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DRAFT B - Results of the CCM Pressure key comparison (Phase B) in gas media and gauge mode from 80 kPa to 7 MPa

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Abstract

This report gives the result of a CCM (Comité Consultatif pour la Masse et les grandeurs apparentéès) key comparison for pressure measurements in gas media, gauge mode, from 80 kPa to 7 MPa. A pressure balance with two piston-cylinder units with nominal effective area of 84 and 8,4 mm^2 was selected and made available by NIST as transfer standards. The purpose of this exercise is to determine and compare the transfer standards' effective areas, with their variation with pressure, as determined by the participants through a pressure cross float against their primary standards. The comparison is divided in two pressure ranges:

- 79,4 kPa to 896,4 kPa with the unit named C 415 (84 mm^2);
- 621,7 kPa to 6792,4 kPa with the unit named V 762 (8,4 mm^2)

The results are presented for both pressure ranges.

They show an agreement of all the participating laboratories in this comparisons (IMGC-CNR, BNM-LNE, PTB, NIST and NRLM) fully within the estimated expanded uncertainties, expressed with a coverage factor k = 2. The full agreement is within an expanded uncertainty, variable from laboratory to laboratory, from 7 to about 30 ppm).

Over 95 average experimental determinations of the effective area of the transfer standards, only 9 average results show a *A'p'* difference in respect of the reference value greater than the standard uncertainty assigned by the laboratories to each *A'p'* determination.

The data contained in this report, approved by all participants, will be included in the BIPM database of key comparison, following the rules of the CCM.

1) Introduction

In the 6th Meeting of the Comité Consultatif pour la Masse et les grandeurs apparentéès (CCM)in 1996 it was decided that a key comparison should be organised for pressure measurements in gas media, gauge mode, from 80 kPa to 7 MPa. Pressure balances with two piston-cylinder units made from tungsten carbide with nominal effective areas of 84 and 8,4 mm^2 were selected and made available by NIST as transfer standards. The purpose of this exercise is the determination and comparison of the transfer standards effective areas, with their variation with pressure, as determined by the participants by pressure cross floating against their primary standards.

The participants are all national metrology laboratories having primary pressure standards directly linked to base SI units. The pilot laboratories were IMGC-CNR for the preparation of procedures and results analysis and NIST for preliminary studies on transfer standards, including the stability evaluation during the comparison period. The route of the comparison was NIST (transfer standards initial evaluation), IMGC-CNR (pressure balances and transfer standards evaluation, procedure preparation), BNM-LNE, PTB, NRLM, NIST (transfer standards final evaluation).

The following time schedule was observed:

ACTIONS	**PERIODS**
Preliminary studies at NIST First set of measurements at NIST	During 1997 August to September 1997
Preliminary studies at IMGC-CNR	October to December 1997
Measurements by IMGC-CNR	December 1997 to February 1998
Procedure as in [1] approved	February 1998
Measurements by BNM-LNE	February 1998 to April 1998
Measurements by PTB	April 1998 to June 1998
Measurements by NRLM	August 1998 to October 1998
Measurements by NIST	end of 1998 till April 1999
All comparison data at IMGC-CNR	May 1999, blind presentation at the IIIth CCM Conference, Torino
Draft A report	distributed to participants in March 2000
Final Draft B report, planned	end of 2000

The measurement results are analysed as specified by the “Guidelines for key comparison carried out by Consultative

Committees” document, up to the consensus on the final report of the comparison (Draft B).

A written procedure [1] was prepared, approved and followed by all participants; the comparison started in November 1997 and ended in spring of 1999.

In the last CCM meeting (May 1999) this comparison was accepted and labelled as **CCM.P-K1.c** comparison and inserted in the BIPM database.

The present report will describe the results of this comparison by a presentation of data obtained by each participating laboratory.

The best way of identifying an effective area reference value and its associated uncertainty for the two piston-cylinder units used as transfer standards is discussed.

The results of each participating laboratory, in terms of effective area of the transfer standards, will be compared with respect to the reference value for each unit as well as the differences in respect of each combination of the five participants will be calculated. The level of agreement reached by each participant, as a base for the mutual recognition of national pressure standards, in the pressure range under consideration will be discussed.

2) Transfer standards description (tests and stability during the comparison)

The transfer standards used are fully described in the Guidelines for the comparison [1] that are to be considered an integral part of this report.

Without repeating the prepared procedures, let us just mention few points.

The piston-cylinder units are two (named C-415 for a piston cylinder nominal effective area of 84 mm^2 to be used in the comparison from 80 kPa to 900 kPa and V-762 for a piston-cylinder of 8,4 mm^2 nominal effective area to be used in the comparison from 0,6 MPa to 7 MPa) and must be mounted on a Ruska base type 2465, fully equipped with weight set, temperature probe, measurement of piston position, fall rate,…, through appropriate instrumentations.

The measurement points were defined in the procedure [1]:

- for the C-415 assembly, 10 nominal pressure points were to be repeated 10 times
- for the V-762 assembly, 9 nominal pressure points were to be repeated 10 times

In Table 1 the main characteristics of the transfer standards are briefly described.

For the preliminary tests, done according to the procedures, the following conclusions can be drawn:

- during all measurements in the five laboratories no surface magnetisation higher than 2 Gauss was found and pistons and cylinders have not been demagnetised;
- cleaning of piston-cylinders was found to be an important point. It was made by usual laboratory practice;
- fall rates of pistons were found to be in agreement with indications in the procedures (typically 0,4 mm/min for C-415 unit at 1 MPa and typically 0,9 mm/min for V-762 unit at 7 MPa, all values for temperatures close to 20 °C);
- piston rotation rate versus time measurements confirmed that this is a good test to evaluate cleaning of piston-cylinder and levelling, also in this case values were found close to the ones indicated in the procedure [1];
- effect of rotation direction of piston (CW or CCW) was found to be negligible, one laboratory reported a systematic shift of about 3 ppm of the obtained effective areas of the transfer standard C 415 when the motor imposed rotation (either CW and CCW) was used instead of the free rotation and when measurements were carried out with the bell-jar on the balance.

Stability tests of the two transfer standard units were performed by NIST at the beginning of the comparison during the preparatory work (August to September 1997) and at the conclusion of measurement loop (beginning of 1999).

In Figure 1 the values of effective area $A'p'$ (20°C, p')/mm^2 versus pressure p'/kPa for the transfer standard **C-415** piston-cylinder unit obtained by NIST in 1997 (serie 1 and 2) and in 1999 (serie 3) are reported. In all measurements the sensitivity of the pressure equilibrium during the cross floating was of the order of less than 1 ppm. The standard deviation of the values of $A'p'$, referred to the average values of $A'p'$ are 8 ppm, 0,7 ppm, 4,6 ppm, 2,5 ppm, 4,8 ppm, 1,6 ppm, 2,3 ppm, 2,9 ppm, 2,1 ppm and 2,6 ppm respectively at the pressures of (79,4 - 137,8 – 196 - 254,5 - 312,8 - 429,5 - 546,2 – 663 - 779,7 - 896,4) kPa.

In Figure 2 the values of effective area $A'p'$ (20°C, p')/mm^2 versus pressure p'/kPa for the transfer standard **V-762** piston-cylinder unit obtained by NIST in 1997 (serie 1 and 2) and in 1999 (serie 3) are reported. In all measurements the sensitivity of the pressure equilibrium during the cross floating was of the order of less than 1,2 ppm. The standard deviation of the values of $A'p'$, referred to the average values of $A'p'$ are 6,5 ppm, 5,0 ppm, 4,5 ppm, 2,7 ppm, 1,9 ppm, 2,0 ppm, 2,9 ppm, 1,6 ppm and 1,1 ppm respectively at the pressures of (622 - 738 – 1077 - 1767 - 2936 - 4104 - 5273 – 6442 - 6792) kPa.

Measurements by NIST in 1997 (serie 1 and 2) were made before the procedure [1] preparation, following the practice of NIST laboratory as well as during the process of transfer standard evaluation, while the second set of data made in 1999 (serie 3) was done strictly referring to the procedures.

Results appear to be typical for apparatus of this type, in that the standard deviation values of the effective area are larger at lower rather than at higher pressure.

It has also to be pointed out that the data on serie 1 and 2 used different mass set on NIST standard and transfer standard in interchangeable order. NIST pilot laboratory corrected the mass value of one mass set, in that sense Figure 1 and 2 are representative of data before the corrections. After the correction the data between serie 1 and 2 can be substituted with their average value; in such a case comparing this result with the ones of serie 3 an estimate of transfer standard stability is 2 ppm and 3 ppm for C-415 and V-762 piston-cylinder respectively.

It is proposed to take account of such contributions, based on the above reported values of the 3 repeated tests made at NIST in about 15 months time, to account for possible instability of the units, being such information useful in the evaluation of the uncertainty of the degree of equivalence between the participants.

3) Participants standards

In Table 1 essential information of the main characteristics of the primary standards used by the different laboratories in this comparison are given. As it can be seen from Table 1 the laboratories mainly used pressure balances of different kind, manufacturer and type.

In two cases (IMGC-CNR and NIST) the laboratory primary standards were almost of the same type as the transfer standard.

Some laboratories also made tests with mercury column manometers.

All piston and cylinder materials of the primary pressure balances used by participants, except the case of the NRLM system, were in tungsten carbide.

All primary standards used in this comparison have been independently characterised under the responsibility of each participant. In this sense the five participants to this exercise are not traceable to each other so that the measurements made at one laboratory are not correlated with the measurements made by the other laboratories.

The effective area of the primary standards are derived either from dimensional measurements or from liquid column comparisons and are fully referenced in the literature of each laboratory.

The procedures [1] required that all information concerning the uncertainty of measurand, should be expressed as a standard uncertainty (k=1). Likewise, all characteristics quantities connected to the primary standards of the laboratories should be expressed as standard uncertainty (K=1) so the analysis of data of the comparison will be made in the same way.

4) Results obtained by participants for C-415 piston-cylinder unit

Table 2 gives the following data for each of the participating laboratory :

- the average value of the effective area of the transfer standard $A'p'$ (20°C, p')/mm^2, in which each value is the arithmetic average of 10 experimental determinations obtained by each participant;
- the standard deviation of the average value, s($A'p'$)/$A'p'$, expressed in ppm;
- the standard uncertainty u($A'p'$) as derived by each participating laboratory according to the procedure [1] and the standard uncertainty of pressure p' measured by the primary standard of the laboratory.

As can be seen from Table 2:

- the standard deviation of the average value, s($A'p'$)/$A'p'$, ranges from 3,9 ppm (higher values are normally obtained in each laboratory at low pressures) to 0,1 ppm
- the standard uncertainty of the effective area of the transfer standard, u($A'p'$), is also different from laboratory to laboratory and ranges from 3 ppm to 12 ppm

In Figure 3 the average values of the effective area of the transfer standard $A'p'$ (20°C, p')/mm^2 versus the pressure p'/kPa are given for all 5 laboratories. Note that in Figure 3 one graduation on the $A'p'$ ordinate scale corresponds to 2,4 ppm and that the largest deviation between two laboratories (at 896 kPa) is 9,6 ppm.

5) Reference value selection for C-415 piston-cylinder unit and estimate of its uncertainty

To obtain a reference value, all the transfer standard data in Table 2 were fit by the linear function

$A'p'$ (20°C, p')=f(p')= $A'o$ (1 + l' p') where $A'o$ is the effective area at atmospheric pressure and 20 °C and l' is the distortion coefficient.

The resulting value is:

$$\boldsymbol{A'p'/\mathrm{mm}^2 = 84{,}00489 + 2{,}962\ 10^{-7}\ p'/\mathrm{kPa}}$$

which is equivalent to $A'o$ = 84,00489 mm^2 and a distortion coefficient l' = 3,52 10^{-9} kPa^{-1}

with a standard deviation of the linear fit of 0,000214 mm^2 equivalent to 2,5 ppm.

The reference value was calculated in several ways in order to decide its appropriate selection. For each pressure it was calculated:

- the $A'p'$ reference value obtained by the above linear fit;
- the $A'p'$ reference value obtained as the arithmetic average of the experimental points as in Table 2;
- the $A'p'$ reference value obtained as the median of the experimental points as in Table 2;
- the differences, expressed in ppm, between the results obtained by linear fitting and the arithmetic average or the median

and are all reported in the following table.

p' nom / kPa	Ref. value by linear fit / mm^2	Ref. value by arith. average / mm^2	Ref. value by median / mm^2	Diff. (fit – arith. average) / ppm	Diff. (fit – median) / ppm
79,4	**84,00491**	84,00497	84,00496	-0,6	-0,6
137,8	**84,00493**	84,00499	84,00485	-0,7	1,0
196	**84,00495**	84,00492	84,00495	0,3	0,0
254,5	**84,00497**	84,00486	84,00493	1,3	0,4
312,8	**84,00498**	84,00501	84,00506	-0,3	-0,9
429,5	**84,00502**	84,00503	84,00502	-0,1	0,0
546,2	**84,00505**	84,00504	84,00493	0,2	1,4
663	**84,00509**	84,00512	84,0052	-0,4	-1,4
779,7	**84,00512**	84,00514	84,00513	-0,2	-0,1
896,4	**84,00516**	84,00516	84,00514	0,0	0,2

As can be seen from the above table the use of a linear fit is equivalent to the use of the arithmetic average or the median for each single pressure point with a maximum difference of 1,4 ppm.

According to Müller [2], the standard uncertainty associated with the median is:

$s(\text{median}) = 1{,}858\ \text{MAD}/(n-1)^{1/2}$

where MAD is the median of the absolute deviations, in our case n=5. We can calculate the estimate uncertainty associated with the median for each single pressure value as u(median)=s(median)/median expressed in ppm :

p' nom / kPa	u(median) / ppm
79,4	1,7
137,8	1,1
196	1,1
254,5	0,6
312,8	1,3
429,5	1,2
546,2	1,1
663	2,2
779,7	2,0
896,4	2,3

As can be seen from the above table, the use of the uncertainty associated with the median is almost equivalent to the use of the standard deviation of the linear fit that was equal to 2,5 ppm.

For the above reasons and in accordance with the normal practice of using a linear fit for the characterisation of a piston-cylinder of a pressure balance, we propose that a reference value of the effective area of the transfer standard from a fit from the above function be used.

From pilot laboratory tests, an instability of the transfer standard of 2 ppm was evaluated for the entire pressure range of the pressure balance; this contribution will be used only in the determination of the degree of equivalence between pair of laboratories but will not be included in the evaluation of the uncertainty of the reference value.

As an uncertainty to be associated with the reference value, we propose to use the standard deviation of the linear fit (2,5 ppm).

According to this choice we have the following situation:

p' nom / kPa	instability of tr. std. / ppm	Re-evaluated instability tr. Std., $u_{tr.std.}$ / ppm	std. dev. of linear fit / ppm	u (A'p' ref. value) / ppm
79,4	8	**2**	2,5	**2,5**
137,8	0,7	**2**	2,5	**2,5**
196	4,6	**2**	2,5	**2,5**
254,5	2,5	**2**	2,5	**2,5**
312,8	4,8	**2**	2,5	**2,5**
429,5	1,6	**2**	2,5	**2,5**
546,2	2,3	**2**	2,5	**2,5**
663	2,9	**2**	2,5	**2,5**
779,7	2,1	**2**	2,5	**2,5**
896,4	2,6	**2**	2,5	**2,5**

In Table 4, and from Figure 4 to Figure 9, data of each laboratory are compared to the reference value; see the discussion in paragraph 8.1

6) <u>Results obtained by participants for V-762 piston-cylinder unit</u>

Table 3 gives the following data for each of the participating laboratory :

- the average value of the effective area of the transfer standard $A'p'$ (20°C, p')/mm^2, in which each value is the arithmetic average of 10 experimental determinations obtained by each participant;
- the standard deviation of the average value, s($A'p'$)/$A'p'$, expressed in ppm;
- the standard uncertainty u($A'p'$) as derived by each participating laboratory according to the procedure [1] and the standard uncertainty of pressure p' measured by the primary standard of the laboratory.

As can be seen from Table 3:

- the standard deviation of the average value, s($A'p'$)/$A'p'$, ranges from 4,5 ppm to 0,2 ppm
- the standard uncertainty of the effective area of the transfer standard, u($A'p'$), is different form laboratory to laboratory and ranges from 3,1 ppm to 15 ppm

In Figure 10 the average values of the effective area of the transfer standard $A'p'$ (20°C, p')/mm^2 versus the pressure p'/kPa are given for all 5 laboratories. Note that in Figure 10 one graduation on the $A'p'$ ordinate scale correspond to 6 ppm and that the largest deviation between two laboratories (at 6441,8 kPa) is 25 ppm.

7) Reference value selection for V-762 piston-cylinder unit and estimate of its uncertainty

To obtain a reference value, all the transfer standard data in Table 3 were fit by the linear function

$A'p'$ (20°C, p')=f(p')= $A'o$ (1 + l' p') where $A'o$ is the effective area at atmospheric pressure and 20 °C and l' is the distortion coefficient.

