Report on a comparison of pressure standards in the range 10 MPa to 100 MPa

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ABSTRACT

A comparison in the hydraulic pressure range between 10 MPa and 100 MPa was undertaken as EUROMET Project 389. The comparison was originally between five national metrology laboratories but was subsequently expanded to include a further ten participants. The pilot laboratory was the National Physical Laboratory. This report presents the results obtained by each laboratory for the effective area of the piston-cylinder assembly used in the comparison. The results of all participants were found to be consistent with each other and with the calculated reference value, within their claimed uncertainties, at all pressures. The results are therefore considered to be very satisfactory.

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Approved on behalf of the Managing Director, NPL
by Dr G R Torr, Head, Centre for Mechanical and Acoustical Metrology

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ILLUSTRATIONS

1. INTRODUCTION

A comparison of hydraulic pressure standards in the range 10 MPa to 100 MPa has been carried out within the framework of EUROMET during the period 1996 to 1999. This paper gives details of the comparison method and details of the results obtained.

The comparison, designated EUROMET Project 389 comprised 15 participants, and was organized on a 'petal' basis, with the transfer standard returning periodically to the pilot laboratory (National Physical Laboratory, UK) for assessment.

The laboratories which took part were:-

Belgium	Service de la Métrologie / Metrologische Dienst (SM/MD)
Czech Republic	Czech Metrological Institute (CMI)
Denmark	Force Instituttet (FORCE)
Finland	Centre for Metrology and Accreditation (MIKES)
France	Bureau National de Métrologie, Laboratoire National d'Essais (BNM-LNE)
Germany	Physikalisch-Technische Bundesanstalt (PTB)
Italy	Istituto di Metrologia "G Colonnetti" del C.N.R. (IMGC)
Netherlands	Nederlands Meetinstituut (NMi)
Portugal	Instituto Português da Qualidade (IPQ)
Slovakia	Slovensky Metrologicky Ustav (SMU)
Spain	Centro Español de Metrologia (CEM)
Sweden	SP Sveriges Provnings- och Forskningsinstitut (SP)
Switzerland	Office Fédéral de Métrologie (OFMET)
Turkey	TUBITAK-Ulusal Metroloji Enstitusu (UME)
United Kingdom	National Physical Laboratory (NPL)

2. PARTICIPANTS' STANDARDS

For the measurement of pressures up to 100 MPa, the standards used are pressure balances. The participants consisted of both those laboratories with *primary* pressure standards, and those with *secondary* pressure standards, ie they are traceable to another laboratory. Indeed, some of the participants within this comparison used standards directly traceable to other laboratories within the comparison.

Those participants with primary pressure standards were NPL, PTB, BNM-LNE, CNR-IMGC, NMi and CMI.

3. TRANSFER STANDARD

The transfer standard used in the comparison was a commercially available piston-cylinder assembly manufactured by Desgranges et Huot. It was of nominal 'Kn' value 1 MPa/kg, thus to achieve the highest pressure of 100 MPa a load of 100 kg was required.

Both piston and cylinder were manufactured from tungsten carbide with a temperature coefficient of expansion for effective area of 9.0×10^{-6} °C^{-1}. The nominal effective area of the piston-cylinder assembly was 9.8 mm^2 and its density was taken to be 8200 kgm^{-3}.

All other equipment required for the calibration of the piston-cylinder, for example the mounting base, ringweights and thermometers, was provided by the participants.

4. CALIBRATION PROCEDURE

Each participant was required to determine, using the calibration method they normally employ, the effective area, A_P, of the piston-cylinder assembly at the nominal pressures of 10, 20, 30, 40, 50, 60 ,70, 80, 90 and 100 MPa. They were also required to report an uncertainty, at a coverage factor k=2, for each value of effective area. A copy of the comparison protocol is in Appendix 2.

Note: As an optional part of the comparison protocol participants were invited to calculate values for A_0, the effective area of the piston-cylinder assembly at zero applied pressure, and λ, a pressure-dependent term. These are the parameters which are typically reported on certificates of calibration for piston-cylinders and values were supplied by all participants. This information, together with its analysis, is presented in Appendix 3, rather than the body of the report, to ensure that it is not confused with the main data and conclusions.

5. TRANSFER STANDARD STABILITY

Throughout the comparison the transfer standard was calibrated three times by NPL, the pilot laboratory. These results are referred to as NPL1, NPL2 and NPL3. The maximum relative difference in any value of A_P between successive calibrations was 5×10^{-6}. Although this figure is small compared with the pilot laboratory's claimed uncertainty, it has been incorporated into the analysis of the data as part of the uncertainty in the degree of equivalence for each participant.

