FINAL REPORT

Key comparison EUROMET.M.P-K1.a

Euromet project 442 A

Pressure range: 0.1 Pa – 1000 Pa

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Content

1. Introduction

At a workshop held at NPL (UK) on 8th October 1997 it was decided that there should be a Europewide comparison in the absolute pressure range (0.1 – 1000) Pa with the main objective of having a set of laboratories, at regional level, connected to each other by a wide comparison in the most commonly required range for calibration in low pressure applications; in that comparison each participating laboratory could perform the calibrations by using its own reference system even if it was of a secondary type, provided it was traceable to known primary devices
The transfer standards were commercially available capacitance diaphragm gauges (CDGs), prepared for the comparison by BNM-LNE (Fr) and IMGC-CNR (It) that was the pilot laboratory and the comparison was made under the EUROMET project 442 A coordinated by J.C. Legras of BNM-LNE.

2. Participating laboratories and their standard systems

Twelve laboratories participated in the comparison and received the transfer gauges. Of these one laboratory, SMU did not return any results and another, CMI, informed the pilot laboratory before data circulation that its results had to be withdrawn; so that ten NMIs[11] were included in the final evaluation.
Tables 1 shows the list of the laboratories that participated in the comparison and kept the two packages for the agreed time interval (six weeks plus fifteen days for data preparation and checking).
The following standards were used by the various participating laboratories:

- Six independent systems; four systems of the static expansion type and one based on pressure balances, one ultrasound manometer [for the (30-1000) Pa range only];
- Six systems equipped with gauges traceable to another primary laboratory [one laboratory only in the (0.1-30) Pa range]..

2.1 Independent standards

2.1.1 IMGC-CNR system

The system consists of three volumes, nominally 10 mL, 500 mL and 50 L, the largest volume being the calibration chamber. The different expansion ratios are measured, and are periodically determined, by application of the multiple expansion method.
The initial pressures between 1 kPa and 100 kPa are measured by secondary transfer standards directly traced to the HG5 mercury manometer. The base pressure, obtained by a turbo pump, is in the 10^{-6} Pa range /1/.

2.1.2 BNM-LNE system

The BNM-LNE standard /2/ consists of a combination of three differential capacitance diaphragm gauges, respectively spanning the ranges 0.1 Pa to 100 Pa, 10 Pa to 1000 Pa and 1 kPa to 10 kPa. All the instruments to be compared are connected symmetrically to a vacuum chamber. The CDGs were initially calibrated at a line pressure near 50 kPa by comparison with two primary pressure balances, with nominal effective area of 20 cm^2. Their reference chambers were then evacuated using a turbomolecular pump. The thermal transpiration effect is corrected by using the Takaishi and Sensui /3/ formulae with the experimentally determined sensor temperature.

[11] NMI= National Metrology Institute

Table 1. Laboratories that received and kept the transfer standards for the time scheduled for the comparison

NMI	Country	Reference system	Notes /CMC presence
IMGC-CNR	Italy	Static expansion system	Independent - participated in the CCM.P-K 4/yes
BNM-LNE	France	Pressure balance and transfer gauges (CDGs)	Independent/yes
MIKES	Finnland	Transfer gauges	Traced to PTB through a German accredited laboratory/yes
SP	Sweden	Transfer gauges	Traced to BNM-LNE/yes
PTB	Germany	Static expansion system	Independent- participated in the CCM.P-K 4/yes
CEM	Spain	Transfer gauges (CDGs)	Traced to NPL/yes
NPL	United Kingdom	Static expansion system	Independent- participated in the CCM.P-K 4/yes
OMH	Hungary	System A: transfer gauges (0,1Pa-10 Pa); System B: ultrasound manometer (30 Pa-1000Pa)	(0,1 – 10) Pa traced to PTB; (30 – 1000) Pa independent/yes
UME	Turkey	Static expansion system	Independent /yes
NMi	The Netherlands	Transfer gauges	Traced to PTB/ no

The calibration of the CDGs is performed for their analogue output signal, with a resolution of 0.01 mV. The modelling of the pressure versus the output signal, and the estimation of the stability of the instruments is based on a historical record spanning 10 years. The consistency between the 3 CDG was checked in their common ranges. The validity of the method at low pressure was demonstrated in the range $1\text{x}10^{-3}$ Pa to 100 Pa using the static expansion method: the consistency of a quartz gauge, a CDG and two spinning rotor gauges was inside 0.2 %.

2.1.3 PTB system

The PTB primary standard is a static expansion system, called SE2, in which pressures are generated by expanding gas of known pressure from two alternative small volumes of nominally 0.1 L and 1 L directly into a volume of 100 L. It is also possible to carry out two expansions in series with intermediate nominal volumes of 100 L and 1 L. The regular operational range of SE2 is 0,1 Pa up to 1 kPa. The system is described in detail in references /4,5/.

2.1.4 NPL system

The medium vacuum standard (SEA III) at the NPL is a three-stage non bakeable static expansion system with a 50 L calibration chamber. By varying the initial pressure and the number of stages of expansion, calculable pressures between 1.5×10^{-2} Pa and 2×10^{3} Pa may be generated. There is a choice of two small vessels from which gas may be expanded into the calibration chamber and this enables a greater range of pressures to be generated from a given range of initial pressures. The pressure of the initial gas sample is measured using a quartz Bourdon tube gauge. The pressure generated is calculated from knowledge of the initial pressure, the ratio of the volumes and the gas temperatures. The ratios of the volumes are determined using Elliott's /6/ experimental procedure of repeated expansions and are calculated using the iterative method described by Redgrave et al /7/.

2.1.5 UME system

A newly constructed multi-stage static expansion system has been used to generate calibration pressures in the range from 1×10^{-1} Pa up to 1×10^{2} Pa. The apparatus consists of 6 vessels that provide a pressure reduction by a factor of about 10^{-6} in the main calibration vessel after three-step expansion. 17 platinum resistance thermometers that are mounted on the vessels are used for temperature corrections. The initial pressure before the first expansion is measured by an absolute quartz Bourdon helical gauge (Ruska DPG 7000) having 172 kPa full scale. The whole apparatus is built using UHV techniques and can be baked up to 400° C.

2.1.6 OMH system B (from 30 Pa to 100Pa)

For the (30 –100) Pa pressure range the reference system (named B) is a modified ultrasonic mercury barometer. The original system, built by Dr Alfred Müller, was called EB3, (0…1150) mbar. The tubes were changed in 1993 from 14 mm inner diameter to 27 mm (to reduce uncertainty caused by variations in capillary depression). The height of mercury column is measured by the original ultrasonic system, but the velocity of sound in mercury is calculated using an equation published by NIST. The densities of mercury and air are calculated by formulae published in Metrologia /8/.

2.2 Secondary systems equipped with transfer gauges

2.2.1 MIKES system

Two CGDs: 1 torr and 10 torr full scale MKS type 690 Baratrons were used in the comparison. They were calibrated in the accredited laboratory of MKS Munich in May 1999. The next calibration in April 2000 in the same laboratory showed that there were no problems with stability. Since 2002 the MIKES standards for this pressure range are a spinning rotor gauge, traced to NPL, and a force balanced piston gauge (model FPG8601 by DH Instruments) whose effective area is traced to BNM-LNE.

2.2.2 SP system

The standards used were two CDGs, 1 torr and 100 torr full scale MKS type 390A Baratrons. They were calibrated at SP against two differential CDGs, 1 torr and 100 torr full scale MKS type 398 HD Baratrons that, in turn, were calibrated (at SP) against two RUSKA 2465 piston gauge standards calibrated at BNM- LNE. The reference side pressure, for the calibration of the absolute CDGs was measured with a MKS SRG-2, calibrated at NPL. The CDGs have been in use since 1992 and have shown good stability.

2.2.3 CEM System

The CEM's laboratory pressure standard is based on the dynamic expansion method, although during this intercomparison the set of calibrations were performed by direct comparison to MKS Baratron capacitance diaphragm gauges traceable to NPL, which were used as CEM's standards. Their indications, the temperature of the calibration system and the indication of the transfer standard used in this comparison were recorded. An ionisation gauge and a spinning rotor gauge, checking the agreement of both readings within the uncertainties interval, determined the base pressure. An auxiliary turbo pump was used for the calibration of the 100 Pa differential CDG (Sensor 1, Table 2).

2.2.4. OMH system A

For the (0,1 … 10) Pa pressure range a reference system named A is used in which a spinning rotor gauge (Leybold Vakuum GmbH/Viscovac VM211) calibrated by PTB is used to measure the generated pressure. Vacuum conditions are produced by a TRIVAC D1, 6B type two stage rotary pump and a type TURBOVAC 50 turbomolecular pump.

A unique chamber is used for this standard and that described in 2.1.6. The volume of the chamber together with connecting pipes and valves used in normal intercomparisons is about 3 L, the typical rate of change in pressure is about Q = (2…6)$\times 10^{-6}$ mbar L s^{-1}.The zero base pressure was measured by a spinning rotor gauge.

2.2.5 NMi system

The vacuum calibration facility of the NMi VSL consists of a non-bakeable vacuum chamber developed according to the DIN 28418 standard and a set of capacitance diaphragm gauges. For the lowest part of the calibration range a spinning rotor gauge is used. To reach an appropriate base vacuum pressure a turbo-molecular pump in combination with a two-stage oil rotary vacuum pump is used. The range of the calibration facility is from 1×10^{-6} hPa to 1000 hPa and is mainly used for the calibration of thermal conductivity gauges and diaphragm gauges. The claimed best measurement capability of the NMi VSL vacuum calibration facility in the range of the transfer standards is 0.04 + $0.002\times p$/Pa. The vacuum reference standards are traceable to PTB.

3. Transfer standards

The transfer standards; consisting of three MKS Baratron sensors, two MKS Signal Conditioners and three cables, were operated in the configuration shown in Table 2.

The absolute sensors (s2, s3) were provided with their own isolation valve; the differential sensor (s1) to be used in absolute mode was connected to two valves (v1 for pumping the reference side, v2 being a valve isolating the two sides of the sensor).

The three sensors were not connected to each other because it was decided to let each participating laboratory be free to mount the gauges according to their usual practice.

Table 2: Configuration details of the transfer standards

Sensor	Type	Serial n	FS range	Controller, type, s/n	Package
1 (s1)	698A01TRA	1060661140A	1 torr, differential	1; 670AD21,s/n 95170207A	Provided by IMGC-CNR
2 (s2)	690A01TRB	24853	1 torr, absolute	2; 270DD-5, s/n 24851 SPF	Provided by BNM-LNE
3 (s3)	690A11TRB	000188946	10 torr, absolute	1; 670D21,s/n 95170207A	Provided by IMGC-CNR

The transfer gauges were circulated in two packages:

One package provided by BNM-LNE contained a sensor head marked 'Sensor 2' (with a valve) and its own control unit marked 'Control 2', cable marked 'Cable 2' and shipping documents (ATA carnet for non EU countries).

