Regional key comparison

EUROMET.M.P-K2

within the pressure range (0,5) 1 MPa to 4 (5) MPa

(optional limits in brackets)

REPORT

on the results of measurements

performed in the period from May 1994 to October 1995

in the framework of the EUROMET Project 305

S. Ban, J. Jäger, J.C. Legras, C. Matilla, M. Rantanen, D. Steindl,

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FOREWORD

The pressure comparison measurements discussed in this report were proposed by several European metrology institutes whose pressure standards for the 5 MPa range of gas pressure (gauge mode) are traceable to the *Laboratoire National d'Essais* (BNM-LNE), Paris, France.

One of the ideas behind the comparison was to involve besides the BNM-LNE a second primary laboratory to demonstrate the mutual agreement of pressure measurements on a broader basis.

The transfer standard was an oil-lubricated gas-operated piston-cylinder assembly of 1 cm^2 nominal effective area to be used in a *Desgranges et Huot* pressure balance available in all participating laboratories. The participants had to measure the effective area A_p of the transfer standard at predefined calibration pressures. Another scope of the comparison was to estimate the contribution of the balance base when the piston-cylinder assembly is calibrate dalone.

The *Physikalisch-Technische Bundesanstalt* (PTB), Braunschweig, Germany, was interested in this project and volunteered to coordinate the respective agreed EUROMET Project 305 (completion date: December 1995).

The PTB presented the final report (revised version of the draft final report) in May 1996. A copy of this final report is attached as Annex 2 with the figures redrawn. The text has been modified in a few details only which had become obsolete as a consequence of results obtained after re-calibration of the PTB's standard instrument in 1996/97 (the calibration data used up to that date had been obtained in 1989).

When the 1997 data were used, agreement between the transfer standard's effective area data measured by BNM-LNE and PTB improved considerably.

On this basis it had been decided to summarise the results of the EUROMET Project 305 in a contribution to the EUROMET M&DQ Newsletter of November 1998. A copy of this contribution is attached to the present report as Annex 1.

In the Annexes the calibration results are analysed in terms of differences $A_{p,\mathrm{lab\_x}} - A_{p,\mathrm{LNE}}$. The normalised error e_n , calculated with the expanded uncertainties (k = 2) $U_\mathrm{lab\_x}$ and U_LNE is used to demonstrate equivalence between the participants' data and the data of the BNM-LNE. Except for two (BEV: e_n = 0,66; e_n = 0,58), all e_n-values reported in Annex 1 were found considerably smaller than 0,5 which means agreement within the standard uncertainty of the difference between laboratory results. This method of evaluation is acceptable for key comparisons where it is necessary

- to calculate a reference value and its uncertainty
- to specify the mutual agreement between any two laboratories having participated in the comparison.

The present report is aimed at providing this information.

SUMMARY OF THE COMPARISON RESULTS

Measured effective area data and uncertainties

Figure 1 of Annex 1 presents a survey of the mean effective area data measured by the participating laboratories at six calibration pressures.

When the uncertainties of measurement as given in Tables 1 to 5, 7 and 8 of Annex 2 are also taken into account it is rather obvious, that there is no point in evaluating reference values for each calibration pressure. It seems that the complete information is obtained already from an analysis of the effective area data measured at 1 MPa and at 4 MPa (in the procedural document it had been pointed out that measurements at 0,5 MPa were optional and the BEV was unable to perform measurements at 5 MPa).

At an auxiliary meeting (Chair: *Pauline Leggat*, NPL Teddington) organised in February 2001 on the occasion of the EUROMET M&DQ Contact Persons' Meeting in Lisbon, Portugal, it was agreed among the participants of the EUROMET Project 305, who were all present, that

> reference values of the comparison should be calculated at these two pressures only
>
> the weighted mean of the effective areas measured by BNM-LNE and PTB should be taken as the reference values at 1 MPa and at 4 MPa.

The participants' results obtained at 1 MPa and at 4 MPa have been compiled in Table 1 of Annex1. The data have been copied into the table below:

Table 1: Effective area data A_p, standard deviations $s(A_p)$ and expanded measurement uncertainties $U(A_p)$ (coverage factor k = 2), all data in mm^2, as obtained by the participating laboratories for the transfer piston-cylinder assembly at two nominal pressures p_N.

	BEV	**FFA**	**MIKES**	**CEM**	**BNM-LNE**	**PTB**	
A_p	98,0509	98,0488	98,0478	98,0492	98,0485	98,0496	**p_N =1MPa**
$s(A_p)$	0,0010	0,0002	0,0003	0,0002	0,0003	0,0004	
$U(A_p)$	0,0039	0,0024	0,0024	0,0037	0,0014	0,0020	
A_p	98,0515	98,0494	98,0479	98,0487	98,0488	98,0497	**p_N =4MPa**
$s(A_p)$	0,0004	0,0001	0,0001	0,00004	0,00016	0,0001	
$U(A_p)$	0,0039	0,0024	0,0022	0,0037	0,0012	0,0021	

Reference values of the comparison and their uncertainties

The reference values R_{1MPa} and R_{4MPa} and their uncertainties are calculated from the following formulae:

$$R = \frac{A_{LNE} u_{PTB}^2 + A_{PTB} u_{LNE}^2}{u_{LNE}^2 + u_{PTB}^2} ;$$

$$u(R) = \sqrt{s_A^2 + s_B^2} ; \qquad s_A^2 = 2 \frac{u_{PTB}^2 (A_{LNE} - R)^2 + u_{LNE}^2 (A_{PTB} - R)^2}{u_{LNE}^2 + u_{PTB}^2} ; \qquad s_B^2 = \frac{u_{LNE}^2 u_{PTB}^2}{u_{LNE}^2 + u_{PTB}^2} .$$

Numerical results:

*) $k = 2$

R / mm²	$U(R)$ / mm² *)	p_N / MPa
98,0489	0,0019	1
98,0490	0,0015	4

In Annex 1 expanded uncertainties U_{1MPa} = 0,00115 mm² and U_{4MPa} = 0,00104 mm² had been attributed to the corresponding reference values R_i. These values corresponded to $U_B(R) = 2s_B$ only. It had been pointed out in a comment by *C. Matilla Vicente*, that this could mean to underestimate the uncertainty.

The present method attributes to the reference values uncertainties comparable in magnitude to the uncertainties claimed by LNE and PTB. When the data of Table 1 are taken into account, most laboratory results can be expected to agree with the reference values of the comparison within the combined standard uncertainties.

As **Table 3** shows, this is in fact observed with only a single exception (marked in grey).

Mutual agreement between pairs of laboratories

Table 1 shows that in almost all laboratories the random uncertainty of the effective area measurements represented by the experimental standard deviations s_A was much smaller than the total uncertainty. As outlined in Annex1, the MIKES as the owner of the transfer standard had no indication of a significant continuous shift of its effective area. The effective area data of any two participants in the present comparison must, therefore, be expected to agree within the expanded uncertainty of the difference between these data.

Table 4 shows that this is in fact true of all possible combinations of laboratories.

In most cases the agreement is even within the standard uncertainty (the exceptions have been marked in grey). This is true in particular of the group of laboratories directly traceable to the LNE.

RELATION BETWEEN KEY COMPARISONS EUROMET.M.P-K2 and CCM.P-K1.c

The results of the present comparison can easily be linked to the results of the key comparison CCM.P-K1.c performed in the gauge pressure range up to 7 MPa, since the relative deviations D_i from the reference values x_R, observed by both primary laboratories (PTB and BNM-LNE) in both comparisons, are not very different from each other and are considerably smaller than the expanded uncertainties of both reference values (see Table 2). Especially the D_i - values observed by the BNM-LNE are practically identical in both comparisons. They allow the relative deviations of all secondary laboratories from the reference value of the present comparison to be transferred directly to the comparison CCM.P-K1.c.

Table 2: Linkage between the key comparisons EUROMET.M.P-K2 and CCM.P-K1.c.

EUROMET.M.P-K2	BNM-LNE		PTB	
$p_{e\ nom}$ / MPa	$10^6 D_i$	$10^6 U_i$	$10^6 D_i$	$10^6 U_i$
1	-3,7	14	7,5	20
4	-2,1	12	7,0	21

CCM.P-K1.c	BNM-LNE		PTB	
$p_{e\ nom}$ / MPa	$10^6 D_i$	$10^6 U_i$	$10^6 D_i$	$10^6 U_i$
1,1	-2,9	16	0,4 *)	17
4,1	-2,2	16	7,1 *) **)	21

For both key comparisons the following definitions are valid:
The degree of equivalence of each laboratory *i* with respect to the reference value x_R is defined by the following two terms:

$D_i = (x_i - x_R)/x_R$ relative deviation from reference value

$U_i = 2(u_i^2 + u_R^2)^{0,5}/x_R$ relative expanded uncertainty (k=2)

*) In this comparison the PTB used different standard instrument at both nominal pressures. **) The standard piston/cylinder used at 4,1 MPa was not idendical with the one used in the comparison EUROMET.M.P-K2, but was also traceable to the high-pressure mercury column of the PTB

CONCLUSION

Measurements of the effective area, nominal value 1 cm^2, of a piston-cylinder assembly of a gas-operated pressure balance in the pressure range between 1 MPa and 4 MPa, performed by the laboratories BEV, FFA, MIKES, CEM, BNM-LNE and PTB in the period from May 1994 to October 1995 within the framework of EUROMET as Project N° 305, could be shown to be well equivalent within the expanded uncertainties claimed by the above laboratories for their data.

The results of these comparison measurements can easily be linked to the key comparison CCM.P-K1.c. A summary of the comparison results can be found in the BIPM key comparison database (see www.bipm.fr).