6. RESULTS

Data from each participant are given in the tables and a graphic analysis is given in the figures. Table 1 and Figure 1 show each participant's measured value of effective area, at each nominal pressure, in mm^2. For clarity, no uncertainty bars have been included in Figure 1. Table 2 shows each participant's reported value of uncertainty, at k=2, for each nominal pressure, in mm^2. No results were received from Force Institute or SMU and those from SM/MD were not included in this report, as they carried out measurements using a 're-entrant' style of mounting rather than the 'simple' style[1].

In order to provide reference values, A_{Pref}, for the comparison, the median of values of A_P at each pressure has been taken, from those participants with primary standards for pressure. To avoid biasing the results, only one set of data from NPL, that designated NPL2, has been used. The main advantage of using the median value rather than a

[1] The mounting method of the piston-cylinder assembly was not stated in the comparison procedure.

weighted mean value is that weighted means are not statistically robust because they can be too easily influenced by individual results.

The uncertainty in the median has been calculated using the method of Müller [1]. This calculation is based on taking the median of absolute deviations from the median of the results contributing to the reference value, multiplying by 1.858 (derived in [1]) and dividing the answer by the square root of one less than the number of results.

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

where s is the uncertainty
n is the number of participants contributing to the reference value
MAD is the median of absolute deviations from the median.

Table 3 shows the reference value at each nominal pressure together with the corresponding uncertainty, at a confidence level of k=2.

The degree of equivalence was then calculated from the difference between each participant's value of A_P and the reference value, at each nominal pressure. The uncertainty in the degree of equivalence was calculated by combining the uncertainty reported by each participant with the uncertainty in the median and the shift in performance of the transfer standard observed by the pilot laboratory, by the root sum of squares method. Table 4 shows the degree of equivalence for each participant together with the uncertainty associated with each degree of equivalence, at a confidence level of k=2. As a summary, figures 2 and 3 show the relative difference between each participant and the reference value, calculated from

$$10^6 \times (A_P - A_{\mathrm{Pr}ef}) / A_{\mathrm{Pr}ef} \qquad (2)$$

Results are shown in order of participation, with the length of each error bar indicating the combined uncertainty. The centre of each error bar indicates the relative difference.

7. CONCLUSION

The results of this comparison are very satisfactory. Participants can be considered as being consistent with the reference value, and each other, within their claimed uncertainties at a confidence level of k=2, if the degree of equivalence is less than the uncertainty in the degree of equivalence. From Tables 4 and Figures 2 and 3 it can be seen that this is the case for all participants at all pressures.

8. REFERENCES

[1] Müller, J.W., *Rapport BIPM-95/2*, 1995

Table 1: Mean reported value of effective area for each participant at each nominal pressure / mm^2

Participant	10 MPa	20 MPa	30 MPa	40 MPa	50 MPa	60 MPa	70 MPa	80 MPa	90 MPa	100 MPa
NPL1	9.806014	9.806094	9.806180	9.806261	9.806366	9.806471	9.806571	9.806668	9.806763	9.806854
CEM	9.805940	9.805990	9.806080	9.806150	9.806230	9.806320	9.806400	9.806480	9.806560	9.806650
SP	9.805902	9.805945	9.806028	9.806112	9.806272	9.806386	9.806468	9.806520	9.806600	9.806645
MIKES	9.805850	9.805970	9.806070	9.806170	9.806270	9.806340	9.806420	9.806510	9.806590	9.806680
NPL2	9.806005	9.806091	9.806177	9.806268	9.806369	9.806462	9.806563	9.806648	9.806751	9.806840
NMi	9.806030	9.806120	9.806190	9.806300	9.806380	9.806480	9.806560	9.806650	9.806730	9.806810
IMGC	9.805982	9.805995	9.806079	9.806181	9.806277	9.806370	9.806461	9.806552	9.806642	9.806727
UME	9.806055	9.806142	9.806249	9.806344	9.806439	9.806530	9.806623	9.806709	9.806800	9.806888
BNM-LNE	9.806032	9.805996	9.806047	9.806101	9.806194	9.806285	9.806384	9.806472	9.806568	9.806663
OFMET	9.805550	9.805660	9.805780	9.805880	9.805840	9.805950	9.806070	9.806170	9.806270	9.806360
PTB	9.805915	9.806025	9.806122	9.806219	9.806310	9.806398	9.806481	9.806571	9.806652	9.806742
IPQ	9.805953	9.806078	9.806186	9.806297	9.806397	9.806494	9.806590	9.806687	9.806785	9.806876
NPL3	9.806033	9.806104	9.806189	9.806303	9.806394	9.806498	9.806582	9.806699	9.806784	9.806884
CMI	9.805907	9.806071	9.806206	9.806300	9.806412	9.806527	9.806610	9.806673	9.806774	9.806893

Table 2: Each participant's claimed uncertainty in effective area (k=2) at each nominal pressure / mm^2

