23rd World Gas Conference, Amsterdam 2006

THE INTERNATIONAL WORLD REFERENCE VALUE FOR HIGH PRESSURE NATURAL GAS FLOW AS APPROVED BY CIPM KEY COMPARISONS

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1. ABSTRACT

Key words: flow measurement, calibration of gas meters, international reference value, BIPM-CIPM Key comparisons, world reference value for natural gas flow measurements Harmonized Reference Value, Harmonized European Gas Cubic Meter.

Under auspices of the BIPM (International Bureau for Weight and Measures) as well as the CIPM (International Conference for Weight and Measures), which is the highest metrological authority worldwide, so called Key Comparisons (KC) have been conducted to get international reference values for all quantities of interest. Among these KCs, the flow area is of economic importance and Key Comparisons for natural gas flow at high pressure and larger flow rates as well as for compressed air have been conducted successfully among all interested National Metrology Institutes.
The outcome of such a KC is the international Key Comparisons Reference Value (KCRV), which is then considered to be the worldwide best available realization of Natural Gas Flow at high pressure. (World Reference Value).

These KCs have been conducted among the National Primary Standards of all nations worldwide, represented by their National Metrology Institutes (NMIs) and have been finalized in December 2004 for natural gas and the Key Comparison Reference Value has been approved by the BIPM in April 2005 and has been published at the BIPM web-site in January 2006.
The paper describes the procedures, the participating high-pressure gas facilities, the outcome and important conclusions for international as well as national gas trade. It turns out, that there are significant differences between the US, Europe and Asia in their view to metrology and their way how to disseminate reference values. An international accepted reference value for the gas cubic meter will be more and more important in a liberalized gas market.

At last the paper gives a view towards the so-called Harmonized European Reference Value for the Natural Gas Cubic Meter which is being disseminated all over Europe since May 4th, 2004. In the meantime it has been accepted also on other continents as the national reference, e.g. Canada via NRC, MC and TCC.
It turns out, that this Harmonized European Reference Value is exactly the same as the above mentioned CIPM/BIPM Key Comparison Reference Value for natural gas.
The metrological consequences and benefits of such a Key comparison Reference value for international trade will be discussed.

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1. THE CHALLENGE of GAS FLOW MEASUREMENT

Since the seventies an increasing use of Natural Gas as energy source and in Europe a vast network (gas-grid) has been realized to allow an average gas consumption in Europe is more than 400 billion cubic meter per year. In this expanding gas grid more and more points of transfer of ownership are installed, leading ultimately to an increasing demand for reliable and stable reference values for high-pressure gas-flow measurements. The principle of Third Party Access, supported in the future by direct invoicing of energy-shipment, makes it of vital importance that Gas-transport organizations have at all times a clear knowledge about the contents of their transport-grid.
Hence, long term stability of reference values is gaining importance. Although small (insignificant) changes in (national) reference values are accepted by metrologists, the impact of variations on e.g. invoicing will probably never be understood nor accepted. The drive for one equivalent reference value in this working field of Natural Gas resulted in an extensive cooperation between three NMI's holding test facilities for High Pressure Natural Gas in Europe. The results of these activities have been verified by means of CIPM Key Comparisons conducted under auspices of the CCM.

2. The INTERNATIONAL ACTIVITIES in FLOW METROLOGY

As the metrological activities of PTB, NMI-VSL and BNM affect the national and international trade of natural gas, the approach of the harmonization process shall be summarized here and we present the latest results to define the "**European Harmonized Reference Level**" or the "**Harmonized European Natural Gas Cubic Meter"** respectively.

The procedure of the harmonization process of the natural gas cubic meter in Europe, leading to the so-called Harmonized European Gas Cubic Meter has been described in a couple of papers before and will be summarized here.
This procedure began in June 1999, among PTB and NMi-VSL and has been completed in May 2004 by the definition, realization and dissemination of this harmonized European Gas Cubic Meter. All national metrology institutes in Europe are disseminating now this reference value and all calibration since this date make use of this reference value.
Figure 1 presents the interaction between the three primary standards of PTB, LNE and NMi-VSL, showing the measurement and calibration range as well as traceability sources, which finally lead to the Harmonized European Reference Value.