TABLES OF EQUIVALENCE

Table 3: Agreement of participants' results with the reference values

EUROMET.M.P-K2	MESURAND:	Effective area $A_i(p_e$, 20°C) of an oil-lubricated gas-operated piston -cylinder assembly DH 4994, determined by laboratory i at the nominal gauge pressure p_e. Nominal value: 98,05 mm^2
KEY COMPARISON REFERENCE VALUES:		Weighted mean of results obtained at LNE and PTB
		p_e = 1 MPa: A_{ref} = 98,0489 mm^2 U_{ref} = 0,0019 mm^2 (k = 2) p_e = 4 MPa: A_{ref} = 98,0490 mm^2 U_{ref} = 0,0015 mm^2 (k = 2) The differences $D_i = (A_i - A_{ref})$ are compared with the combined standard uncertainties $u_i' = (u_i^2 + u_{ref}^2)^{0,5}$ except for LNE and PTB: D_{LNE} and D_{PTB} are compared with the standard uncertainties u_{LNE} and u_{PTB}

	BEV		FFA		MIKES		CEM		BNM-LNE		PTB	
***p*$_e$ = 1 MPa**	0,0020	0,0022	-0,0001	0,0015	-0,0011	0,0015	0,0003	0,0021	-0,0004	0,0007	0,0007	0,0010
***p*$_e$ = 4 MPa**	0,0025	0,0021	0,0004	0,0014	-0,0011	0,0013	-0,0003	0,0020	-0,0002	0,0006	0,0007	0,0011
	D	*u´*	*D*	*u´*	*D*	*u´*	*D*	*u´*	*D*	*u´*	*D*	*u´*

Table 4: Mutual agreement between pairs of laboratories

EUROMET.M.P-K2	MESURAND:	Effective area $A_i(p_e, 20°C)$ of an oil-lubricated gas-operated piston -cylinder assembly DH 4994, determined by laboratory i at the nominal gauge pressure p_e. Nominal value: 98,05 mm^2

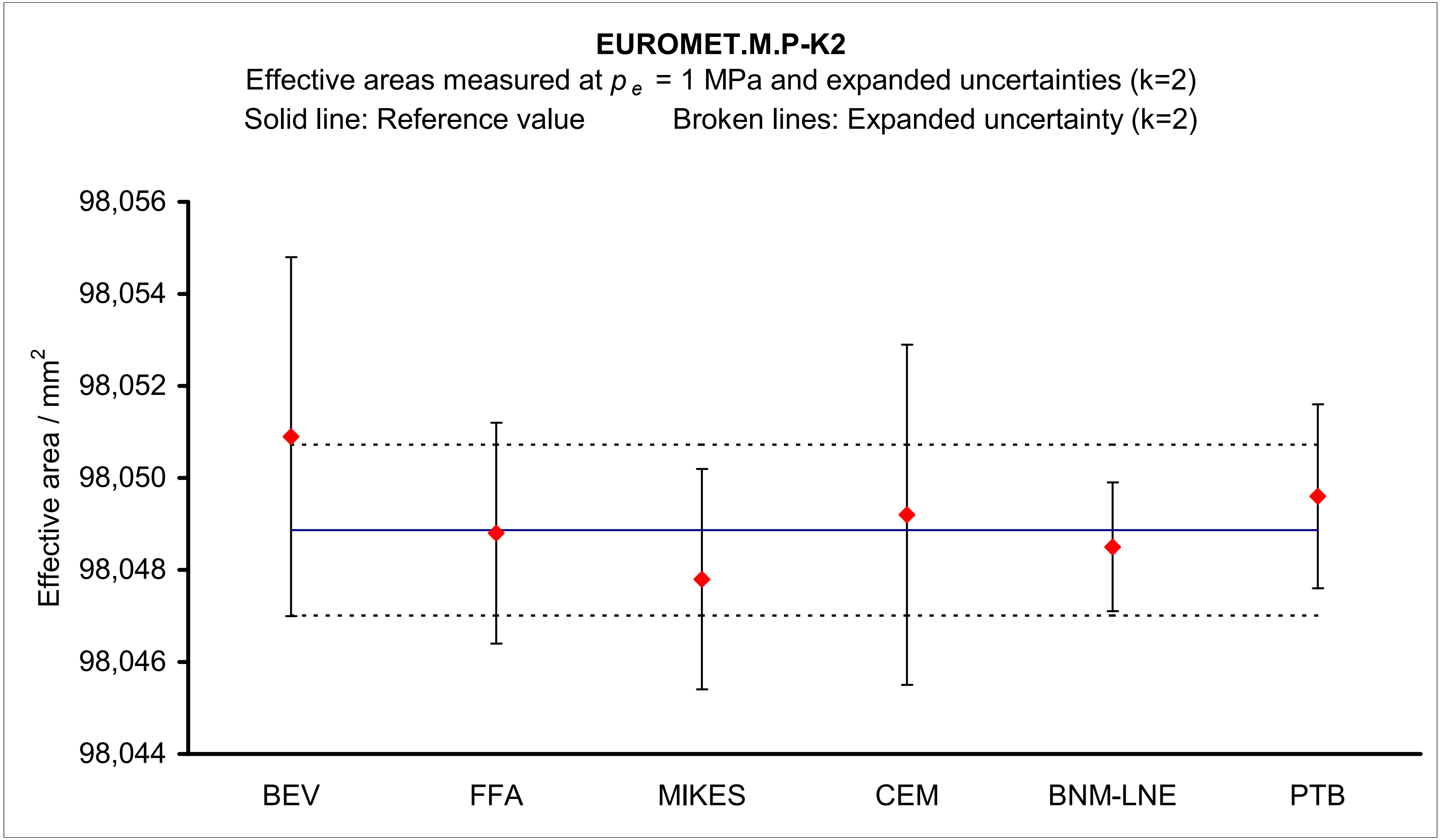
The degree of equivalence between two laboratories is given by a pair of numbers:

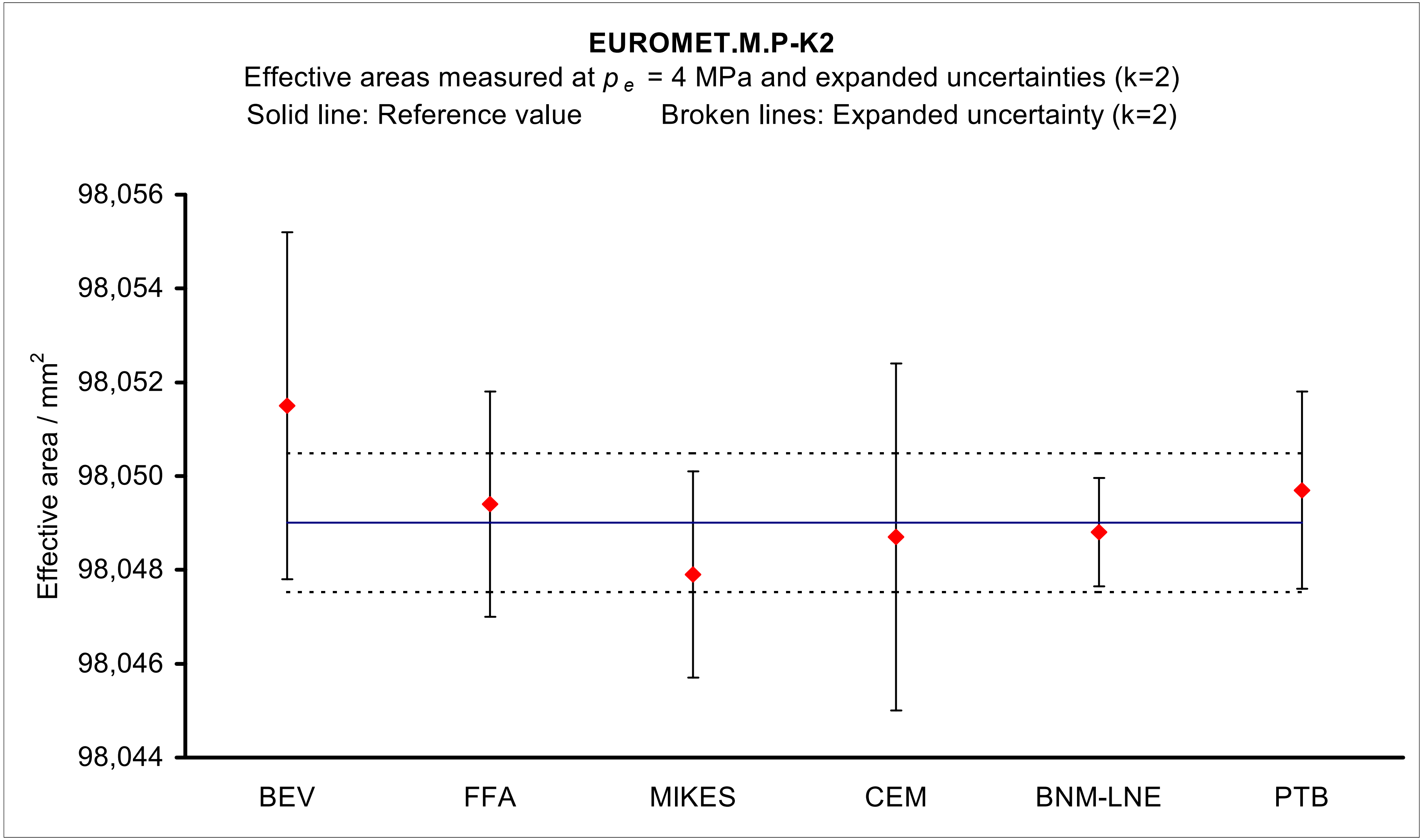
$D_{ij} = A_i - A_j$ — difference of the results of laboratories i and j (mm^2)

$U_{ij} = (U_i^2 + U_j^2)^{0,5}$ — expanded uncertainty of this difference (k = 2) (mm^2)

p_e = 1 MPa	**BEV**		**FFA**		**MIKES**		**CEM**		**BNM-LNE**		**Lab j**
BEV											
FFA	-0,0021	0,0046									
MIKES	-0,0031	0,0046	-0,0010	0,0034							
CEM	-0,0017	0,0054	0,0004	0,0044	0,0014	0,0044					
BNM-LNE	-0,0024	0,0041	-0,0003	0,0028	0,0007	0,0028	-0,0007	0,0040			
PTB	-0,0013	0,0044	0,0008	0,0031	0,0018	0,0031	0,0004	0,0042	0,0011	0,0024	
p_e = 4 MPa											
BEV											
FFA	-0,0021	0,0046									
MIKES	-0,0036	0,0045	-0,0015	0,0033							
CEM	-0,0028	0,0054	-0,0007	0,0044	0,0008	0,0043					
BNM-LNE	-0,0027	0,0041	-0,0006	0,0027	0,0009	0,0025	0,0001	0,0039			
PTB	-0,0018	0,0044	0,0003	0,0032	0,0018	0,0030	0,0010	0,0043	0,0009	0,0024	
Lab i	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	

GRAPHS OF EQUIVALENCE




EUROMET.M.P-K2
Effective areas measured at p_e = 4 MPa and expanded uncertainties (k=2)
Solid line: Reference value
Broken lines: Expanded uncertainty (k=2)
Effective area / mm^2
98,056
98,054
98,052
98,050
98,048
98,046
98,044
BEV
FFA
MIKES
CEM
BNM-LNE
PTB

ANNEX 1 Report reproduced from
EUROMET Mass & Derived Quantities Newsletter
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Project 305

Comparison of Gas Pressure Measurements (gauge mode) in the Range 0,5 to 5 MPa

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Abstract. An oil-lubricated piston-cylinder assembly for the measurement of gas pressures was calibrated by six European national metrology institutes by measuring its effective area at six nominal pressures. The calibration results of any two laboratories agreed well within the combined expanded uncertainty using a coverage factor k = 2. When they are compared in terms of the combined standard uncertainties, small discrepancies occur which are of interest for the concept of traceability of calibration results.