The resulting value is:

$$\mathbf{A'p'/mm^2 = 8{,}3885165 + 3{,}947\ 10^{-8}\ p'/kPa}$$

which is equivalent to $A'o$ = 8,3885165 mm^2 and a distortion coefficient l' = 4,71 10^{-9} kPa^{-1}

with a standard deviation of the linear fit of 6,075 10^{-5} mm^2 equivalent to 7,2 ppm.

The reference value was calculated in several ways in order to decide its appropriate selection. For each pressure it was calculated:

- the $A'p'$ reference value obtained by the above linear fit;
- the $A'p'$ reference value obtained as the arithmetic average of the experimental points as in Table 3;
- the $A'p'$ reference value obtained as the median of the experimental points as in Table 3;
- the differences, expressed in ppm, between the result obtained by linear fitting and the arithmetic average or the median

and are reported in the following table.

p' nom / kPa	Ref. value by linear fit / mm^2	Ref. value by arith. average / mm^2	Ref. value by median / mm^2	Diff. (fit – arith. average) / ppm	Diff. (fit – median) / ppm
621,7	**8,38854**	8,388551	8,388533	-1,1	1,0
738,5	**8,38855**	8,388534	8,388534	1,3	1,4
1077,5	**8,38856**	8,388545	8,388535	1,7	2,9
1767	**8,38859**	8,388585	8,388547	0,1	4,7
2935,7	**8,38863**	8,388648	8,388619	-1,8	1,6
4104,4	**8,38868**	8,388691	8,388668	-1,5	1,3
5273,1	**8,38872**	8,388726	8,388708	-0,1	2,0
6441,8	**8,38877**	8,388769	8,388747	0,2	2,8
6792,4	**8,38878**	8,388774	8,388758	1,3	3,2

As can be seen from the above table the use of a linear fit is equivalent to the use of the arithmetic average or the median for each single pressure point with a maximum difference of 4,7 ppm.

According to Müller [2], the standard uncertainty associated with the median is:

$s(\text{median}) = 1{,}858\ \text{MAD}/(n-1)^{1/2}$

where MAD is the median of the absolute deviations, in our case n=5. We can calculate the estimate uncertainty associated with the median for each single pressure value as u(median)=s(median)/median expressed in ppm :

p' nom / kPa	u(median) / ppm
621,7	0,9
738,5	3,9
1077,5	3
1767	1
2935,7	4,3
4104,4	6,4
5273,1	6,6
6441,8	6
6792,4	5,9

As can be seen from the above table the use of the uncertainty associated with the median is almost equivalent to the use of the standard deviation of the linear fit that was equal to 7,2 ppm.

For the above reasons and in accordance with the normal practice of using a linear fit for the characterisation of a piston-cylinder of a pressure balance, we propose that a reference value of the effective area of the transfer standard from a fit from the above function be used.

From pilot laboratory tests, an instability of the transfer standard of 3 ppm was evaluated for the entire pressure range of the pressure balance; this contribution will be used only in the determination of the degree of equivalence between pair of laboratories but will not be included in the evaluation of the uncertainty of the reference value.

As an uncertainty to be associated with the reference value, we propose to use the standard deviation of the linear fit (7,2 ppm).

According to this choice we have the following situation:

p' nom / kPa	instability of tr. std. / ppm	Re-evaluated instability tr. Std., $u_{tr.std.}$ / ppm	std. dev. of linaer fit / ppm	u (A'p' ref. value) / ppm
621,7	6,5	**3**	7,2	**7,2**
738,5	5,0	**3**	7,2	**7,2**
1077,5	4,5	**3**	7,2	**7,2**
1767	2,7	**3**	7,2	**7,2**
2935,7	1,9	**3**	7,2	**7,2**
4104,4	2,0	**3**	7,2	**7,2**
5273,1	2,9	**3**	7,2	**7,2**
6441,8	1,6	**3**	7,2	**7,2**
6792,4	1,1	**3**	7,2	**7,2**

In Table 5, and from Figure 11 to Figure 16, data of each laboratory are compared to the reference value; see the discussion in paragraph 8.2

8) Discussion of results compared to the reference value

8.1) C-415 piston-cylinder unit

In Table 4 the average values of the effective area of the transfer standard $A'p'$ (20°C, p')/mm^2 and standard uncertainty of $A'p'$ obtained by each laboratory (in ppm) are given. It is also reported the $A'p'_{REF}$ reference value with its uncertainty (in ppm), and the differences between laboratory values and reference values ($A'p'_{\mathrm{LAB}}$ – $A'p'_{\mathrm{REF}}$)/$A'p'_{\mathrm{REF}}$ (in ppm) and the standard uncertainty of the difference (in ppm). The standard uncertainty of the difference is calculated as the root mean square of the squares of the standard uncertainty of $A'p'$ obtained by the laboratory and the standard uncertainty of the reference value.

In Figures 4 to 8 (respectively for IMGC-CNR, BNM-LNE, PTB, NIST and NRLM) the following results versus pressure p' are given.

In ordinate scales:

1-Difference between laboratory values and reference values ($A'p'_{\mathrm{LAB}}$ – $A'p'_{\mathrm{REF}}$)/ $A'p'_{\mathrm{REF}}$ (in ppm);

2- Standard uncertainty of the effective area of the transfer standard $A'p'$ (20°C, p') as declared by each laboratory, in ppm;

3- Standard uncertainty of the difference ($A'p'_{\mathrm{LAB}}$ – $A'p'_{\mathrm{REF}}$), in ppm.

As it can be seen from Figures 4 to 8, only in one case (BNM-LNE as in Figure 5) the difference (for pressures higher than 500 kPa) is higher than the $A'p'$ laboratory standard uncertainty, but also in this case the difference is close to the standard uncertainty of the difference ($A'p'_{\mathrm{LAB}}$ – $A'p'_{\mathrm{REF}}$). Also in this case there are no problems if the agreement is considered in terms of expanded uncertainty with a coverage factor k=2 (in such a case, for BNM-LNE, the $A'p'$ laboratory expanded uncertainty will be from 6 to 7 ppm).

In Figure 9, for all the 5 laboratories, the difference between laboratory values and reference values ($A'p'_{\mathrm{LAB}}$ – $A'p'_{\mathrm{REF}}$)/ $A'p'_{\mathrm{REF}}$ (in ppm) versus pressure p' is given.

- Analysis of the difference between laboratory values and reference values ($A'p'_{\mathrm{LAB}}$ – $A'p'_{\mathrm{REF}}$)/ $A'p'_{\mathrm{REF}}$ (in ppm)
  - IMGC-CNR – the maximum difference is 6,3 ppm at 137,8 kPa [always lower than the standard laboratory uncertainty of $A'p'$ (from 10 ppm to 12 ppm)]
  - BNM-LNE – the maximum difference is 4,7 ppm at 896,4 kPa [higher than the standard laboratory uncertainty of $A'p'$ (2,8 to 3,4 ppm) and also higher than the standard uncertainty of the difference at the highest pressures]
  - PTB – the maximum difference is 2,5 ppm at 663 kPa [always lower than the standard laboratory uncertainty of $A'p'$ (from 3,9 ppm to 4,9 ppm)]

- NIST – the maximum difference is 2,2 ppm at 137,8 kPa [always lower than the standard laboratory uncertainty of $A'p'$ (from 9 ppm to 11 ppm)]
- NRLM – the maximum difference is 4,3 ppm at 79,4 kPa [always lower than the standard laboratory uncertainty of $A'p'$ (from 8,2 ppm to 8,6 ppm)]

- The following table is useful to evidence the results:

Lab.	Highest diff. (*) / ppm	Highest std. unc. of $A'p'$ (°)/ ppm	Agreement within / ppm	Comments
IMGC-CNR	6,3	12,1	12,1	Inside std. lab. unc.
BNM-LNE	4,7	3,4	5	For some points also outside std. unc. of the difference (§)
PTB	2,5	4,9	4,9	Inside std. lab. unc.
NIST	- 2,2	11,1	11,1	Inside std. lab. unc.
NRLM	- 4,3	8,6	8,6	Inside std. lab. unc.

(*) Difference between laboratory values and reference values $(A'p'_{\mathrm{LAB}} - A'p'_{\mathrm{REF}})/ A'p'_{\mathrm{REF}}$ (in ppm).

(°) Standard uncertainty of the effective area of the transfer standard $A'p'$ (20°C, p') as declared by each laboratory, in ppm;

(§) Standard uncertainty of the difference $(A'p'_{\mathrm{LAB}} - A'p'_{\mathrm{REF}})$, in ppm.

8.2) V-762 piston-cylinder unit

In Table 5 the average values of the effective area of the transfer standard $A'p'$ (20°C, p')/mm^2 and standard uncertainty of $A'p'$ obtained by each laboratory (in ppm) are given. It is also reported the $A'p'_{REF}$ reference value with its uncertainty (in ppm), and the differences between laboratory values and reference values $(A'p'_{\mathrm{LAB}} - A'p'_{\mathrm{REF}})/A'p'_{\mathrm{REF}}$ (in ppm) and the standard uncertainty of the difference (in ppm). The standard uncertainty of the difference is calculated as the root mean square of the squares of the standard uncertainty of $A'p'$ obtained by the laboratory and the standard uncertainty of the reference value.

In Figures 11 to 15 (respectively for IMGC-CNR, BNM-LNE, PTB, NIST and NRLM) the following results versus pressure p' are given. In ordinate scales:

1-Difference between laboratory values and reference values ($A'p'_{LAB}$ – $A'p'_{REF}$)/ $A'p'_{REF}$ (in ppm);

2- Standard uncertainty of the effective area of the transfer standard $A'p'$ (20°C, p') as declared by each laboratory, in ppm;

3- Standard uncertainty of the difference ($A'p'_{LAB}$ – $A'p'_{REF}$), in ppm.

As it can be seen from Figures 11 to 15, in few cases (NIST and NRLM as in Figures 14 and 15) the differences are higher than the $A'p'$ laboratory standard uncertainty, and also for some points the differences are higher than the standard uncertainty of the difference ($A'p'_{LAB}$ – $A'p'_{REF}$). Also in this case there are no problems if the agreement is considered in terms of expanded uncertainty with a coverage factor k=2

In Figure 16, for all the 5 laboratories, the difference between laboratory values and reference values ($A'p'_{LAB}$ – $A'p'_{REF}$)/ $A'p'_{REF}$ (in ppm) versus pressure p' is given.

- Analysis of the difference between laboratory values and reference values ($A'p'_{LAB}$ – $A'p'_{REF}$)/ $A'p'_{REF}$ (in ppm)
  - IMGC-CNR – the maximum difference is - 5,8 ppm at 1767 kPa [always lower than the standard laboratory uncertainty of $A'p'$ (from 11 ppm to 14 ppm)]
  - BNM-LNE – the maximum difference is - 4,7 ppm at 1767 kPa [inside the standard laboratory uncertainty of $A'p'$ (3,1 to 4,5 ppm) except in one point, but always within the standard uncertainty of difference (from 7,8 to 8,5 ppm), full agreement within 5 ppm]
  - PTB – the maximum difference is 7,3 ppm at 2936 kPa [always lower than the standard laboratory uncertainty of $A'p'$ (from 4,6 ppm to 8,3 ppm)]
  - NIST – the maximum difference is 14,2 ppm at 621,7 kPa [different points outside the standard uncertainty of $A'p'$ (from 8,7 to 15 ppm), inside the standard uncertainty of the difference (from 11 ppm to 16,6 ppm) except in three points, full agreement within 15 ppm]
  - NRLM – the maximum difference is - 12,5 ppm at 6792 kPa [different points shows differences higher than standard uncertainty of $A'p'$ (from 7,4 to 8,5 ppm), inside the standard uncertainty of the difference (from 10,3 ppm to 11,1 ppm) except the two highest pressure points, full agreement within 13 ppm]
- The following table is useful to evidence the results:

Lab.	Highest diff. (*) / ppm	Highest std. unc. of $A'p'$ (°)/ ppm	Agreement within / ppm	Comments
IMGC-CNR	- 5,8	13,9	13,9	Inside std. lab. unc.
BNM-LNE	- 4,7	4,5	5	Inside std. lab. unc. (close for one point)
PTB	7,3	8,3	8,3	Inside std. lab. unc.
NIST	14,2	14,4	15	3 points are out of std. unc. of differences (§)
NRLM	- 12,5	8,5	13	2 points out of std. unc. of difference

(*) Difference between laboratory values and reference values ($A'p'_{LAB}$ – $A'p'_{REF}$)/ $A'p'_{REF}$ (in ppm).

(°) Standard uncertainty of the effective area of the transfer standard $A'p'$ (20°C, p') as declared by each laboratory, in ppm;

(§) Standard uncertainty of the difference ($A'p'_{LAB}$ – $A'p'_{REF}$), in ppm.

9) Discussion of results compared between participating laboratories

A complementary method, also useful for the interpretation of the comparison results, can be based on the analysis of the mutual differences between participants.

9.1) C-415 piston-cylinder unit

In Tables 6 to 10 the mutual differences between each of the 5 participating laboratories and the relative standard uncertainty of such differences are given.

In these Tables the upper values are the relative differences (in ppm) of effective area $A'p'$ (A_e (I) – A_e (J)/ A_e ref) · 10^6 determined by two laboratories I and J. Lower values, in parenthesis, are the relative standard uncertainties (in ppm) of these differences calculated as

$$\{[\ u\ (A_e\ (I)\ )/\ A_e\ (I)]^2 + [\ u\ (A_e\ (J)\ )/\ A_e\ (J)]^2 + [u_{\ tr.std.}]^2\ \}^{½}$$

where u are the relative standard uncertainties as declared by the laboratories I and J and $u_{\mathrm{tr.std.}}$ is the stability contribution of the transfer standard, evaluated by the pilot laboratory, and equal to 2 ppm.

Tables are generated for the following five pressure values: 79,4 kPa (minimum value of the comparison), 196 kPa, 429,5 kPa, 663 kPa and 896,4 kPa (maximum value of the comparison for the unit C 415). As can be seen from Figure 3 the selected pressure points cover the typical situation of the largest differences between the laboratories.

As can be seen from the tables 6 to 10:

- all differences, for all laboratories and for all pressures, are within the combined standard uncertainty of the effective area $A'p'$ of the transfer standard calculated starting from the standard uncertainty of $A'p'$ as declared by each participating laboratories;
- the largest differences are – 8,6 ppm (at 79,4 kPa), + 3,3 ppm (at 196 kPa), - 4,9 ppm (at 429,5 kPa), + 7,4 ppm (at 663 kPa) and + 9,6 ppm (at 896,4 kPa);
- the systematic differences observed between the participants at higher pressures (and particularly close to 1 MPa) are not observed at lower pressures.

9.2) V-762 piston-cylinder unit

In Tables 11 to 13 the mutual differences between each of the 5 participating laboratories and the relative standard uncertainty of such differences are given.

Tables are generated only for three pressures (621,7 kPa the minimum pressure of the V 762 comparison, 4104,4 kPa and 6792,4 kPa the maximum pressure of the V 762 comparison). As can be seen from Figure 10 the selected pressure points cover the typical situation of the largest differences between the laboratories.

Tables 11 to 13 show that:

- the differences between the laboratories are in some cases outside the combined standard uncertainties (at 621,7 kPa the maximum difference between NIST and NRLM is – 19 ppm while the combined standard uncertainty is 11,8 ppm, at 4104,4 kPa there are 4 cases where the differences are higher than the combined standard uncertainties and the maximum difference between NRLM and NIST amount to – 20,3 ppm while the combined standard uncertainty is 13,8 ppm, at 6792,4 kPa there are 3 cases where the differences are higher than the combined standard uncertainties and the maximum difference between NRLM and NIST amount to – 22,6 ppm while the combined standard uncertainty is 17,5 ppm);

- there is a clear evidence of a systematic shift between the results;
- the maximum difference at low pressures is – 19 ppm and at higher pressure is – 22,6 ppm. In such cases the maximum differences are greater than the combined standard uncertainty (11,8 ppm and 17,5 ppm);
- for all laboratories, at all pressures the maximum differences are always smaller than the combined expanded uncertainties (k=2).

10) Conclusions

10.1) Comparison in the pressure range 79,4 kPa to 896,4 kPa, unit C-415, gas media, gauge mode

- the standard deviation of the average value , s($A'p'$)/$A'p'$, obtained by the participating laboratories ranges from 3,9 ppm to 0,1 ppm
- the standard uncertainty of the effective area of the transfer standard, $u(A'p')$,is different from laboratory to laboratory and ranges from 3 ppm to 12 ppm
- the reference value is selected as the result of linear fit based on all average data of participants:

  $$A'p'/\text{mm}^2 = 84{,}00489 + 2{,}962\ 10^{-7}\ p'/\text{kPa}$$

  which is equivalent to $A'o$ = 84,00489 mm^2 and a distortion

  coefficient l' = 3,52 10^{-9} kPa^{-1}

  The linear fit has a standard deviation of 0,000214 mm^2

  equivalent to 2,5 ppm.
- the standard uncertainty associated with this reference value, is the standard deviation of the linear fit (2,5 ppm)
- for all the laboratories the differences in respect to the reference values are always lower than the standard uncertainty of this difference;
- over 50 experimental determinations of the effective area, $A'p'$, of the transfer standard only 4 average results show a difference in respect of the reference value greater than the standard uncertainty assigned by the laboratories to each $A'p'$ determination;
- comparing the differences between each pair of laboratories, it can be shown that all differences, for all laboratories and for all pressures, are within the combined standard uncertainty of the effective area $A'p'$ of the transfer standard declared by each laboratory;

- a full agreement exists in terms of expanded uncertainty with a coverage factor k=2 (in such a case, the expanded uncertainty will change from laboratory to laboratory from 7,6 to 24,8 ppm)
- the comparison results can be considered fully satisfactory as the differences from the reference values never exceeded 6,3 ppm, this result is fully consistent with similar results obtained in another CCM pressure comparison in gas media from 50 kPa to 1 MPa, Phase A2 [3].

