 40 kPa**

| | Ref value | | NMi | | METAS | | PTB | | NIST | | NIM | | NPL | | NRC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $d_i$ | $U(d_i)$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ |
| | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ |
| NMi | 0.0012 | 0.011 | | | 0.01789 | 0.028 | 0.0007 | 0.011 | 0.0025 | 0.011 | 0.0012 | 0.011 | 0.0012 | 0.011 | 0.0022 | 0.011 |
| METAS | -0.0167 | 0.026 | -0.0179 | 0.028 | | | -0.0172 | 0.026 | -0.0154 | 0.026 | -0.0167 | 0.026 | -0.0167 | 0.026 | -0.0157 | 0.026 |
| PTB | 0.0005 | 0.0032 | -0.0007 | 0.011 | 0.01719 | 0.026 | | | 0.0018 | 0.0035 | 0.0005 | 0.0040 | 0.0005 | 0.0035 | 0.0015 | 0.0034 |
| NIST | -0.0013 | 0.0026 | -0.0025 | 0.011 | 0.01540 | 0.026 | -0.0018 | 0.0035 | | | -0.0013 | 0.0035 | -0.0013 | 0.0029 | -0.0003 | 0.0028 |
| NIM | 0.0000 | 0.0032 | -0.0012 | 0.011 | 0.01669 | 0.026 | -0.0005 | 0.0040 | 0.0013 | 0.0035 | | | 0.0000 | 0.0034 | 0.0010 | 0.0034 |
| NPL | 0.0000 | 0.0025 | -0.0012 | 0.011 | 0.01670 | 0.026 | -0.0005 | 0.0035 | 0.0013 | 0.0029 | 0.0000 | 0.0034 | | | 0.0010 | 0.0028 |
| NRC | -0.0010 | 0.0025 | -0.0022 | 0.011 | 0.01570 | 0.026 | -0.0015 | 0.0034 | 0.0003 | 0.0028 | -0.0010 | 0.0034 | -0.0010 | 0.0028 | | |

**Table 10 Participants' equivalence at 50 kPa**

| | Ref value | | NMi | | METAS | | PTB | | NIST | | NIM | | NPL | | NRC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $d_i$ | $U(d_i)$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ |
| | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ |
| NMi | 0.0011 | 0.011 | | | 0.0230 | 0.025 | 0.0005 | 0.011 | 0.0024 | 0.011 | 0.0008 | 0.011 | 0.0011 | 0.011 | 0.0016 | 0.011 |
| METAS | -0.0219 | 0.023 | -0.0230 | 0.025 | | | -0.0225 | 0.023 | -0.0206 | 0.023 | -0.0222 | 0.023 | -0.0219 | 0.023 | -0.0214 | 0.023 |
| PTB | 0.0006 | 0.0032 | -0.0005 | 0.011 | 0.0225 | 0.023 | | | 0.0019 | 0.0036 | 0.0003 | 0.0040 | 0.0006 | 0.0035 | 0.0012 | 0.0036 |
| NIST | -0.0013 | 0.0023 | -0.0024 | 0.011 | 0.0206 | 0.023 | -0.0019 | 0.0036 | | | -0.0016 | 0.0034 | -0.0013 | 0.0027 | -0.0007 | 0.0028 |
| NIM | 0.0003 | 0.0028 | -0.0008 | 0.011 | 0.0222 | 0.023 | -0.0003 | 0.0040 | 0.0016 | 0.0034 | | | 0.0003 | 0.0032 | 0.0008 | 0.0033 |
| NPL | 0.0000 | 0.0020 | -0.0011 | 0.011 | 0.0219 | 0.023 | -0.0006 | 0.0035 | 0.0013 | 0.0027 | -0.0003 | 0.0032 | | | 0.0005 | 0.0026 |
| NRC | -0.0005 | 0.0021 | -0.0016 | 0.011 | 0.0214 | 0.023 | -0.0012 | 0.0036 | 0.0007 | 0.0028 | -0.0008 | 0.0033 | -0.0005 | 0.0026 | | |