Introduction. The transfer standards commonly applied to pressure comparison measurements between national standard institutes are complete pressure balances. The laboratory standards can be used to measure the pressure generated by the transfer instrument or to determine the effective area of its piston-cylinder (p-c) assembly at selected nominal pressures. If all participants in such comparison measurements posses pressure balance base units of the same pattern and if they can calibrate their weights with a relative uncertainty of the order of $2 \cdot 10^{-6}$ or better, the procedure can be simplified by circulating a p-c assembly only. This latter method was adopted for the present comparison. It requires special attention to be paid by each laboratory to the precise determination of the mass of piston and head and to the way of mounting the measuring cylinder in the pressure balance.

The comparison was undertaken in the period from June 1994 to October 1995 within the framework of EUROMET as project no. 305 with the PTB, Braunschweig, acting as pilot laboratory.

Small but significant discrepancies observed between certain results as described in the final report on the EUROMET project 305 presented in May 1996 caused the pilot laboratory to reinvestigate the calibration of its standard used for these comparison measurements. The new data were available in 1997. They gave rise to the present short description of the final results of the EUROMET project 305.

The participants. Besides the pilot laboratory already mentioned (coordinator: *J. Jäger*) the following laboratories took part in the comparison measurements:

Bundesamt für Eich- und Vermessungswesen (BEV), Wien, Austria (*D. Steindl*)

Centro Espanol de Metrologia (CEM), Tres Cantos, Spain (*C. Matilla*)

Centre of Metrology and Accreditation (CMA), Helsinki, Finland (*M. Rantanen*)

The Aeronautical Research Institute (FFA), Bromma, Sweden (*S. Ban*)

Laboratoire National d´Essais (LNE), Paris, France (*J.C. Legras*)

The transfer standard. The transfer standard was an oil-lubricated gas-operated p-c assembly no. 4994, nominal effective area 98 mm^2, class S^2, k_n = 0,1 bar/kg, as used in pressure balances belonging to the series 5200 manufactured by Desgranges et Huot (D&H), France. It was made available by the CMA.

The CMA collected stability data for this unit which was calibrated several times in the period between August 1991 and October 1994 using a reference standard calibrated at the LNE in 1991 (effective area 98,0500 mm^2, U_r = 12 $\cdot 10^{-6}$, k = 2) and in 1993 (effective area 98,0488 mm^2, U_r = 7,7$\cdot 10^{-6}$, k = 2). Before the recalibration of the reference standard in 1993, eight calibrations of unit no. 4994 were performed (results: $A_{o\ min}$ = 98,0486 mm^2, $A_{o\ max}$ = 98,0494 mm^2, $A_{o\ mean}$ = 98,0489 mm^2).

The spread of these results is smaller than the change in the calibration data of the reference standard, and the CMA had no indication of a continuous shift of its effective area. The reference standard was again recalibrated at the LNE in November 1995, i.e. after the time of the present comparison. The result (effective area 98,0495 mm^2, U_r = 8,4 $\cdot 10^{-6}$, k = 2) is very close to the one obtained in 1991.

Obviously, possible mounting effects (removal of the p-c assembly from the pressure balance and reinstallation) on the effective area of the transfer standard are small. It is, however, important to investigate the effect of technical changes, for instance of the seal at the external cylindrical surface of the p-c assembly . These investigations were performed at the LNE as follows:

a) Calibrations were carried out with the transfer standard mounted first in the left and then in the right measuring block of a D&H series 5500 pressure balance base unit.

b) A further calibration was carried out with the transfer standard mounted in the left measuring block again after changing the O-rings and the steel collar, and by adding a washer to keep the elements in position.

c) Calibration b) was repeated after replacing the initial O-rings and retaining the washer.

As a result of these investigations at pressures equal to or larger than 2 MPa, all effective area data were found in the range between 98,0483 mm^2 and 98,0498 mm^2, i.e. all results are well within the limits $\pm$ 10 $\cdot 10^{-6} \cdot A_{o\ mean}$.

The CMA performed two complete series of measurements with the laboratory standard p-c assembly and the transfer assembly both installed in D&H series 5200 pressure balances. In the second series the pressure balance bodies were interchanged without any significant effect on the effective area results obtained for the transfer assembly.

The laboratory standards. The instruments used by BEV, CEM, CMA, FFA and PTB were all D&H pressure balances equipped with 0,1 MPa/kg p-c assemblies like the transfer unit. The standards of CEM, CMA and FFA are directly traceable to LNE.

The standard of the BEV was calibrated by the manufacturer who belongs to the French calibration service COFRAC, i.e. the BEV standard is indirectly traceable to LNE.

As a second laboratory standard for the range up to 2 MPa the CEM used a D&H gas pressure balance with a 0,02 MPa/kg p-c assembly also calibrated at the LNE.

The BNM-LNE standard was the 10 MPa National Reference operating in oil medium. This standard is equipped with 6 p-c assemblies of 1 cm² effective area. The comparison was carried out using the p-c assembly no.1 and an integrated oil-gas interface. The effective area at zero pressure of this standard was determined by comparison with the gas-operated 1 MPa standard. The pressure-distortion coefficient of the p-c assembly was calculated using a simple method. The effect of the interface was evaluated during the comparison.

The calibration of the PTB pressure balance standard, equipped with p-c assembly no. 5/3, from pressure measurements with the high-pressure primary standard mercury manometer of the PTB for the 5 MPa range of measurement is described in reference /1/. The zero-pressure effctive area obtained in 1989 for this p-c assembly was
$A_{0(5/3)} = (98{,}0517 \pm 0{,}0007)\ \text{mm}^2$. Based on investigations carried out in 1996 and 1997, i.e. after the comparison measurements described here, this value had to be revised for reasons outlined below:

The Final Report on the results of the EUROMET project no. 305 /2/ revealed that the effective areas reported by all participants directly traceable to LNE were in agreement with the data reported by LNE within the respective combined standard uncertainties whereas a relative difference

$$\delta_{\text{rel}} = 16 \cdot 10^{-6} > (u_{\text{rel LNE}}^2 + u_{\text{rel PTB}}^2)^{1/2} = 12 \cdot 10^{-6}$$

was observed between the results of LNE and PTB at the highest pressure (5 MPa). This discrepancy was regarded as significant since the concept of traceability would require the relative differences between calibration results obtained for the same calibration objects in different primary laboratories to be smaller than the uncertainty of the calibration results reported in the calibration certificates. Therefore the pilot laboratory decided to check the metrological data of its own standard as one step towards confirmation or removal of the discrepancy between the effective areas reported for the transfer standard by LNE and PTB.

In 1996 the standard was compared with a new oil-operated primary pressure balance for the 10 MPa range /3/ equipped with p-c assembly no. 279, the effective area of which (nominal value: 4,9 cm²) had been determined from dimensional measurements. From this comparison $A_0'_{(5/3)}$ = (98,0511 ± 0,0007) mm^2 was derived (the agreement of the uncertainty statements attributed to the values $A_{0(5/3)}$ and $A_0'_{(5/3)}$ is accidental).

In 1997 the standard was recalibrated using the high-pressure mercury manometer of the PTB as the primary standard as described in reference /1/. These measurements resulted in a new effective area value $A_{0(5/3)}$ = (98,0509 ± 0,0007) mm^2.

This latter value obtained in the same way as that of 1989 is regarded as the final one which is in perfect agreement with the result of the preliminary pressure balance comparison measurements performed in 1996.

For p-c assemblies of the type used for the EUROMET project 305 as transfer standard unit and as the PTB laboratory standard a relative shift of 8 $\cdot 10^{-6}$ (i.e. from 98,0517 to 98,0509 mm^2) in a period of 8 years is not beyond experimental experience. It is however significant in view of the fact that the relative experimental standard deviation of the effective area data derived for the PTB p-c assembly no. 5/3 in 1989 and in 1997 from measurements with the high-pressure mercury column was about 3 $\cdot 10^{-6}$ in both cases.

Methods and Conditions of Measurement. Each laboratory determined the effective area of the transfer p-c assembly installed in a D&H series 5200 pressure balance from pressure comparison measurements with the laboratory standard at reference temperature 20 ^{o}C and nominal pressures 0,5; 1,0; 2,0; 3,0; 4,0; 5,0 (optional); 4,0; 3,0; 2,0; 0,5 MPa. Three complete cycles had to be performed. After each cycle the p-c assembly was taken out of the measuring block and reinstalled again. Each laboratory used its own values for the total load on the transfer piston including the mass of the piston and piston head. The temperature of the p-c assembly was identified with the temperature of the measuring block, which had to be measured within ± 0,1 K or better (thermal expansivity of piston and cylinder material: $\alpha_{\text{tungsten carbide}}$ = (4,5 ± 0,5)10^{-6} K^{-1}).
The cylinder was mounted with a torque of 5 Nm using a torque wrench provided by the pilot laboratory. The piston rotated anti-clockwise (seen from above) with a frequency of about 20 rpm to 25 rpm. The working position of the piston was defined by a difference (7,5 ± 0,3) mm between the bottom surfaces of piston and cylinder. The bottom position of the piston in its working position defined the plane of reference for pressure measurements with the transfer p-c assembly. The lubricating fluid was chosen according to the recommendation of the manufacturer (D&H).

Results and Conclusion. Table 1 summarises selected results obtained by the participants in the comparison measurements described here (the complete results are compiled in an EUROMET Report available from the pilot laboratory). The result of the PTB is based on the recalibration of the laboratory standard in 1997 (see above).

One way of comparing the effective area data reported by the participating laboratories is to calculate their deviations from an appropriate reference value in terms of the normalised error

$$e_{\text{n}} = (A_{\text{laboratory}} - A_{\text{reference}}) / (U_{A\ \text{lab}}{}^2 + U_{A\ \text{ref}}{}^2)^{1/2} \ .$$

Since all laboratories except the PTB are traceable to the LNE, it seems reasonable in this case to take the effective area results obtained at the LNE as reference data. Then all e_n -values except for BEV are found to be smaller than 0,5. This means that the data of all but one of the participants agree with the reference data not only within the combined expanded uncertainties $U_{A\,\mathrm{lab}}$, $U_{A\,\mathrm{ref}}$ (coverage factor k = 2) but also within the combined standard uncertainties. However, if the results of the PTB were taken as reference data, the data of PTB and CMA for instance would not agree within the combined standard (1σ) uncertainties. This observation suggests that from the point of view of a customer who wants to have his pressure balance calibrated, the concept of traceability may need a slight extension in order to guarantee that the certified standard uncertainty in the calibration results covers small but existing differences between the standards of those laboratories which offer traceability to others. In the present case the problem could be solved if the weighted mean (1) of the data of LNE and PTB

$A' = 98{,}04886$ mm², $U_A' = 0{,}00115$ mm² (p_N = 1 MPa)
$A' = 98{,}04902$ mm², $U_A' = 0{,}00104$ mm² (p_N = 4 MPa)

were taken as the reference data.