10.2) Comparison in the pressure range 621,7 kPa to 6792,4 kPa, unitV-762, gas media, gauge mode

- the standard deviation of the average value , s($A'p'$)/$A'p'$, obtained by the participating laboratories ranges from 4,5 ppm to 0,2 ppm
- the standard uncertainty of the effective area of the transfer standard , u($A'p'$), is different from laboratory to laboratory and ranges from 3 ppm to 15 ppm
- the reference value is selected as the result of linear fit based on all average data of participants:

$$A'p'/\mathrm{mm}^2 = 8{,}3885165 + 3{,}947\ 10^{-8}\ p'/\mathrm{kPa}$$

which is equivalent to $A'o$ = 8,3885165 mm^2 and a distortion

coefficient l' = 4,71 10^{-9} kPa^{-1}

with a standard deviation of the linear fit of 6,075 10^{-5} mm^2

equivalent to 7,2 ppm.

- the standard uncertainty associated with this reference value, is the standard deviation of the linear fit (7,2 ppm
- over 45 average experimental determinations of the effective area $A'p'$ for all the laboratories, only in 5 cases we obtain differences in respect to the reference values higher than the standard uncertainty of this difference;
- comparing the differences between each pair of laboratories, it can be shown that there is evidence of systematic shift of results. Difference between laboratories are sometime outside their combined standard uncertainty. The maximum differences ranges from – 19 ppm at lower pressures to –22,6 ppm at higher pressures, while the combined standard uncertainties in such cases range from 11,8 ppm to 17,5 ppm.
- a full agreement exists in terms of expanded uncertainty with a coverage factor k=2 (in such a case, the expanded uncertainty will change from laboratory to laboratory from 9,2 to 30 ppm)
- the comparison results can be considered satisfactory as the differences from the reference values never exceeded 14,2 ppm,

the results are fully consistent if compared in terms of expanded uncertainty (k=2 coverage factor).

Figure captions

- Figure 1 - Values of effective area $A'p'$ (20°C, p')/mm^2 versus pressure p'/kPa for the transfer standard C-415 piston-cylinder unit obtained by NIST in 1997 (serie 1 and 2) and in 1999 (serie 3).
- Figure 2 - Values of effective area $A'p'$ (20°C, p')/mm^2 versus pressure p'/kPa for the transfer standard V-762 piston-cylinder unit obtained by NIST in 1997 (serie 1 and 2) and in 1999 (serie 3).
- Figure 3 - Average values of the effective area of the transfer standard C-415, $A'p'$ (20°C, p')/mm^2 versus the pressure p'/kPa for the 5 participating laboratories.
- Figure 4 – C-415 piston cylinder unit. IMGC-CNR results versus pressure p'. In ordinate scale: 1- Difference between laboratory values and reference values ($A'p'_{\mathrm{LAB}}$ – $A'p'_{\mathrm{REF}}$)/ $A'p'_{\mathrm{REF}}$ (in ppm) 2- Standard uncertainty of the effective area of the transfer standard $A'p'$ (20°C, p') as declared by IMGC-CNR, in ppm. 3- Standard uncertainty of the difference ($A'p'_{\mathrm{LAB}}$ – $A'p'_{\mathrm{REF}}$), in ppm.
- Figure 5 – C-415 piston cylinder unit. BNM-LNE results versus pressure p'. In ordinate scale: 1- Difference between laboratory values and reference values ($A'p'_{\mathrm{LAB}}$ – $A'p'_{\mathrm{REF}}$)/ $A'p'_{\mathrm{REF}}$ (in ppm) 2- Standard uncertainty of the effective area of the transfer standard $A'p'$ (20°C, p') as declared by BNM-LNE, in ppm. 3- Standard uncertainty of the difference ($A'p'_{\mathrm{LAB}}$ – $A'p'_{\mathrm{REF}}$), in ppm.
- Figure 6 – C-415 piston cylinder unit. PTB results versus pressure p'. In ordinate scale: 1- Difference between laboratory values and reference values ($A'p'_{\mathrm{LAB}}$ – $A'p'_{\mathrm{REF}}$)/ $A'p'_{\mathrm{REF}}$ (in ppm) 2- Standard uncertainty of the effective area of the transfer standard $A'p'$ (20°C, p') as declared by PTB, in ppm. 3- Standard uncertainty of the difference ($A'p'_{\mathrm{LAB}}$ – $A'p'_{\mathrm{REF}}$), in ppm.
- Figure 7 – C-415 piston cylinder unit. NIST results versus pressure p'. In ordinate scale: 1- Difference between laboratory values and reference values ($A'p'_{\mathrm{LAB}}$ – $A'p'_{\mathrm{REF}}$)/ $A'p'_{\mathrm{REF}}$ (in ppm) 2- Standard uncertainty of the effective area of the transfer standard $A'p'$ (20°C, p') as declared by NIST, in ppm. 3- Standard uncertainty of the difference ($A'p'_{\mathrm{LAB}}$ – $A'p'_{\mathrm{REF}}$), in ppm.
- Figure 8 – C-415 piston cylinder unit. NRLM results versus pressure p'. In ordinate scale: 1- Difference between laboratory values and reference values ($A'p'_{\mathrm{LAB}}$ – $A'p'_{\mathrm{REF}}$)/ $A'p'_{\mathrm{REF}}$ (in ppm) 2- Standard uncertainty of the effective area of the transfer standard $A'p'$ (20°C, p') as declared by NRLM, in ppm. 3-

Standard uncertainty of the difference ($A'p'_{LAB}$ – $A'p'_{REF}$), in ppm.

- Figure 9 – C-415 piston cylinder unit. Difference between laboratory values and reference values ($A'p'_{LAB}$ – $A'p'_{REF}$)/ $A'p'_{REF}$ (in ppm) versus pressure p' for all 5 participating laboratories
- Figure 10 - Average values of the effective area of the transfer standard V-762, $A'p'$ (20°C, p')/mm^2 versus the pressure p'/kPa for the 5 participating laboratories.
- Figure 11 – V-762 piston cylinder unit. IMGC-CNR results versus pressure p'. In ordinate scale: 1- Difference between laboratory values and reference values ($A'p'_{LAB}$ – $A'p'_{REF}$)/ $A'p'_{REF}$ (in ppm) 2- Standard uncertainty of the effective area of the transfer standard $A'p'$ (20°C, p') as declared by IMGC-CNR, in ppm. 3- Standard uncertainty of the difference ($A'p'_{LAB}$ – $A'p'_{REF}$), in ppm.
- Figure 12 – V-762 piston cylinder unit. BNM-LNE results versus pressure p'. In ordinate scale: 1- Difference between laboratory values and reference values ($A'p'_{LAB}$ – $A'p'_{REF}$)/ $A'p'_{REF}$ (in ppm) 2- Standard uncertainty of the effective area of the transfer standard $A'p'$ (20°C, p') as declared by BNM-LNE, in ppm. 3- Standard uncertainty of the difference ($A'p'_{LAB}$ – $A'p'_{REF}$), in ppm.
- Figure 13 – V-762 piston cylinder unit. PTB results versus pressure p'. In ordinate scale: 1- Difference between laboratory values and reference values ($A'p'_{LAB}$ – $A'p'_{REF}$)/ $A'p'_{REF}$ (in ppm) 2- Standard uncertainty of the effective area of the transfer standard $A'p'$ (20°C, p') as declared by PTB, in ppm. 3- Standard uncertainty of the difference ($A'p'_{LAB}$ – $A'p'_{REF}$), in ppm.
- Figure 14 – V-762 piston cylinder unit. NIST results versus pressure p'. In ordinate scale: 1- Difference between laboratory values and reference values ($A'p'_{LAB}$ – $A'p'_{REF}$)/ $A'p'_{REF}$ (in ppm) 2- Standard uncertainty of the effective area of the transfer standard $A'p'$ (20°C, p') as declared by NIST, in ppm. 3- Standard uncertainty of the difference ($A'p'_{LAB}$ – $A'p'_{REF}$), in ppm.
- Figure 15 – V-762 piston cylinder unit. NRLM results versus pressure p'. In ordinate scale: 1- Difference between laboratory values and reference values ($A'p'_{LAB}$ – $A'p'_{REF}$)/ $A'p'_{REF}$ (in ppm) 2- Standard uncertainty of the effective area of the transfer standard $A'p'$ (20°C, p') as declared by NRLM, in ppm. 3- Standard uncertainty of the difference ($A'p'_{LAB}$ – $A'p'_{REF}$), in ppm.
- Figure 16 – V-762 piston cylinder unit. Difference between laboratory values and reference values ($A'p'_{LAB}$ – $A'p'_{REF}$)/ $A'p'_{REF}$ (in ppm) versus pressure p' for all 5 participating laboratories.

Table captions

- Table 1 - Primary standards, almost all pressure balances, used by the participating laboratories in the CCM Comparison (Phase B) in gas media, gauge mode up to 7 MPa
- Table 2 – C-415 piston cylinder unit. Average values of the effective area of the transfer standard $A'p'$ (20°C, p')/mm^2, standard deviation of the average value , s($A'p'$)/$A'p'$, in ppm and standard uncertainty , u($A'p'$), as obtained by each participating laboratory.
- Table 3 – V-762 piston cylinder unit. Average values of the effective area of the transfer standard $A'p'$ (20°C, p')/mm^2, standard deviation of the average value , s($A'p'$)/$A'p'$, in ppm and standard uncertainty , u($A'p'$), as obtained by each participating laboratory.
- Table 4 – C-415 piston cylinder unit. Average values of the effective area of the transfer standard $A'p'$ (20°C, p')/mm^2 and standard uncertainty of $A'p'$ for each laboratory. $A'p'$ reference value with its uncertainty, differences between laboratory values and reference values ($A'p'_{\mathrm{LAB}}$ – $A'p'_{\mathrm{REF}}$), and standard uncertainty of the difference.
- Table 5 – V-762 piston cylinder unit. Average values of the effective area of the transfer standard $A'p'$ (20°C, p')/mm^2 and standard uncertainty of $A'p'$ for each laboratory. $A'p'$ reference value with its uncertainty, differences between laboratory values and reference values ($A'p'_{\mathrm{LAB}}$ – $A'p'_{\mathrm{REF}}$), and standard uncertainty of the difference.
- Table 6 – C-415 piston-cylinder unit. Pressure 79,4 kPa. Upper values are the relative differences (in ppm) of effective area $A'p'$ (A_e (I) – A_e (J)/ A_e ref) · 10^6 determined by two laboratories I and J. Lower values, in parenthesis, are the relative standard uncertainties (in ppm) of these differences calculated as
  $$\{[\ u\ (A_e\ (I)\ )/\ A_e\ (I)]^2 + [\ u\ (A_e\ (J)\ )/\ A_e\ (J)]^2 + [u_{\mathrm{tr.std.}}]^2\ \}^{½}$$

where u are the relative standard uncertainties as declared by the laboratories I and J and $u_{\mathrm{tr.std.}}$ is the stability contribution of the transfer standard, evaluated by the pilot laboratory, and equal to 2 ppm.

- Table 7 – Similar information as in Table 6, C-415 piston-cylinder unit. Pressure 196 kPa
- Table 8 – Similar information as in Table 6, C-415 piston-cylinder unit. Pressure 429,5 kPa
- Table 9 – Similar information as in Table 6, C-415 piston-cylinder unit. Pressure 663 kPa
- Table 10 – Similar information as in Table 6, C-415 piston-cylinder unit. Pressure 896,4 kPa

- Table 11 – V-762 piston-cylinder unit. Pressure 621,7 kPa. Upper values are the relative differences (in ppm) of effective area *A′p′* (A_e (I) – A_e (J)/ A_e ref) · 10^6 determined by two laboratories I and J. Lower values, in parenthesis, are the relative standard uncertainties (in ppm) of these differences calculated as

$$\{[\, u\,(A_e\,(I)\,)/\,A_e\,(I)]^2 + [\, u\,(A_e\,(J)\,)/\,A_e\,(J)]^2 + [u_{\,tr.std.}]^2\,\}^{½}$$

where u are the relative standard uncertainties as declared by the laboratories I and J and $u_{\,tr.std.}$ is the stability contribution of the transfer standard, evaluated by the pilot laboratory, and equal to 3 ppm.

- Table 12 – Similar information as in Table 11, V-762 piston-cylinder unit. Pressure 4104,4 kPa
- Table 13 – Similar information as in Table 11, V-762 piston-cylinder unit. Pressure 6792,4 kPa

References

[1] **Guideline for Phase B**, CCM International Pressure key comparison in gas media (gauge mode) in the range from 80 kPa to 7 MPa. Pressure measurements and calculation of the effective area of the transfer standard piston-cylinder assemblies, Final version approved by all participants, 20 February 1998

[2] J. Müller, Possible advantage of a robust evaluation of comparisons, BIPM Report-)5/2, 1995

[3] J. Jäger, J.C. Legras, G. Molinar and S. Tison, Final Report of the Phase A2 CCM key comparison in the pressure range 50 to 1000 kPa (gas media, gauge mode), October 1998

see also

J.C. Legras, W. Sabuga, G. Molinar and J. Schmidt, CCM Key comparison in the pressure range 50 kPa to 1000 kPa (gas medium, gauge mode). Phase A2:Pressure measurements, *Metrologia* **36 (6)**, 1999, 663-668

and

G. Molinar et al., CCM Key comparison in the pressure range 0,05 MPa to 1 MPa (gas medium, gauge mode). Phase A1:Dimensional measurements and calculations of effective area, *Metrologia* **36 (6)**, 1999, 657-662

Table 1/ 1

Laboratory	Name of laborat. std.	Ao / mm^2	Pressure range / kPa	Notes	Additional tests	Comments	Reports
Transfer standard Ruska 2465	C-415	84	80 - 900	Acceptance tests OK as in guidelines [1]		Use of transfer standard was OK	[1]
	V-762	8,4	600 - 7000	Acceptance tests OK as in guidelines [1]		Use of transfer standard was OK	[1]
IMGC-CNR	IMGC-R-L	336	7 - 138	C-415 only (79 and 138 kPa)	Tests also with HG5 Hg manometer (29 to 114 kPa), internal checks		IMGC internal reports R467 and R468, June 1998
	IMGC-R-M	84	12 - 900	C-415 (254 and 896 kPa) and V-762 (from 621 kPa to 1 MPa)		Similar design as transfer standard	
	IMGC-R-H	8,4	14 - 7000	V762 only from 1,7 to 6,8 MPa		Similar design as transfer standard	
BNM-LNE	1 MPa std Unit # 5	980	10 - 1000	C 415 only	3 ppm difference (manual to motor imposed rotation)		LNE internal reports by J.C. Legras et al., August 1998
	10 MPa std. Unit # 1	98	200 - 10000	V 762 only	No rotational differences		
PTB	Hg manometer		up to 200	C415 at 79,4 kPa	Other pressures as internal tests		PTB internal report by J. Jäger and W. Schultz, August 1998
	PTB/DH 6222	490	up to 2000	C 415 from 138 kPa to 896 kPa V 762 from 621 kPa to 1767 kPa			
	PTB/DH 1310 (5/1) oil lubr.	98	up to 5000	V 762 from 2935 kPa to 5273 kPa	Other pressures as internal tests		
	PTB/DHI 302	49	up to 7000	V 762 from 6441 kPa to 6792 kPa	Other pressures as internal tests		
NIST	PG 37	84	18 - 1300	Used for C 415 comparison in 1997 and 1999 tests		Similar design as transfer standard	Report of calibration P/8579B-98 and P/8579C-98 with similar information also for 1997 tests
	PG 13	8,4	82 - 6890	Used for V 762 comparison in 1997 and 1999 tests		Similar design as transfer standard	
NRLM	re-entrant	196	25 - 1750	Used for C 415 comparison		Ceramic piston	e-mail of 22 April 1999 (SUM-C415-rep and SUM-V762-rep)
	re-entrant	49	100 - 7000	Used for V 762 comparison			

<u>Table 1</u>
Primary standards, mostly pressure balances, used by the participating laboratories in the CCM comparison (Phase B) in gas media, gauge mode up to 7 MPa.