The second package provided by IMGC-CNR contained: a sensor head marked 'Sensor 1'connected to an ion pump through valves and related pipes; a sensor head marked 'Sensor 3' with valve, control unit marked 'Control 1', cables marked 'Cable 1' and 'Cable 3',control unit for the ion pump and connecting cable, shipping documents (ATA carnet for non EU countries), instruction manual for sensor heads, instruction manual for the control unit, instruction manual for ion pump and control unit and a copy of the agreed protocol.

All the CDGs were equipped with built-in heaters.

4. Organization of the EUROMET.M.P-K1.a comparison

4.1 Chronology of the measurements

Table 3 shows the chronology of the measurements performed at the various participating laboratories. At the beginning twelve laboratories were scheduled for the comparison and they kept the packages for the planned period.
At the end of the comparison data were made available by ten NMIs for the final evaluation.

Table 3: Dates of the three calibrations performed at each NMI and at IMGC-CNR

Laboratory	Sensor 1	Sensor 2	Sensor 3
IMGC-CNR (IMGC1)	1998/09/29-30;1999/02/04	1998/11/25-27;1999/02/02	1998/12/12-14;1999/02/05
BNM-LNE	1999/03/09-10-11	1999/03/09-10-11	1999/03/16-17-18
MIKES	1999/08/26;1999/09/08-09	1999/08/26;1999/08-09	1999/08/20-23-24
IMGC-CNR (IMGC2)	1999/11/17-18-19	1999/11/01-05-08	1999/12/11-14-15
SP	2000/01/24-25-26	1999/12/22-29;2000/01-11	2000/01/18-19-20
PTB	2000/02/14-15-16	2000/02/14-15-16	2000/02/18-21-22
IMGC-CNR (IMGC3)	2000/04/11-12-13	2000/03/29-30-31	2000/04/04-05-06-10
CEM	2000/06/05-06-07	2000/05/19-23-29	2000/06/09-12-13
Repair and controls on all the sensors			
IMGC-CNR (IMGC4)	2000/10/27-30-31	2000/12/04-05-06	2000/11/14-15-20
NPL	2001/01/22-23-24	2001/01/25-26-27	2001/01/17-18-19
IMGC-CNR (IMGC5)	2001/07/26-27-28	2001/07/20-23-24	No longer available
OMH	2001/03/14-19-20	2001/04/09-11-12	No longer available
UME	2001/10/31;2001/11/01-02	2001/11/08-09-11-12	
NMi	2002/02/07	2002/02/05	
IMGC-CNR (IMGC6)	2002/05/06-07-08	2002/04/19-22-23	

4.2 General calibration procedure

Sensors had to be connected by means of suitable pipes to the reference system of the participating laboratory and mounted with the base plate as horizontal as possible. The valves had to be operated following the technical protocol of the comparison.
All the participating laboratories had a good knowledge of the CDG sensors and control units, so that no special instructions were given. The control unit and the heating had to be switched on at least 48 hours before starting the calibrations.
Both the control units had to be operated with the range selection in the position ×1 except for the lowest pressure range (0.1 Pa and 0.3 Pa) where the range selector had to be in the ×0.1 position. All the sensors were calibrated using the display of the signal conditioners. The calibration runs were performed in nitrogen.
Before starting the calibration, NULL and FS indications had to be adjusted; at the lowest pressure, the gauges had to be checked for zero reading, but not adjusted**,** following the specific conditions given in the technical protocol.
Following the protocol, the zero reading of the transfer gauges had to be measured before and after each calibration run and at each pressure level when possible.
The calibrations were performed in the range from 0.1 Pa to 1000 Pa at the following pressure values:

0.1 Pa, 0.3 Pa, 1 Pa, 3 Pa, 10 Pa, 30 Pa, 100 Pa for s1 and s2 (1 torr full scale).
0.1 Pa, 0.3 Pa, 1 Pa, 3 Pa, 10 Pa, 30 Pa, 100 Pa, 300 Pa, 1000 Pa for s3 (10 torr full scale).
The generated pressure values had to be as close as possible to indicated target pressure (at least within 2%).
At each pressure value the participating NMIs had to provide three sets of: generated pressures of the reference standard and their standard uncertainties, the readings of the gauges, the values of the calibration vessel temperature.
Three complete calibration runs were performed, preferably on three different days.
Due to the problems described in Sec. 5, six complete sets of calibrations were performed at IMGC-CNR for the sensors s1 and s2 while for the sensor s3 there were four.

4.3. Data presentation by the participating laboratories

The generated pressure values with their standard uncertainties corresponding to the nominal values (*pt*), the gauges readings (at the base and at generated pressures) and the temperature of the calibration vessel were recorded on Excel sheets and sent to the pilot laboratory.

5. Problems

Initially it was intended that the sensor s1 could be operated with its reference side pumped by the ion pump included in package 1, while each participating laboratory should provide a roughing pump. However, in the middle of the comparison, the ion pump was left exposed to the atmosphere for a long time and became heavily contaminated. Consequently it was decided to proceed without the ion pump and each NMI had then to provide a pumping system for the reference side of that sensor (beginning at CEM).
On the way from CEM to NPL all the sensors suffered serious damage. One package was sent back to BNM-LNE and the second one to IMGC-CNR for inspection and repair. Evidently the bodies of the gauges were twisted and the pipes disconnected from the heads. All the gauges were welded at IMGC-CNR (s1 and s3) and at BNM-LNE (s2) and kept under control to check their operational behavior; finally all the three transfer gauges were calibrated again at IMGC-CNR.
After several calibration cycles it was decided to proceed with the comparison because the characteristics of the sensors were comparable with those shown before they were damaged, although the range of sensor s3 had to be reduced to 3 Pa at its lower limit.
The two packages were sent again to NPL and the transfer gauges were calibrated there; after that the two packages were sent to OMH. On arrival at OMH s3 was found to be damaged again. Considering that the comparison time schedule was already increased, IMGC-CNR decided to continue the comparison at the other laboratories with only the remaining transfer gauges, s1 and s2, which were shipped by OMH to SMU, then to IMGC-CNR, UME and NMi.
The damage to the transfer standards caused a shift in the time schedule and consequently the ATA carnets expired and had to be renewed twice.

6. Data handling at the pilot laboratory

All the data from the various NMIs were checked and evaluated at the pilot laboratory in terms of calibration ratios, given by the ratio of the gauge readings to the generated/measured pressure appropriately corrected as regards zero reading and temperature.

6.1 Correction for the readings at base pressure

The NMIs equipped with primary systems provided the generated pressures without the need for any correction for the base pressure which was negligible low; so that only the readings of the transfer gauges had to be corrected for the zero readings. For those NMIs the mean zero reading was subtracted from the gauge readings at the target.

For the data provided by NMIs equipped with secondary reference gauges both the generated/measured pressures and transfer gauge readings were corrected for their own average zero readings.

6.2 Correction for temperature

Following the protocol all the transfer gauges were operated with their heaters switched on, so that their operation temperature was always close to 45 °C, while the temperature of the standards to which the gauges were connected ranged from 19 °C to 23 °C.

To determine the temperature of the heads several tests were performed at IMGC-CNR to find the most probable temperature of the sensors when in operation. In particular, sensor s2 was calibrated with its heater first switched on then off but with the head located in a climatic cell in which the temperature could be changed, controlled (at $\pm 7\times 10^{-2}$ °C) and measured. Comparing the curves of the calibration ratio versus the pressure it was decided that, in general, 45 °C could be considered as the real average working temperature.

Although several fitting curves have been reported /9,10/ that take into account the different temperatures of the calibration systems and "linearize" the curve of the calibration ratio as a function of the pressure, it was decided to apply the fitting formula presented first in /3,11/ as it was applied to the data of the CCM comparison CCM.P-K4 /12/.

The effect of the different operating temperatures was minimized by determining the pressure that a primary or reference standard would generate/measure if it was operating at the same temperature as the transfer standard gauges by the following relationship:

$$p_{s,h,l,i,j} = (p_{s,h,l,i,j})_{listed} \cdot [aY^2 + bY + cY^{0.5} + 1]/[aY^2 + bY + cY^{0.5} + (T_{s,h,,l,i,j}/T_{g,h,,l,i,j})^{0.5}] \qquad [1]$$

where s stands for standard and g for gauge; i for pressure level and j for the considered laboratory, h for repeated measurements (9) and l for the considered gauges (1,2, 3, corresponding to s1, s2 and s3). Y is given by: $Y=2p_{s,h,l,i,j}d/[133(T_{s,h,l,i,j}+T_{g,h,l,i,j})]$, where $T_{s,h,l,i,j}$ and $T_{g,h,l,i,j}$ are the absolute temperatures respectively of the standard and of the gauge to be calibrated; $(p_{s,h,l,i,j})_{listed}$ is the generated pressure in the reference system as determined by each participating NMI.

The remaining quantities are: internal diameter of the gauge inlet tube d= 4.6 mm and, for nitrogen: $a = 1.2 \times 10^6$ K^2 torr^{-2} mm^{-2}, $b = 1.0 \times 10^3$ K torr^{-1}mm^{-1}, $c = 14$ K$^{0.5}$ torr$^{-0.5}$mm$^{-0.5}$/3,10/.

As the empirical formula [1] was applied for the nominal 45 °C gauge temperature it should be noted that the precise uncertainty of the method is not known. However, since the correction is applied to all the data from all the involved laboratories at each pressure level and for repeated measurements, the contribution of the fitting curve to the uncertainty is disregarded (see also ref./12/).