The establishment of a world-wide system of key comparisons between national metrology laboratories is now in progress. Such a system would reflect the „state of the art“ in the measurement of certain physical quantities in certain ranges, so that one could define minimum measurement uncertainties based on comparison results obtained by those laboratories capable of performing the most accurate measurements.

These minimum uncertainties could be taken into account in uncertainty statements made in calibration certificates issued for the customers of metrology laboratories. It seems that this would be in line with efforts to enable a world-wide mutual acceptance of calibration certificates issued by national calibration services.

Figure 1 shows a survey of the results of the EUROMET project 305. Only the supplementary data reported by the CEM in the range up to 2 MPa have been omitted for the sake of clarity. In relative units all data presented are within a range $\pm 2 \cdot 10^{-5}$ which may be regarded as a very satisfactory result of this EUROMET interlaboratory comparison.

References.

/1/ *Jäger, J., Klingenberg, G., Schultz, W.*: The Standard Instruments of the PTB for the 5 MPa Range of Pressure Measurement. PTB-Mitt.**100** (1990), p. 429-438.

/2/ EUROMET Project 305, Final Report, May 1996.
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pressure section (PTB-3.13),
Bundesallee 100, D-38116 Braunschweig

/3/ *Jäger, J.*: Ein neues Hauptnormalgerät für Druckmessungen bis 10 MPa.
Annual Report 1996 of the PTB, p. 213, no. 2.3.9

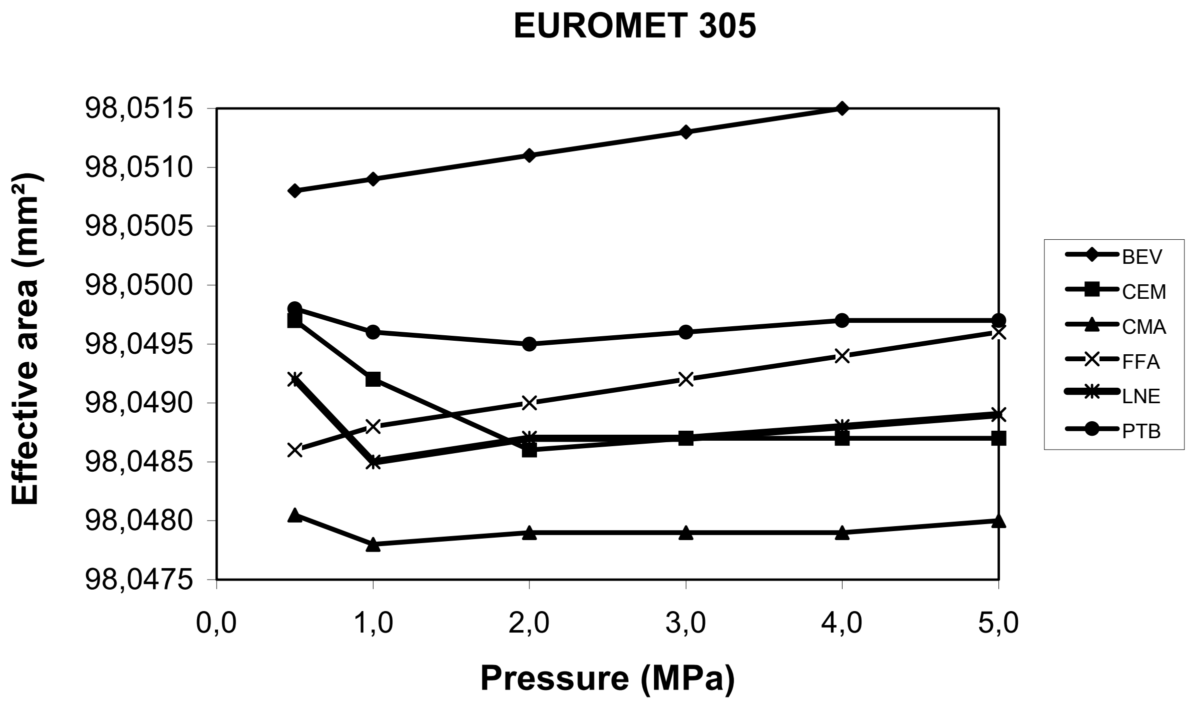
/4/ *Matilla Vicente, C.*: Private communication

(1) It has been pointed out that the calculatio of a reference valaue andits ujncertainty from the results of international comparison experiments requires careful consideration. Taking the weighted mean may not generally äbe the appropriate procedure [4]

Table 1. Effective area data A_p, standard deviations s_A and expanded measurement uncertainties U_A (coverage factor k = 2), all data in mm², as obtained for the transfer piston-cylinder assembly by the participating laboratories at two nominal pressures p_N. The normalised error e_n is calculated using the data of the LNE as reference data and the combined expanded uncertainties $U_{A\ lab}$ and $U_{A\ ref}$.

	BEV	**FFA**	**CMA**	**CEM**	**LNE**	**PTB**	
A_p	98,0509	98,0488	98,0478 2nd standard:	98,0492 98,0490	98,0485	98,0496	p_N **=1MPa**
s_A	0,0010	0,0002	0,0003	0,0002 0,0003	0,0003	0,0004	
U_A	0,0039	0,0024	0,0024	0,0037 0,0008	0,0014	0,0020	
e_n	0,58	0,11	- 0,25	0,18 0,31		0,45	
A_p	98,0515	98,0494	98,0479	98,0487	98,0488	98,0497	p_N **=4MPa**
s_A	0,0004	0,0001	0,0001	0,00004	0,00016	0,0001	
U_A	0,0039	0,0024	0,0022	0,0037	0,0012	0,0021	
e_n	0,66	0,22	- 0,36	- 0,03		0,37	

Figure 1. Effective area results obtained for the transfer piston-cylinder assembly by the participating laboratories in the pressure range 0,5 to 5,0 MPa.



ANNEX 2

EUROMET PROJECT No.305

FINAL REPORT

May 1996

EUROMET INTERCOMPARISON

IN THE GAS PRESSURE RANGE

0.5 to 5.0 MPa (gauge)

1 - INTRODUCTION

In the past few years, the *Centre for Metrology and Accreditation (CMA), Helsinki*, Finland, and the Aeronautical Research Institute of Sweden (FFA), Bromma, carried out several bilateral intercomparisons. As both institutes are traceable to LNE, they discussed a possible participation of the Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany, in a new interlaboratory comparison in the 5 MPa range using as a transfer standard an oil-lubricated gas-operated piston-cylinder (p-c) assembly for Desgranges & Huot gas pressure balances. The objective of the work would be to determine the effective area of the transfer p-c unit from pressure measurements with the laboratory standards at selected nominal pressures. All laboratories have complete pressure balance base units (with calibrated weights) at their disposal that can take up the transfer p-c unit.

To the PTB this idea seemed attractive for the following reasons:

1. The LNE and the PTB use different methods to characterize their primary standard pressure balances for the 5 MPa range. Bilateral comparison measurements were performed only in the 1 MPa range /1/. In this range the effective area values obtained in both institutes from crossfloat experiments with gas-operated transfer p-c assemblies (effective area A_0 = 10 cm^2) disagreed by roughly $10 \cdot 10^{-6} \cdot A_0$. The measurements proposed by CMA and FFA were to show if this disagreement exists also in the 5 MPa range of gas pressures and if it exceeds the limits set by the combined measurement uncertainties (as was the case for the 10 cm^2 assemblies). Clearly, such observations are important for the concept of traceability.

2. The PTB's primary standard pressure balances for the 5 MPa range of gas pressures work with p-c assemblies (and corresponding measuring blocks) similar to that proposed as a transfer standard by CMA and FFA. It has been argued that the repeatability of pressure measurements using such units is limited by mounting effects (due to constructional details of the measuring blocks) which influence the apparent effective area of the units when the latter are installed in different measuring blocks or when they are removed from, and then reinstalled in, the same measuring block. Such effects have to be included in the uncertainty budget. This requires a reliable assessment of their magnitude. The circulation of just a p-c unit as a transfer standard as proposed by CMA and FFA may allow conclusions to be drawn regarding this problem. If satisfactory comparison results are obtained, simplified and less expensive methods may become feasible to establish traceability with these p-c units or at least to assure the quality of pressure measurements by regularly repeated intercomparisons.

It was agreed that a EUROMET project of the type "intercomparison of pressure standards" should be proposed, with partners) Finland (FI), Germany (DE) and Sweden (SE) and that the PTB should coordinate the measurements. The CMA was prepared to make available the transfer p-c unit.

The project was agreed at the EUROMET contact persons meeting, held at Boras, Sweden, from January 20 to 21, 1994. At that meeting, the Bundesamt für Eich- und Vermessungswesen (BEV), Vienna, Austria, expressed its interest in participating. Since the CMA as the owner of the transfer p-c unit was agreeable, the BEV was included in the schedule. The PTB made available a pressure balance base unit and a stack of calibrated weights since the BEV did not have a second instrument of its own that could have taken up the transfer p-c unit.

At the end of 1994 the experimental results of BEV, CMA, FFA and PTB were available. A preliminary evaluation showed that any two sets of results agreed within the combined 2s uncertainties. Nevertheless, it was felt with respect to the very small random errors in the effective area data that the spread of the results of the different laboratories deserved further consideration. It was therefore decided to ask the Laboratoire National d'Essais (BNM/LNE), Paris, France, to participate and also to include the Centro Espanol de Metrologia (CEM), Madrid, Spain, in the schedule (like CMA and FFA, the CEM, too, is traceable to LNE).

The complete comparison work was carried out between May 1994 and October 1995. The list of the participating laboratories and the names of the metrologists involved in the work are given below in the order of their participation:

Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany, acting as the pilot laboratory (J. Jäger)

Bundesamt für Eich- und Vermessungswesen (BEV), Vienna, Austria (H. Tömböl)

The Aeronautical Research Institute of Sweden (FFA), Bromma, Sweden (S. Ban, C. Bergström)

Center for Metrology and Accreditation (CMA), Helsinki, Finland (M. Rantanen)

Centro Espanol de Metrologia (CEM), Madrid, Spain
(S. Palomino Salguero, C. M. Vicente, U. Martinez, S. Ruiz)

Laboratoire National d'Essais (BNM/LNE), Paris, France
(J. le Guinio, J. C. Legras)

2 - DETAILS OF THE TRANSFER STANDARD

The transfer standard was a Desgranges et Huot piston-cylinder assembly no.4994, nominal effective area: 98 mm^2, class S2, KN = 0.1 MPa/kg, to be used in D&H pressure balances belonging to the 5200 series. Piston and cylinder are made from tungsten carbide (density: 14720 kg/m^3 as measured at the LNE). The piston head is made from stainless steel (density: 7920 kg/m^3).