[1] CCM International Pressure key Comparison in gas media (Gauge mode) in the range from 80 kPa to 7 MPa. Guideline for Phase B pressure measurements and calculations of the effective area of the transfer standards piston-cylinder assemblies. Final Version approved by all participants, Version 20 February 1998

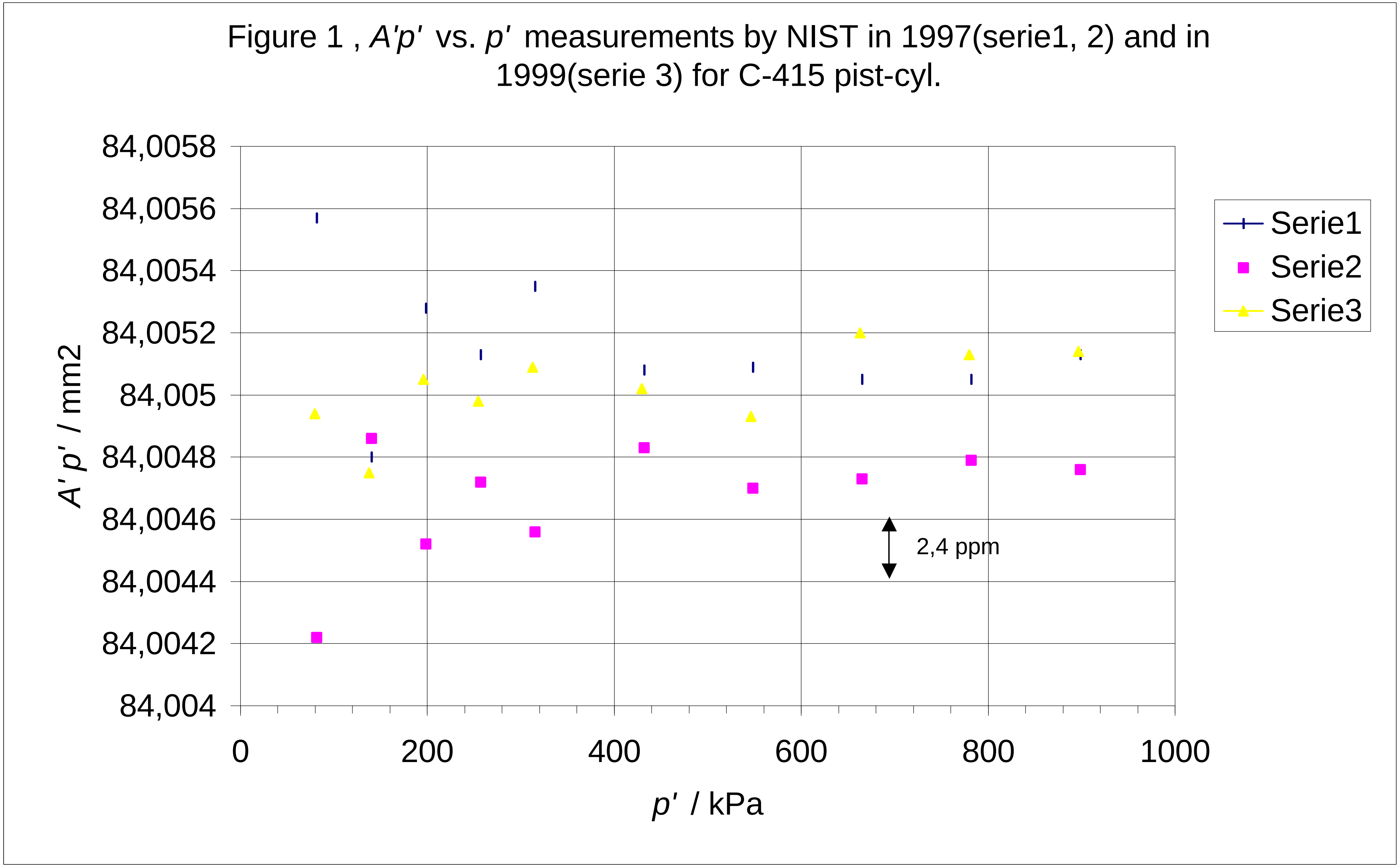


Figure 1 , A'p' vs. p' measurements by NIST in 1997(serie1, 2) and in 1999(serie 3) for C-415 pist-cyl.
84,0058
84,0056
84,0054
84,0052
84,005
84,0048
84,0046
84,0044
84,0042
84,004
A' p' / mm2
0
200
400
600
800
1000
p' / kPa
Serie1
Serie2
Serie3
2,4 ppm

Figure 2, *A'p'* vs. *p'* measurements by NIST in 1997(serie 1, 2) and in 1999 (serie 3) for V-762 pist.-cyl.

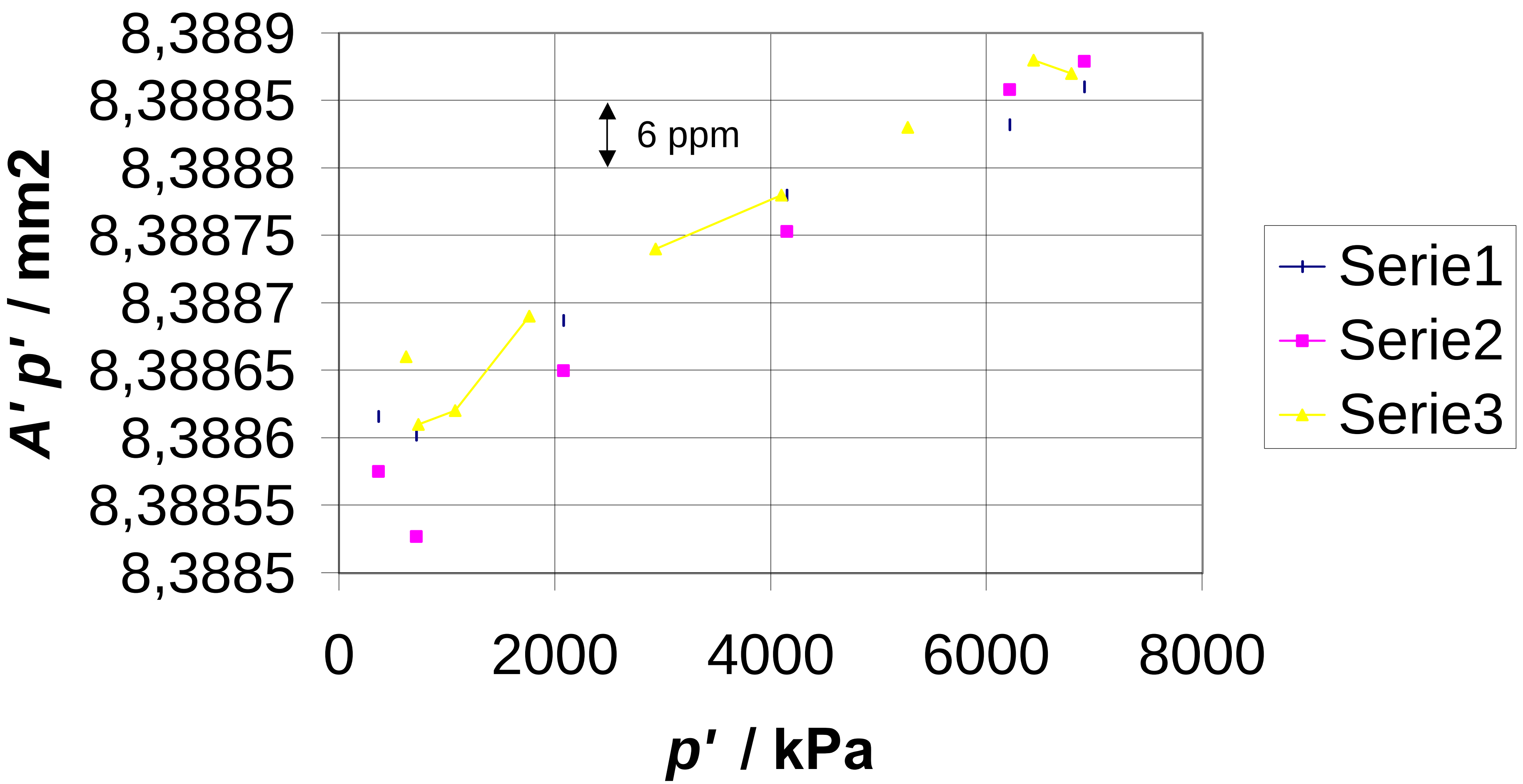


TABLE 2

CCM Comparison, Gas media, gauge mode up to 7 MPa

Piston-Cylinder C-415, 27 July 2000

	CNR-IMGC data			BNM-LNE data			PTB data		
p' nom / kPa	Av. A'(p', 20 °C) / mm^2	s (A'p')/A'p' in ppm	u(A'p') K=1 / ppm	Av. A'(p', 20 °C) / mm^2	s (A'p')/A'p' in ppm	u(A'p') K=1 / ppm	Av. A'(p', 20 °C) / mm^2	s (A'p')/A'p' in ppm	u(A'p') K=1 / ppm
79,4	84,00527	3,9	12,1	84,00496	0,5	3,4	84,00511	0,9	3,9
137,8	84,00546	2,6	10,3	84,00485	0,5	3,2	84,00507	1,5	4,9
196	84,00477	3	12,1	84,00495	0,4	3	84,00498	1,5	4,8
254,5	84,00475	3,3	11,8	84,00493	0,3	3	84,00497	1,3	4,7
312,8	84,00494	2	11,4	84,00519	0,1	2,9	84,00506	1,1	4,6
429,5	84,00491	1,3	11	84,00525	0,2	2,9	84,00511	1,1	4,6
546,2	84,00483	1,6	10,9	84,00533	0,2	2,9	84,00521	0,9	4,6
663	84,00478	1,9	10,7	84,0054	0,1	2,8	84,0053	0,9	4,6
779,7	84,00481	1,8	10,9	84,00549	0,1	2,8	84,0053	1	4,6
896,4	84,00474	1,1	10,7	84,00555	0,2	2,8	84,00535	1,1	4,6

	NIST March 1999 data			NRLM August 1998		
p' nom / kPa	Av. A'(p', 20 °C) / mm^2	s (A'p')/A'p' in ppm	u(A'p') K=1 / ppm	Av. A'(p', 20 °C) / mm^2	s (A'p')/A'p' in ppm	u(A'p') K=1 / ppm
79,4	84,00494	1	8,8	84,00455	1,4	8,6
137,8	84,00475	0,5	9	84,0048	1	8,4
196	84,00505	0,4	9,1	84,00485	0,6	8,4
254,5	84,00498	0,2	9,3	84,00467	0,7	8,5
312,8	84,00509	0,2	9,5	84,00477	0,8	8,6
429,5	84,00502	0,6	9,8	84,00484	0,6	8,5
546,2	84,00493	0,5	10,1	84,00489	0,4	8,5
663	84,0052	0,5	10,5	84,00494	0,2	8,3
779,7	84,00513	0,2	10,8	84,00495	0,4	8,2
896,4	84,00514	0,2	11,1	84,005	0,2	8,2

Figure 3 -CCM Comp. Phase B, C 415
***A'p'* versus *p'* as obtained by the 5 participating laboratories**

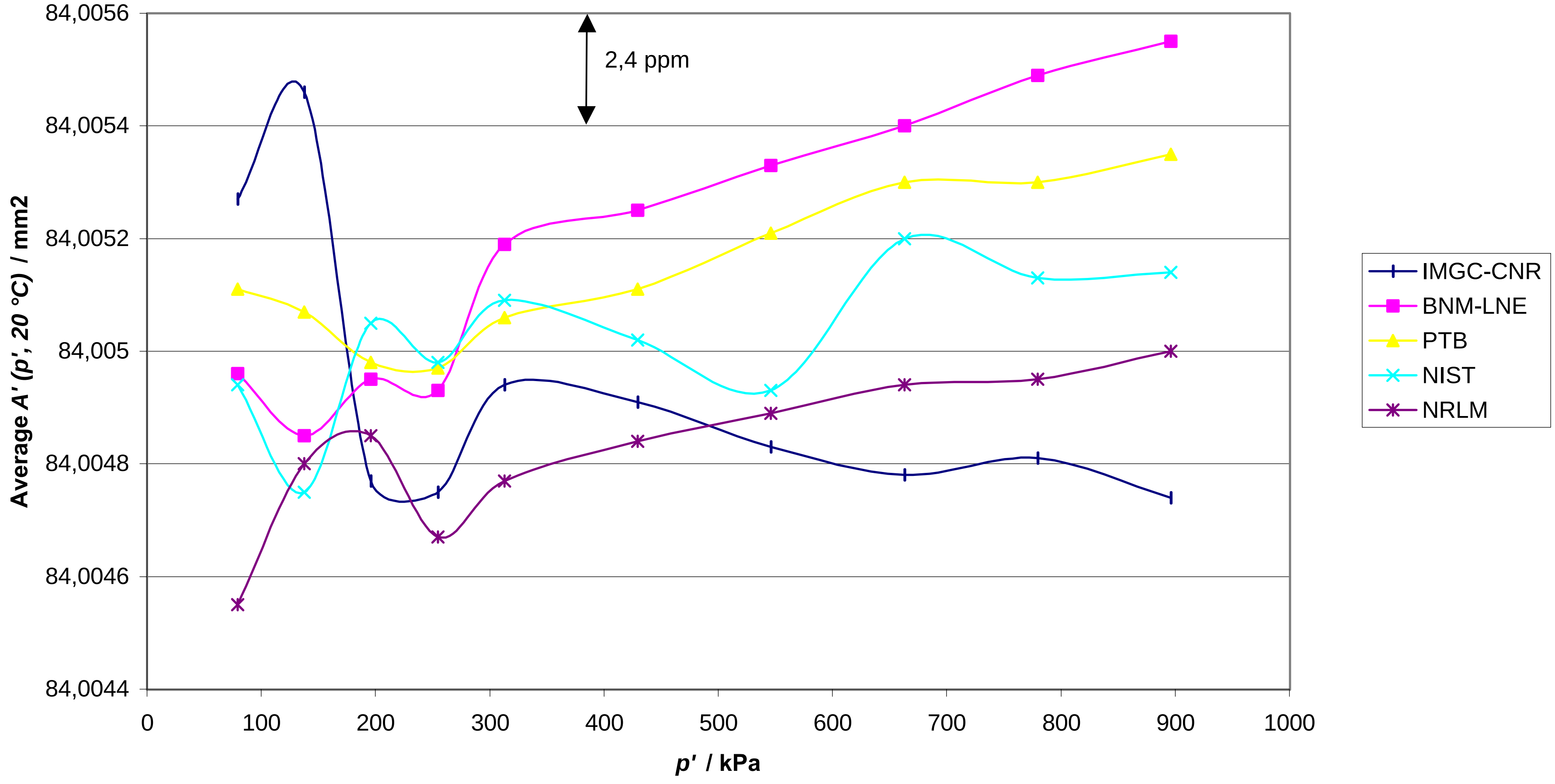


TABLE 3

CCM Comparison, Gas media, Gauge Mode up to 7 MPa									
Piston-Cylinder V-762, 27 July 2000									
	CNR-IMGC data			BNM-LNE data			PTB data		
p' nom / kPa	Av. A'(p', 20 °C) / mm^2	s (A'p')/A'p' in ppm	u(A'p') K=1 / ppm	Av. A'(p', 20 °C) / mm^2	s (A'p')/A'p' in ppm	u(A'p') K=1 / ppm	Av. A'(p', 20 °C) / mm^2	s (A'p')/A'p' in ppm	u(A'p') K=1 / ppm
621,7	8,388533	2,9	10,9	8,388535	2,8	4,5	8,388525	1,7	4,8
738,5	8,388499	3,4	11	8,388534	1,2	3,6	8,388539	1,5	4,7
1077,5	8,388512	3,7	11	8,388535	0,7	3,3	8,388562	1	4,6
1767	8,388538	4	13,2	8,388547	0,8	3,3	8,38861	1	4,6
2935,7	8,388619	3,5	13	8,388606	0,6	3,2	8,388694	1,1	7,4
4104,4	8,388668	4,2	13,1	8,38866	0,5	3,1	8,388738	1	7,4
5273,1	8,388683	3,2	13,2	8,388708	0,3	3,1	8,388768	1,3	7,4
6441,8	8,388746	3,5	13,3	8,388747	0,3	3,1	8,388801	1	8,2
6792,4	8,388751	4,5	13,9	8,388758	0,4	3,2	8,388811	1,2	8,3

	NIST 1999 data			NRLM data (August 1998)		
p' nom / kPa	Av. A'(p', 20 °C) / mm^2	s (A'p')/A'p' in ppm	u(A'p') K=1 / ppm	Av. A'(p', 20 °C) / mm^2	s (A'p')/A'p' in ppm	u(A'p') K=1 / ppm
621,7	8,38866	0,5	8,7	8,3885	0,9	7,4
738,5	8,38861	1,2	8,8	8,38849	0,9	7,4
1077,5	8,38862	0,9	8,8	8,388496	1,3	7,4
1767	8,38869	0,3	9	8,38854	0,8	7,5
2935,7	8,38874	0,3	9,8	8,38858	0,7	7,6
4104,4	8,38878	0,3	11	8,38861	0,7	7,8
5273,1	8,38883	0,2	12,6	8,38864	0,8	8,1
6441,8	8,38888	0,3	14,4	8,38867	0,6	8,4
6792,4	8,38887	0,3	15	8,38868	0,9	8,5

TABLE 4

CCM Comparison in Gas media and gauge mode up to 7 MPa

Piston-Cylinder C-415

									Diff. = Lab value - ref. value		
											IMGC
	IMGC data	BNM-LNE data	PTB data	NIST data	NRLM data	REF. VALUE	STABILITY, NISTtests	Estimate of Unc. REF. VALUE	IMGC diff.	IMGC std. unc.	std. unc. of
p' nom / kPa	Av. A'(p', 20 °C) / mm^2	Av. A'(p', 20 °C) / mm^2	Av. A'(p', 20 °C) / mm^2	Av. A'(p', 20 °C) / mm^2	Av. A'(p', 20 °C) / mm^2	A'(p', 20 °C) lin. fit / mm^2	$u_{tr.\ Std.}$/ ppm	std. Unc. Fit $u_{ref.}$ / ppm	/ ppm	/ ppm	difference / ppm
79,4	84,00527	84,00496	84,00511	84,00494	84,00455	84,00491	2,0	2,5	4,2	12,1	12,4
137,8	84,00546	84,00485	84,00507	84,00475	84,0048	84,00493	2,0	2,5	6,3	10,3	10,6
196	84,00477	84,00495	84,00498	84,00505	84,00485	84,00495	2,0	2,5	-2,1	12,1	12,4
254,5	84,00475	84,00493	84,00497	84,00498	84,00467	84,00497	2,0	2,5	-2,6	11,8	12,1
312,8	84,00494	84,00519	84,00506	84,00509	84,00477	84,00498	2,0	2,5	-0,5	11,4	11,7
429,5	84,00491	84,00525	84,00511	84,00502	84,00484	84,00502	2,0	2,5	-1,3	11	11,3
546,2	84,00483	84,00533	84,00521	84,00493	84,00489	84,00505	2,0	2,5	-2,6	10,9	11,2
663	84,00478	84,0054	84,0053	84,0052	84,00494	84,00509	2,0	2,5	-3,6	10,7	11,0
779,7	84,00481	84,00549	84,0053	84,00513	84,00495	84,00512	2,0	2,5	-3,7	10,9	11,2
896,4	84,00474	84,00555	84,00535	84,00514	84,005	84,00516	2,0	2,5	-4,9	10,7	11,0
							eval. as std. dev. of repeated cal. in 2 years	As std. unc. of linear fit		Quadrature std. unc. ref. value and std. unc. lab.	