6.3 Calibration ratios

The calibration ratios (Fc) have been evaluated by the ratio of the transfer gauge readings ($p_{g,h,l,i,j}$) to the standard pressures ($p_{s,h,l,i,j}$) as corrected by [1]. When necessary, both $p_{g,h,l,i,j}$ and $p_{s\ h,l,i,j}$ have been corrected for zero readings. At each target pressure pt_i and for each transfer gauge the mean values of the nine $Fc_{h,l,i,j}$ has been calculated as:

$$Fc_{l,i,j} = \frac{1}{9}\sum_{h=1}^{9} Fc_{h,l,i,j} = \frac{1}{9}\sum_{h=1}^{9} \frac{\left(p_{g,h,l,i,j} - (p_{g,h,l,i,j})_{zero}\right)_{listed}}{\left(p_{s,h,l,i,j} - (p_{s,h,l,i,j})_{zero}\right)_{corr}} = \frac{1}{9}\sum_{h=1}^{9} \frac{p_{g,h,l,i,j}}{p_{s,h,l,i,j}} \qquad [2]$$

So that for each participating laboratory seven values of $Fc_{l,i,j}$ and its relative standard deviation are derived for s1 and s2 transfer gauges and, in general and when possible, nine values for s3 transfer gauge.
To have, at each pressure level, only one set of gauge factors for IMGC-CNR the average of the mean values of the six calibration sets for s1 and s2 and of four calibration sets for s3 has been evaluated:

$$Fc_{l,i,IMGC-CNR} = \frac{1}{6}\sum_{k=1}^{6} Fc_{l,i,IMGC-CNR,k}$$

$$[3]$$

$$Fc_{3,i,IMGC-CNR} = \frac{1}{4}\sum_{k=1}^{4} Fc_{3,i,IMGC-CNR,k}$$

6.4 Uncertainty of the calibration ratios

The relative combined variance of each calibration ratio is given by:

$$\left[u_r(Fc_{l,i,j})\right]^2 = \left[u_{rst}(Fc_{l,i,j})\right]^2 + \left[u_{rlts}\left(Fc_{l,i,j}\right)\right]^2 + \left[u_{rstr}\left(Fc_{l,i,j}\right)\right]^2 + \left[u_{rresol}\left(Fc_{l,i,j}\right)\right]^2 +$$

$$+\left[u_{r,zero}\left(Fc_{l,i,j}\right)\right]^2 + \left[u_{r,T}\left(Fc_{l,i,j}\right)\right]^2 \qquad [4]$$

Where:
u_{rst} is the relative uncertainty quoted by each NMI for its standard, as indicated in Table 4. The uncertainty of the standard reading at the base pressure is taken into account when necessary.
u_{rlts} is the relative uncertainty due to long term instability. Since there is no evidence of continuous systematic shift of the gauge factors in the various calibrations performed at IMGC-CNR over the long calibration period, the relative uncertainty component due to long term instability of gauge factors (as determined by [2]) is evaluated for the s1 and s2 sensors by the six sets of calibrations performed at IMGC-CNR for the whole comparison period and is given, for s3, by the four sets of calibration results. It is calculated by the half difference between the maximum and the minimum values of the $Fc_{i,l,IMGC\text{-}CNR}$ as follows

$$u_{rlts} = (1/2)\,[(Fc_{l,i,IMGC\text{-}CNR})_{max} - (Fc_{l,i,IMGC\text{-}CNR})_{min}] \qquad [5]$$

where i is associated with the two highest pressure levels. The values obtained at 30 Pa and 100 Pa for s1 and s2 sensors, 300 Pa and 1000 Pa for s3 sensor are averaged.
Those average values are considered as type B components and are applied to all the NMIs including the pilot laboratory at each pressure level.
u_{rstr} is the relative uncertainty component due to short term repeatability of the calibration ratio in three runs performed at each NMI (i.e. for the nine values for each level of pressure). Even if there are some systematic effects evident for day-to-day calibration at the same laboratory it was decided to represent the repeatability by the standard deviation of the mean, since any other choice may be equally arbitrary.

Table 4: relative standard uncertainty values as quoted by each NMI for its reference standard

NMI	PTB	BNM-LNE	BNM-LNE	MIKES	SP	IMGC-CNR	CEM	CEM	NPL	OMH	OMH	UME	NMi
p t(Pa)		(s1,s2)	(s3)				(s1,s2)	(s3)		(s1)	(s2)		
0.1	1.4E-03	6.0E-03	6.0E-03	1.9E-01	4.0E-02	2.1E-03	5.5E-03	9.4E-03	4.1E-03	5.7E-02	8.2E-02	5.2E-03	2.5E-01
0.3	1.2E-03	2.7E-03	3.0E-03	6.8E-02	2.4E-02	2.0E-03	4.4E-03	8.4E-03	4.0E-03	2.7E-02	3.3E-02	3.8E-03	8.4E-02
1	1.1E-03	1.8E-03	2.0E-03	2.2E-02	1.9E-02	1.9E-03	3.2E-03	6.2E-03	3.0E-03	4.0E-02	4.1E-02	3.8E-03	2.6E-02
3	1.0E-03	1.3E-03	1.5E-03	8.2E-03	1.1E-02	1.1E-03	3.1E-03	6.1E-03	3.0E-03	4.0E-02	4.0E-02	3.8E-03	9.3E-03
10	9.0E-04	5.7E-04	8.8E-04	3.4E-03	6.1E-03	8.2E-04	3.1E-03	6.1E-03	3.0E-03	5.0E-02	4.0E-02	3.8E-03	3.5E-03
30	7.0E-04	2.3E-04	7.0E-04	2.4E-03	4.7E-03	8.5E-04	2.5E-03	2.0E-03	1.8E-03	5.0E-02	5.0E-02	2.6E-03	1.8E-03
100	7.0E-04	2.0E-04	7.0E-04	2.1E-03	4.2E-03	8.4E-04	2.2E-03	1.9E-03	1.8E-03	1.5E-02	1.5E-02	2.6E-03	1.3E-03
300	7.5E-04		7.0E-04	2.0E-03	1.9E-03	8.3E-04		1.9E-03	1.8E-03				
1000	8.0E-04		7.0E-04	2.0E-03	6.9E-04	8.3E-04		1.9E-03	1.8E-03				

For the pilot laboratory, where *Fc* is evaluated from [3], the short-term repeatability is evaluated as follows:

$$[u_{rstr}(Fc_{l,i,IMGC-CNR})]^2 = \left(\frac{1}{6}\right)^2 \sum_{k=1}^{6} u_{rstr}^2\left(Fc_{l,i,k,IMGC-CNR}\right) \quad [6a]$$

for sensors s1 and s2, and

$$[u_{rstr}(Fc_{l,i,IMGC-CNR})]^2 = \left(\frac{1}{4}\right)^2 \sum_{k=1}^{4} u_{rstr}^2\left(Fc_{l,i,k,IMGC-CNR}\right) \quad [6b]$$

for the sensor s3.

Since there are only nine values available for each laboratory at each pressure level the standard deviation of the mean is multiplied by the factor $\sqrt{(n-1)/(n-3)}$, that is by a factor 1.155 as suggested in /13/.

u_{rresol} is the relative uncertainty component due to the resolution of the Signal Conditioners used with the sensors; the resolution of the zero readings at base pressure is also included; this component has been included for reason of completeness.

$u_{r,zero}$ is the component due to the fluctuations and drift of the zero readings of the transfer gauges. For the majority of the NMIs the resolution covers the possible fluctuations of the zero readings. When the fluctuations are outside of the resolution a component of the uncertainty has been considered by taking the rectangular distribution and averaging among the various runs at each pressure level.[12] This component is then considered as type B and added arithmetically to the resolution.

$u_{r,T}$ is the component of the uncertainty due to the temperature of the primary or reference standards. The uncertainty with which the temperature of the standards is measured is not taken into account; however, applying equations [1] and [2] and assuming a reasonable value of 0.2°C, the relative contribution is less than $3x10^{-4}$ for pressures below 1 Pa and is in the region of 10^{-5} Pa for higher pressures.

[12] Two NMIs (BNM-LNE and CEM) show a considerable fluctuation of the zero readings. For BNM-LNE the zero readings for all the transfer gauges show variations considerably outside of the resolutions while CEM has similar variations only for sensor 1.

6.5 Results –calibration ratios and their uncertainties

In the following tables more digits than are significant are given for the calibration ratios to facilitate the computation checks.

Table 6 summarizes the results in terms of the average of the gauge factors for the various transfer gauges and for each NMI as calculated by the relationship [2] with $p_{s,h,l,i,j}$ corrected for thermal transpiration as described in Sec. 6.2 equation [1] and for the zero readings when necessary; the relative standard deviations s of the means and the relative combined standard uncertainty ur are also given. The IMGC-CNR data are average values, as for the other NMIs, and are related to six sets of calibrations for the sensors s1 and s2 and to four sets of calibrations for sensor s3. The last column of tables 6 are related to the average values for IMGC-CNR as calculated from equation [3] and the uncertainty values evaluated from the various components described in Sec. 6.4.

Table 6 a: mean calibration ratio (Fc) for each laboratory as calculated with $p_{s,h,l,i,j}$ corrected for thermal transpiration, the relative standard deviation s of the mean (s=$u_{rstr}\sqrt{(n-1)/(n-3)}$) and the relative standard uncertainty ur: sensor 1