The apparent mass of the piston plus head can be split up into a tungsten carbide contribution (value estimated from piston geometry) and the resulting steel contribution. Applying this method the pilot laboratory arrived at the following true mass values for piston and piston head:

$$m_{\text{piston}} = 0.083995 \text{ kg} \qquad m_{\text{head}} = 0.115997 \text{ kg}$$

These values were used (together with the respective densities) to recalculate the effective area results of all participants in order to eliminate any scatter in the low-pressure data that could be due to differences between the laboratory values for the contribution of piston and head to the total force acting.

3 - INSTRUMENTS USED IN THE PARTICIPATING LABORATORIES

BEV: The standard used was a D&H type 5200 pressure balance with a 1 bar/kg p-c assembly calibrated by the manufacturer who is a member of the French calibration service COFRAC, which means that the calibration is traceable to the LNE. The transfer p-c unit was installed in a second D&H type 5200 pressure balance. The relative uncertainty at the 2s-level in the load applied to the transfer piston ranged from $3.5 \cdot 10^{-6}$ at 4.8 kg to $2.0 \cdot 10^{-6}$ at 39.8 kg.

FFA: The standard used was a D&H type 5200 pressure balance with a 1 bar/kg p-c assembly no.3795 (A_0 = 98.050878 mm^2 traceable to LNE). The transfer p-c unit was installed in a second D&H type 5200 pressure balance. The relative uncertainty at the 2s-level in the load applied to the transfer piston ranged from $3.5 \cdot 10^{-6}$ at 4.8 kg to $1.0 \cdot 10^{-6}$ at 49.8 kg.

CMA: The standard p-c unit used was the D&H 1 bar/kg p-c assembly no.4012 (effective area traceable to LNE; calibration date: 6.12.1993). The standard p-c unit and the transfer p-c unit were both installed in D&H type 5200 pressure balances. The relative uncertainty at the 2s-level in the load applied to the transfer piston (4.8 kg to 49.8 kg) was $6 \cdot 10^{-6}$. Two complete series of measurements (each consisting of 3 pressure cycles) were performed, one in September 1994 and one in October 1994. In the second series, the pressure balance bodies were interchanged.

CEM: Two different standards were used:

1. D&H type 5203 pressure balance with 1 bar/kg p-c units nos. 5845 (6 cycles) and 3485 (two cycles),
2. D&H type 5111 pressure balance with 0.2 bar/kg p-c unit no. 5849 (5 cycles).

The calibration of all standards is traceable to LNE.
The transfer p-c unit was mounted in a D&H type 5213 pressure balance. The set of weights used on the transfer piston was calibrated by the mass laboratory of the CCM with a relative uncertainty (2s level) of $1 \cdot 10^{-6}$.

LNE: The BNM-LNE standard was the 10 MPa National Reference operating in oil medium. This standard is equipped with 6 piston-cylinder assemblies of 1 cm^2 effective area. The comparison was carried out using the piston-cylinder assembly no.1 and an integrated oil-gas interface. The effective area at null pressure of this standard was determined by comparison with the gas-operated 1 MPa standard. The effect of the interface was evaluated during the comparison. The pressure-distortion coefficient of the p-c assembly was calculated using a simple method. The estimated type uncertainty is $(0.4\ \text{Pa} + 2.8 \cdot 10^{-6} p + 0.3 \cdot 10^{-13} p^2)$.
The transfer standard was mounted on the left side of the type 5500 D&H twin pressure balance no. 1913 (the measuring blocks of this balance and of the type 5200 pressure balances are identical in construction). The lubricating oil was SPINELF. The direction of rotation was counter-clockwise. The set of weights used on the transfer piston was calibrated by the mass laboratory of BNM/LNE with a relative uncertainty of $1.5 \cdot 10^{-6}$.

PTB: The primary standard pressure balance of the PTB for the 5 MPa range of gas pressure measurement, that was used in this comparison, works with p-c assemblies of the same type as the transfer p-c unit. The instrument and its calibration using the PTB's high-pressure mercury manometer has been described in detail in reference /2/. Three p-c assemblies nos. 5/1 to 5/3 (see table 1 of reference /2/) are available. As can be seen from the table, most calibration data were obtained for unit 5/3. On this basis it was decided to use the p-c assembly no. 5/3 as the standard for this comparison work. The transfer standard was mounted in a D&H type 5200 pressure balance. The relative uncertainty at the 2s-level in the load applied to the transfer piston ranged from $3.5 \cdot 10^{-6}$ at 4.8 kg to $2.0 \cdot 10^{-6}$ at 49.8 kg.

Uniform conditions in all laboratories: All laboratories were able to measure the temperature of the p-c unit within +/- 0.1 K. The measured temperature is identified with the true p-c temperature. The maximum deviation of the p-c temperature from the reference value (20 ^{o}C) was 2.6 K. Since the relative uncertainty in the coefficient of thermal expansion of the transfer p-c assembly may be assumed to be within 10%, this value seems acceptable. In general, the type B temperature contributions to the uncertainty in the effective area data are not expected to exceed the order of magnitude of the random scatter in the data.
The ambient pressure could be measured within +/- 1 hPa. The relative humidity may be assumed to be within limits <40 %; 60 %> if it is not specified. The uncertainty in the average air density during each measurement cycle is therefore negligible.

4 - MEASUREMENT AND CALCULATION METHODS

Each laboratory installed the transfer p-c assembly in a D&H type 5200 pressure balance and used a suitable laboratory standard to measure the pressures generated by the transfer standard at the nominal values 0.5, 1.0, 2.0, 3.0, 4.0 and (if possible) 5.0 MPa. The transfer piston was loaded with weights the true mass values of which (including weight carrier and trim weights if any) were reported to the pilot laboratory together with ambient pressure and temperature data (or the average air density at the time of the measurements), the temperature of the p-c unit and the local acceleration of gravity. It had been proposed to use the data sheet enclosed as appendix 1a. The data sheet informs about the structure of the measurement cycles. A minimum of three complete pressure cycles had to be performed. Each laboratory had to determine the mass of the transfer piston and to use the value obtained to calculate the mean effective area of the transfer piston at the nominal pressures. These values - together with their experimental (random) standard deviation and their uncertainty (type A and B combined) and with the uncertainty in the pressures measured by the standard at the reference level of the transfer piston - were reported to the pilot laboratory using the data sheet enclosed as appendix 1b These data which are reproduced in tables 1 to 8 are regarded as the contribution of each laboratory to this EUROMET project.

The pilot laboratory used the information in the data sheets according to appendix 1a to recalculate the participants' results and to produce the graphical representations shown in figures 1 to 8. The recalculations were based on the piston mass as determined in the pilot laboratory. In some cases, at the lowest nominal pressure in particular, this caused small deviations from the participants' mean effective area results.

It had been proposed to report all uncertainties at the 2s level. To compare the effective area data reported by the participating laboratories, the pilot laboratory calculated the normalized errors

$$e_n = \frac{lab_x - lab_r}{\sqrt{U_x^2 + U_r^2}}$$

using the data of the LNE as reference values $\langle lab_r, U_r \rangle$. This seemed reasonable since all laboratories except the PTB are traceable to the LNE.

5 - RESULTS

Tables 1 to 8 show the results as reported by the participants in this EUROMET project.

In **table 9** the e_n values are compiled as calculated from the laboratory data (mean effective area values with 2s uncertainties) and from the corresponding LNE data as reference.

In **figures 1 to 8** the experimental effective area data are shown from which each laboratory derived the mean values given in tables 1 to 8. As was mentioned above, the figures are based on the calculations of the pilot laboratory. The *mean* effective area values are indicated by the centres of the error bars which show the expanded uncertainty (k = 2).

6 - DISCUSSION AND CONCLUSIONS

1. Table 9 shows that the effective area data of all participants in this interlaboratory comparison agree well with the data of the LNE within the combined **2s** uncertainties ($-1 < e_n < +1$).

2. When the e_n values of table 9 are multiplied by 2, agreement at the 1s level is reached. Since the absolute e_n values of all laboratories but BEV and PTB are smaller than 0,5, it is evident that the effective area data of all laboratories directly traceable to the LNE agree with the data of the LNE within the combined 1s uncertainties.

3. It must be concluded that in the 5 MPa range the gas pressure scales of the LNE and the PTB disagree by 10 to 15 ppm in relative units.

4. The CMA collected stability data for the p-c unit D&H no. 4994 which was used as the transfer standard in this intercomparison. The unit was calibrated several times in the period between August 1991 and October 1994 using a reference standard calibrated at the

LNE in 1991 (effective area: 98.0500 mm^2, U_r = 12 ppm, k = 2) and in 1993 (effective area: 98.0488 mm^2, U_r = 7.7 ppm, k = 2). Before the recalibration of the reference standard in 1993, eight calibrations of unit no. 4994 were performed (results: A_{0min} = 98.0486 mm^2, A_{0max} = 98.0494 mm^2, A_{0mean} = 98.0489$_4$ mm^2). After recalibration of the reference standard, 4 calibrations of unit no. 4994 were performed (results: A_{0min} = 98.0478 mm^2, A_{0max} = 98.0481 mm^2, A_{0mean} = 98.0479$_3$ mm^2).

The scatter in the calibration results obtained at the CMA for p-c unit no. 4994 is smaller than the change in the effective area of the reference standard, and the CMA had no indication of a continuous shift of the reference standard.

The calibration data obtained at the CMA *before* recalibration of the reference standard almost coincide with the results reported by the LNE in the present intercomparison, so that using these earlier data the mutual agreement between the laboratories directly traceable to the LNE would have been even better.

> *Note added in proof*: The CMA reference standard used in this project was again recalibrated at the LNE in November 1995 (A_0 = 98.0495 mm^2, $U_r = 8.4\cdot10^{-6}$, k = 2). This result, which was communicated in January 1996, is very close to the result of 1991.

5. The stability information about the transfer p-c unit made available by the CMA indicates that reliable information may be expected if only the p-c unit (and not a complete pressure balance) is circulated as a transfer standard in an interlaboratory comparison. This is in agreement with the small experimental (random) scatter in the effective area data reported by all laboratories, at least at pressures above 2 MPa. Obviously, possible mounting effects (removal of the p-c unit from the pressure balance and reinstallation) on the effective area of the transfer standard are small if the technical conditions remain unchanged. It is, however, important to investigate the effect of technical changes, for instance of the seal at the external cylindrical surface of the p-c unit. Such investigations were performed at the LNE and described as follows:

a) Calibrations were carried out with the transfer standard mounted first in the left and then in the right measuring block of a D&H type 5500 balance base.

b) A further calibration was carried out with the transfer standard mounted in the left measuring block again after changeing the O-rings and the collar in steel, and by adding a washer to maintain the elements in position.

c) Calibration b) was repeated after replacing the initial O-rings and keeping the washer.