			BNM-LNE			PTB			NIST			NRLM
	BNM-LNE diff.	BNM-LNE std. unc.	std. unc. of	PTB diff.	PTB std. unc.	std. unc. of	NIST diff.	NIST std. unc.	std. unc. of	NRLM diff.	NRLM std. unc.	std. unc. of
p' nom / kPa	/ ppm	/ ppm	difference / ppm	/ ppm	/ ppm	difference / ppm	/ ppm	/ ppm	difference / ppm	/ ppm	/ ppm	difference / ppm
79,4	0,6	3,4	4,2	2,3	3,9	4,6	0,3	8,8	9,1	-4,3	8,6	9,0
137,8	-1,0	3,2	4,1	1,7	4,9	5,5	-2,2	9	9,3	-1,6	8,4	8,8
196	0,0	3	3,9	0,4	4,8	5,4	1,2	9,1	9,4	-1,2	8,4	8,8
254,5	-0,4	3	3,9	0,1	4,7	5,3	0,2	9,3	9,6	-3,5	8,5	8,9
312,8	2,5	2,9	3,8	0,9	4,6	5,2	1,3	9,5	9,8	-2,5	8,6	9,0
429,5	2,8	2,9	3,8	1,1	4,6	5,2	0,0	9,8	10,1	-2,1	8,5	8,9
546,2	*3,3*	2,9	3,8	1,9	4,6	5,2	-1,4	10,1	10,4	-1,9	8,5	8,9
663	*3,7*	2,8	3,8	2,5	4,6	5,2	1,4	10,5	10,8	-1,7	8,3	8,7
779,7	*4,4*	2,8	3,8	2,1	4,6	5,2	0,1	10,8	11,1	-2,0	8,2	8,6
896,4	*4,7*	2,8	3,8	2,3	4,6	5,2	-0,2	11,1	11,4	-1,9	8,2	8,6

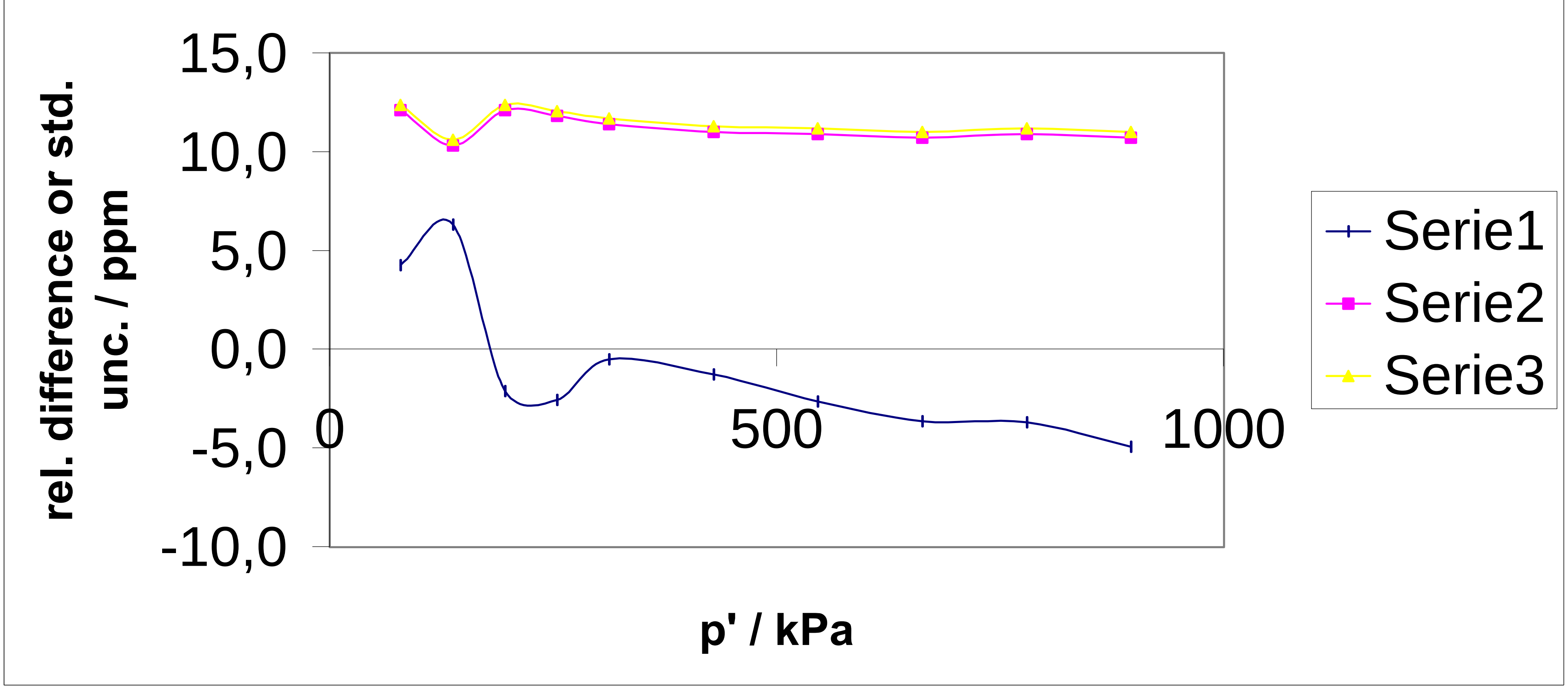


Figure 4, IMGC-CNR results. (1-rel. difference, 2-lab std. unc., 3- unc. of diff.)

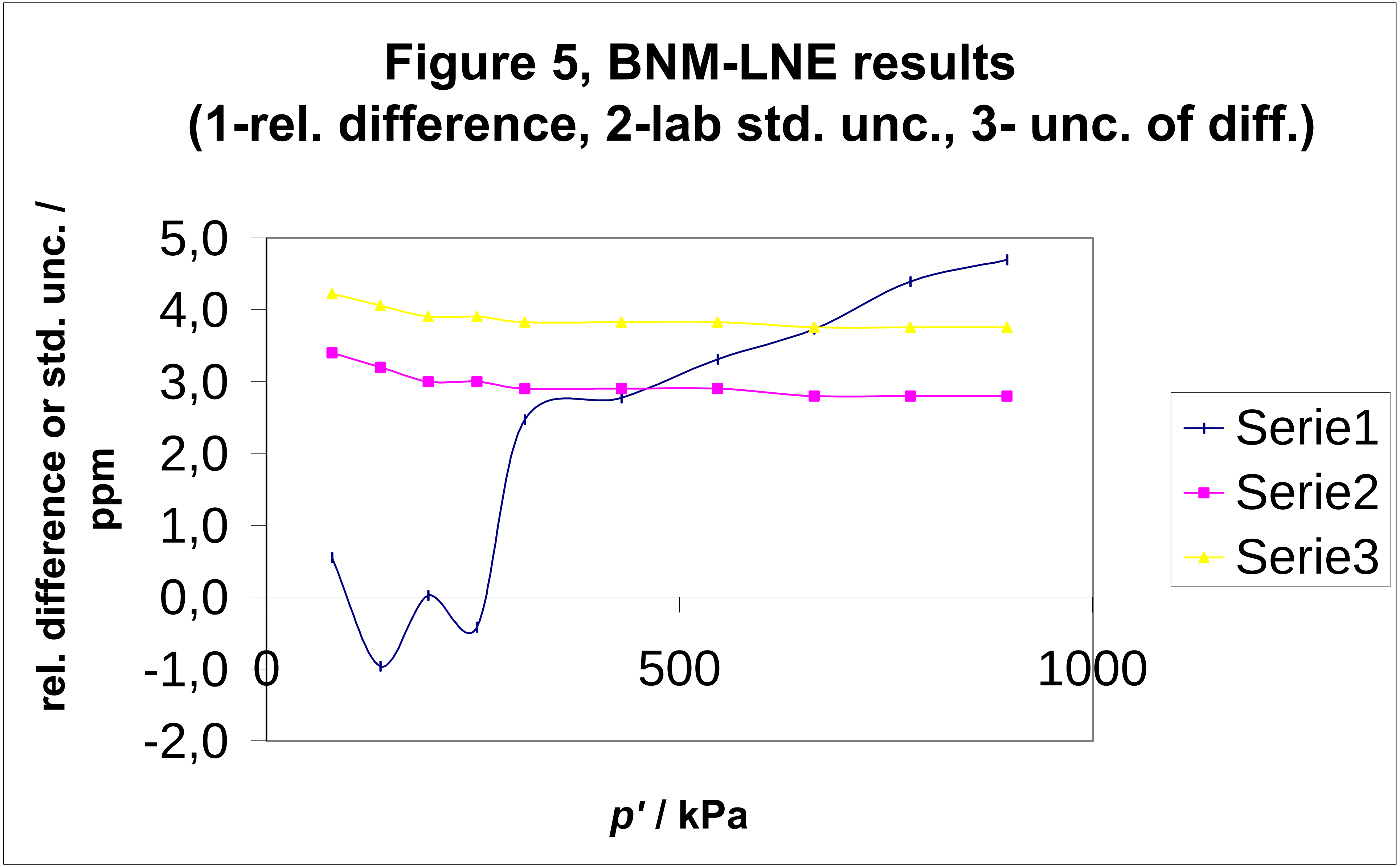


Figure 5, BNM-LNE results
(1-rel. difference, 2-lab std. unc., 3- unc. of diff.)
rel. difference or std. unc. / ppm
5,0
4,0
3,0
2,0
1,0
0,0
-1,0
-2,0
0
500
1000
p' / kPa
Serie1
Serie2
Serie3

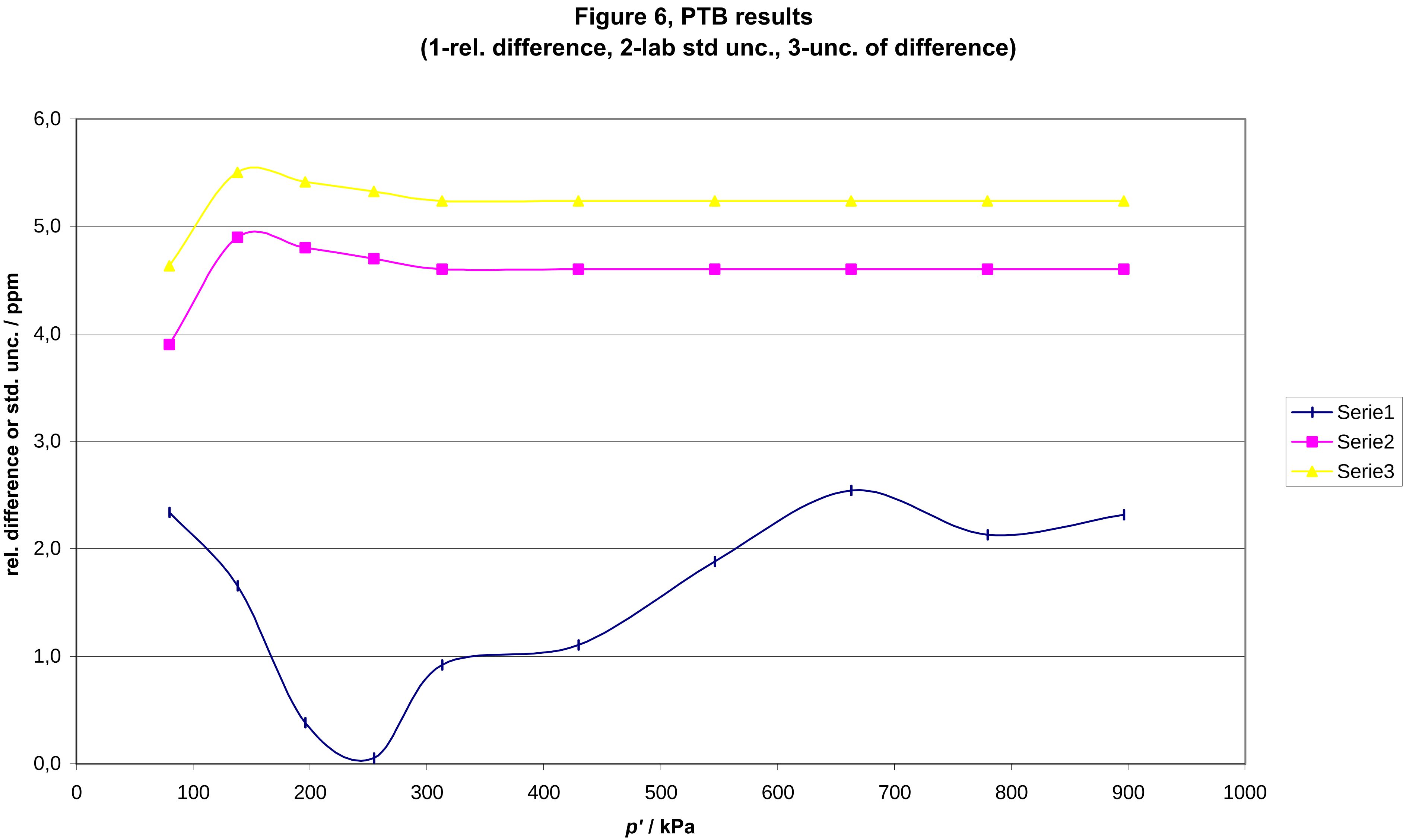


Figure 6, PTB results
(1-rel. difference, 2-lab std unc., 3-unc. of difference)
rel. difference or std. unc. / ppm
6,0
5,0
4,0
3,0
2,0
1,0
0,0
0
100
200
300
400
500
600
700
800
900
1000
p' / kPa
Serie1
Serie2
Serie3

Figure 7, NIST results
(1-rel. difference, 2-lab std unc., 3-unc. of difference)