In parallel to the initiative of the leading European NMIs to get the most stable reference value, the CIPM decided t conduct Key Comparisons among all national metrology institutes in order to get Key Comparison Reference Values (KCRV) for all subject fields, including natural gas flow at high pressure.

The German PTB has been elected to pilot the Key Comparisons among all NMIs worldwide. It turned out after four years of negotiation with all responsible institutes in the US and Russia as well as Asia, that or the time being only three institutes have been ready to conduct there Key Comparisons at high pressure natural gas, namely PTB, NMi-VSL and LNE. All other institutions in the world refrained from participation as they have not been ready. The outcome of such a Key Comparison (KC) is the Key Comparison Reference Value (KCRV), which can be considered to be the best available realization of that quantity. The KCs for natural gas have been conducted in 2004, have been approved by the Committee

Consultative for Mass and related quantities (CCM) of the CIPM and have been published 2006 at the BIPM web-site as well as in the international journal Metrologia, see [1].

3. THE EUROPEAN ACTIVITIES

The aforementioned Key Comparisons for natural gas flow to he get the KCRV, the worldwide best realization of the gas cubic meter have followed strict guidelines and recommendation of the BIPM, which is the office of the CIPM. These recommended procedures for Key Comparisons among National Metrology Institutes (NMIs) have been prepared by the BIPM director's advisory group on uncertainties with members from all major NMIs. This expert group has summarized its recommendations in [11] in a very comprehensive way. Fig. 1 gives a overview on the calibration and measuring capabilities of the participating and completely independent primary standards of NMi-VSL, LNE and PTB.

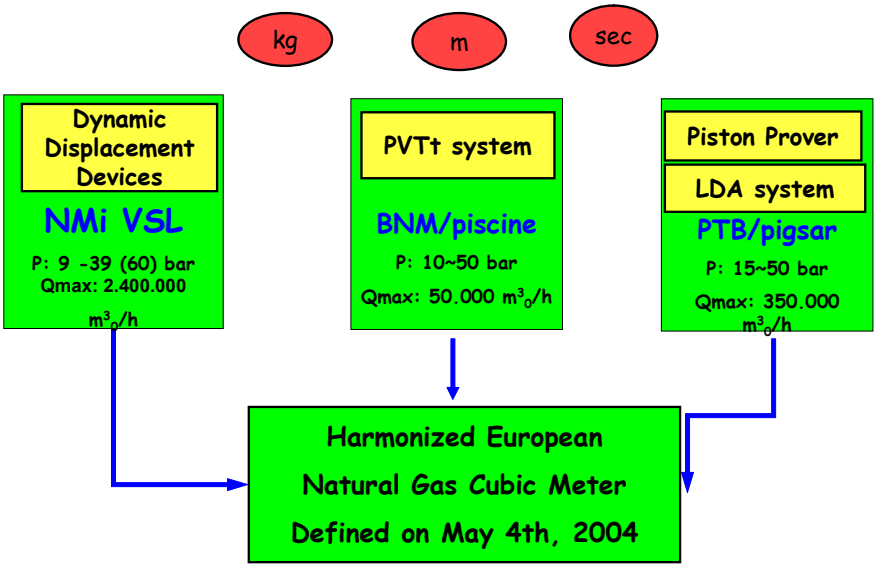

Fig. 1 visualizes the calibration and measuring range of the three completely independent national primary standards of NMi-VSL, LNE and PTB and their interaction to realize the Harmonized European Natural Gas Cubic Meter.

The European activities for the Harmonized European Gas Cubic Meter have followed the same guidelines and regulations and finalized their work in May 2004. Therefore, the KCs under supervision of the CIPM/CCM can be considered to be a confirmation of the Harmonized European Gas Cubic Meter as the worldwide best available realization of the high-press gas cubic meter.
However, the rules for the Harmonization process are up to a certain degree much stronger.

Prerequisites for Harmonization Procedure

In previous papers and mainly during the last FLOMEKO 2003 in Groningen and FLOMEKO 2004 in Guilin the authors have already described the harmonization procedure between PTB-***pigsar*** and NMi-VSL and partly with BNM in detail, see e. g. [3] and [4]. The participating facilities at NMi-VSL are presented in [5], the German National Standard ***pigsar*** has been described in [6] in detail. In addition, this conference proceedings give an update of the German facility, see [7].