**Table 11 Participants' equivalence at 60 kPa**

| | Ref value | | NMi | | METAS | | PTB | | NIST | | NIM | | NPL | | NRC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $d_i$ | $U(d_i)$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ |
| | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ |
| NMi | 0.0010 | 0.011 | | | 0.0168 | 0.020 | 0.0000 | 0.011 | 0.0024 | 0.011 | 0.0001 | 0.011 | 0.0010 | 0.011 | 0.0020 | 0.011 |
| METAS | -0.0158 | 0.018 | -0.0168 | 0.020 | | | -0.0168 | 0.018 | -0.0144 | 0.018 | -0.0167 | 0.018 | -0.0158 | 0.018 | -0.0148 | 0.018 |
| PTB | 0.0010 | 0.0037 | 0.0000 | 0.011 | 0.0168 | 0.018 | | | 0.0024 | 0.0039 | 0.0001 | 0.0044 | 0.0010 | 0.0037 | 0.0020 | 0.0038 |
| NIST | -0.0014 | 0.0026 | -0.0024 | 0.011 | 0.0144 | 0.018 | -0.0024 | 0.0039 | | | -0.0023 | 0.0035 | -0.0014 | 0.0026 | -0.0004 | 0.0028 |
| NIM | 0.0009 | 0.0032 | -0.0001 | 0.011 | 0.0167 | 0.018 | -0.0001 | 0.0044 | 0.0023 | 0.0035 | | | 0.0009 | 0.0032 | 0.0019 | 0.0034 |
| NPL | 0.0000 | 0.0022 | -0.0010 | 0.011 | 0.0158 | 0.018 | -0.0010 | 0.0037 | 0.0014 | 0.0026 | -0.0009 | 0.0032 | | | 0.0010 | 0.0024 |
| NRC | -0.0010 | 0.0024 | -0.0020 | 0.011 | 0.0148 | 0.018 | -0.0020 | 0.0038 | 0.0004 | 0.0028 | -0.0019 | 0.0034 | -0.0010 | 0.0024 | | |

**Table 12 Participants' equivalence at 70 kPa**

| | Ref value | | NMi | | METAS | | PTB | | NIST | | NIM | | NPL | | NRC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $d_i$ | $U(d_i)$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ |
| | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ |
| NMi | 0.0007 | 0.011 | | | 0.0120 | 0.026 | -0.0001 | 0.011 | 0.0026 | 0.011 | -0.0001 | 0.011 | 0.0007 | 0.011 | 0.0019 | 0.011 |
| METAS | -0.0113 | 0.023 | -0.0120 | 0.026 | | | -0.0121 | 0.024 | -0.0094 | 0.023 | -0.0121 | 0.023 | -0.0113 | 0.023 | -0.0101 | 0.023 |
| PTB | 0.0008 | 0.0038 | 0.0001 | 0.011 | 0.0121 | 0.024 | | | 0.0027 | 0.0041 | 0.0000 | 0.0045 | 0.0008 | 0.0038 | 0.0019 | 0.0040 |
| NIST | -0.0019 | 0.0024 | -0.0026 | 0.011 | 0.0094 | 0.023 | -0.0027 | 0.0041 | | | -0.0027 | 0.0035 | -0.0019 | 0.0025 | -0.0007 | 0.0028 |
| NIM | 0.0008 | 0.0031 | 0.0001 | 0.011 | 0.0121 | 0.023 | 0.0000 | 0.0045 | 0.0027 | 0.0035 | | | 0.0008 | 0.0031 | 0.0020 | 0.0034 |
| NPL | 0.0000 | 0.0019 | -0.0007 | 0.011 | 0.0113 | 0.023 | -0.0008 | 0.0038 | 0.0019 | 0.0025 | -0.0008 | 0.0031 | | | 0.0012 | 0.0023 |
| NRC | -0.0012 | 0.0022 | -0.0019 | 0.011 | 0.0101 | 0.023 | -0.0019 | 0.0040 | 0.0007 | 0.0028 | -0.0020 | 0.0034 | -0.0012 | 0.0023 | | |