As a result of these investigations at pressures equal to or larger than 2 MPa, all effective area data have been found in a range between 98.0483 mm^2 and 98.0498 mm^2, i.e all results are well within limits $\pm 10 \cdot 10^{-6} \cdot A_{0mean}$. This is in agreement with an estimation of such effects made in reference /2/.

An analysis of the data presented in figures 1 to 8 of this report with respect to possible differences between results obtained at increasing and decreasing pressure showed that no significant differences appeared.

6. At pressures equal to or larger than 2 MPa - at lower pressures the effect of small force errors may be predominant -, two of the six participating laboratories observed a clear pressure dependence of the effective area of the transfer standard (BEV and FFA). This pressure dependence can be described by distortion coefficients $\lambda > 2 \cdot 10^{-6} MPa^{-1}$. Such values are larger than would have been expected for p-c units of the type used in this work. If more significant force errors can be excluded, it may therefore be assumed that the pressure dependence observed by BEV and FFA reflects properties of the laboratory standards. Experimental results obtained in the FFA support this assumption (S. Ban, private communication).

7. As a general result of this interlaboratory comparison it may be concluded that, with p-c units like the one used as a transfer standard in this work, international pressure comparison measurements can be performed at a relative uncertainty of ± 10 ppm due to the comparison procedure, provided that the force acting on the piston and the piston temperature are known with sufficient accuracy.

7 - REFERENCES

/1/ Klingenberg, G. and J.C. Legras: Bilateral Comparative Pressure Measurements of the LNE and the PTB Using 10 cm^2 Piston-Cylinder Assemblies.
Metrologia 1993/94,**30**,603-606.

/2/ Jäger, J., G. Klingenberg and W. Schultz: The Standard Instruments of the PTB for the 5 MPa Range of Pressure Measurement.
PTB-Mitteilungen 1990,**100**,429-438.

8 - ENCLOSURES

Tables 1 to 9

Appendices 1a and 1b (data sheets)

Figures 1 to 9

Tables

Table 1 Name of laboratory: **BEV**

$(p_e)_{nominal}$:	0.5	1.0	2.0	3.0	4.0	MPa
$U(p_e)$ (Pa):						
A_p (mm^2):	98.0508	98.0509	98.0511	98.0513	98.0515	
	98.0509			*(pilot laboratory)*		
s_A (mm^2):	0.0028	0.0010	0.0004	0.0003	0.0004	
$U(A_p)$ (mm^2):	0.0039	0.0039	0.0039	0.0039	0.0039	

Table 2 Name of laboratory: **FFA**

$(p_e)_{nominal}$:	0.5	1.0	2.0	3.0	4.0	5.0 MPa
$U(p_e)$ (Pa):	11.5	22	44	66	88	110
A_p (mm^2):	98.0486	98.0488	98.0490	98.0492	98.0494	98.0496
	98.0480	98.0485	*(pilot laboratory)*		98.0494	
s_A (mm^2):	0.00053	0.00018	0.00009	0.00006	0.00009	0.00009
$U(A_p)$ (mm^2):	0.0027	0.0024	0.0024	0.0024	0.0024	0.0023

Table 3 Name of laboratory: **CMA1** (5.-7.9.1994)

$(p_e)_{nominal}$:	0.5	1.0	2.0	3.0	4.0	5.0 MPa
$U(p_e)$ (Pa):	12.5	22.8	44.5	66.4	88.3	110
A_p (mm^2):	98.0484	98.0478	98.0480	98.0480	98.0480	98.0481
	98.0484				*(pilot laboratory)*	
s_A (mm^2):	0.0004	0.0003	0.0001	0.0001	0.0001	0.0000
$U(A_p)$ (mm^2):	0.0027	0.0024	0.0022	0.0022	0.0022	0.0022

Transfer standard p-c assembly in balance body no. 4993
CMA reference p-c assembly in balance body no. 4401

Table 4 Name of laboratory: **CMA2** (17.-18.10.1994)

$(p_e)_{nominal}$:	0.5	1.0	2.0	3.0	4.0	5.0 MPa
U(p_e) (Pa):	12.5	22.8	44.5	66.4	88.3	110
A_p (mm^2):	98.0477	98.0478	98.0477	98.0478	98.0478	98.0479
	98.0476				(*pilot laboratory*)	
s_A (mm^2):	0.0004	0.0003	0.0001	0.0001	0.0001	0.0000
U(A_p) (mm^2):	0.0027	0.0024	0.0022	0.0022	0.0022	0.0022

The transfer standard cylinder was not disassembled between 1st and 2nd nor between 2nd and 3rd measurement series. In this measurements the balance bodies were exchanged:
Transfer standard p-c assembly in balance body no. 4993
CMA reference p-c assembly in balance body no. 4401

Table 5 Name of laboratory: **CEM1** (Standard: P/C s/n 5845)

$(p_e)_{nominal}$:	0.5	1.0	2.0	3.0	4.0	5.0 MPa
U(p_e) (Pa):	18.5	37	74	111	148	185
A_p (mm^2):	98.0497	98.0492	98.0486	98.0487	98.0487	98.0487
	98.0495				(*pilot laboratory*)	
s_A (mm^2):	0.0008	0.0002	0.0001	0.00006	0.00004	0.00003
U(A_p) (mm^2):	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037

Table 6 Name of laboratory: **CEM2** (Standard: P/C s/n 5849)

$(p_e)_{nominal}$:	0.5	1.0	1.5	2.0	MPa
U(p_e) (Pa):	3.8	7.5	11.3	15.0	
A_p (mm^2):	98.0490	98.0490	98.0485	98.0491	
	98.0485			98.0487	(*pilot laboratory*)
s_A (mm^2):	0.00035	0.00029	0.00025	0.00025	
U(A_p) (mm^2):	0.00082	0.00082	0.00082	0.00082	

Note added in proof: After correcting a small error in the calculation of the piston mass, CEM finds closer agreement with pilot lab's results.

Table 7 Name of laboratory: **LNE**

$(p_e)_{nominal}$:	0.5	1.0	2.0	3.0	4.0	5.0 MPa
$U(p_e)$ (Pa):	14	17	29	32	51	65
A_p (mm^2):	98.0492	98.0485	98.0487	98.0487	98.0488	98.0489
	98.0492				(*pilot laboratory*)	
s_A (mm^2):	0.00059	0.00030	0.00035	0.0002	0.00016	0.00016
$U(A_p)$ (mm^2):	0.00201	0.00142	0.00153	0.00122	0.00115	0.00115

Table 8 Name of laboratory: **PTB**

$(p_e)_{nominal}$:	0.5	1.0	2.0	3.0	4.0	5.0 MPa
$U(p_e)$ (Pa):	10	16	30	45	60	75
A_p (mm^2):	98.0506	98.0504	98.0503	98.0504	98.0505	98.0505
s_A (mm^2):	0.0009	0.0004	0.0002	0.0001	0.0001	0.0001
$U(A_p)$ (mm^2):	0.0025	0.0020	0.0019	0.0019	0.0021	0.0021

Table 9

nominal pressure MPa	normalized error	laboratory
.500	.377	BEV
1.000	.577	
2.000	.541	
3.000	.648	
4.000	.656	
.500	-.376	FFA
1.000	.012	
2.000	.008	
3.000	.163	
4.000	.210	
5.000	.238	
.500	-.240	CMA1
1.000	-.211	
2.000	-.323	
3.000	-.270	
4.000	-.303	
5.000	-.319	
.500	-.484	CMA2
1.000	-.250	
2.000	-.416	
3.000	-.345	
4.000	-.384	
5.000	-.359	
.500	.068	CEM1
1.000	.165	
2.000	-.043	
3.000	.012	
4.000	-.016	
5.000	-.039	
.500	-.355	CEM2
1.000	.032	
2.000	-.085	
.500	.436	PTB
1.000	.764	
2.000	.603	
3.000	.753	
4.000	.716	
5.000	.675	

Note: This table is based on the effective area data calculated by the pilot laboratory

Appendices

Appendix 1a:

5 MPa INTERLABORATORY COMPARISON

Name of laboratory etc: g_{loc} = (+/-)m/s^2

pressures generated by lab's standard in ref.pln. of transfer standard	true mass on transfer piston (weight carrier + stainless st. weights) (***) value +/- unc. (**)	sum of small weights for pressure adjustment (if used on transfer piston) value +/- unc.	p_{amb}	t_{amb}	measured temp. of transfer pstn/cyl assembly t
MPa	**kg** ± **mg**	**g** ± **mg**	**hPa**	**°C**	**°C**
nom. | exact	ρ: 7920 kg/m^3 (*)	ρ: kg/m^3			
0.5					
1.0		(1st series of measurements)			
2.0					
3.0					
4.0					
5.0					
wait 15 minutes					
5.0					
4.0					
3.0					
2.0					
1.0					
0.5					
Take the transfer piston-cylinder assembly out of its pressure balance base unit and reinstall it again.					
second series of measurements					
Take the transfer piston-cylinder assembly out of its pressure balance base unit and reinstall it again.					
third series of measurements					

(*) Density values to be used for buoyancy correction. (The uncertainty of these values will enter the uncertainty budget and will be estimated by the pilot laboratory).

(**) 2s-uncertainty of the mass values in mg

(***) Mass of piston and head **not** included; the data determined in the pilot laboratory will be used to evaluate the measurements of all participants in the intercomparison.

Appendix 1b

5 MPa INTERLABORATORY COMPARISON

Name of laboratory etc:

	0.5	1.0	2.0	3.0	4.0	5.0
$(p_e)_{nominal}$:	0.5	1.0	2.0	3.0	4.0	5.0
$u(p_e)$:						
A_p in cm^2 :						
s_A :						
$u(A_p)$:						
Remarks :	*optional, not rec.*					*optional, recommended*

$u(p_e)$ is the total uncertainty in the measurement of pressures close to the nominal values with the laboratory standard at the 2s-level under the conditions of the calibration of the transfer piston-cylinder unit (this information is used together with the exact pressures given in table 2).

$u(A_p)$ is the total uncertainty in the measurement of one single value of the effective area of the transfer piston-cylinder unit at the 2s-level. s_A is the experimental standard deviation.

A_p is the mean of 6 values measured at each nominal pressure. Participants use their own procedures to calculate A_p at the reference temperature 20 ^{o}C.