Participant	10 MPa	20 MPa	30 MPa	40 MPa	50 MPa	60 MPa	70 MPa	80 MPa	90 MPa	100 MPa
NPL1	0.000238	0.000255	0.000273	0.000291	0.000308	0.000326	0.000344	0.000361	0.000379	0.000397
CEM	0.000140	0.000136	0.000136	0.000135	0.000136	0.000136	0.000136	0.000136	0.000136	0.000136
SP	0.000206	0.000196	0.000196	0.000206	0.000392	0.000382	0.000382	0.000373	0.000373	0.000373
MIKES	0.000294	0.000294	0.000294	0.000294	0.000294	0.000294	0.000294	0.000294	0.000294	0.000294
NPL2	0.000238	0.000255	0.000273	0.000291	0.000308	0.000326	0.000344	0.000361	0.000379	0.000397
NMi	0.000588	0.000588	0.000588	0.000588	0.000588	0.000588	0.000588	0.000588	0.000588	0.000588
IMGC	0.000264	0.000254	0.000251	0.000258	0.000254	0.000253	0.000257	0.000258	0.000261	0.000263
UME	0.000397	0.000396	0.000396	0.000396	0.000396	0.000397	0.000397	0.000398	0.000398	0.000399
BNM-LNE	0.000151	0.000124	0.000118	0.000116	0.000116	0.000118	0.000120	0.000124	0.000126	0.000129
OFMET	0.000588	0.000588	0.000588	0.000588	0.000588	0.000588	0.000588	0.000588	0.000588	0.000588
PTB	0.000218	0.000218	0.000222	0.000228	0.000235	0.000243	0.000253	0.000265	0.000277	0.000290
IPQ	0.000549	0.000549	0.000549	0.000549	0.000549	0.000549	0.000549	0.000549	0.000549	0.000549
NPL3	0.000238	0.000255	0.000273	0.000291	0.000308	0.000326	0.000344	0.000361	0.000379	0.000397
CMI	0.000343	0.000343	0.000343	0.000343	0.000353	0.000353	0.000373	0.000382	0.000392	0.000412

Table 3: Calculated reference value and associated uncertainty (k=2) at each nominal pressure / mm^2

	10 MPa	20 MPa	30 MPa	40 MPa	50 MPa	60 MPa	70 MPa	80 MPa	90 MPa	100 MPa
Reference value	9.805994	9.806048	9.806149	9.806244	9.806339	9.806430	9.806521	9.806609	9.806691	9.806776
Uncertainty	0.000062	0.000087	0.000093	0.000099	0.000085	0.000092	0.000085	0.000081	0.000090	0.000094

Table 4: Deviation from reference value (and associated uncertainty) for each participant at each nominal pressure / mm^2 x 10^5

Participant	10 MPa	20 MPa	30 MPa	40 MPa	50 MPa	60 MPa	70 MPa	80 MPa	90 MPa	100 MPa
NPL1	2.0 (25.2)	4.7 (27.5)	3.1 (29.4)	1.7 (31.6)	2.7 (32.7)	4.2 (34.7)	5.2 (36.1)	6.0 (38.1)	7.3 (39.9)	7.9 (41.8)
CEM	-5.5 (15.8)	-5.9 (16.5)	-7.1 (16.8)	-9.5 (17.6)	-11.2 (16.6)	-11.2 (17.1)	-12.3 (16.4)	-13.2 (17.0)	-13.4 (17.0)	-12.8 (17.4)
SP	-9.4 (22.1)	-10.5 (21.9)	-12.4 (22.1)	-13.4 (23.7)	-6.9 (41.0)	-4.5 (40.3)	-5.4 (40.0)	-9.1 (39.2)	-9.3 (39.2)	-13.4 (39.4)
MIKES	-14.7 (30.8)	-7.9 (31.3)	-8.1 (31.5)	-7.5 (31.9)	-7.1 (31.4)	-9.2 (31.6)	-10.2 (31.3)	-10.1 (31.5)	-10.3 (31.6)	-9.8 (31.8)
NPL2	1.2 (25.2)	4.4 (27.5)	2.8 (29.4)	2.5 (31.6)	3.0 (32.7)	3.3 (34.7)	4.3 (36.1)	3.9 (38.1)	6.1 (39.9)	6.5 (41.8)
NMi	3.7 (60.4)	7.3 (60.7)	4.1 (60.8)	5.8 (61.0)	4.1 (60.7)	5.1 (60.8)	4.0 (60.7)	4.1 (60.8)	4.0 (60.8)	3.5 (60.9)
IMGC	-1.2 (27.8)	-5.4 (27.4)	-7.2 (27.3)	-6.4 (28.5)	-6.3 (27.5)	-6.2 (27.7)	-6.1 (27.7)	-5.8 (28.1)	-5.0 (28.3)	-5.0 (28.8)
UME	6.2 (41.0)	9.6 (41.4)	10.2 (41.5)	10.2 (41.9)	10.2 (41.4)	10.2 (41.7)	10.5 (41.5)	10.2 (41.7)	11.1 (41.8)	11.4 (42.1)
BNM-LNE	3.9 (16.9)	-5.3 (15.5)	-10.4 (15.3)	-14.5 (16.1)	-14.8 (14.9)	-14.8 (15.7)	-13.9 (15.1)	-14.0 (15.9)	-12.5 (16.1)	-11.5 (16.9)
OFMET	-45.3 (60.4)	-39.6 (60.7)	-37.7 (60.7)	-37.1 (61.0)	-50.9 (60.7)	-49.0 (60.8)	-45.9 (60.6)	-44.8 (60.8)	-42.9 (60.8)	-42.4 (60.9)
PTB	-8.0 (23.2)	-2.3 (23.9)	-2.8 (24.5)	-2.5 (25.7)	-3.0 (25.7)	-3.3 (26.8)	-4.0 (27.3)	-3.9 (28.7)	-4.0 (29.9)	-3.5 (31.4)
IPQ	-4.1 (56.4)	3.0 (56.7)	3.7 (56.8)	5.4 (57.1)	5.9 (56.7)	6.5 (56.9)	7.1 (56.7)	7.9 (56.8)	9.6 (56.9)	10.2 (57.0)
NPL3	4.0 (25.2)	5.7 (27.5)	4.0 (29.4)	6.0 (31.6)	5.6 (32.7)	6.9 (34.7)	6.2 (36.1)	9.1 (38.1)	9.5 (39.9)	11.0 (41.8)
CMI	-8.8 (35.7)	2.3 (36.1)	5.8 (36.3)	5.7 (36.7)	7.4 (37.2)	9.9 (37.4)	9.2 (39.0)	6.5 (40.2)	8.5 (41.2)	11.9 (43.3)