sensor 1

NMI pt/Pa	IMGC1 *F*c rel *s* *u*r	BNM-LNE Fc rel *s* *u*r	MIKES Fc rel *s* *u*r	IMGC2 Fc rel *s* *u*r	SP Fc rel *s* *u*r	PTB Fc rel *s* *u*r	IMGC3 Fc rel *s* *u*r	CEM Fc rel *s* *u*r	IMGC4 Fc rel *s* *u*r	NPL Fc rel *s* *u*r	OMH Fc rel *s* *u*r	IMGC5 Fc rel *s* *u*r	UME Fc rel *s* *u*r	NMi Fc rel *s* *u*r	IMGC6 Fc rel *s* *u*r	IMGC-CNR Fc rel *s* *u*r
0.1	0.9955	0.9872	1.0130	0.9967	0.9995	0.9986	0.9970	0.6794	0.9939	1.0010	0.5886	1.0016	1.0022	0.9449	1.0004	0.9975
	1.4E-03	6.5E-03	3.0E-02	2.0E-03	1.6E-03	7.4E-04	1.2E-03	6.2E-02	1.7E-03	5.5E-04	3.2E-02	3.2E-04	4.7E-03	5.2E-03	7.1E-04	5.5E-04
		1.1E-02	2.0E-01		4.0E-02	3.2E-03		6.2E-02		5.0E-03	6.5E-02		7.6E-03	2.5E-01		3.6E-03
0.3	0.9966	0.9927	1.0071	0.9946	0.9992	0.9995	0.9947	0.8949	0.9994	1.0000	1.0223	1.0006	1.0009	0.9783	0.9992	0.9975
	1.1E-03	8.9E-04	7.1E-03	1.9E-04	8.5E-04	5.1E-04	2.4E-04	1.6E-02	2.0E-04	1.6E-04	8.0E-03	2.9E-04	5.0E-04	1.6E-03	2.4E-04	2.0E-04
		4.3E-03	6.9E-02		2.4E-02	3.0E-03		1.7E-02		4.8E-03	2.8E-02		4.7E-03	8.4E-02		3.3E-03
1	0.9978	0.9932	1.0020	0.9955	1.0001	0.9999	0.9964	0.9984	0.9995	0.9999	0.9967	1.0006	1.0040	0.9976	0.9996	0.9983
	4.5E-04	3.9E-04	3.5E-03	2.5E-04	2.6E-04	2.9E-04	1.4E-04	4.0E-03	7.1E-05	4.2E-04	3.3E-03	2.5E-04	4.9E-04	5.4E-04	1.0E-04	1.0E-04
		3.4E-03	2.2E-02		1.9E-02	2.9E-03		5.8E-03		4.1E-03	4.1E-02		4.7E-03	2.6E-02		3.4E-03
3	0.9977	0.9953	0.9986	1.0001	1.0012	0.9997	0.9962	0.9997	1.0005	1.0007	0.9648	1.0009	1.0061	0.9856	1.0000	0.9992
	8.3E-04	1.1E-04	8.7E-04	6.1E-04	6.6E-05	2.3E-04	8.0E-05	1.2E-03	5.3E-05	8.9E-05	1.1E-03	2.3E-04	1.4E-04	3.2E-04	5.6E-05	1.8E-04
		3.0E-03	8.7E-03		1.1E-02	2.8E-03		4.3E-03		4.0E-03	4.0E-02		4.6E-03	9.7E-03		2.9E-03
10	0.9978	0.9985	0.9991	1.0015	1.0005	1.0011	1.0014	1.0003	1.0014	1.0018	0.9541	1.0019	1.0071	1.0018	1.0009	1.0008
	4.5E-04	3.2E-05	2.7E-04	1.7E-04	1.9E-05	1.3E-04	1.5E-04	4.2E-04	7.9E-05	3.6E-05	1.6E-03	2.1E-04	1.3E-04	1.3E-04	7.3E-05	9.2E-05
		2.7E-03	4.3E-03		6.7E-03	2.8E-03		4.1E-03		4.0E-03	5.0E-02		4.6E-03	4.4E-03		2.8E-03
30	0.9986	1.0003	0.9999	1.0009	0.9998	1.0013	0.9995	1.0001	1.0037	1.0020	1.0364	1.0037	1.0058	1.0038	1.0022	1.0014
	5.0E-04	2.5E-05	3.0E-04	1.2E-04	4.1E-05	2.8E-04	4.0E-05	1.0E-04	2.3E-04	7.7E-05	6.5E-03	2.7E-04	6.6E-05	5.1E-05	5.4E-05	1.1E-04
		2.7E-03	3.6E-03		5.4E-03	2.7E-03		3.6E-03		3.2E-03	5.1E-02		3.7E-03	3.2E-03		2.8E-03
100	0.9981	1.0012	1.0030	1.0007	1.0001	1.0017	0.9998	0.9996	1.0029	1.0015	1.0198	1.0035	1.0055	1.0022	1.0016	1.0011
	2.7E-04	1.7E-05	2.3E-03	1.4E-04	1.3E-05	9.7E-05	7.5E-05	1.4E-04	9.0E-05	4.8E-05	5.3E-04	1.1E-04	7.8E-05	6.9E-05	5.3E-05	5.8E-05
		2.6E-03	4.1E-03		5.0E-03	2.7E-03		3.4E-03		3.2E-03	1.5E-02		3.7E-03	2.9E-03		2.8E-03

Table 6 b: mean calibration ratio (Fc) for each laboratory as calculated with $p_{s,h,l,i,j}$ corrected for thermal transpiration, the relative standard deviation s of the mean (s=$u_{rstr}\sqrt{(n-1)/(n-3)}$) and the relative standard uncertainty ur: sensor 2

sensor 2

NMI	IMGC1	BNM-LNE	MIKES	IMGC2	SP	PTB	IMGC3	CEM	IMGC4	NPL	OMH	IMGC5	UME	NMi	IMGC6	IMGC-CNR
pt/Pa	Fc	Fc	Fc	Fc	Fc	Fc	Fc	Fc	Fc	Fc	Fc	Fc	Fc	Fc	Fc	Fc
	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*
	*u*r	*u*r	*u*r	*u*r	*u*r	*u*r	*u*r	*u*r	*u*r	*u*r	*u*r	*u*r	*u*r	*u*r	*u*r	*u*r
0.1	1.0103	1.0160	0.9733	1.0128	1.0114	1.0165	1.0199	1.0420	1.0155	1.0168	0.9625	1.0175	1.0224	1.0151	1.0185	1.0158
	7.0E-04	3.9E-03	6.3E-03	1.8E-03	2.4E-03	5.8E-04	1.3E-03	3.0E-03	7.9E-04	1.7E-04	1.1E-02	8.8E-04	6.4E-04	3.6E-03	4.0E-04	4.4E-04
		8.0E-03	1.9E-01		4.0E-02	3.4E-03		7.0E-03		5.1E-03	8.2E-02		6.0E-03	2.5E-01		3.7E-03
0.3	1.0113	1.0075	1.0027	1.0124	1.0164	1.0162	1.0145	1.0292	1.0163	1.0159	0.9783	1.0163	1.0218	1.0087	1.0175	1.0147
	5.4E-04	8.6E-04	2.0E-03	5.4E-04	2.4E-04	3.3E-04	1.0E-04	1.2E-03	9.9E-05	1.1E-04	3.7E-03	1.7E-04	1.5E-04	6.8E-04	3.2E-04	1.4E-04
		4.1E-03	6.8E-02		2.4E-02	3.2E-03		5.4E-03		5.0E-03	3.3E-02		4.8E-03	8.4E-02		3.6E-03
1	1.0121	1.0085	1.0124	1.0118	1.0186	1.0160	1.0149	1.0207	1.0155	1.0163	1.0179	1.0164	1.0214	1.0226	1.0170	1.0146
	3.0E-04	7.1E-04	1.8E-03	1.3E-04	3.7E-04	3.2E-04	2.1E-04	4.1E-04	2.7E-04	2.0E-04	4.8E-03	2.6E-04	2.0E-04	4.3E-04	3.8E-04	1.1E-04
		3.6E-03	2.2E-02		1.9E-02	3.2E-03		4.4E-03		4.3E-03	4.1E-02		4.9E-03	2.6E-02		3.6E-03
3	1.0114	1.0089	1.0114	1.0163	1.0179	1.0146	1.0140	1.0170	1.0147	1.0159	0.9882	1.0152	1.0210	1.0077	1.0168	1.0147
	2.8E-04	8.0E-05	3.0E-04	7.4E-04	8.1E-05	3.1E-04	1.8E-04	1.1E-04	1.1E-04	7.5E-05	5.9E-04	1.8E-04	1.2E-04	3.0E-04	2.3E-04	1.5E-04
		3.2E-03	8.8E-03		1.1E-02	3.2E-03		4.3E-03		4.2E-03	4.0E-02		4.8E-03	9.8E-03		3.2E-03
10	1.0111	1.0108	1.0121	1.0159	1.0154	1.0153	1.0165	1.0157	1.0144	1.0156	0.9826	1.0152	1.0205	1.0168	1.0170	1.0150
	2.0E-04	2.6E-05	6.4E-05	2.7E-04	7.5E-05	1.7E-04	2.2E-04	1.7E-04	2.7E-05	7.2E-05	3.0E-04	2.8E-04	1.1E-04	3.0E-04	2.0E-04	8.8E-05
		3.0E-03	4.5E-03		6.8E-03	3.1E-03		4.3E-03		4.2E-03	4.0E-02		4.8E-03	4.6E-03		3.1E-03
30	1.0111	1.0118	1.0127	1.0149	1.0139	1.0150	1.0147	1.0147	1.0164	1.0149	1.1121	1.0163	1.0186	1.0179	1.0172	1.0151
	1.5E-04	1.4E-05	2.7E-04	4.7E-04	6.4E-05	3.1E-04	1.9E-04	1.1E-04	1.4E-04	5.7E-05	2.3E-03	1.0E-03	1.0E-04	8.6E-05	2.6E-04	2.0E-04
		3.0E-03	3.9E-03		5.6E-03	3.1E-03		3.9E-03		3.5E-03	5.0E-02		4.0E-03	3.5E-03		3.1E-03
100	1.0100	1.0125	1.0157	1.0138	1.0139	1.0151	1.0146	1.0144	1.0153	1.0143	1.0469	1.0154	1.0180	1.0169	1.0160	1.0142
	2.2E-04	8.5E-06	2.3E-03	2.5E-04	5.5E-05	1.3E-04	1.7E-04	5.2E-05	1.5E-05	2.5E-05	1.6E-03	4.8E-04	8.3E-05	7.9E-05	1.9E-04	1.1E-04
		2.9E-03	4.3E-03		5.2E-03	3.1E-03		3.7E-03		3.5E-03	1.5E-02		3.9E-03	3.2E-03		3.1E-03

Table 6 c: mean calibration ratio (Fc) for each laboratory as calculated with $p_{s,h,l,i,j}$ corrected for thermal transpiration, the relative standard deviation s of the mean (s=$u_{rstr}\sqrt{(n-1)/(n-3)}$) and the relative standard uncertainty ur: sensor 3