The European Harmonized Reference Level or Gas Cubic Level comprises of a weighted average of three different individual national realizations of the gas cubic meter (reference levels). This weighted average is based upon the following metrological prerequisites:

#1. PTB, NMi-VSL and LNE operate independently realized Traceability-Chains.
At NMi VSL a system based on mass-comparison of gas-flow is in use (basis verification system), whereas the German National facility for high-pressure gas-flow standards, PTB-***pigsar*** has its traceability-chain in operation based mainly on a Piston-Prover as well as on LDA (Volume comparison plus density determination via pressure, temperature) and LNE applies the pVTt-method (mass comparison).

#2. The uncertainty-budget of each of the systems is fully known, understood and mutually accepted.

#3. A permissible difference between the three systems smaller than the Root Square Sum of the corresponding uncertainties (2σ) is established.

#4. The stability of each chain (sets of reference values) is demonstrated. Stability refers to the reproducibility of the Reference Values over the years.

#5. The Degree of Equivalence is established (based on historic performance and on accepted uncertainties).

This procedure has been applied in all overlapping flow rate and pressure ranges of ***pigsar-*** PTB, NMi-VSL and LNE. This ancillary condition can be considered as prerequisite
LNE, PTB and NMi-VSL have applied three to four sets of different turbine meters (two in series) to allow a maximum of overlap. In addition, we have applied a choked nozzle too.

Fig. 2 presents the calibration and measuring capabilities of the participating NMIs in the harmonization procedure as well as in the Key Comparison procedure. The degree of overlap in flow rate and pressure range is quite large. This allows detailed comparisons at the same conditions for flow rate as well as pressure. It shall be pointed out, that only a very few facilities worldwide overlap so well.

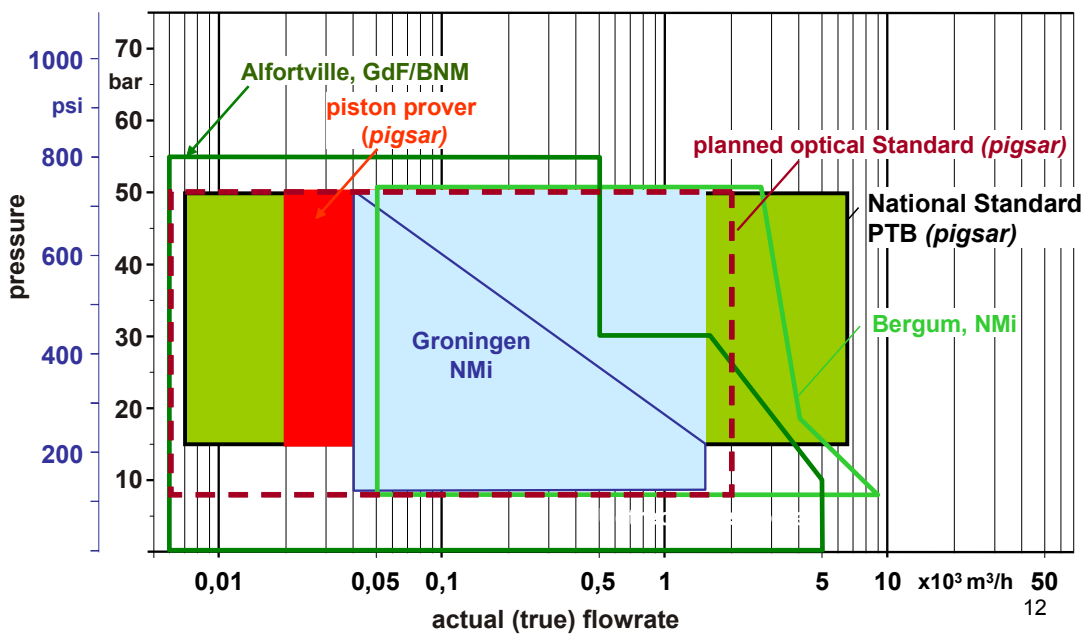

Fig. 2: Calibration and measuring capabilities of the European National Facilities PTB-***pigsar***, NMi-VSL and LNE, the former BNM. Harmonization has realized mainly applied in the overlapping range of flow rate and pressure.