**Table 13 Participants' equivalence at 80 kPa**

| | Ref value | | NMi | | METAS | | PTB | | NIST | | NIM | | NPL | | NRC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $d_i$ | $U(d_i)$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ |
| | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ |
| NMi | 0.0006 | 0.011 | | | 0.0116 | 0.021 | -0.0003 | 0.011 | 0.0023 | 0.011 | -0.0004 | 0.011 | 0.0006 | 0.011 | 0.0015 | 0.011 |
| METAS | -0.0110 | 0.018 | -0.0116 | 0.021 | | | -0.0119 | 0.019 | -0.0093 | 0.018 | -0.0120 | 0.019 | -0.0110 | 0.018 | -0.0102 | 0.018 |
| PTB | 0.0009 | 0.0039 | 0.0003 | 0.011 | 0.0119 | 0.019 | | | 0.0026 | 0.0041 | -0.0001 | 0.0045 | 0.0009 | 0.0038 | 0.0018 | 0.0040 |
| NIST | -0.0017 | 0.0025 | -0.0023 | 0.011 | 0.0093 | 0.018 | -0.0026 | 0.0041 | | | -0.0027 | 0.0034 | -0.0017 | 0.0024 | -0.0008 | 0.0028 |
| NIM | 0.0010 | 0.0031 | 0.0004 | 0.011 | 0.0120 | 0.019 | 0.0001 | 0.0045 | 0.0027 | 0.0034 | | | 0.0010 | 0.0031 | 0.0019 | 0.0034 |
| NPL | 0.0000 | 0.0019 | -0.0006 | 0.011 | 0.0110 | 0.018 | -0.0009 | 0.0038 | 0.0017 | 0.0024 | -0.0010 | 0.0031 | | | 0.0008 | 0.0023 |
| NRC | -0.0008 | 0.0024 | -0.0015 | 0.011 | 0.0102 | 0.018 | -0.0018 | 0.0040 | 0.0008 | 0.0028 | -0.0019 | 0.0034 | -0.0008 | 0.0023 | | |

**Table 14 Participants' equivalence at 90 kPa**

| | Ref value | | NMi | | METAS | | PTB | | NIST | | NIM | | NPL | | NRC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $d_i$ | $U(d_i)$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ |
| | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ |
| NMi | 0.0005 | 0.011 | | | 0.0146 | 0.019 | -0.0003 | 0.011 | 0.0021 | 0.011 | -0.0007 | 0.011 | 0.0005 | 0.011 | 0.0019 | 0.011 |
| METAS | -0.0142 | 0.016 | -0.0146 | 0.019 | | | -0.0149 | 0.016 | -0.0125 | 0.016 | -0.0153 | 0.016 | -0.0142 | 0.016 | -0.0127 | 0.016 |
| PTB | 0.0008 | 0.0032 | 0.0003 | 0.011 | 0.0149 | 0.016 | | | 0.0024 | 0.0033 | -0.0004 | 0.0038 | 0.0008 | 0.0028 | 0.0022 | 0.0032 |
| NIST | -0.0016 | 0.0027 | -0.0021 | 0.011 | 0.0125 | 0.016 | -0.0024 | 0.0033 | | | -0.0028 | 0.0034 | -0.0016 | 0.0023 | -0.0002 | 0.0027 |
| NIM | 0.0012 | 0.0033 | 0.0007 | 0.011 | 0.0153 | 0.016 | 0.0004 | 0.0038 | 0.0028 | 0.0034 | | | 0.0012 | 0.0030 | 0.0026 | 0.0033 |
| NPL | 0.0000 | 0.0022 | -0.0005 | 0.011 | 0.0142 | 0.016 | -0.0008 | 0.0028 | 0.0016 | 0.0023 | -0.0012 | 0.0030 | | | 0.0014 | 0.0022 |
| NRC | -0.0014 | 0.0026 | -0.0019 | 0.011 | 0.0127 | 0.016 | -0.0022 | 0.0032 | 0.0002 | 0.0027 | -0.0026 | 0.0033 | -0.0014 | 0.0022 | | |