NMI	IMGC1	BNM-LNE	MIKES	IMGC2	SP	PTB	IMGC3	CEM	IMGC4	NPL	IMGC-CNR
pt/Pa	*F*c	*F*c	*F*c	*F*c	*F*c	*F*c	*F*c	*F*c	*F*c	*F*c	Fc
	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*	rel *s*
	*u*r	*u*r	*u*r	*u*r	*u*r	*u*r	*u*r	*u*r	*u*r	*u*r	*u*r
0.1	1.0014	0.9989	0.9863	1.0026	0.9967		0.9997	1.0257	0.9937		0.9994
	3.4E-03	2.1E-03	5.7E-03	1.8E-03	3.8E-03		4.9E-03	1.6E-03	7.1E-03		2.4E-03
		1.4E-02	1.9E-01		4.0E-02			1.1E-02			1.0E-02
0.3	1.0009	0.9943	1.0001	0.9963	1.0026		0.9998	1.0115	0.9997		0.9992
	2.7E-03	6.0E-04	6.6E-03	1.9E-03	1.9E-03		1.1E-03	1.1E-03	2.8E-03		1.1E-03
		5.5E-03	6.9E-02		2.4E-02			8.7E-03			4.0E-03
1	0.9997	0.9842	0.9924	0.9972	1.0185	0.9924	0.9986	1.3069	0.9981		0.9984
	1.2E-03	2.6E-03	2.5E-03	3.4E-04	4.2E-03	1.8E-03	3.0E-04	2.0E-03	8.8E-04		3.9E-04
		7.4E-03	2.3E-02		2.0E-02	6.2E-03		8.7E-03			1.0E-02
3	0.9989	0.9922	0.9973	1.0030	1.0079	0.9993	0.9988	1.1040	0.9986	1.0014	0.9998
	1.3E-04	4.2E-04	6.2E-04	1.5E-04	9.3E-04	1.0E-03	2.9E-04	8.7E-04	2.1E-04	1.1E-03	1.0E-04
		2.8E-03	8.5E-03		1.1E-02	2.5E-03		6.5E-03		3.8E-03	3.5E-03
10	0.9996	0.9970	0.9979	1.0028	1.0031	1.0011	1.0022	1.0332	0.9996	1.0029	1.0010
	8.9E-04	9.1E-05	1.1E-03	2.8E-04	4.2E-04	3.1E-04	3.8E-04	3.1E-04	1.9E-04	4.0E-04	2.6E-04
		1.3E-03	3.6E-03		6.2E-03	1.3E-03		6.1E-03		3.2E-03	1.5E-03
30	1.0015	0.9998	0.9991	1.0021	1.0016	1.0025	1.0004	1.0119	1.0019	1.0034	1.0015
	6.3E-04	6.9E-05	5.9E-04	7.1E-05	8.3E-05	1.8E-04	3.3E-05	1.6E-04	1.7E-04	1.8E-04	1.6E-04
		1.0E-03	2.6E-03		4.8E-03	1.0E-03		2.2E-03		4.6E-03	1.2E-03
100	1.0012	1.0008	1.0010	1.0016	1.0015	1.0020	1.0005	1.0034	1.0020	1.0031	1.0013
	1.8E-04	3.2E-05	7.6E-04	6.6E-05	4.4E-05	3.8E-05	9.3E-05	4.6E-05	3.5E-05	3.5E-05	5.4E-05
		1.0E-03	2.4E-03		4.3E-03	1.0E-03		2.1E-03		1.9E-03	1.1E-03
300	1.0007	1.0006	0.9989	1.0017	1.0011	1.0017	1.0003	1.0014	1.0009	1.0025	1.0009
	1.0E-04	2.4E-05	9.1E-06	1.5E-04	3.9E-05	6.0E-05	1.2E-04	3.9E-04	9.2E-05	4.9E-05	6.0E-05
		1.0E-03	2.2E-03		2.1E-03	1.0E-03		2.1E-03		1.9E-03	1.1E-03
1000	1.0004	1.0004	0.9991	1.0018	1.0009	1.0011	1.0006	0.9994	1.0003	1.0007	1.0008
	1.6E-04	2.7E-05	4.4E-04	9.6E-05	2.6E-05	6.1E-05	2.2E-04	1.1E-04	7.1E-06	3.4E-05	7.1E-05
		1.0E-03	2.2E-03		1.0E-03	1.1E-03		2.0E-03		1.9E-03	1.1E-03

7. Evaluation of the comparison results

To evaluate the results of the comparison it is necessary to generate common reference values of the pressure at the various considered levels; then the differences of the pressures generated by each NMI with respect to the reference values can be evaluated with their uncertainties. Consequently, the following quantities must be defined and calculated so that the degree of equivalence can be evaluated for each NMI.

7.1 Predicted gauge readings and common reference values

The calibration ratios (*Fc*), as calculated from [2] and [3] for all the NMIs, are used to calculate the values of the gauge readings that would have been measured if the reference standards had generated exactly the common hypothetical target pressures, that is pt_i /12/. Those gauge readings are evaluated by multiplying the calibration ratios $Fc_{l,i,j}$ by the target pressures as follows:

$$p_{l,i,j} = Fc_{\ l,i,j} \times \ pt_i \qquad [7]$$

In the (0.1-100) Pa pressure range all the laboratories have calibrated two gauges (s1 and s2), while for the higher-pressure range not all the laboratories could perform the calibrations Sec. 5.) of gauge s3. Consequently up to 100 Pa there are two values of pressure gauge readings as calculated by [7] so that mean gauge readings are evaluated by simple arithmetic means /12/:

$$[p_{i,j}]_{1+2} = (p_{1,i,j}+p_{2,i,j})/2 \qquad [8a\ ]$$

while for s3 pressure gauge readings are simply given by:

$$[p_{i,j}]_3 = Fc_{\ 3,i,j} \times \ pt_i \qquad [8b]$$

For the pilot laboratory the mean values are evaluated from the three average values of all the loops as given by [3].

Common EUROMET comparison reference values pr_i at the target pressures pt_i, may be obtained by simple arithmetic means[13] of the $p_{i,j}$ as deduced from the data of the five independent NMIs (IMGC-CNR, BNM-LNE, PTB, NPL, UME):

$$pr_i = \frac{1}{5} \sum_{j=1}^{5} p_{i,j} \qquad [9]$$

To have $pr_i=pt_i$, correction factors are required that are given by $[\mathrm{fn}_i]_{1+2} = pt_i/[pr_i]_{1+2}$, for sensors s1+s2 and $[\mathrm{fn}_i]_3 = pt_i/[pr_i]_3$ for the gauge s3.

To subsequently derive $p_{i,j}$ that would have been read at each NMI if the generated/measured pressure was exactly equal to the target pressure each $[p_{i,j}]_{1+2}$ and $[p_{i,j}]_3$ have to be multiplied by the fn_i factors:

$$p_{1+2,i,j} = [\mathrm{fn}_i]_{1+2} \cdot [p_{i,j}]_{1+2} \qquad [10a]$$
$$p_{3,i,j} = [\mathrm{fn}_i]_3 \cdot [p_{i,j}]_3 \qquad [10b]$$

13 From consistency checks (based on χ^2) at 95% probability, the weighted and arithmetic means may be considered equivalent for sensors s1 and s2 while for sensor s3, in general, it seems better to avoid the weighted mean. The arithmetic mean has been adopted over the whole pressure range for reasons of harmonization with the treatment of the data in the CCM.P-K4 comparison to which the present comparison data is to be linked.

for the two sets of data regarding s1 and s2 together and s3. The same procedure is applied when the data for s1 and s2 gauges are treated separately.

7.2 Difference between $p_{i,j}$ and pr_i

To compare the data, every mean $p_{i,j}$ value obtained for each laboratory and at each pressure is compared with pr_i through the difference given by /14,15/

$$\Delta p_{i,j} = p_{i,j} - pr_i \qquad [11]$$

7.3 Calculation of the uncertainty of the involved quantities

Variances from the following sources have been considered /16/:

predicted gauge reading ($p_{l,i,j}$): the relative combined variance given by [4] is also the relative variance of $p_{l,i,j}$ as defined by [7]; so that the variance of the predicted gauge readings is obtained by multiplying the relative combined variance of $Fc_{l,i,j}$ by the target pressure pt_i. Using the relationship in [10], that variance is given by:

$$u^2(p_{l,i,j}) = [pt_i \, \mathrm{fn}_i \, u_r(Fc_{l,i,j})]^2$$

Since the terms fn_i may be considered as factors with zero uncertainty and values very near to one, the variance of $p_{l,i,j}$ is given by:

$$u^2(p_{l,i,j}) = [pt_i \, u_r(Fc_{l,i,j})]^2 \qquad [12]$$

mean values of $p_{l,i,j}$: for the mean values of the sensors s1 and s2 as given by [8a] and [10a] correlations must be considered due to the fact that at each NMI the two sensors have been calibrated with the same standard system. They therefore have in common the component of the variance due to the standards.

For the mean values of the two gauges s1 and s2 we have:

$$u^2(p_{i,j}) = u^2\left(\frac{p_{1,i,j} + p_{2,i,j}}{2}\right) = \frac{1}{4}\left[u^2\left(p_{1,i,j}\right) + u^2\left(p_{2,i,j}\right)\right] + 2 \cdot \left(\frac{1}{2}\right) \cdot \left(\frac{1}{2}\right) u(p_{1,i,j}, p_{2,i,j}) \qquad [13]$$

The correlation through the standard (Sec. F.1.2 ref. /16/, particularly Sec. F.1.2.3), is given by:

$$u(p_{1,i,j}, p_{2,i,j}) = u_{st}(p_{1,i,j}) \cdot u_{st}(p_{2,i,j})$$

hence

$$u^2(p_{i,j}) = \frac{1}{4}\left[u^2\left(p_{1,i,j}\right) + u^2\left(p_{2,i,j}\right)\right] + \left(\frac{1}{2}\right) u_{st}(p_{1,i,j}) \cdot u_{st}(p_{2,i,j}) \qquad [14]$$

The two values $u_{\mathrm{st}}(p_{1,i,j})$ and $u_{\mathrm{st}}(p_{2,i,j})$ are considered separately because the pressure values may be different. If the relative uncertainty for the standard is considered the two values are equal.

reference value pr_i: being pr_i calculated as the arithmetic mean of the five independent NMIs (IMGC-CNR, BNM-LNE, PTB, NPL and UME). Its variance is given by the average of the variance of the $p_{i,j}$ calculated for those laboratories:

$$u^2(pr_i) = \frac{1}{25}\sum_{j=1}^{5} u^2\left(p_{i,j}\right) \qquad [15]$$

difference $\Delta p_{i,j}$: from the definition given in [11], $u^2(\Delta p_{i,j})$ is given by

$$u^2(\Delta p_{i,j}) = u^2(p_{i,j} - pr_i)$$

at each pressure level.
For the correlation between $p_{i,j}$ and pr_i the following groups of NMIs must be considered differently:

1. IMGC-CNR, PTB, NPL, BNM- LNE, UME: $p_{i,j}$ and pr_i are correlated because pr_i is evaluated from their data;
2. NMIs whose standards are traceable to another primary laboratory, as is the case for:
   MIKES traced to PTB
   SP traced to BNM-LNE
   CEM traced to NPL
   OMH traced to PTB through an accredited German laboratory for the (0.1 – 10) Pa range and it is independent from the other NMIs for the (30 –100) Pa range
   NMi traced to PTB

For all the NMIs in 1. the correlation has been estimated as follows:

$$u^2[\Delta(p_{i,j})] = u^2(p_{i,j} - pr_i) = u^2\left(p_{i,j}\right) + u^2\left(pr_i\right) - 2u\left(p_{i,j}, pr_i\right)$$

$$u^2\left[\Delta\left(p_{i,j}\right)\right] = u^2(p_{i,j}) + u^2(pr_i) - \frac{2}{5}u^2(p_{i,j}) \qquad [16]$$

$$u^2[\Delta(p_{i,j})] = u^2(pr_i) + \frac{3}{5}u^2(p_{i,j})$$

Equation [16] has been obtained by considering, for the specific NMI, the correlation between $p_{i,j}$ and pr_i through the component of $u(pr_i)$ due to that laboratory [$u(p_{i,j})$].
For the laboratories traced to one of five NMIs in group 1, the correlation is through their reference standards and that of the laboratory to which they are traceable. The variance of $\Delta p_{i,j}$ (see Sec. F 1.2 of ref /15/) of the NMIs in group 2 is therefore estimated by:

$$u^2(\Delta(p_{m,i}) = u^2(p_{m,i}) + u^2(pr_i) - \frac{2}{5}u_{st}(p_{i,j})u_{st}(p_{i,j}) = u^2(p_{m,i}) + u^2(pr_i) - \frac{2}{5}u_{st}^2(p_{i,j}) \qquad [17]$$

where m indicates one of the NMIs in group2 while j stands for PTB or BNM-LNE or NPL depending on the specific case.
The term due to the correlation in [17] is considerably smaller than the other two components and it may be disregarded.
The expanded uncertainty is then given by

$$U\left[\Delta\left(p_{i,j}\right)\right] = 2 \cdot \sqrt{u^2\left[\Delta\left(p_{i,j}\right)\right]} \qquad [18]$$

for all the laboratories

7.4 Degree of equivalence

The degree of equivalence can be evaluated by considering of the differences $\Delta p_{i,j}$ as given by [11], together with their expanded uncertainties $U(\Delta(p_{i,j})$ as given by [18] since for equivalence the following conditions must be fulfilled

$$E(\Delta p_{i,j}) = \frac{ABS(\Delta p_{i,j})}{U(\Delta p_{i,j})} \le 1 \qquad [19]$$

where E, as is usual, stands for normalized error.