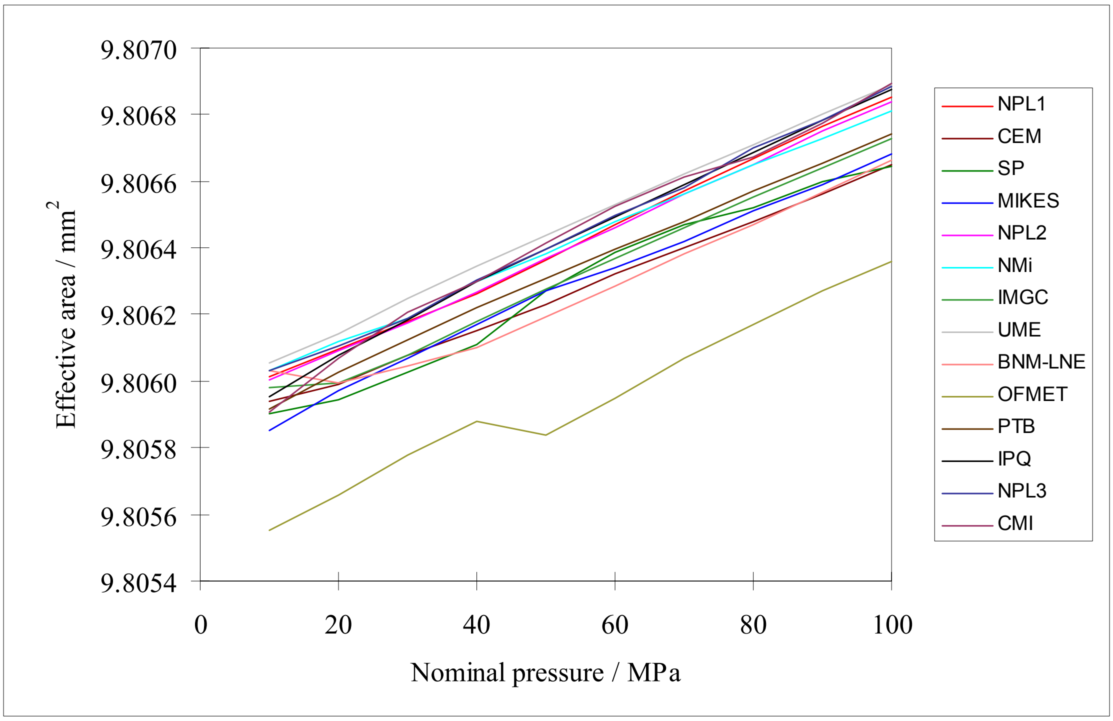

Figure 1: Values of effective area obtained by each participant at each nominal pressure