Figures

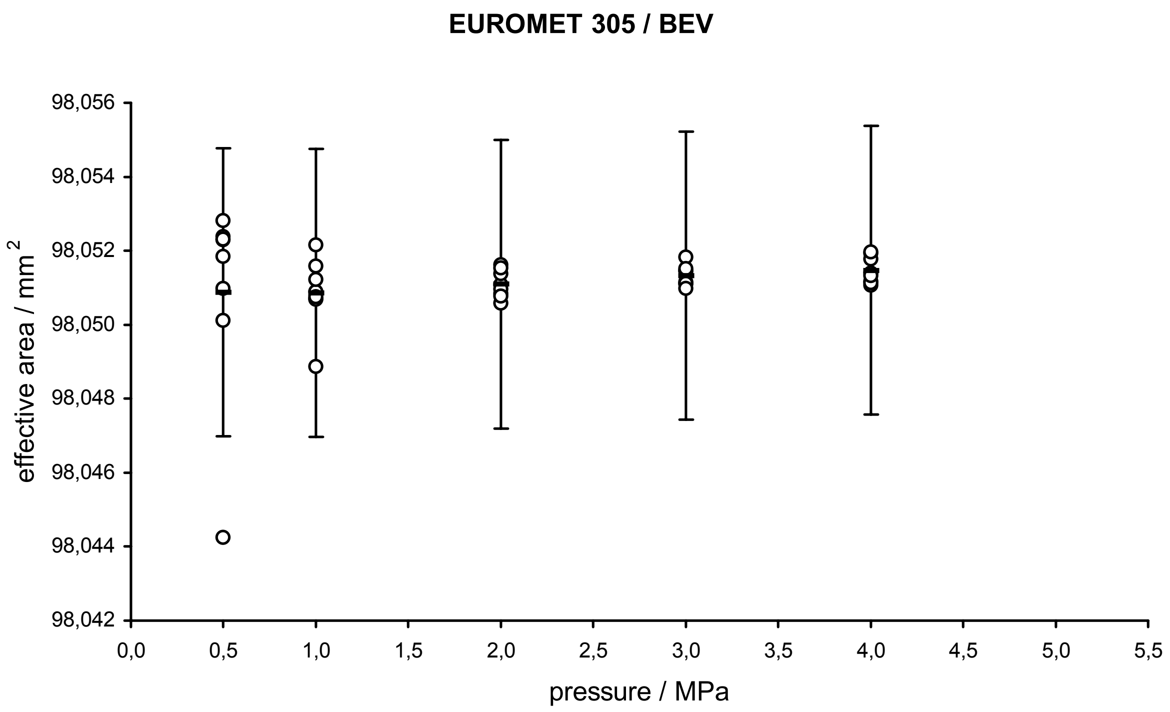


Figure 1

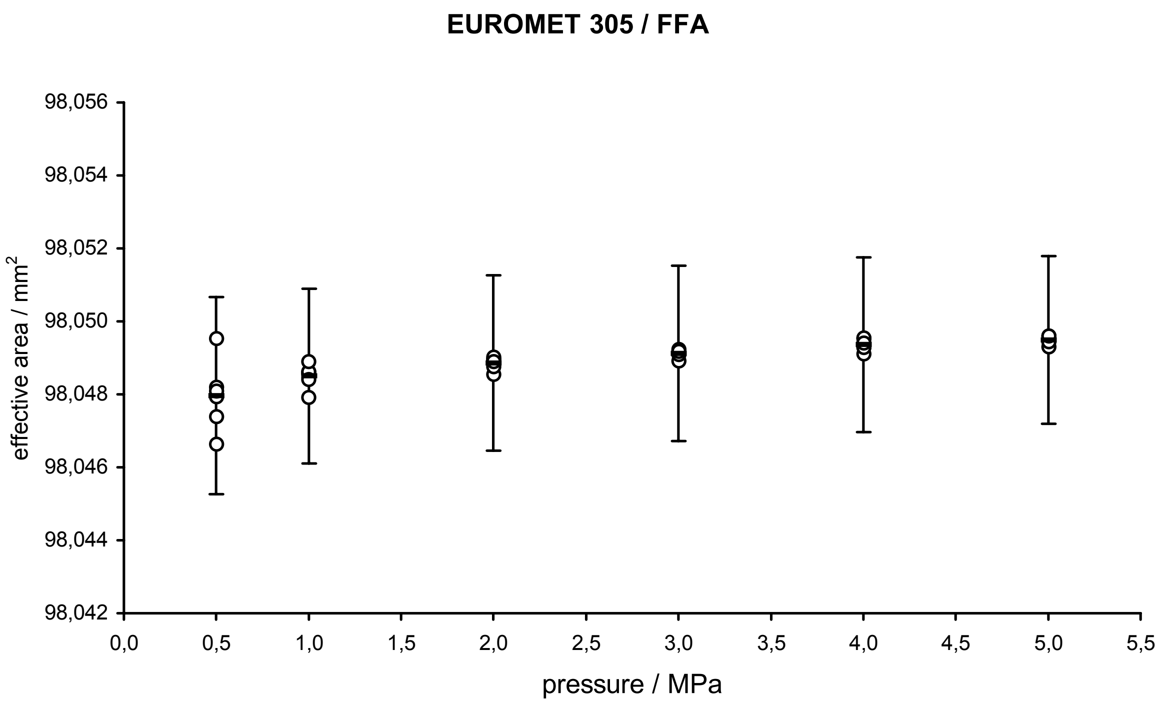
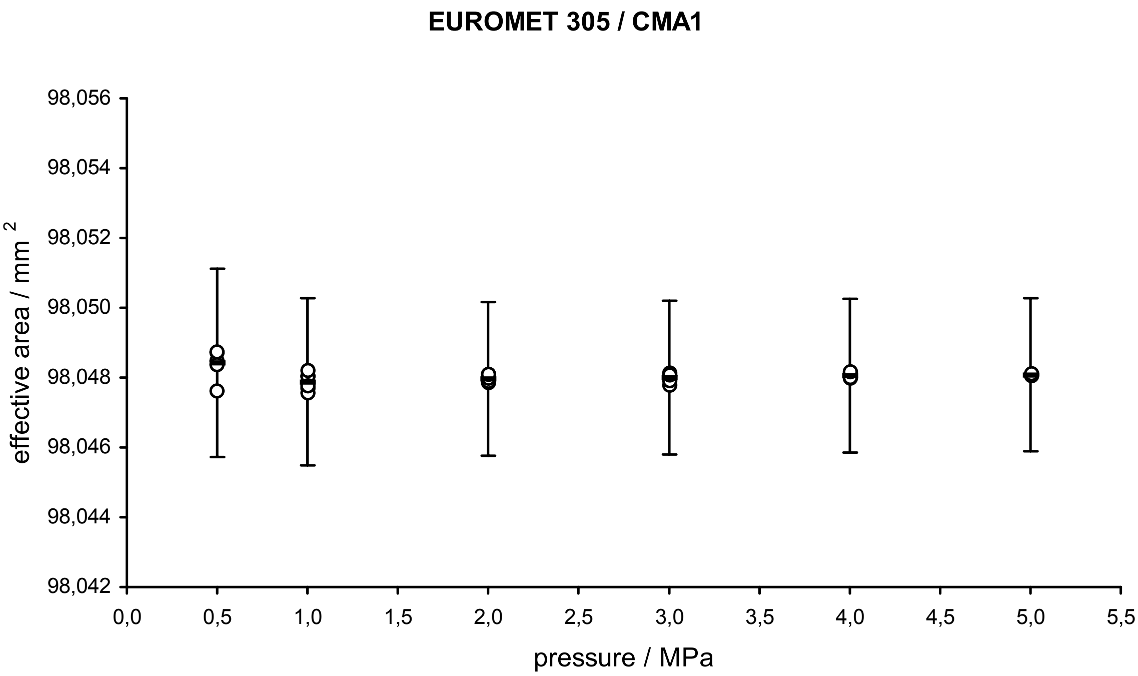


Figure 2



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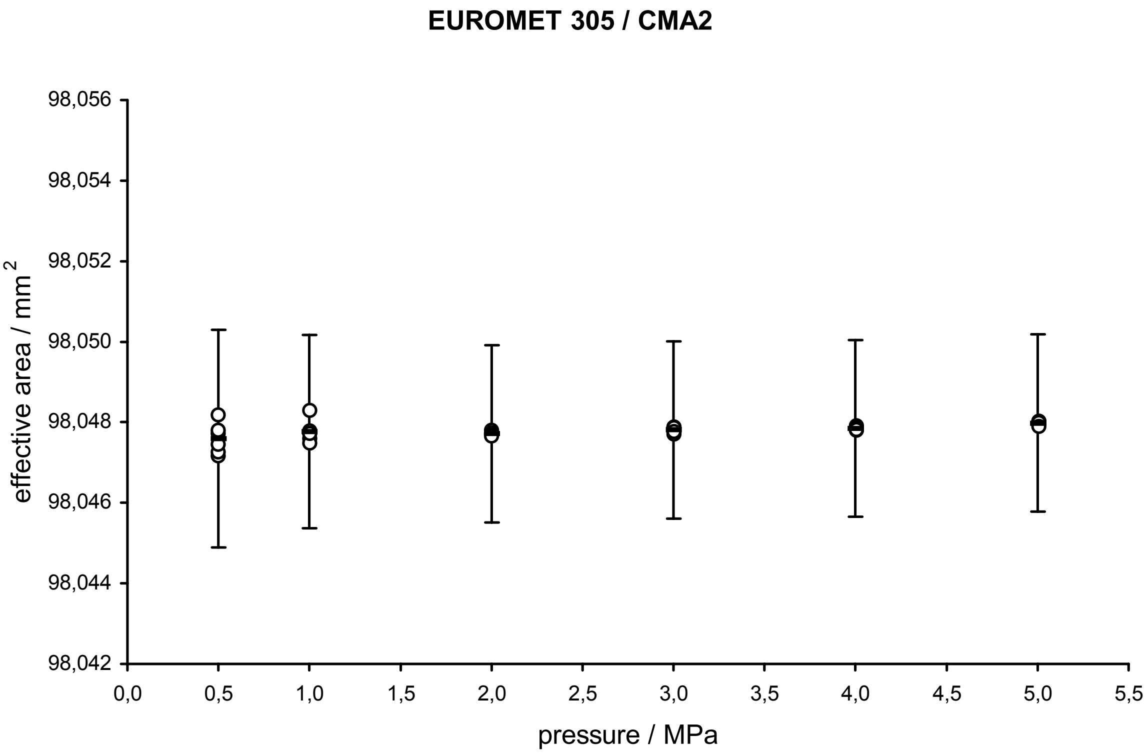