7.5 Tables of the comparison results

The results of the comparison calculations are presented in tables 7 and 8.
Each table shows, for each NMI, the gauge reading as evaluated by multiplying the calibration ratio by the target pressure (by applying the equations [7], [8], [9] and [10]); the related combined uncertainty values (as calculated by the equations [13] and [14]); the differences $\Delta p_{i,j}$ (as calculated by using the relationships [11] with their expanded uncertainties as given by the equation [18] through [16] and [17]). The normalized errors as given by [19] are also listed to facilitate the analysis of the data.
Table 7 relates to the combination of sensors s1 and s2 while table 8 is related to sensor s3.

Table 7: Laboratory values ($p_{i,j}$) with their standard uncertainty $u(p_{i,j})$, differences ($\Delta p_{i,j}$) from pr_i with their expanded uncertainty $U(\Delta(p_{i,j}))$ (k=2) and the normalized error values: combination of sensor s1 and s2.

NMI	pt Pa	$p_{i,j}$ Pa	$u(p_{i,j})$ Pa	$\Delta(p_{i,j})$ Pa	$U(\Delta(p_{i,j}))$ Pa	$E_{i,j}$
IMGC-CNR	0.1	0.0999	3.0E-04	-7.4E-05	6.4E-04	1.1E-01
	0.3	0.2998	8.5E-04	-1.7E-04	1.6E-03	1.1E-01
	1	0.9992	2.9E-03	-7.7E-04	5.2E-03	1.5E-01
	3	2.9981	7.0E-03	-1.9E-03	1.3E-02	1.4E-01
	10	9.9928	2.2E-02	-7.2E-03	4.2E-02	1.7E-01
	30	29.9893	6.6E-02	-1.1E-02	1.2E-01	8.9E-02
	100	99.9152	2.2E-01	-8.5E-02	4.0E-01	2.1E-01
BNM-LNE	0.1	0.0994	8.0E-04	-5.8E-04	1.3E-03	4.4E-01
	0.3	0.2980	1.1E-03	-2.0E-03	1.9E-03	1.0E+00
	1	0.9937	2.8E-03	-6.3E-03	5.1E-03	1.2E+00
	3	2.9835	7.2E-03	-1.6E-02	1.3E-02	1.2E+00
	10	9.9605	2.1E-02	-3.9E-02	4.1E-02	9.7E-01
	30	29.9233	6.0E-02	-7.7E-02	1.1E-01	6.8E-01
	100	99.8351	2.0E-01	-1.6E-01	3.8E-01	4.4E-01
MIKES	0.1	0.0986	1.9E-02	-1.4E-03	3.9E-02	3.7E-02
	0.3	0.2995	2.1E-02	-5.2E-04	4.1E-02	1.3E-02
	1	1.0000	2.2E-02	-1.2E-05	4.4E-02	2.6E-04
	3	2.9922	2.6E-02	-7.8E-03	5.2E-02	1.5E-01
	10	9.9696	3.9E-02	-3.0E-02	8.2E-02	3.7E-01
	30	29.9311	9.5E-02	-6.9E-02	2.0E-01	3.4E-01
	100	100.0842	3.4E-01	8.4E-02	7.0E-01	1.2E-01
SP	0.1	0.0998	4.0E-03	-1.9E-04	8.1E-03	2.4E-02
	0.3	0.3003	7.4E-03	3.3E-04	1.5E-02	2.2E-02
	1	1.0021	1.9E-02	2.1E-03	3.8E-02	5.5E-02
	3	3.0057	3.4E-02	5.7E-03	6.8E-02	8.4E-02
	10	9.9927	6.5E-02	-7.3E-03	1.3E-01	5.6E-02
	30	29.9467	1.5E-01	-5.3E-02	3.2E-01	1.7E-01
	100	99.8536	4.7E-01	-1.5E-01	9.6E-01	1.5E-01

Table 7: ……………………continued

NMI	p_t Pa	$p_{i,j}$ Pa	$u(p_{i,j})$ Pa	$\Delta(p_{i,j})$ Pa	$U(\Delta(p_{i,j}))$ Pa	$E_{i,j}$
PTB	0.1	0.1000	2.55E-04	1.9E-05	6.0E-04	3.2E-02
	0.3	0.3004	7.15E-04	3.6E-04	1.4E-03	2.5E-01
	1	1.0008	2.34E-03	7.5E-04	4.5E-03	1.7E-01
	3	2.9986	6.78E-03	-1.4E-03	1.3E-02	1.1E-01
	10	9.9954	2.21E-02	-4.6E-03	4.2E-02	1.1E-01
	30	29.9861	6.42E-02	-1.4E-02	1.2E-01	1.2E-01
	100	99.9896	2.13E-01	-1.0E-02	3.9E-01	2.6E-02
CEM	0.1	0.0854	2.2E-03	-1.5E-02	4.4E-03	3.3E+00
	0.3	0.2867	2.6E-03	-1.3E-02	5.3E-03	2.5E+00
	1	1.0023	4.3E-03	2.3E-03	9.0E-03	2.6E-01
	3	3.0022	1.1E-02	2.2E-03	2.4E-02	9.0E-02
	10	9.9935	3.7E-02	-6.5E-03	7.9E-02	8.2E-02
	30	29.9640	9.6E-02	-3.6E-02	2.0E-01	1.8E-01
	100	99.8530	3.0E-01	-1.5E-01	6.3E-01	2.3E-01
NPL	0.1	0.1001	4.6E-04	1.5E-04	8.4E-04	1.8E-01
	0.3	0.3004	1.4E-03	3.8E-04	2.3E-03	1.7E-01
	1	1.0009	3.7E-03	8.5E-04	6.3E-03	1.3E-01
	3	3.0020	1.1E-02	2.0E-03	1.9E-02	1.1E-01
	10	10.0001	3.6E-02	7.8E-05	6.2E-02	1.3E-03
	30	29.9945	8.2E-02	-5.5E-03	1.4E-01	3.9E-02
	100	99.9376	2.7E-01	-6.2E-02	4.7E-01	1.3E-01
OMH	0.1	0.0770	5.7E-03	-2.3E-02	1.1E-02	2.0E+00
	0.3	0.2981	8.6E-03	-1.9E-03	1.7E-02	1.1E-01
	1	1.0001	4.1E-02	9.1E-05	8.2E-02	1.1E-03
	3	2.9073	1.2E-01	-9.3E-02	2.3E-01	3.9E-01
	10	9.6006	4.6E-01	-4.0E-01	9.2E-01	4.3E-01
	30	31.9529	1.6E+00	2.0E+00	3.2E+00	6.0E-01
	100	102.4624	1.6E+00	2.5E+00	3.1E+00	7.8E-01
UME	0.1	0.1005	4.9E-04	4.8E-04	8.8E-04	5.5E-01
	0.3	0.3014	1.0E-03	1.4E-03	1.8E-03	7.6E-01
	1	1.0054	3.4E-03	5.4E-03	6.0E-03	9.1E-01
	3	3.0177	1.0E-02	1.8E-02	1.8E-02	1.0E+00
	10	10.0512	3.4E-02	5.1E-02	5.8E-02	8.8E-01
	30	30.1068	8.3E-02	1.1E-01	1.4E-01	7.5E-01
	100	100.3225	2.7E-01	3.2E-01	4.7E-01	6.8E-01
NMi	0.1	0.0973	1.8E-02	-2.7E-03	3.5E-02	7.7E-02
	0.3	0.2961	1.8E-02	-3.9E-03	3.6E-02	1.1E-01
	1	1.0029	1.9E-02	2.9E-03	3.7E-02	7.7E-02
	3	2.9673	2.1E-02	-3.3E-02	4.2E-02	7.8E-01
	10	10.0065	3.2E-02	6.5E-03	6.9E-02	9.4E-02
	30	30.0655	7.2E-02	6.5E-02	1.6E-01	4.2E-01
	100	100.1013	2.2E-01	1.0E-01	4.9E-01	2.1E-01

Table 8: Laboratory values ($p_{i,j}$) with their standard uncertainty $u(p_{i,j})$, differences ($\Delta p_{i,j}$) from pr_i with their expanded uncertainty $U(\Delta(p_{i,j}))$ (k=2) and the normalized error values: sensor s3