All partners have agreed to search continuously for improvements of the metrological independent traceability chains to meet future demands for more stable Reference Values with smaller uncertainties. The main benefit for customers is the same and equivalent calibration of meters at any calibration test rig in Germany, The Netherlands and France. The harmonization as accomplished by PTB, NMi-VSL and LNE is principally open to third parties if all five prerequisites can be met and if it is practically feasible. So far however, there is no other national facility available in the world, which meets all prerequisites.

The result of the harmonization procedure is presented in Fig. 3 showing one of the many comparisons and the weighted mean between the three partners. They all have agreed to accept this weighted mean as their common reference level. This common reference level is indicated in Fig. 3 by the blue line, for which an assorted uncertainty has been calculated, see blue dashed line in Fig. 3. It can be recognized from Fig. 3, that all uncertainty bars of the labs overlap nicely with the common reference level as well as with each other.

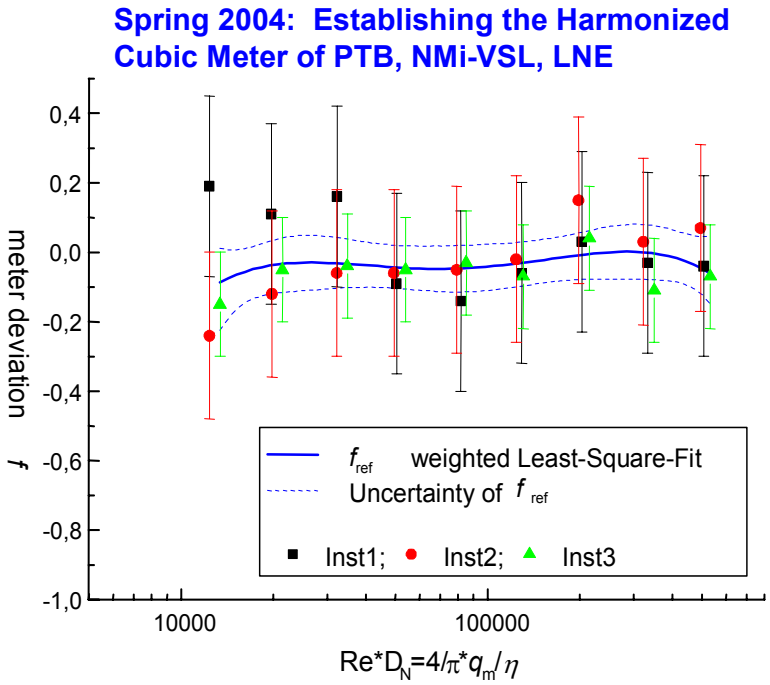

Fig. 3: Visualization of an intercomparison during the harmonization procedure among PTB(Inst3), NMi-VSL(Inst2) and LNE(Inst1). in order to get the common reference level, the blue line. This blue line has been taken as the Harmonized European Reference Level and has been disseminated sine May 4th, 2004.

4 THE CIPM KCRVs and the EUROPEAN HARMONIZED REFERENCE VALUE

The CIPM decided, in accordance with the CIPM Mutual Recognition Arrangement (MRA) [8], to conduct Key Comparisons (KCs) [9] among national primary standards of selected NMIs in the subject field high-pressure gases. This includes natural gas and compressed air and/or Nitrogen. The members of the responsible CCM Working Group for Fluid Flow (WGFF) elected PTB and NMi-VSL as the pilot laboratories for this Key Comparison (KC).

All facilities worldwide have been invited to participate, but all of them have not been ready, but the European ones, namely PTB-***pigsar***^{TM}, NMi-VSL, and LNE. Fig. 4 gives an overview of the most important high-pressure gas facilities in the world. The privately operated facilities have been marked with red crosses, as they did not participate and as they do not disseminate under supervision of the national metrology institutes.

Please note, that the following countries do not maintain their own national standards for high pressure natural gas calibration: USA; Russia and Asia, in spite of their very large gas consumption. The KCs have been conducted in autumn 2004 and the final results have been published in January 2006, see [1].