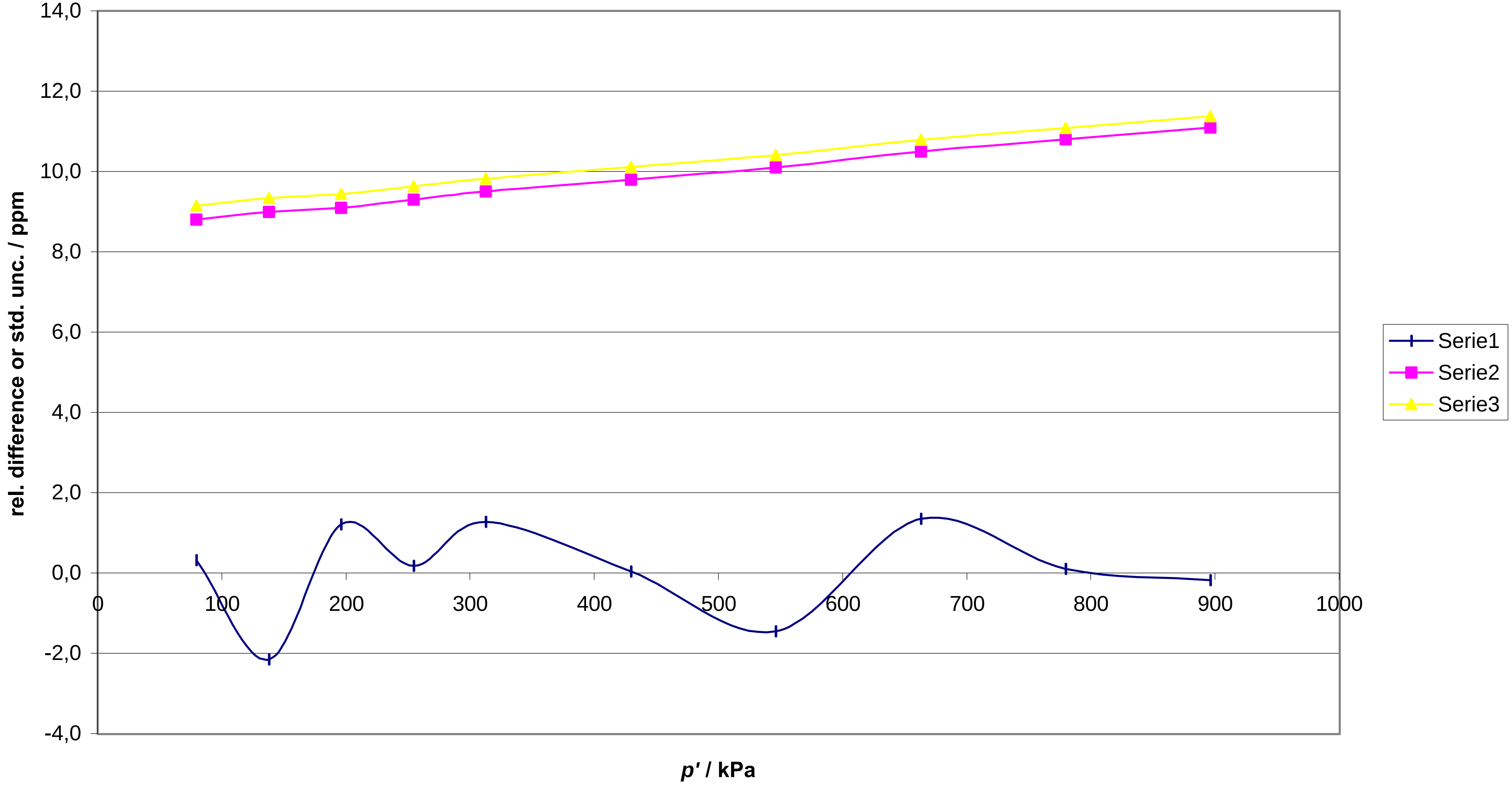


Figure 8, NRLM Results
(1 -rel. difference, 2 - lab. standard uncertainty, 3 - uncertainty of the difference)

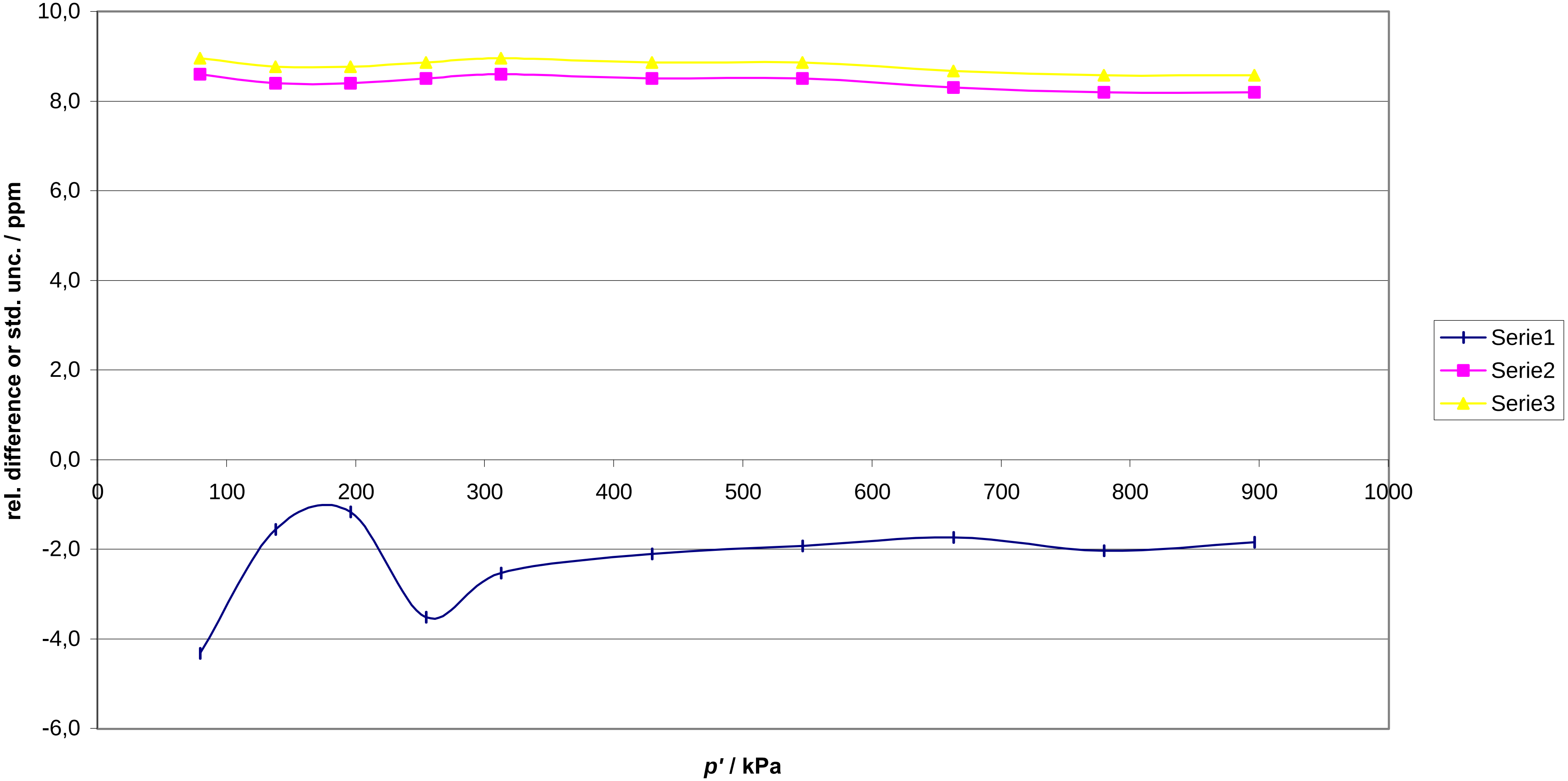


Figure 9, C-415 piston cylinder
rel. differences in respect of reference value of all labs

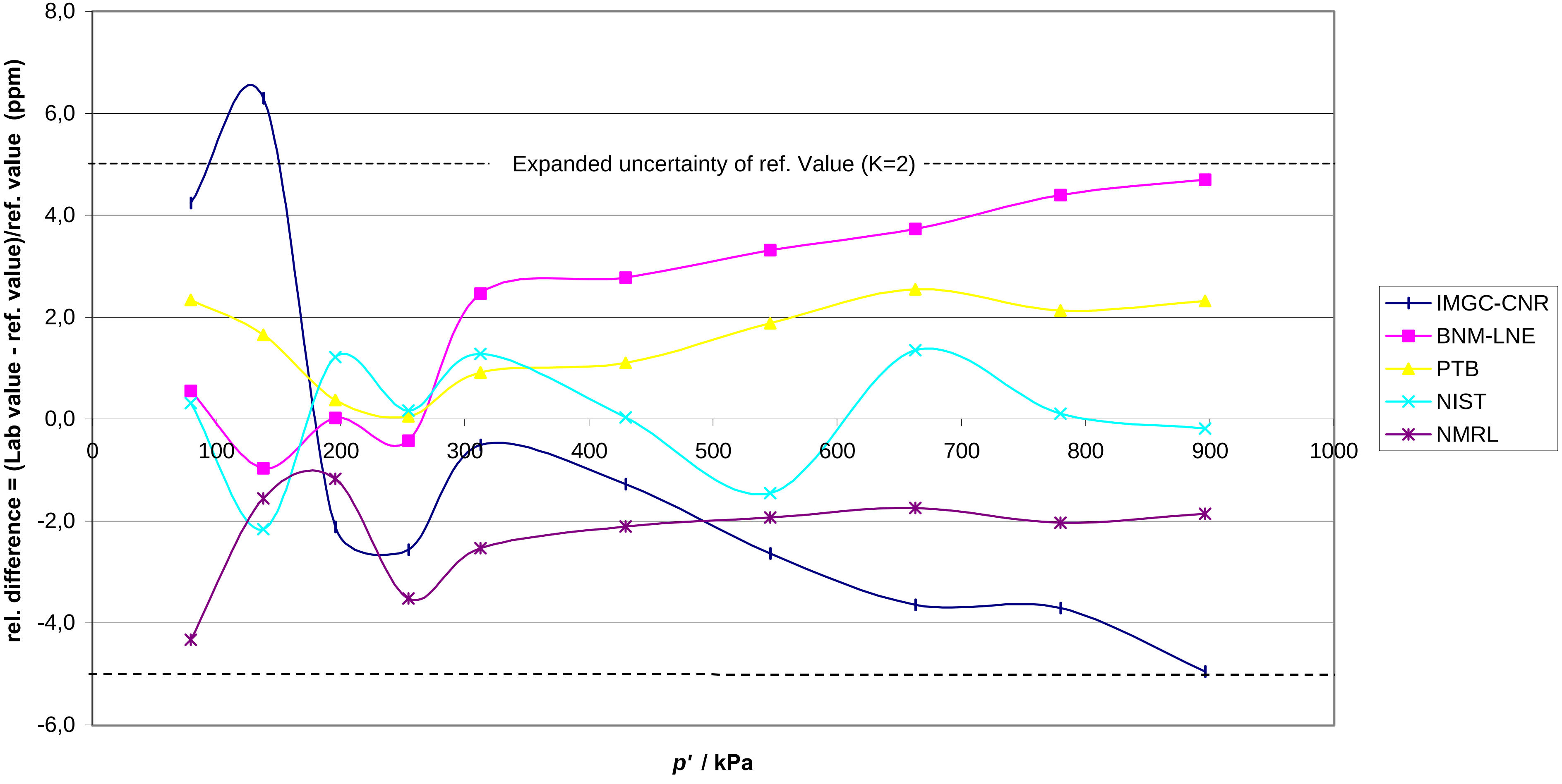


Figure 10 - CCM Comp. Phase B, V-762
***A'p'* versus *p'* as obtained by the 5 participating laboratories**

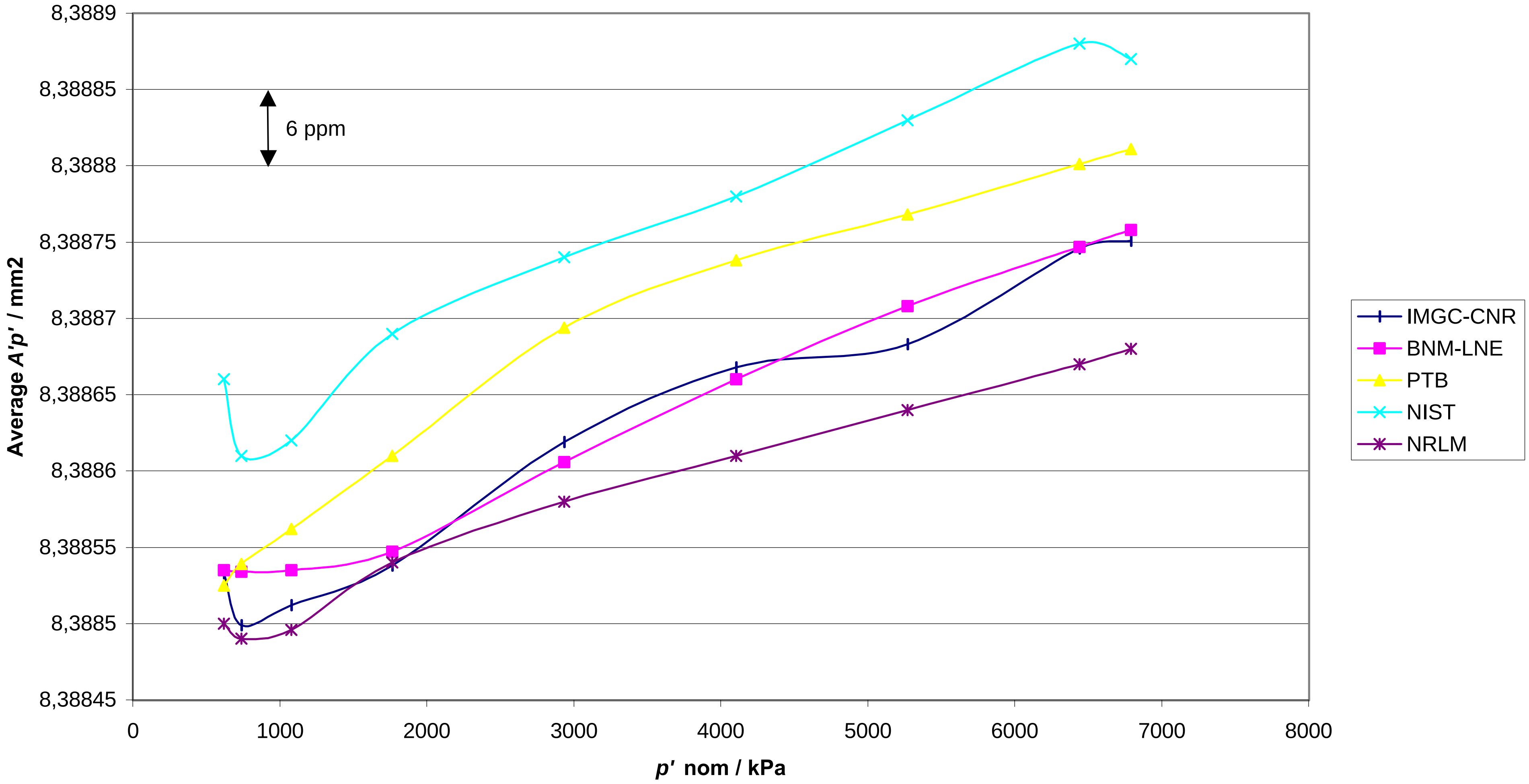


TABLE 5

CCM Comparison, Gas media, gauge mode up to 7 MPa

Piston-Cylinder V-762, 28 July 2000

Diff. = Lab value - ref. value

p' nom / kPa	IMGC data Av. A'(p', 20 °C) / mm²	LNE data Av. A'(p', 20 °C) / mm²	PTB data Av. A'(p', 20 °C) / mm²	NIST data Av. A'(p', 20 °C) / mm²	NRLM data Av. A'(p', 20 °C) / mm²	REF. VALUE A'(p', 20 °C) lin. fit / mm²	STABILITY by pilot lab. $U_{tr.std.}$ / ppm	Estimate of Unc. Ref. VALUE u_{REF} std. unc. / ppm	IMGC diff. / ppm	IMGC std. unc. / ppm	IMGC std. unc. of difference / ppm
621,7	8,388533	8,388535	8,388525	8,38866	8,3885	8,38854	3,0	7,2	-1,0	10,9	13,1
738,5	8,388499	8,388534	8,388539	8,38861	8,38849	8,38855	3,0	7,2	-5,6	11	13,1
1077,5	8,388512	8,388535	8,388562	8,38862	8,388496	8,38856	3,0	7,2	-5,6	11	13,1
1767	8,388538	8,388547	8,38861	8,38869	8,38854	8,38859	3,0	7,2	-5,8	13,2	15,0
2935,7	8,388619	8,388606	8,388694	8,38874	8,38858	8,38863	3,0	7,2	-1,6	13	14,9
4104,4	8,388668	8,38866	8,388738	8,38878	8,38861	8,38868	3,0	7,2	-1,3	13,1	14,9
5273,1	8,388683	8,388708	8,388768	8,38883	8,38864	8,38872	3,0	7,2	-5,0	13,2	15,0
6441,8	8,388746	8,388747	8,388801	8,38888	8,38867	8,38877	3,0	7,2	-3,0	13,3	15,1
6792,4	8,388751	8,388758	8,388811	8,38887	8,38868	8,38878	3,0	7,2	-4,0	13,9	15,7
							eval. as std. dev. of repeated cal. in 2 years	std. unc. of linear fit		Quadrature std. unc. ref. value and std. unc. lab.	

p' nom / kPa	LNE diff. / ppm	LNE std. unc. / ppm	BNM-LNE std. unc. of difference / ppm	PTB diff. / ppm	PTB std. unc. / ppm	PTB std. unc. of difference / ppm	NIST diff. / ppm	NIST std. unc. / ppm	NIST std. unc. of difference / ppm	NRLM diff. / ppm	NRLM std. unc. / ppm	NRLM std. unc. of difference / ppm
621,7	-0,7	4,5	8,5	-1,9	4,8	8,7	*14,2*	8,7	11,3	-4,9	7,4	10,3
738,5	-1,4	3,6	8,0	-0,8	4,7	8,6	7,7	8,8	11,4	-6,6	7,4	10,3
1077,5	-2,9	3,3	7,9	0,4	4,6	8,5	7,3	8,8	11,4	*-7,5*	7,4	10,3
1767	*-4,7*	3,3	7,9	2,8	4,6	8,5	*12,4*	9	11,5	-5,5	7,5	10,4
2935,7	-3,1	3,2	7,9	7,3	7,4	10,3	*12,8*	9,8	12,2	-6,2	7,6	10,5
4104,4	-2,2	3,1	7,8	7,1	7,4	10,3	*12,1*	11	13,1	*-8,2*	7,8	10,6
5273,1	-2,0	3,1	7,8	5,2	7,4	10,3	*12,6*	12,6	14,5	*-10,1*	8,1	10,8
6441,8	-2,8	3,1	7,8	3,6	8,2	10,9	13,0	14,4	16,1	*-12,0*	8,4	11,1
6792,4	-3,2	3,2	7,9	3,1	8,3	11,0	10,2	15	16,6	*-12,5*	8,5	11,1