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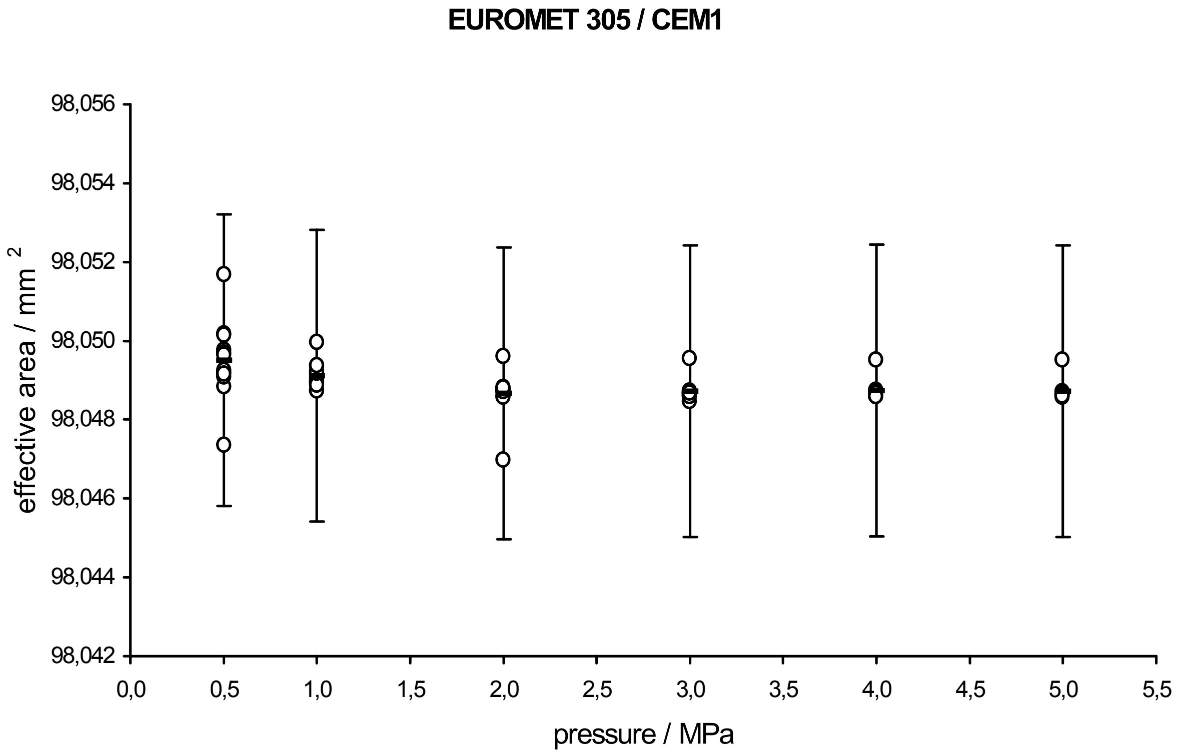

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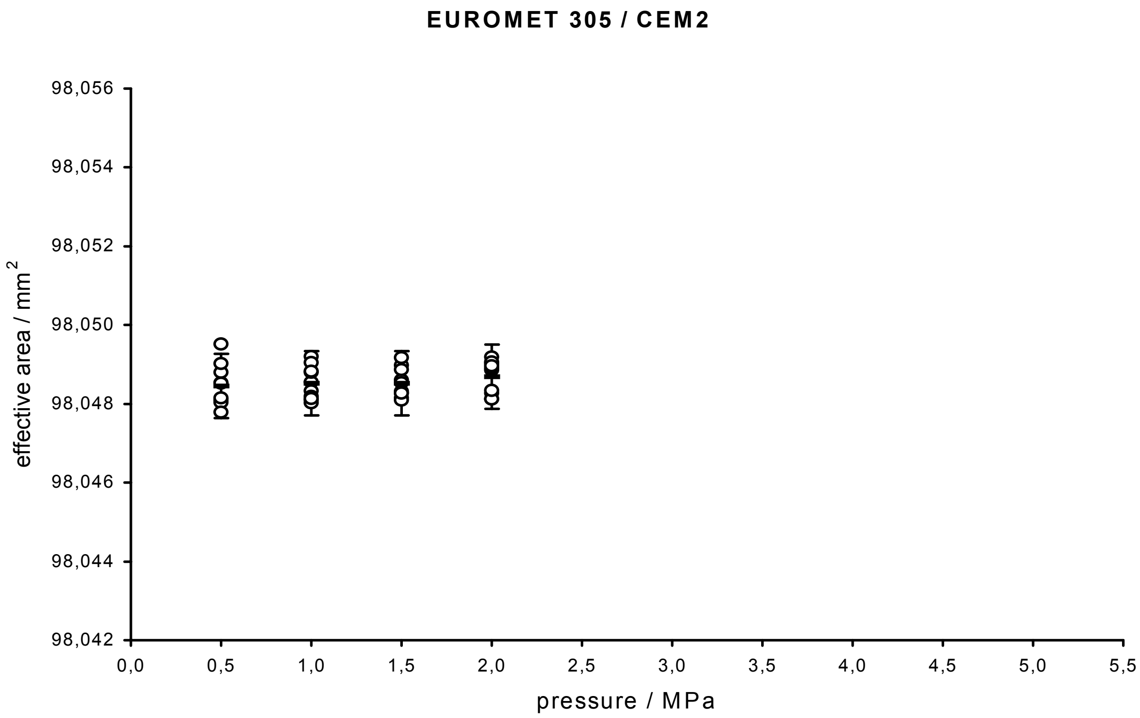

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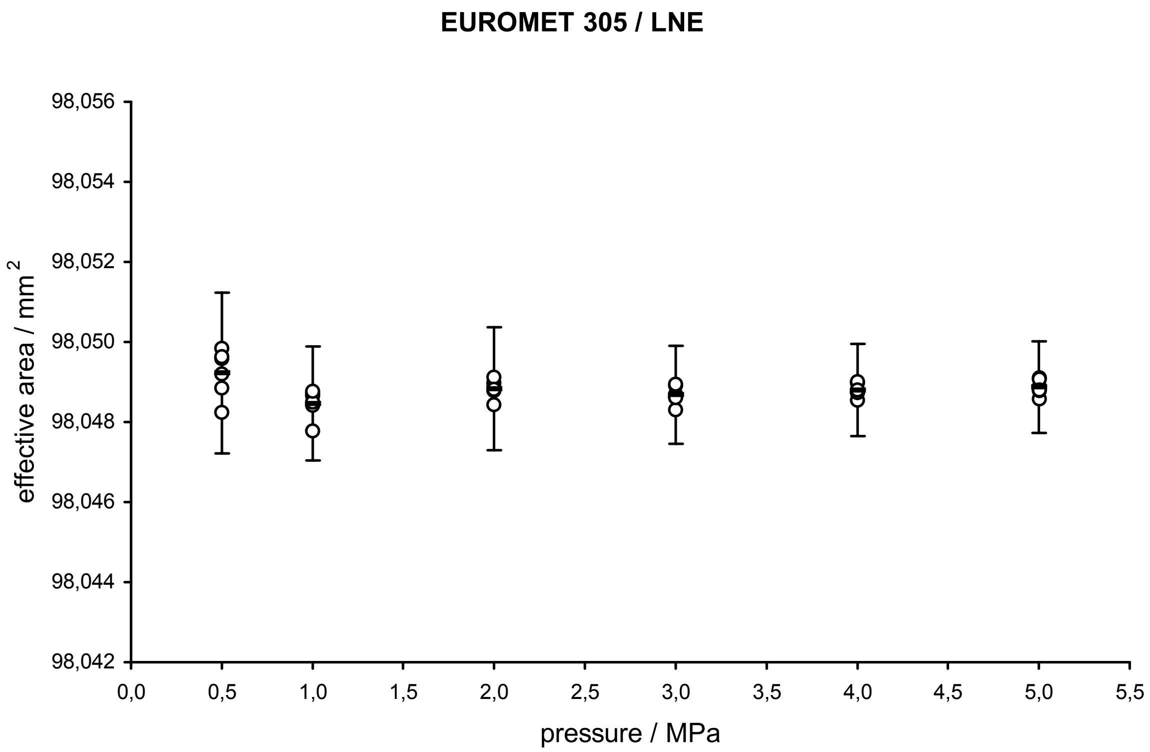

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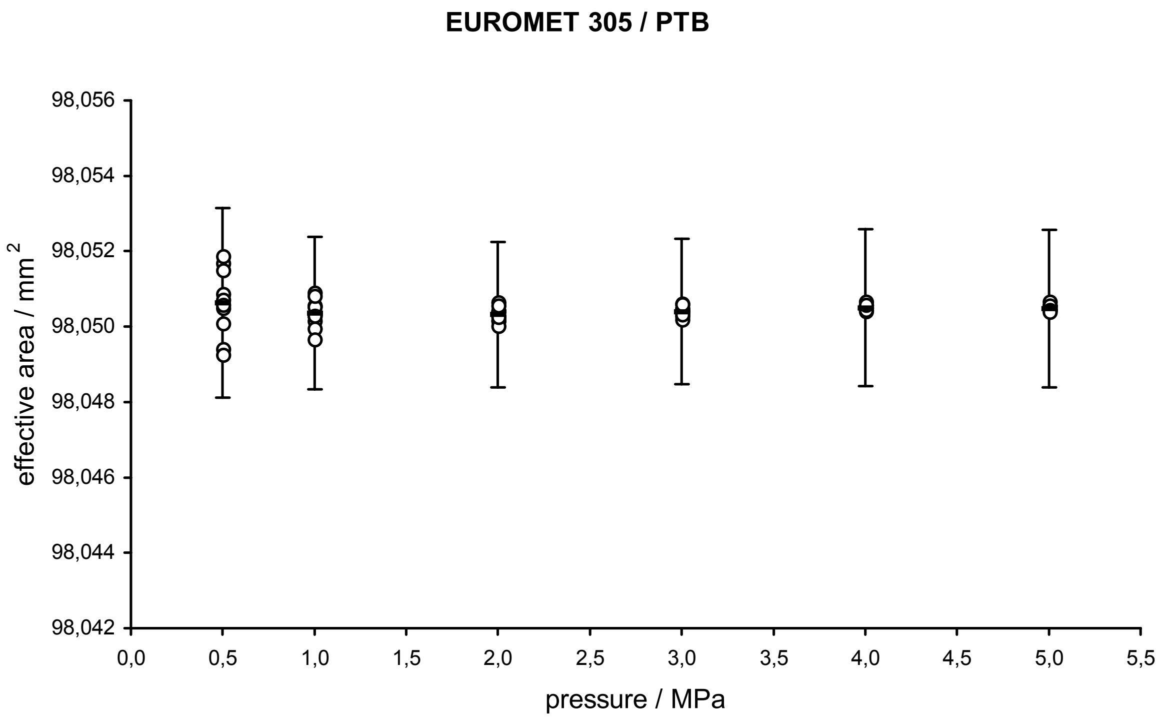

Figure 8

Figure 9: Interlaboratory comparison project EUROMET 305: Synoptic presentation of the results obtained by the participating laboratories for the effective area of the transfer piston-cylinder assembly.