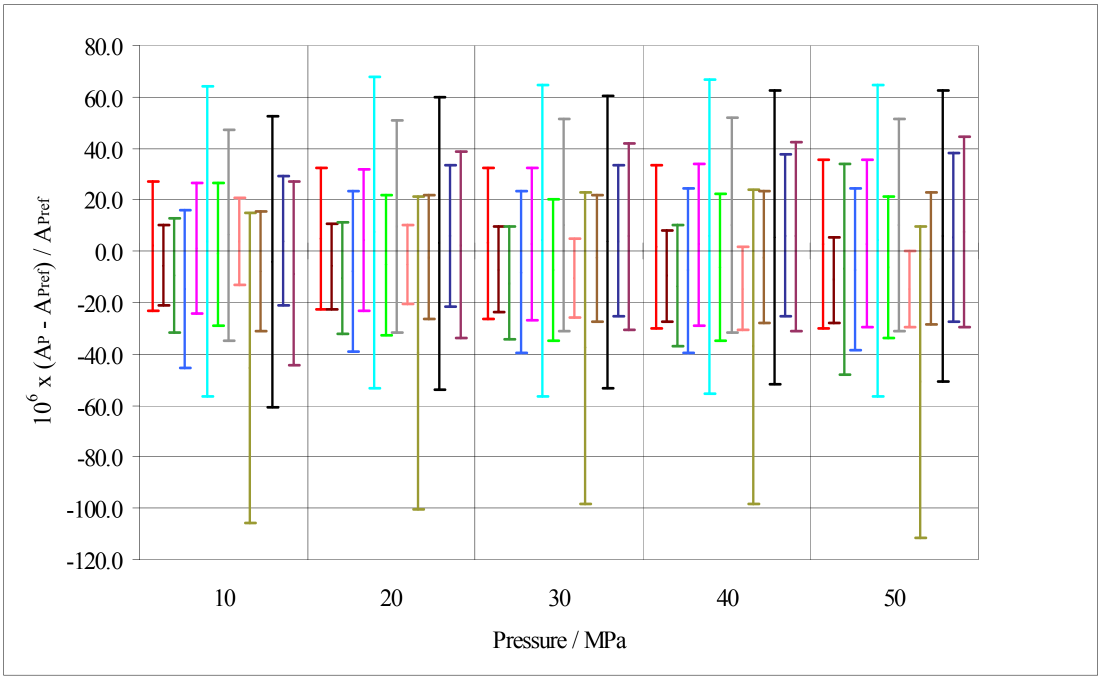

Figure 2: Relative difference between each participant's value of A_P and the reference value A_{Pref} at pressures between 10 MPa and 50 MPa

(Key: from left to right participants are as listed in key to Figure 1)

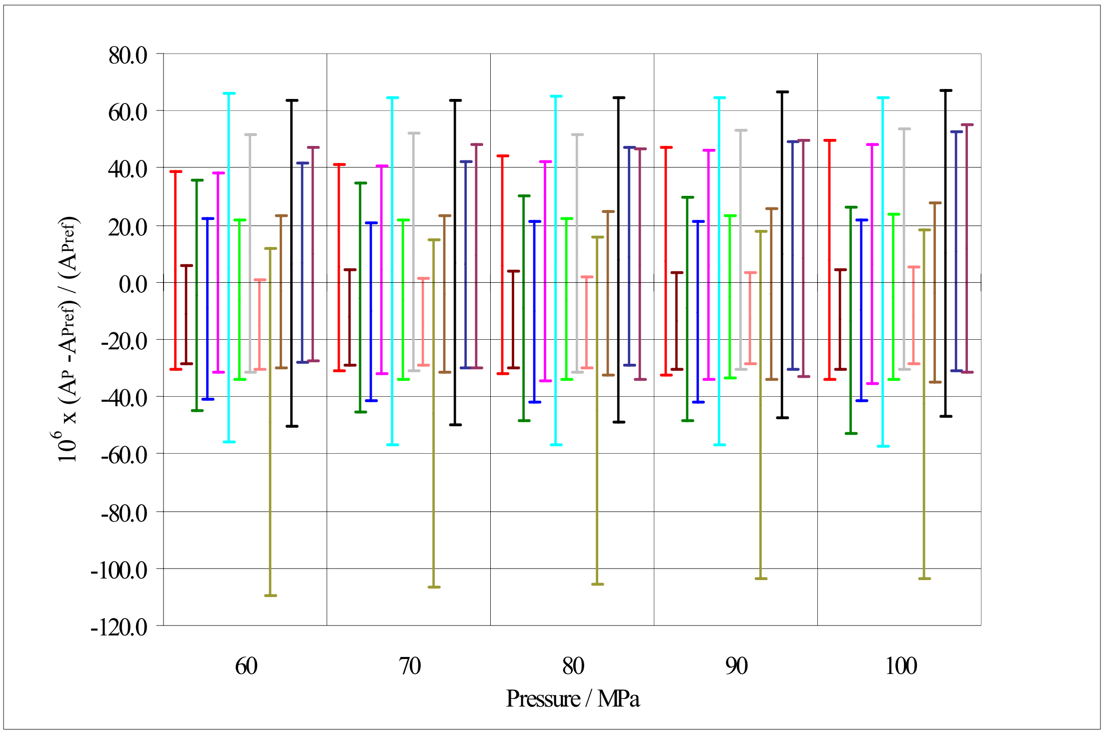

Figure 3: Relative difference between each participant's value of A_P and the reference value A_{Pref} at pressures between 60 MPa and 100 MPa