NMI	pt Pa	$p_{i,j}$ Pa	$u(p_{i,j})$ Pa	$\Delta(p_{i,j})$ Pa	$U(\Delta(p_{i,j}))$ Pa	$E_{i,j}$
IMGC-CNR	3	3.005	1.1E-02	5.0E-03	1.8E-02	2.8E-01
	10	10.005	1.5E-02	5.3E-03	2.8E-02	1.9E-01
	30	29.990	3.5E-02	-9.7E-03	8.1E-02	1.2E-01
	100	99.951	1.1E-01	-4.9E-02	2.0E-01	2.4E-01
	300	299.828	3.3E-01	-1.7E-01	6.1E-01	2.8E-01
	1000	999.998	1.1E+00	-1.7E-03	2.0E+00	8.4E-04
BNM-LNE	3	2.982	8.2E-03	-1.8E-02	1.5E-02	1.2E+00
	10	9.965	1.3E-02	-3.5E-02	2.6E-02	1.4E+00
	30	29.940	3.1E-02	-6.0E-02	7.7E-02	7.8E-01
	100	99.896	1.0E-01	-1.0E-01	1.9E-01	5.5E-01
	300	299.758	3.1E-01	-2.4E-01	5.7E-01	4.2E-01
	1000	999.661	1.0E+00	-3.4E-01	1.9E+00	1.8E-01
MIKES	3	2.998	2.5E-02	-2.4E-03	5.1E-02	4.8E-02
	10	9.974	3.6E-02	-2.6E-02	7.4E-02	3.5E-01
	30	29.918	7.9E-02	-8.2E-02	1.7E-01	4.8E-01
	100	99.921	2.4E-01	-7.9E-02	4.9E-01	1.6E-01
	300	299.244	6.5E-01	-7.6E-01	1.3E+00	5.7E-01
	1000	998.327	2.2E+00	-1.7E+00	4.5E+00	3.7E-01
SP	3	3.029	3.4E-02	2.9E-02	6.9E-02	4.3E-01
	10	10.026	6.2E-02	2.6E-02	1.3E-01	2.1E-01
	30	29.993	1.4E-01	-6.8E-03	2.9E-01	2.3E-02
	100	99.966	4.3E-01	-3.4E-02	8.6E-01	3.9E-02
	300	299.904	6.3E-01	-9.6E-02	1.3E+00	7.4E-02
	1000	1000.126	1.0E+00	1.3E-01	2.3E+00	5.5E-02
PTB	3	3.003	7.5E-03	3.3E-03	1.4E-02	2.4E-01
	10	10.006	1.3E-02	6.2E-03	2.6E-02	2.4E-01
	30	30.022	3.1E-02	2.2E-02	7.7E-02	2.8E-01
	100	100.019	1.0E-01	1.9E-02	1.9E-01	1.0E-01
	300	300.089	3.2E-01	8.9E-02	5.8E-01	1.5E-01
	1000	1000.375	1.1E+00	3.7E-01	2.0E+00	1.9E-01
CEM	3	3.318	2.2E-02	3.2E-01	4.4E-02	7.3E+00
	10	10.327	6.4E-02	3.3E-01	1.3E-01	2.6E+00
	30	30.304	6.5E-02	3.0E-01	1.4E-01	2.1E+00
	100	100.164	2.1E-01	1.6E-01	4.3E-01	3.8E-01
	300	299.988	6.3E-01	-1.2E-02	1.3E+00	9.1E-03
	1000	998.664	2.0E+00	-1.3E+00	4.2E+00	3.2E-01
NPL	3	3.010	1.1E-02	9.7E-03	1.9E-02	5.0E-01
	10	10.024	3.2E-02	2.4E-02	5.2E-02	4.6E-01
	30	30.048	1.4E-01	4.8E-02	2.2E-01	2.2E-01
	100	100.134	1.9E-01	1.3E-01	3.2E-01	4.2E-01
	300	300.325	5.7E-01	3.2E-01	9.4E-01	3.4E-01
	1000	999.966	1.9E+00	-3.4E-02	3.1E+00	1.1E-02

8. Link with CCM.P-K4 comparison

The present results of the EUROMET.M.P-K1.a comparison can be linked to the results obtained in the CCM.P-K4 comparison /12/. Eight primary laboratories took part in the CCM.P-K4 comparison: four participants used static expansion systems and the other four used different types of column manometers in which the liquid levels were measured by laser or ultrasound interferometry.
For the evaluation of the reference pressure values for EUROMET.M.P-K1a, the data from the five completely independent NMIs (IMGC-CNR, BNM-LNE, PTB, NPL, UME) have been considered three of which (IMGC-CNR, PTB, NPL) participated in both comparisons. IMGC-CNR participated in the CCM key comparison with two systems (static expansion system and interferometric manobarometer) while in the present comparison the static system was used for the full pressure range; so, for this laboratory, only the data in the (1-30) Pa range from the CCM comparison are considered in the linking procedure. The other two laboratories used the same system in both comparisons.
In the present EUROMET comparison the calibrations were performed in the (0.1 – 1000) Pa pressure range while in the CCM.P-K4 comparison the range considered was from 1 Pa to 1000 Pa. To link the results of the two comparisons the common (1 - 1000) Pa range has been considered.
Table 9 shows a summary of the results for the three NMIs that participated in both the comparisons.
As the transfer standards were not the same (even though they were based on the same principle) in the two comparisons, the reference values can be considered as not being related to the same quantity; consequently, a method of shifting one to the other must be applied. As suggested in /17/, the reference values of the EUROMET.M.P-K1a comparison should be shifted to the reference values of the CCM.P-K4 comparison. The size of the shift can be evaluated by considering the combined differences $\Delta comb_i$ /17/ of the three (or two) NMIs, calculated for each comparison, by the weighted mean of the respective differences $\Delta p_{i,j}$ as follows:

$$\Delta comb_i = \frac{\dfrac{\Delta(p_{i,IMGC})}{U^2(\Delta(p_{i,iMGC}))} + \dfrac{\Delta(p_{i,NPL})}{U^2(\Delta(p_{i,NPL}))} + \dfrac{\Delta(p_{i,PTB})}{U^2(\Delta(p_{pi,PTB}))}}{\dfrac{1}{U^2(\Delta p_{i,IMGC})} + \dfrac{1}{U^2(\Delta p_{i,NPL})} + \dfrac{1}{U^2(\Delta p_{i,PTB})}} \qquad [20]$$

So that it is possible to calculate the differences $\Delta comb_{CCM}$ and $\Delta comb_{EUROMET}$ for the CCM.P-K4 and EUROMET.M.P.-K1a comparisons respectively (table 10) and, consequently, the shift between the references values of EUROMET from CCM reference values as given by

$$\Delta comb_{i,CCM-EUROMET} = \Delta comb_{i,CCM} - \Delta comb_{i,\ EUROMET}$$

Finally, the differences $\Delta p_{i,j}$ of those NMIs that participated only in EUROMET comparison [and of IMGC-CNR for the (100-1000) Pa range] are shifted to the CCM reference values by using the combined differences $\Delta comb_{i,CCM-EUROMET}$:

$$\Delta(p_{i,j})_{CCM} = \Delta(p_{i,j}) + \Delta comb_{i,CCM-EUROMET}$$

For linking purposes, for the NMIs that participated in both comparisons data from CCM comparison are considered; for IMGC-CNR this only applies for the pressure interval (1-30) Pa.
If the standards of the NMIs that participated in both comparison are stable it is suggested /17/ there should not be any additional uncertainty to consider when shifting the reference values.
The linkage of the comparison results to CCM.P-K4 is summarized in table 11 (and in figure 1) in which the data for IMGC-CNR [(1-30)Pa range], PTB and NPL come from table 9 and originate from the CCM.P-K4 comparison and for the other NMIs that took part only in the EUROMET M.P-K1

comparison [and for IMGC-CNR in the (100-1000) Pa range] the data represent a combination of tables 7 [(1-100) Pa range] and 8 [(300-1000) Pa range] shifted as indicated in table 10.

Table 9: Results of the EUROMETM.P-K1.a and CCM.P-K4 comparison (from table 6 of ref /12/)

		EUROMET.M.P-K1.a		CCM.P-K4	
NMI	pt Pa	$\Delta(p_{i,j})$ Pa	$U(\Delta(p_{i,j}))$ Pa	$\Delta(p_{i,j})$ Pa all static systems	$U(\Delta(pi,j))$ Pa
IMGC-CNR	0.1	-7.4E-05	6.4E-04		
	0.3	-1.7E-04	1.6E-03		
	1	-7.7E-04	5.2E-03	2.3E-03	5.4E-03
	3	-1.9E-03	1.3E-02	4.0E-03	1.6E-02
	10	-7.2E-03	4.2E-02	1.5E-02	5.3E-02
	30	-1.1E-02	1.2E-01	6.0E-02	1.6E-01
	100	-8.5E-02	4.0E-01		
	300	-1.7E-01	6.1E-01		
	1000	-1.7E-03	2.0E+00		
PTB	0.1	1.9E-05	6.0E-04		
	0.3	3.6E-04	1.4E-03		
	1	7.5E-04	4.5E-03	2.0E-04	2.9E-03
	3	-1.4E-03	1.3E-02	-1.3E-03	7.5E-03
	10	-4.6E-03	4.2E-02	-5.0E-03	2.5E-02
	30	-1.4E-02	1.2E-01	2.0E-03	6.2E-02
	100	-1.0E-02	3.9E-01	0.0E+00	1.9E-01
	300	8.9E-02	5.8E-01	-8.0E-02	5.6E-01
	1000	3.7E-01	2.0E+00	-3.0E-01	1.9E+00
NPL	0.1	1.5E-04	8.4E-04		
	0.3	3.8E-04	2.3E-03		
	1	8.5E-04	6.3E-03	1.3E-03	5.4E-03
	3	2.0E-03	1.9E-02	1.0E-03	1.6E-02
	10	7.8E-05	6.2E-02	3.0E-03	5.3E-02
	30	-5.5E-03	1.4E-01	-4.0E-02	1.0E-01
	100	-6.2E-02	4.7E-01	-8.0E-02	3.0E-01
	300	3.2E-01	9.4E-01	-2.0E-01	9.0E-01
	1000	-3.4E-02	3.1E+00	7.0E-01	3.0E+00

Table 10: Values of the combined differences between the two comparisons

pt Pa	Δcomb $_{EUROMET}$ Pa	Δcomb $_{CCM}$ Pa	Δcomb $_{CCM-EUROMET}$ Pa
1	1.6E-05	7.4E-04	7.3E-04
3	-8.1E-05	-2.7E-04	-1.9E-04
10	-1.8E-04	-8.9E-04	-7.1E-04
30	-1.3E-03	-2.7E-03	-1.4E-03
100	-3.2E-02	-3.7E-02	-4.9E-03
300	1.5E-01	-1.5E-01	-3.0E-01
1000	2.6E-01	-1.3E-01	-3.8E-01

Table 11: Comparison results as evaluated by $\Delta p_{i,j}$ shifted for the NMIs participating only in the EUROMET.M.P-k1.a comparison and the expanded uncertainty from tables 7, 8 and 9.