**Table 15 Participants' equivalence at 100 kPa**

| | Ref value | | NMi | | METAS | | PTB | | NIST | | NIM | | NPL | | NRC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $d_i$ | $U(d_i)$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ |
| | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ |
| NMi | 0.0005 | 0.011 | | | 0.0123 | 0.021 | -0.0004 | 0.011 | 0.0021 | 0.011 | -0.0006 | 0.011 | 0.0005 | 0.011 | 0.0013 | 0.011 |
| METAS | -0.0117 | 0.019 | -0.0123 | 0.021 | | | -0.0127 | 0.019 | -0.0102 | 0.019 | -0.0129 | 0.019 | -0.0117 | 0.019 | -0.0110 | 0.019 |
| PTB | 0.0010 | 0.0027 | 0.0004 | 0.011 | 0.0127 | 0.019 | | | 0.0025 | 0.0030 | -0.0002 | 0.0036 | 0.0010 | 0.0025 | 0.0017 | 0.0029 |
| NIST | -0.0015 | 0.0025 | -0.0021 | 0.011 | 0.0102 | 0.019 | -0.0025 | 0.0030 | | | -0.0027 | 0.0035 | -0.0015 | 0.0023 | -0.0008 | 0.0027 |
| NIM | 0.0011 | 0.0032 | 0.0006 | 0.011 | 0.0129 | 0.019 | 0.0002 | 0.0036 | 0.0027 | 0.0035 | | | 0.0011 | 0.0031 | 0.0019 | 0.0034 |
| NPL | 0.0000 | 0.0019 | -0.0005 | 0.011 | 0.0117 | 0.019 | -0.0010 | 0.0025 | 0.0015 | 0.0023 | -0.0011 | 0.0031 | | | 0.0007 | 0.0021 |
| NRC | -0.0007 | 0.0024 | -0.0013 | 0.011 | 0.0110 | 0.019 | -0.0017 | 0.0029 | 0.0008 | 0.0027 | -0.0019 | 0.0034 | -0.0007 | 0.0021 | | |

**Table 16 Participants' equivalence at 110 kPa**

| | Ref value | | NMi | | METAS | | PTB | | NIST | | NIM | | NRC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $d_i$ | $U(d_i)$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ | $d_{i,j}$ | $U(d_{i,j})$ |
| | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ | $mm^2$ |
| NMi | 0.0009 | 0.011 | | | 0.0111 | 0.019 | -0.0003 | 0.011 | 0.0021 | 0.011 | -0.0013 | 0.011 | 0.0017 | 0.011 |
| METAS | -0.0103 | 0.016 | -0.0111 | 0.019 | | | -0.0114 | 0.016 | -0.0090 | 0.016 | -0.0124 | 0.016 | -0.0094 | 0.016 |
| PTB | 0.0011 | 0.0027 | 0.0003 | 0.011 | 0.0114 | 0.016 | | | 0.0024 | 0.0027 | -0.0010 | 0.0032 | 0.0020 | 0.0026 |
| NIST | -0.0012 | 0.0028 | -0.0021 | 0.011 | 0.0090 | 0.016 | -0.0024 | 0.0027 | | | -0.0034 | 0.0034 | -0.0004 | 0.0027 |
| NIM | 0.0022 | 0.0033 | 0.0013 | 0.011 | 0.0124 | 0.016 | 0.0010 | 0.0032 | 0.0034 | 0.0034 | | | 0.0030 | 0.0032 |
| NRC | -0.0009 | 0.0027 | -0.0017 | 0.011 | 0.0094 | 0.016 | -0.0020 | 0.0026 | 0.0004 | 0.0027 | -0.0030 | 0.0032 | | |

**Table 17 Participants' equivalence at 120 kPa**

Note: NPL did not take measurements at 120 kPa