(Key: from left to right participants are as listed in key to Figure 1)

APPENDIX 1: MEASUREMENT DATES

Laboratory	Date of Participation
NPL1	28 to 30 August 1996
CEM	May 1997
SP	17 to 19 June 1997
MIKES	22 to 23 July 1997
Force Institute	September 1997
NPL2	24 September to 3 October 1997
NMi	10 to 11 February 1998
IMGC	7 to 24 April 1998
UME	25 May 1998 to 08 June 1998
BNM-LNE	26 June to 1st July 1998
SM/MD	24 to 30 September 1998
OFMET	20 to 28 October 1998
PTB	23 to 26 November 1998
SMU	December 1998 to January 1999
IPQ	4 to 16 March 1999
NPL3	19 to 22 March 1999
CMI	December 1999

APPENDIX 2: PROCEDURE PROTOCOL

Objective

The objective of the project is to compare the performance of hydraulic pressure standards in participating laboratories, in the pressure range 10 MPa to 100 MPa.

Equipment

The transfer standard is a Desgranges et Huot piston-cylinder, serial number 1000, belonging to NPL. Its temperature coefficient should be taken to be 9.0 ppm/°C and the mean density of its floating element taken to be 8200 kg/m^3. All other equipment (eg mounting columns, ring-weights and thermometers) is to be provided by each participant.

Calibration method

The calibration method should be that which is normally employed by each participant for determining the effective area (A_p) of a pressure-balance at nominal pressures of 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 MPa. The values of A_p, together with the respective measurement uncertainties, will be the main basis of the comparison.

Additional calculation (optional)

Participants are invited to calculate the effective area of the piston-cylinder at zero pressure (A_0) together with any pressure dependent term (λ), with associated uncertainties. This will allow a second method of comparing participants' results.

Information to be reported

1 Values of A_p at the 10 nominal pressures specified, each with an uncertainty in the measurement (coverage factor k=2) and the date(s) on which practical work was undertaken.

2 A short description of standard(s) against which the transfer standard was calibrated, including the origin of its traceability to the SI.

3 A short description of the method of calibration including whether the p-method or Δp-method was used.

4 Optionally, the calculated values of A_0 and λ, each with an uncertainty in the measurement.

APPENDIX 3: ALTERNATIVE REPRESENTATION OF DATA

As an optional part of the comparison, participants were invited to calculate values for A_0, the effective area of the piston-cylinder assembly at zero applied pressure, and λ, a pressure-dependent term. These are the parameters which are typically reported on certificates of calibration for piston-cylinders. Values of these parameters were supplied by participants, and they are shown, together with their associated uncertainties, in Table 5.

The use of such terms to model pressure balance area vs pressure data can result in additional errors – essentially because the 'residuals' (the difference between a measured value and a value calculated from a straight line model) are not zero. Although not expected to be significant in this case, the comparison results were re-computed from the A_0 and λ values supplied.

Values of A_P' were calculated for each of the nominal pressures, where measurements were taken, using the equation:

$$A_P' = A_0 (1 + \lambda P)$$

where P is the pressure in MPa

From these data, new reference values and their uncertainties were calculated, again using the method described in Section 6. The differences between each participants' calculated values of A_P' and the new reference values, together with the associated uncertainties, are shown in Table 6 and graphically in Figures 4 and 5. Note that the values of uncertainty in A_P' were not computed but were taken to be the same as the uncertainties in $A_{p.}$

As can be seen from both Table 6 and Figures 4 and 5, when using the alternative method of representing pressure balance effective area data, all participants remain consistent, with the reference values and with each other, within their claimed uncertainties at a confidence level of k=2. It should be noted, however, that whilst good agreement between the laboratories is shown in both methods of presenting effective area data, they produce noticeably different numbers. The 'A_0 and λ modelling' technique, by its nature, introduces additional errors which depend on the particular method used to determine the 'best-fit' equation and the degree of linearity of the pressure balance's effective area vs pressure characteristic. The differences should be taken into account when considering the relationship between international comparisons and routine calibration services.