The KCs have been done in accordance to the *Guidelines for CIMP Key Comparisons* [9] and have been performed to fulfill the requirements of the CIPM MRA [8] and the requirements from the CIPM Committee Consultative for Mass and Related Quantities [10]. The aim of these KCs is to verify the claimed Calibration and Measurement Capabilities (CMCs) of the NMIs and to quantify the degree of equivalence of the national flow standards as maintained in the participating NMIs. In addition, a CIPM Key Comparison Reference Value (KCRV) should be the outcome of a key comparison. To achieve the intended quantification, these KCs are intended to produce a set of tabulated results: the first set of tables presents the measured differences between the participants and the KCRV and the second set will quantify the laboratory-to-laboratory equivalencies with the associated uncertainties of these differences, and the last set shall comprise the degree of equivalence of all laboratories to the KCRV.

The German PTB has been elected to pilot the Key Comparisons among all NMIs worldwide. It turned out after four years of negotiation with all responsible institutes in the US and Russia as well as Asia, that or the time being only three institutes have been ready to conduct there Key Comparisons at high pressure natural gas, namely PTB, NMi-VSL and LNE. All other institutions in the world refrained from participation as they have not been ready. The outcome of such a Key Comparison (KC) is the Key Comparison Reference Value (KCRV), which can be considered to be the best available realization of that quantity. The KCs for natural gas have been conducted in 2004, have been approved by the Committee Consultative for Mass and related quantities (CCM) of the CIPM and have been published 2006 at the BIPM web-site as well as in the international journal Metrologia, see [1].

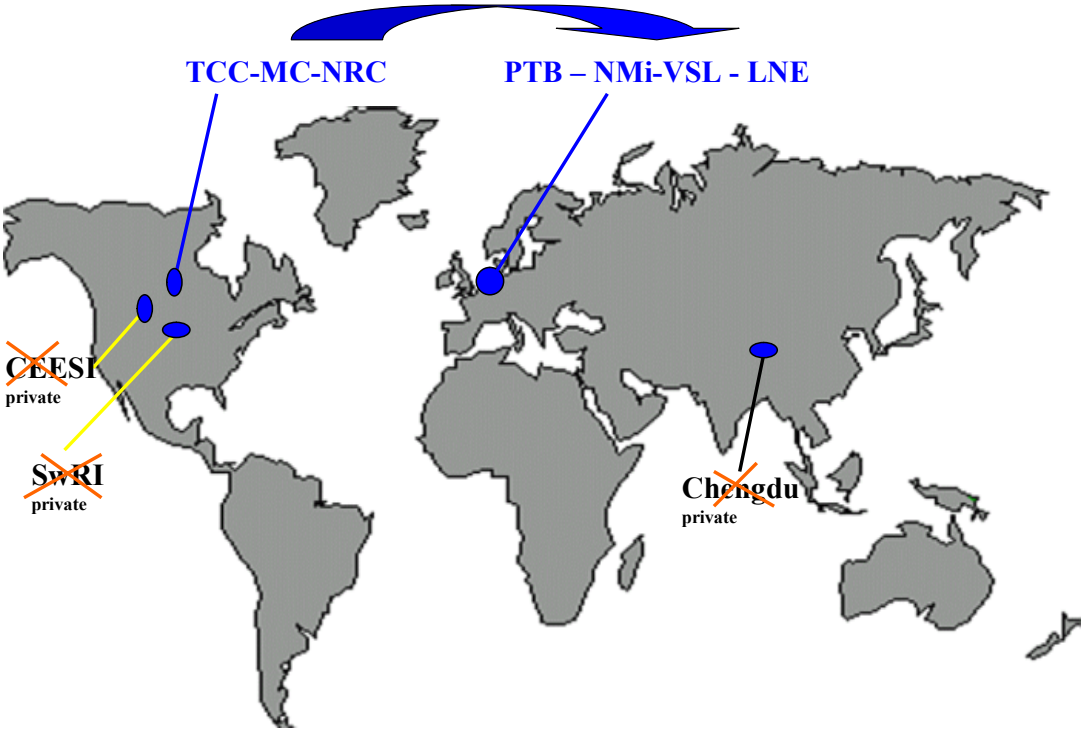

Fig. 4 Overview of all high-pressure calibration facilities for natural gas worldwide. The facilities in Europe, PTB, NMI-VSL and LNE are national standards as well the Canadian facility TCC; which is under supervision of NRC. All other facilities are private institutes or companies are disseminating their own individual units for gas flow, which are not supervised by a national metrology institute.