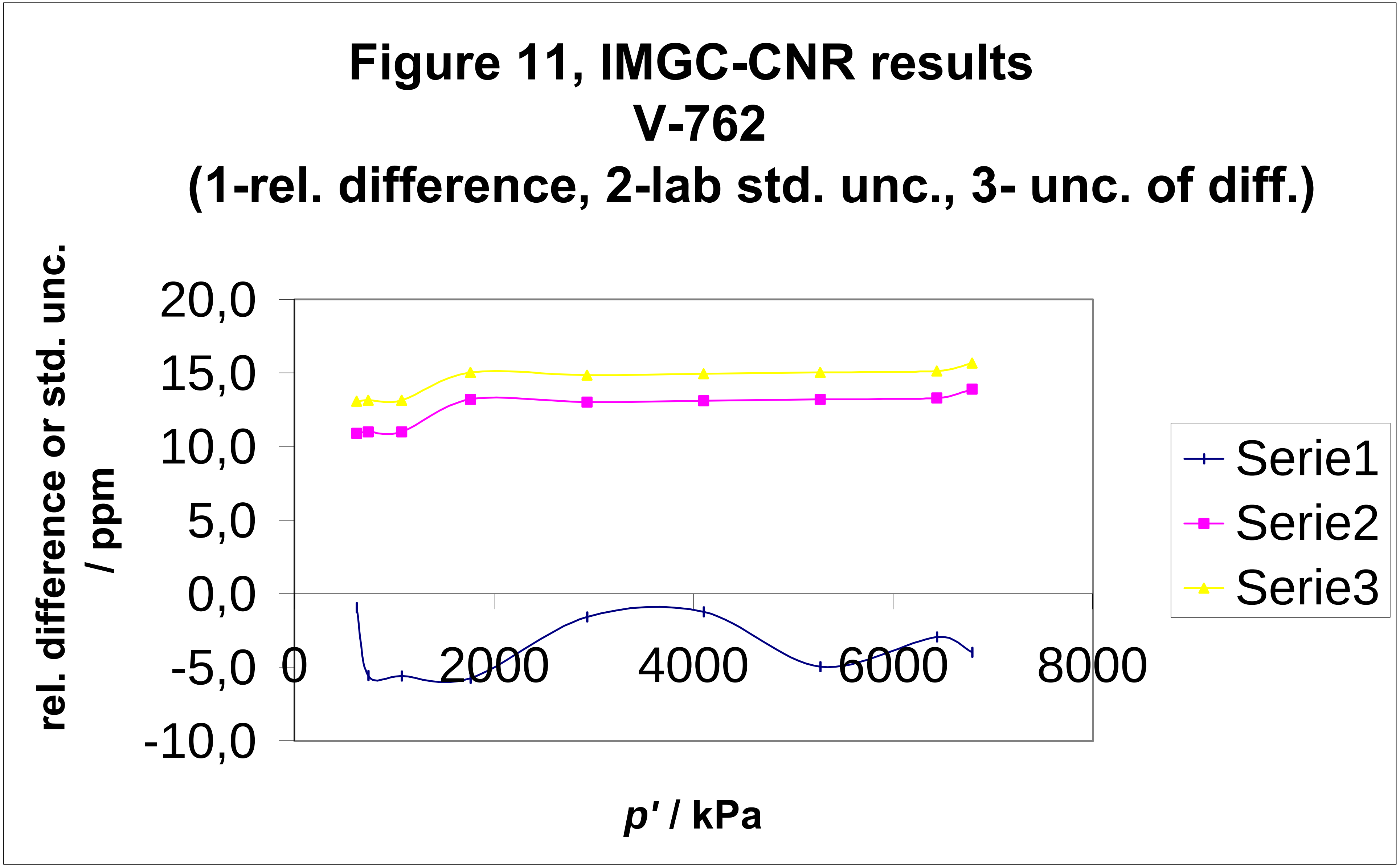


Figure 11, IMGC-CNR results
V-762
(1-rel. difference, 2-lab std. unc., 3- unc. of diff.)
rel. difference or std. unc. / ppm
20,0
15,0
10,0
5,0
0,0
-5,0
-10,0
0
2000
4000
6000
8000
p' / kPa
Serie1
Serie2
Serie3

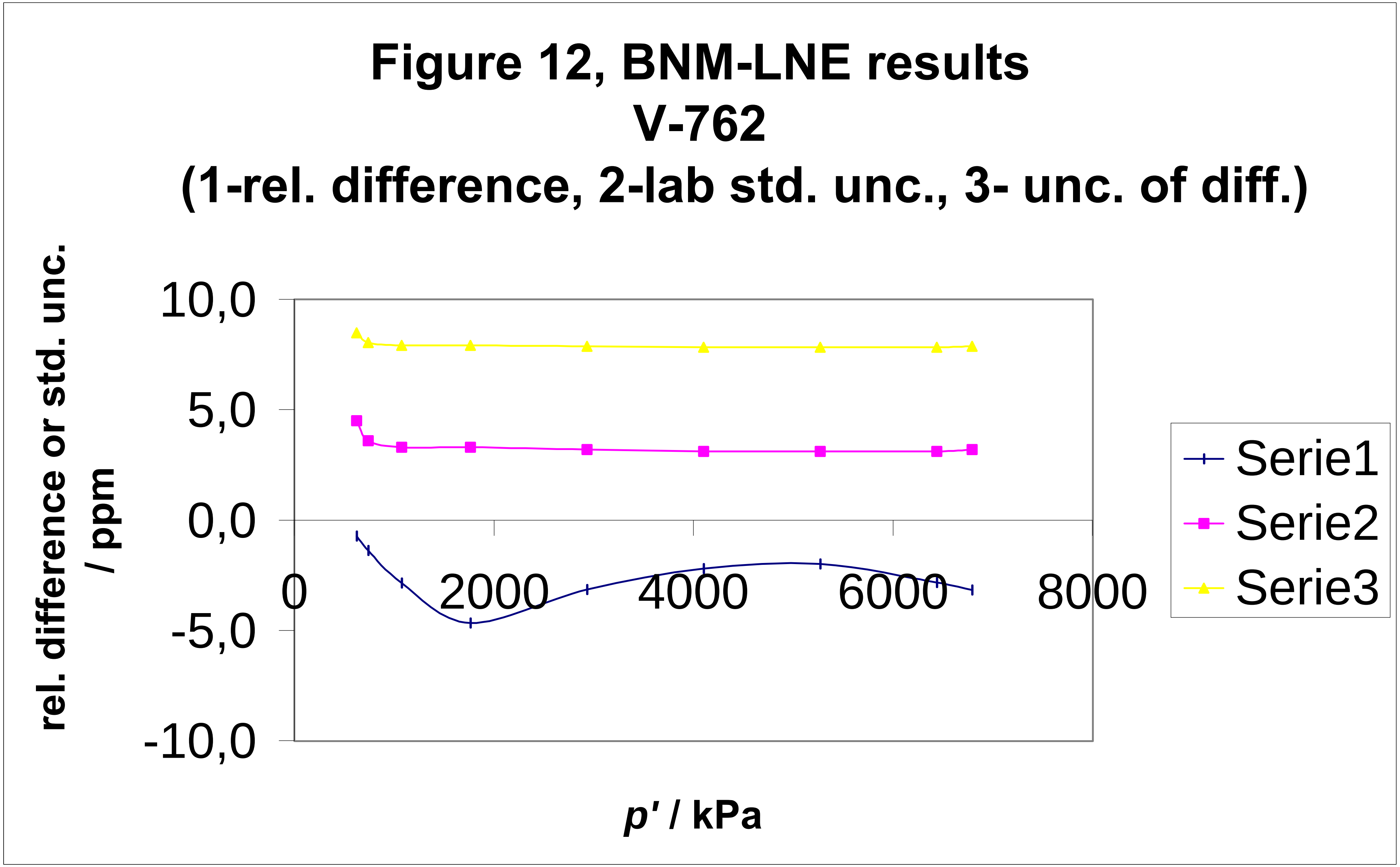
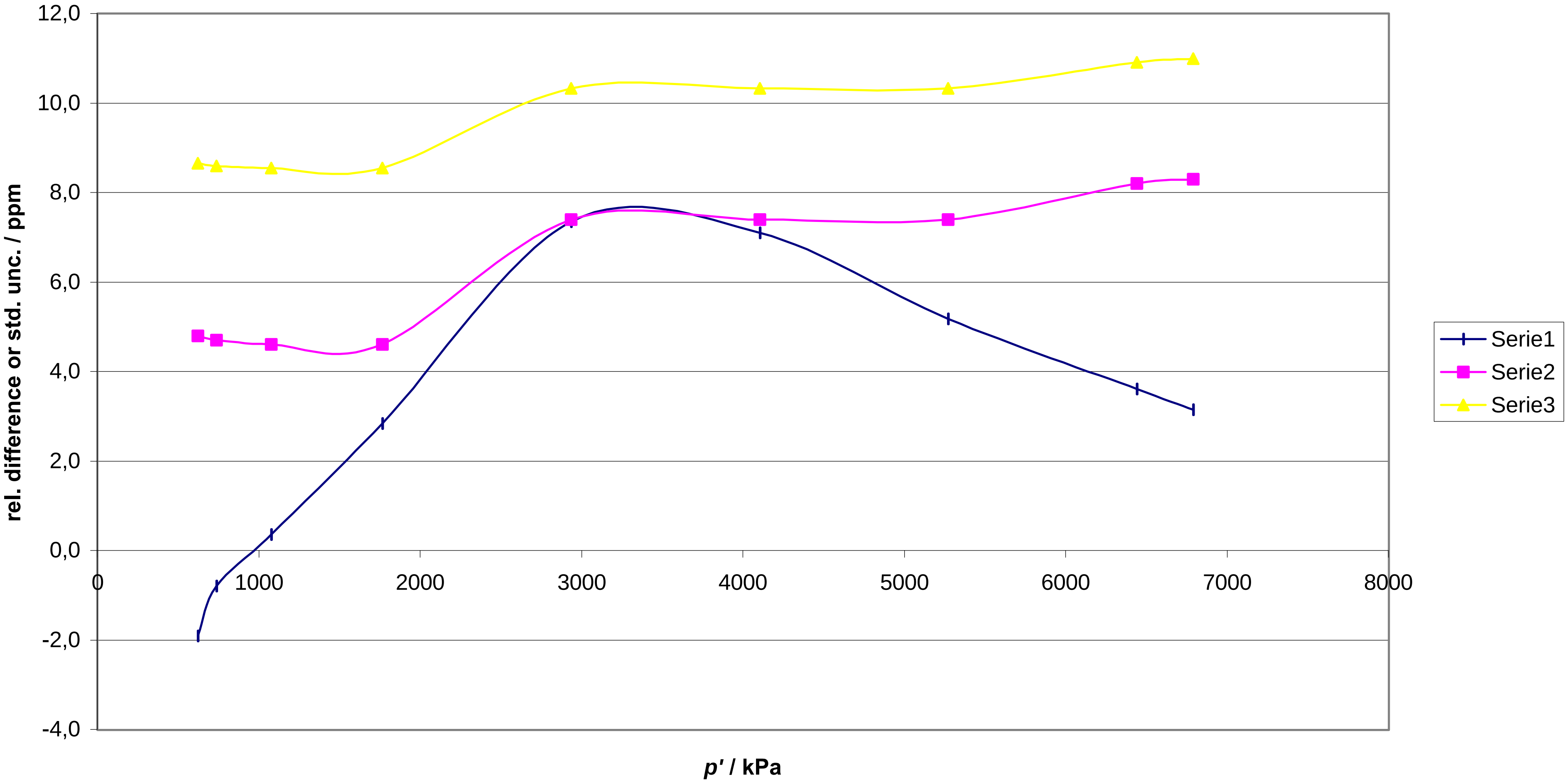


Figure 12, BNM-LNE results
V-762
(1-rel. difference, 2-lab std. unc., 3- unc. of diff.)
rel. difference or std. unc. / ppm
10,0
5,0
0,0
-5,0
-10,0
0
2000
4000
6000
8000
p' / kPa
Serie1
Serie2
Serie3

Figure 13, PTB results
V-762
(1-rel. difference, 2-lab std unc., 3-unc. of difference)



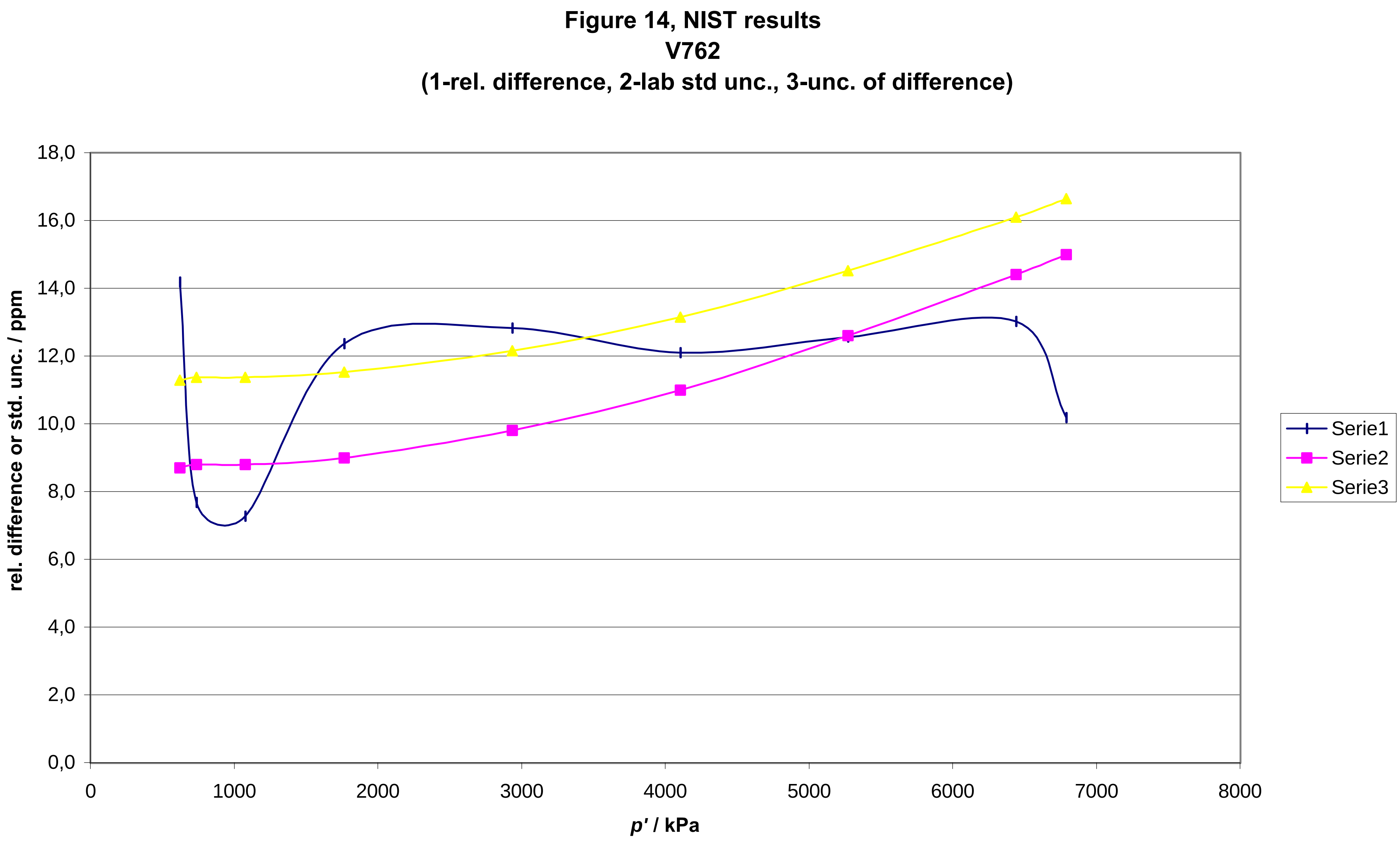
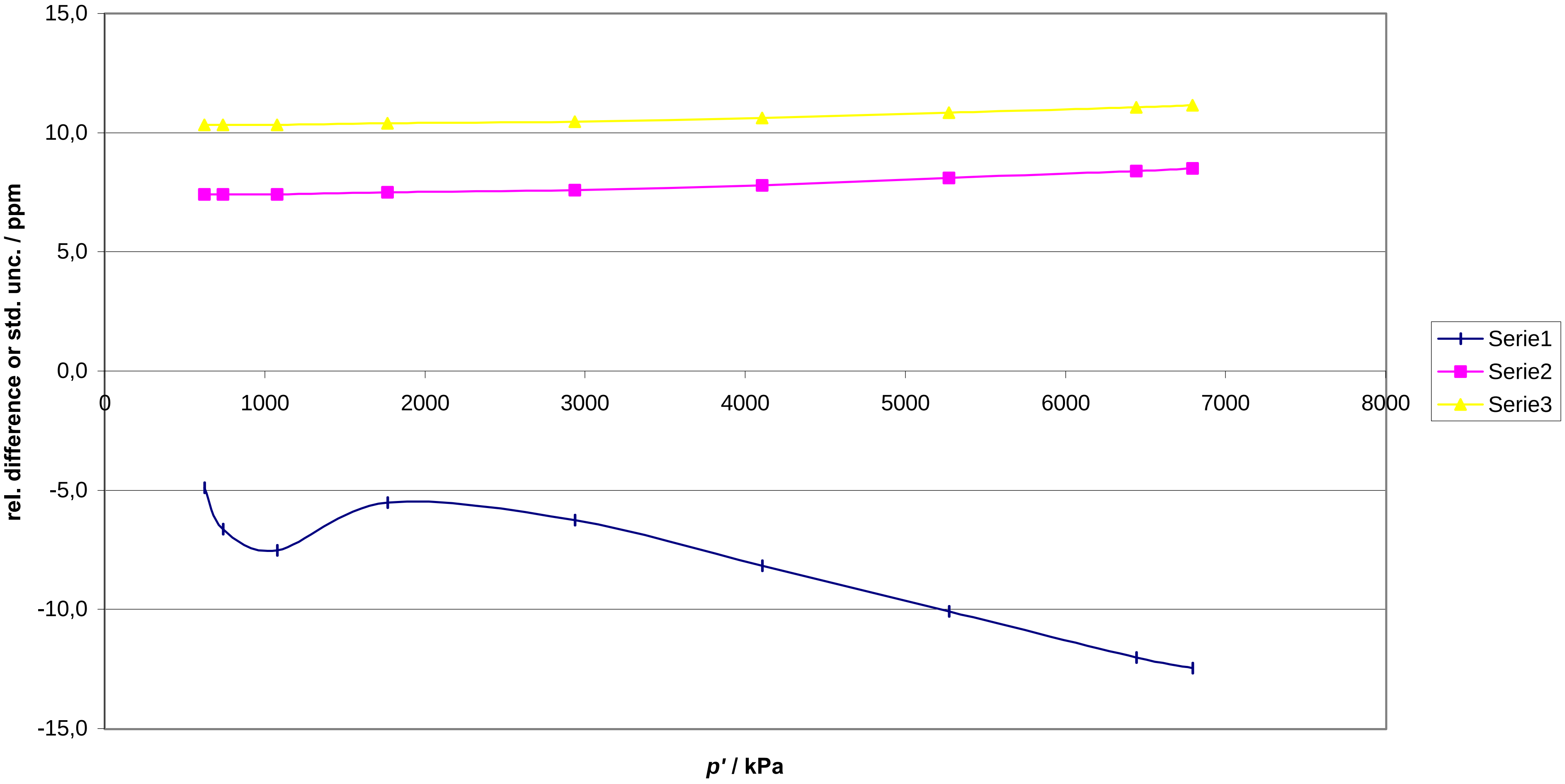