Table 5: Each participants' calculated value of A_0 and λ

Participant	A_0 mm^2	Uncertainty in A_0 mm^2	λ $10^{-6}.MPa^{-1}$	Uncertainty in λ $10^{-6}.MPa^{-1}$
NPL1	9.805 83	0.000 22	1.09	0.18
CEM	9.805 84	0.000 17	0.82	0.03
SP	9.805 79	0.000 38	0.92	0.09
MIKES	9.805 79	0.000 30	0.92	0.09
NPL2	9.805 90	0.000 22	0.95	0.18
NMi	9.805 94	0.000 60	0.90	0.16
IMGC	9.805 84	0.000 26	0.90	0.07
UME	9.806 00	0.000 41	0.95	0.09
BNM-LNE	9.805 85	0.000 15	0.79	0.06
OFMET	9.805 48	0.000 59	0.88	-
PTB	9.805 84	0.000 22	0.92	0.22
IPQ	9.805 88	0.000 55	1.03	0.03
NPL3	9.805 92	0.000 22	0.98	0.18
CMI	9.805 87	0.000 41	1.06	0.11

Table 6 : Deviation from reference value (and associated uncertainty) for each participant at each nominal pressure / $mm^2 \times 10^5$
Calculated for illustrative purposes from values of A_0 and λ

Participant	10 MPa	20 MPa	30 MPa	40 MPa	50 MPa	60 MPa	70 MPa	80 MPa	90 MPa	100 MPa
NPL1	-1.5 (25.0)	-0.5 (27.0)	0.6 (29.1)	2.1 (31.1)	3.7 (32.7)	5.2 (34.5)	6.8 (36.1)	8.3 (38.2)	10.1 (39.8)	11.9 (41.8)
CEM	-3.4 (15.5)	-5.1 (15.6)	-6.7 (16.3)	-7.9 (16.8)	-9.0 (16.5)	-10.2 (16.7)	-11.3 (16.4)	-12.5 (17.1)	-13.4 (16.9)	-14.3 (17.4)
SP	-7.2 (21.9)	-7.9 (21.2)	-8.5 (21.8)	-8.7 (23.1)	-8.8 (41.0)	-9.0 (40.1)	-9.1 (40.0)	-9.3 (39.3)	-9.2 (39.2)	-9.1 (39.4)
MIKES	-7.3 (30.6)	-8.0 (30.8)	-8.6 (31.2)	-8.8 (31.5)	-8.9 (31.3)	-9.1 (31.4)	-9.2 (31.3)	-9.4 (31.6)	-9.3 (31.5)	-9.2 (31.8)
NPL2	4.2 (25.0)	3.8 (27.0)	3.5 (29.1)	3.7 (31.1)	3.8 (32.7)	4.0 (34.5)	4.1 (36.1)	4.3 (38.2)	4.6 (39.8)	5.0 (41.8)
NMi	7.8 (60.3)	6.9 (60.4)	6.1 (60.6)	5.7 (60.8)	5.4 (60.7)	5.0 (60.7)	4.7 (60.6)	4.3 (60.8)	4.2 (60.8)	4.1 (60.9)
IMGC	-2.4 (27.6)	-3.4 (26.8)	-4.2 (27.0)	-4.5 (28.0)	-4.9 (27.5)	-5.3 (27.5)	-5.6 (27.7)	-6.0 (28.2)	-6.2 (28.3)	-6.3 (28.8)
UME	14.1 (40.9)	13.6 (41.0)	13.3 (41.3)	13.5 (41.5)	13.6 (41.4)	13.7 (41.5)	13.9 (41.4)	14.0 (41.8)	14.3 (41.7)	14.7 (42.0)
BNM-LNE	-2.5 (16.6)	-4.5 (14.4)	-6.4 (14.8)	-7.8 (15.2)	-9.3 (14.9)	-10.7 (15.2)	-12.2 (15.0)	-13.6 (16.1)	-14.9 (16.0)	-16.1 (16.8)
OFMET	-39.4 (60.3)	-40.5 (60.4)	-41.5 (60.6)	-42.1 (60.8)	-42.7 (60.7)	-43.3 (60.7)	-43.9 (60.6)	-44.5 (60.8)	-44.9 (60.8)	-45.2 (60.9)
PTB	-2.2 (23.1)	-2.9 (23.3)	-3.5 (24.2)	-3.7 (25.1)	-3.8 (25.6)	-4.0 (26.5)	-4.1 (27.3)	-4.3 (28.8)	-4.2 (29.8)	-4.1 (31.4)
IPQ	2.6 (56.3)	3.1 (56.4)	3.6 (56.7)	4.6 (56.8)	5.6 (56.7)	6.6 (56.8)	7.6 (56.7)	8.6 (56.9)	9.8 (56.8)	11.1 (57.0)
NPL3	6.5 (25.0)	6.4 (27.0)	6.4 (29.1)	6.9 (31.1)	7.3 (32.7)	7.8 (34.5)	8.2 (36.1)	8.7 (38.2)	9.4 (39.8)	10.1 (41.8)
CMI	2.2 (35.6)	2.9 (35.7)	3.7 (36.0)	5.0 (36.3)	6.2 (37.1)	7.5 (37.2)	8.7 (39.0)	10.0 (40.3)	11.5 (41.1)	13.0 (43.3)