The blue arrow in Fig. 4 between TCC and the European facilities indicates the traceability between the European facilities and the Canadian national standard TCC-NRC. Canada is since a couple of years fully traceable to the European Harmonized reference value.

As obviously the participants of the CIPM Key Comparisons are the same as the participants of the procedure for the Harmonized European Natural Gas Cubic Meter, the KCRV of the CIPM-KCs must be the same as the harmonized European reference level.

Fig. 5 shows the test points which have been used for the CIPM KCs in the flow rate range between 65 and 1000 m3/h and pressures between 10, 20 and 47 bar in order to get the desired data for the demonstration of the equivalence of the labs and the key comparison reference value (KCRV), which can be considered to be the best available realization of the natural gas cubic meter.

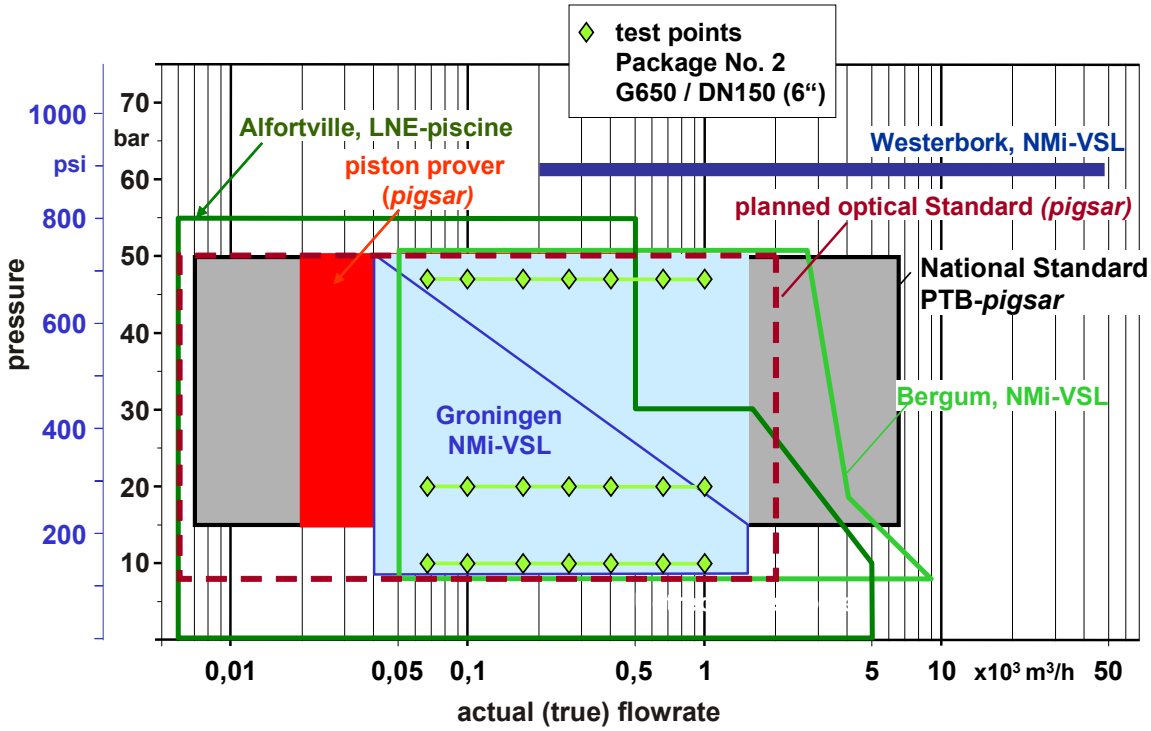

Fig.5: Visualization of selected flow rates as well as pressures during CIPM/KCs among PTB-***pigsar***^{TM}, LNE-LADG (BNM-LNE) and NMi-VSL

It shall be mentioned here that during the harmonization procedure much more comparison work has been done at all pressures and flow rates to get the best available reference values.