Figure 14, NIST results
V762
(1-rel. difference, 2-lab std unc., 3-unc. of difference)
rel. difference or std. unc. / ppm
18,0
16,0
14,0
12,0
10,0
8,0
6,0
4,0
2,0
0,0
0
1000
2000
3000
4000
5000
6000
7000
8000
p' / kPa
Serie1
Serie2
Serie3

Figure 15, NRLM results
V762
(1-rel. difference, 2-lab std unc., 3-unc. of difference)



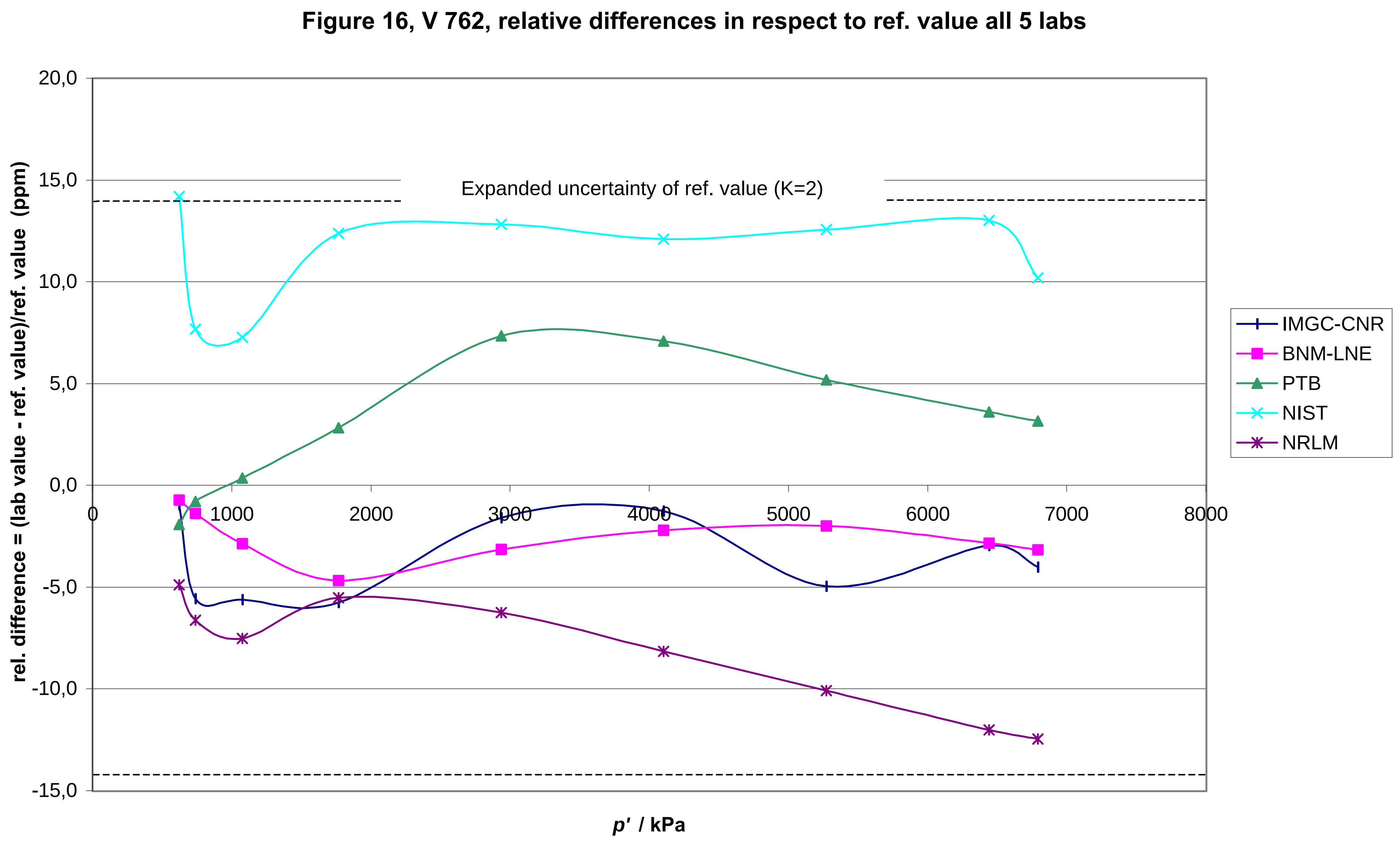


Figure 16, V 762, relative differences in respect to ref. value all 5 labs
20,0
15,0
10,0
5,0
0,0
-5,0
-10,0
-15,0
0
1000
2000
3000
4000
5000
6000
7000
8000
Expanded uncertainty of ref. value (K=2)
rel. difference = (lab value - ref. value)/ref. value (ppm)
p' / kPa
IMGC-CNR
BNM-LNE
PTB
NIST
NRLM

Table 6
Upper values are the relative differences (in ppm) of effective area for C-415 transfer standard at the pressure of 79,4 kPa, $(A_e\,(I) - A_e\,(J)/\,A_e\,\mathrm{ref}) \cdot 10^6$

determined by two laboratories I and J. Lower values, in parenthesis, are the relative standard uncertainties (in ppm) of these differences calculated as

$$\{\,[\,u\,(A_e\,(I)\,)/\,A_e\,(I)]^2 + [\,u\,(A_e\,(J)\,)/\,A_e\,(J)]^2 + [u_{\,tr.std.}]^2\,\}^{1/2}$$

where u are the relative standard uncertainties as declared by the laboratories I and J and $u_{\,tr.std.}$ is the stability contribution of the transfer standard equal to 2 ppm.

BNM - LNE	- 3,7 (12,7)			
PTB	- 1,9 (12,8)	1,8 (5,6)		
NIST	- 3,9 (15,1)	- 0,2 (9,6)	- 2,0 (9,8)	
NRLM	- 8,6 (14,9)	- 4,9 (9,4)	- 6,7 (9,6)	- 4,6 (12,4)
I / J	IMGC-CNR	BNM - LNE	PTB	NIST

Table 7

Upper values are the relative differences (in ppm) of effective area for C-415 transfer standard at the pressure of 196 kPa, $(A_e\,(I) - A_e\,(J)/ A_e\,\mathrm{ref}) \cdot 10^6$

determined by two laboratories I and J. Lower values, in parenthesis, are the relative standard uncertainties (in ppm) of these differences calculated as

$$\{ [u (A_e\,(I))/ A_e\,(I)]^2 + [u (A_e\,(J))/ A_e\,(J)]^2 + [u_{tr.std.}]^2 \}^{½}$$

where u are the relative standard uncertainties as declared by the laboratories I and J and $u_{tr.std.}$ is the stability contribution of the transfer standard equal to 2 ppm.

BNM - LNE	**2,1** **(12,6)**			
PTB	**2,5** **(13,1)**	**0,4** **(6,0)**		
NIST	**3,3** **(15,2)**	**1,2** **(9,8)**	**0,8** **(10,5)**	
NRLM	**0,9** **(14,8)**	**- 1,2** **(9,1)**	**- 1,5** **(9,9)**	**- 2,4** **(12,6)**
I / J	**IMGC-CNR**	**BNM - LNE**	**PTB**	**NIST**

Table 8

Upper values are the relative differences (in ppm) of effective area for C-415 transfer standard at the pressure of 429,5 kPa, $(A_e (I) - A_e (J)/ A_e \text{ ref}) \cdot 10^6$

determined by two laboratories I and J. Lower values, in parenthesis, are the relative standard uncertainties (in ppm) of these differences calculated as

$$\{ [u (A_e (I))/ A_e (I)]^2 + [u (A_e (J))/ A_e (J)]^2 + [u_{tr.std.}]^2 \}^{½}$$

where u are the relative standard uncertainties as declared by the laboratories I and J and $u_{tr.std.}$ is the stability contribution of the transfer standard equal to 2 ppm.

BNM - LNE	**4,0** **(11,6)**			
PTB	**2,4** **(12,0)**	**- 1,7** **(5,8)**		
NIST	**1.3** **(14,8)**	**- 2,7** **(10,4)**	**- 1,1** **(11,0)**	
NRLM	**- 0,8** **(14,0)**	**- 4,9** **(9,2)**	**- 3,2** **(9,9)**	**- 2,1** **(13,2)**
I / J	**IMGC-CNR**	**BNM - LNE**	**PTB**	**NIST**

Table 9
Upper values are the relative differences (in ppm) of effective area for C-415 transfer standard at the pressure of 663 kPa, $(A_e\,(I) - A_e\,(J)/\,A_e\,\mathrm{ref}) \cdot 10^6$

determined by two laboratories I and J. Lower values, in parenthesis, are the relative standard uncertainties (in ppm) of these differences calculated as

$$\{\, [\, u\,(A_e\,(I)\,)/\,A_e\,(I)]^2 + [\, u\,(A_e\,(J)\,)/\,A_e\,(J)]^2 + [u_{\,tr.std.}]^2\, \}^{1/2}$$

where u are the relative standard uncertainties as declared by the laboratories I and J and u $_{tr.std.}$ is the stability contribution of the transfer standard equal to 2 ppm.

BNM - LNE	**7,4** **(11,3)**			
PTB	**6,2** **(11,8)**	**- 1,2** **(5,8)**		
NIST	**5,0** **(15,1)**	**- 2,4** **(5,8)**	**- 0,8** **(11,7)**	
NRLM	**1,9** **(13,6)**	**- 5,5** **(9,0)**	**- 3,0** **(9,7)**	**- 3,1** **(13,5)**
I / J	**IMGC-CNR**	**BNM - LNE**	**PTB**	**NIST**

Table 10
Upper values are the relative differences (in ppm) of effective area for C-415 transfer standard at the pressure of 896,4 kPa, $(A_e\ (I) - A_e\ (J) / A_e\ ref) \cdot 10^6$

determined by two laboratories I and J. Lower values, in parenthesis, are the relative standard uncertainties (in ppm) of these differences calculated as

$$\{ [u (A_e\ (I)) / A_e\ (I)]^2 + [u (A_e\ (J)) / A_e\ (J)]^2 + [u_{tr.std.}]^2 \}^{½}$$

where u are the relative standard uncertainties as declared by the laboratories I and J and u $_{tr.std.}$ is the stability contribution of the transfer standard equal to 2 ppm.

I \ J	IMGC-CNR	BNM - LNE	PTB	NIST
BNM - LNE	9,6 (11,3)			
PTB	7,3 (11,8)	- 2,4 (5,8)		
NIST	4,8 (15,5)	- 4,9 (11,6)	- 2,5 (12,2)	
NRLM	3,1 (13,6)	- 6,5 (8,9)	- 4,2 (9,6)	- 1,7 (13,9)

Table 11
Upper values are the relative differences (in ppm) of effective area for V-762 transfer standard at the pressure of 621,7 kPa, $(A_e\,(I) - A_e\,(J) / A_e\,\text{ref}) \cdot 10^6$ determined by two laboratories I and J.

Lower values, in parenthesis, are the relative standard uncertainties (in ppm) of these differences calculated as

$$\{ [\, u\,(A_e\,(I)\,) / A_e\,(I)]^2 + [\, u\,(A_e\,(J)\,) / A_e\,(J)]^2 + [u_{\,tr.std.}]^2 \}^{1/2}$$

where u are the relative standard uncertainties as declared by the laboratories I and J and $u_{\,tr.std.}$ is the stability contribution of the transfer standard equal to 3 ppm.

BNM - LNE	0,2 (12,2)			
PTB	- 0,95 (12,3)	- 1,2 (7,2)		
NIST	15,1 (14,2)	14,9 (10,2)	16,0 (10,3)	
NRLM	- 3,9 (13,5)	- 4,2 (9,2)	- 3,0 (9,3)	- 19,0 (11,8)
I / J	IMGC-CNR	BNM - LNE	PTB	NIST

Table 12
Upper values are the relative differences (in ppm) of effective area for V-762 transfer standard at the pressure of 4104,4 kPa, $(A_e\,(I) - A_e\,(J) / A_e\,\text{ref}) \cdot 10^6$ determined by two laboratories I and J.

Lower values, in parenthesis, are the relative standard uncertainties (in ppm) of these differences calculated as

$$\{ [\,u\,(A_e\,(I)\,)/\,A_e\,(I)]^2 + [\,u\,(A_e\,(J)\,)/\,A_e\,(J)]^2 + [u_{\text{tr.std.}}]^2 \}^{1/2}$$

where u are the relative standard uncertainties as declared by the laboratories I and J and $u_{\text{tr.std.}}$ is the stability contribution of the transfer standard equal to 3 ppm.

I \ J	IMGC-CNR	BNM - LNE	PTB	NIST
BNM - LNE	- 0,95 (13,8)			
PTB	8,3 (15,3)	9,3 (8,5)		
NIST	13,4 (17,9)	14,3 (11,8)	5,0 (13,6)	
NRLM	- 6,9 (15,5)	- 6,0 (8,9)	- 15,3 (11,2)	- 20,3 (13,8)

Table 13
Upper values are the relative differences (in ppm) of effective area for V-762 transfer standard at the pressure of 6792,4 kPa, $(A_e\,(I) - A_e\,(J)/\,A_e\,\text{ref}) \cdot 10^6$ determined by two laboratories I and J.

Lower values, in parenthesis, are the relative standard uncertainties (in ppm) of these differences calculated as

$$\{\,[\,u\,(A_e\,(I)\,)/\,A_e\,(I)]^2 + [\,u\,(A_e\,(J)\,)/\,A_e\,(J)]^2 + [u_{\,tr.std.}]^2\,\}^{1/2}$$

where u are the relative standard uncertainties as declared by the laboratories I and J and $u_{\,tr.std.}$ is the stability contribution of the transfer standard equal to 3 ppm.

I \ J	IMGC-CNR	BNM - LNE	PTB	NIST
BNM - LNE	0,8 (14,6)			
PTB	7,2 (16,5)	6,3 (9,4)		
NIST	14,2 (20,6)	13,4 (15,6)	7,0 (17,4)	
NRLM	- 8,5 (16,6)	- 9,3 (9,6)	- 15,6 (12,3)	- 22,6 (17,5)