NMI n.of NMI	p_t Pa	$\Delta p_{i,j}$ Pa	$U(\Delta p_{i,j})$ Pa
IMGC-CNR 1	1	2.3E-03	5.4E-03
	3	4.0E-03	1.6E-02
	10	1.5E-02	5.3E-02
	30	6.0E-02	1.6E-01
	100	-8.0E-02	4.0E-01
	300	1.3E-01	6.1E-01
	1000	3.8E-01	2.0E+00
BNM.LNE 2	1	-5.6E-03	5.1E-03
	3	-1.7E-02	1.3E-02
	10	-4.0E-02	4.1E-02
	30	-7.8E-02	1.1E-01
	100	-1.7E-01	3.8E-01
	300	-3.0E-01	5.7E-01
	1000	-3.8E-01	1.9E+00
MIKES 3	1	3.9E-02	4.4E-02
	3	4.1E-02	5.2E-02
	10	4.3E-02	8.2E-02
	30	5.0E-02	2.0E-01
	100	7.7E-02	7.0E-01
	300	-1.0E-01	1.3E+00
	1000	3.2E-01	4.5E+00
SP 4	1	2.8E-03	3.8E-02
	3	5.6E-03	6.8E-02
	10	-8.0E-03	1.3E-01
	30	-5.5E-02	3.2E-01
	100	-1.5E-01	9.6E-01
	300	-3.0E-01	1.3E+00
	1000	5.1E-01	2.3E+00
PTB 5	1	2.0E-04	2.9E-03
	3	-1.3E-03	7.5E-03
	10	-5.0E-03	2.5E-02
	30	2.0E-03	6.2E-02
	100	0.0E+00	1.9E-01
	300	-8.0E-02	5.6E-01
	1000	-3.0E-01	1.9E+00

NMI n.of NMI	p_t Pa	$\Delta p_{i,j}$ Pa	$U(\Delta p_{i,j})$ Pa
CEM 6	1	3.1E-03	9.0E-03
	3	2.0E-03	2.4E-02
	10	-7.2E-03	7.9E-02
	30	-3.7E-02	2.0E-01
	100	-1.5E-01	6.3E-01
	300	-3.0E-01	1.3E+00
	1000	-3.8E-01	4.2E+00
NPL 7	1	1.3E-03	5.4E-03
	3	1.0E-03	1.6E-02
	10	3.0E-03	5.3E-02
	30	-4.0E-02	1.0E-01
	100	-8.0E-02	3.0E-01
	300	-2.0E-01	9.0E-01
	1000	7.0E-01	3.0E+00
OMH 8	1	8.2E-04	8.2E-02
	3	-9.3E-02	2.3E-01
	10	-4.0E-01	9.2E-01
	30	2.0E+00	3.2E+00
	100	2.5E+00	3.1E+00
UME 9	1	6.2E-03	6.0E-03
	3	1.8E-02	1.8E-02
	10	5.1E-02	5.8E-02
	30	1.1E-01	1.4E-01
	100	3.2E-01	4.7E-01
NMi 10	1	3.6E-03	3.5E-02
	3	-3.3E-02	3.6E-02
	10	5.8E-03	3.7E-02
	30	6.4E-02	4.2E-02
	100	9.6E-02	6.9E-02

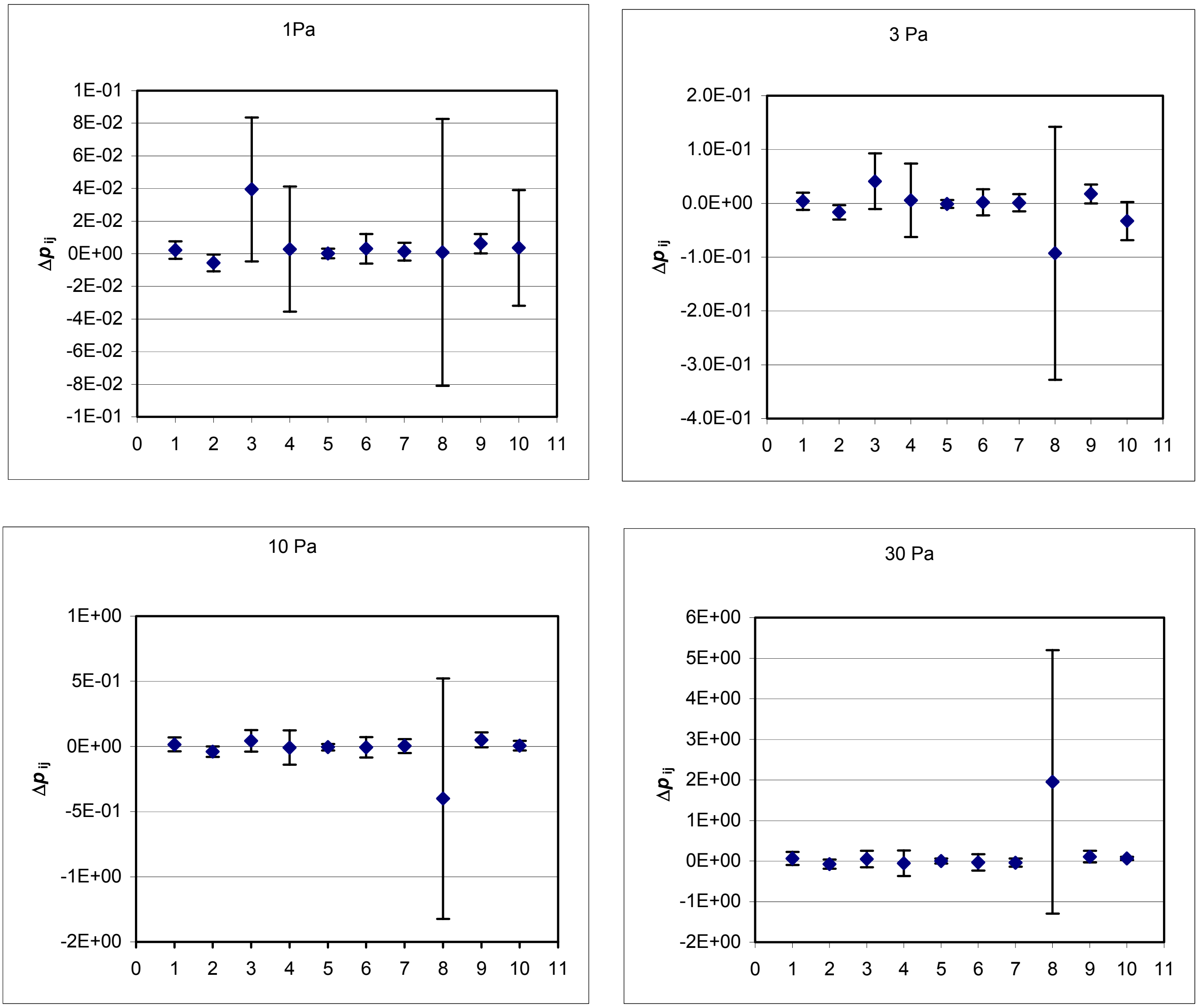

Figure 1 a: Comparison results: the differences $\Delta p_{i,j}$ with their expanded uncertainty, for each participating NMI at the pressure level from 1 Pa to 30 Pa.

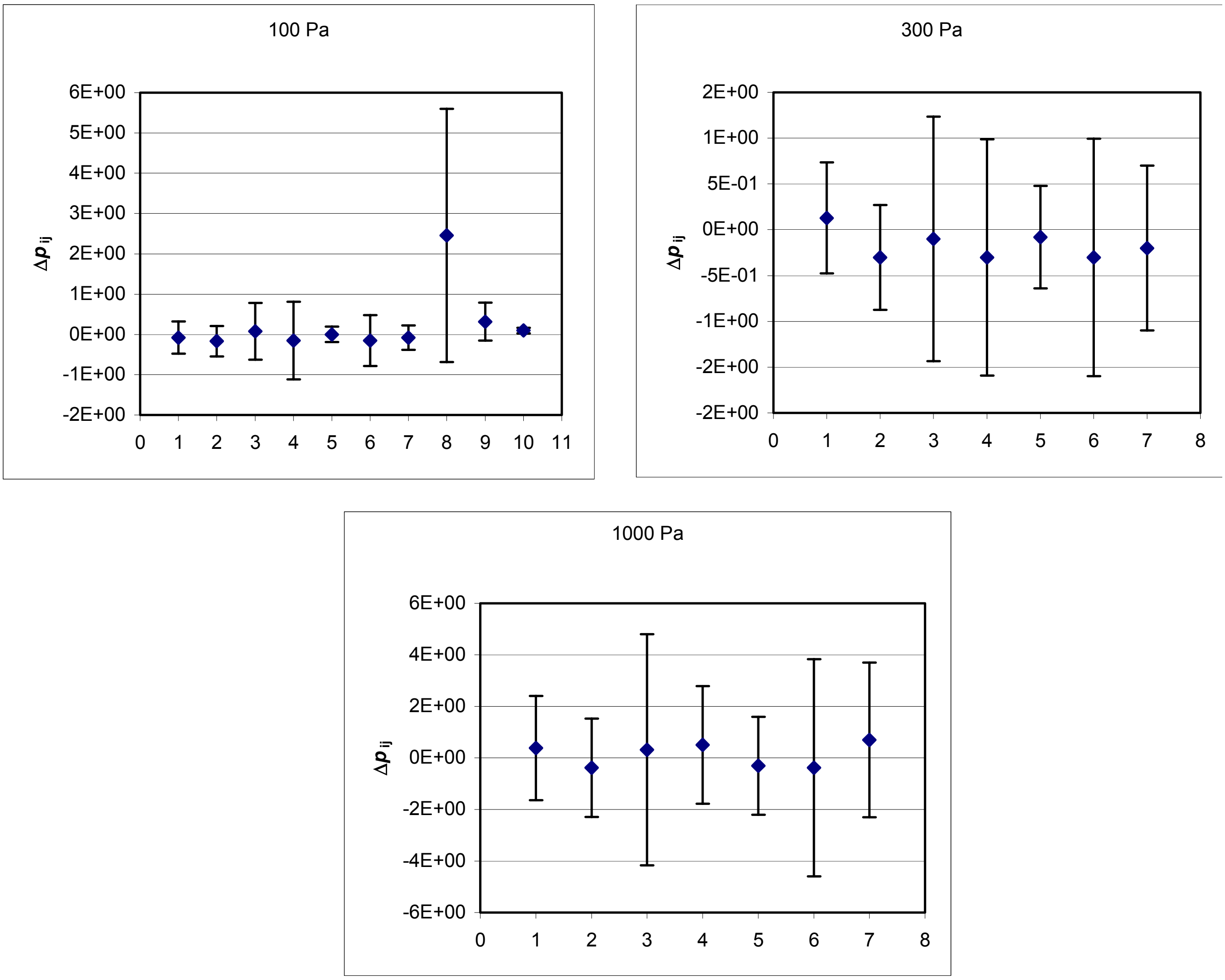

Figure 1 b: Comparison results: the differences $\Delta p_{i,j}$ with their expanded uncertainty, for each participating NMI at the pressure level from 100 Pa to 1000 Pa

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