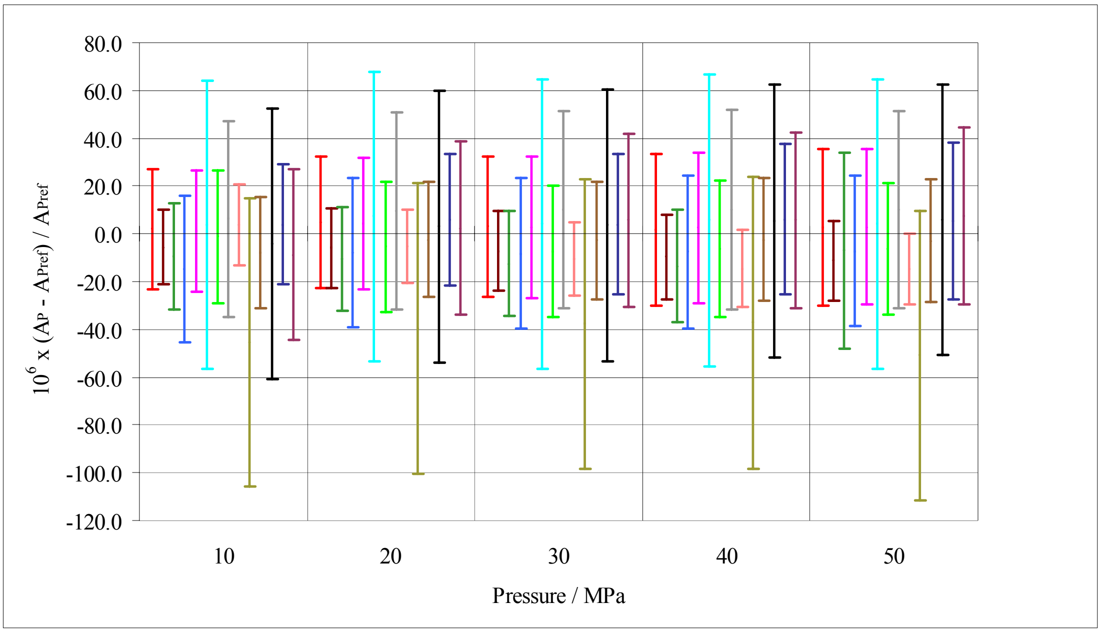

Figure 4: Relative difference between each participant's value of A_P' and the reference value $A_P'_{ref}$ at pressures between 10 MPa and 50 MPa

(Key: from left to right participants are as listed in Figure 1)

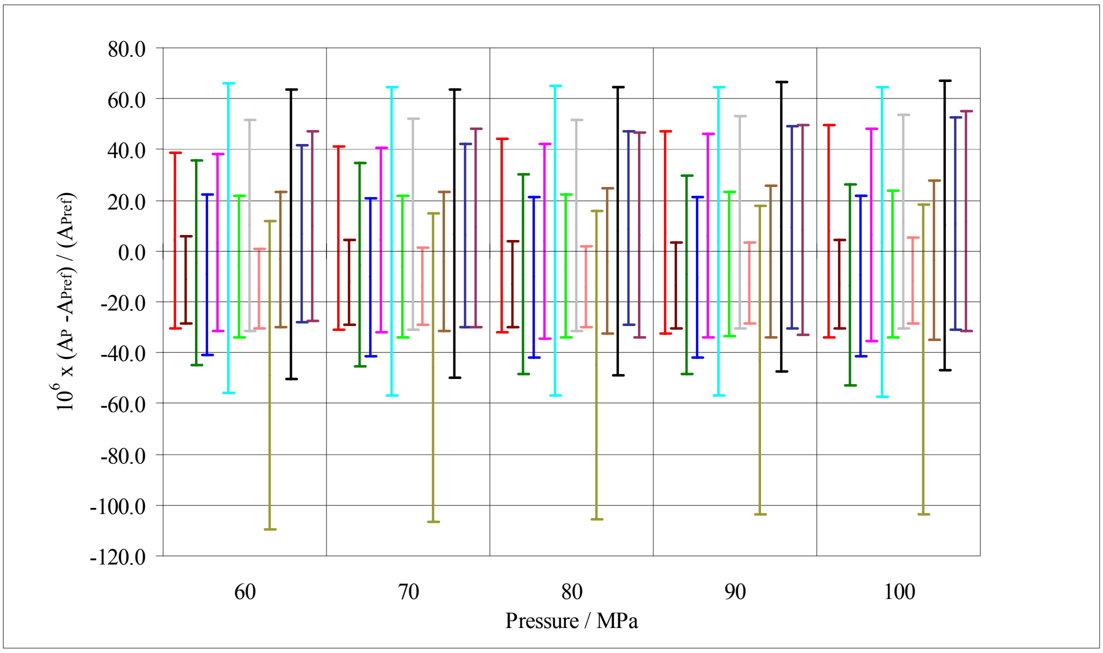

Figure 5: Relative difference between each participant's value of A_P' and the reference value $A_P'_{ref}$ at pressures between 60 MPa and 100 MPa

(Key: from left to right participants are as listed in Figure 1)