In order to get the KCRV or the Harmonized Reference Value, the weighted average / mean of the calibration results at all the facilities have been used as described by Cox, see [11]. This is the procedure recommended by an advisory group on statistics as explained in [11]. The pilot lab has decided to follow the BIPM recommendations and the weighted mean has been taken for the KCRV function. The weighing factors are the claimed and mutually recognized uncertainties (u^{-2})of the facilities. The KCRV will be calculated as:

KCRV = weighted mean y

$$y = \frac{\frac{x_1}{u^2(x_1)} + \ldots\ldots + \frac{x_N}{u^2(x_N)}}{\frac{1}{u^2(x_1)} + \ldots\ldots + \frac{1}{u^2(x_N)}}$$

This KCRV is associated with its uncertainty u^2 as follows:

Variance associated with KCRV *y*

$$\frac{1}{u^2(y)} = \frac{1}{u^2(x_1)} + ... + \frac{1}{u^2(x_N)}$$

N is the number of equivalent participants, which are participating using their metrological independent facilities.

Very stable transfer packages using turbine meters have been selected for these KCRVs.

In order to demonstrate the excellent results of the CIPM KCs, some of the comparisons might be shown here in Fig. 6 and 7. A G650 transfer package has been used, comprising of an Elster-Instromet turbine and ultrasonic meter put in series to do the comparisons at 3 different pressures. This package show excellent reproducibility and stability. For clearness of this presentation, “non-harmonized”, namely the original facility data have been used here in the CIPM KC.

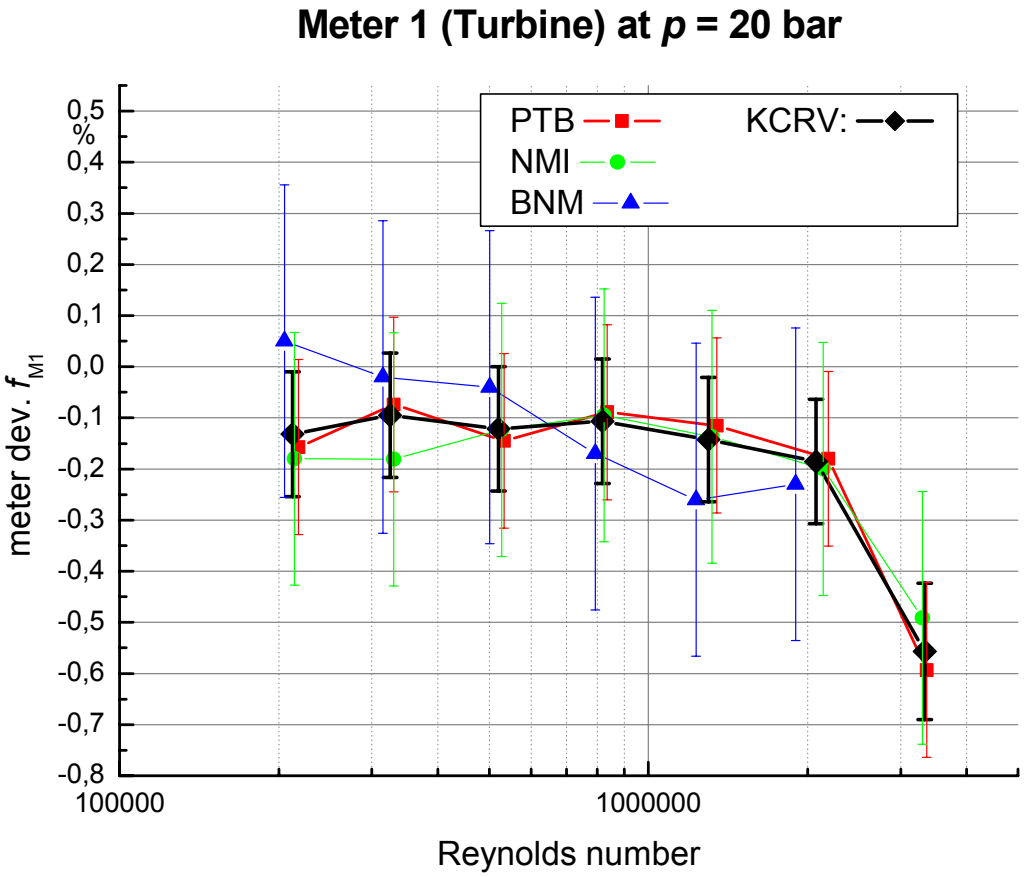

Fig. 6: Calibration of a turbine transfer standard at PTB, NMi and LNE, the former BNM at 20 bar during the BIPM/CIPM KCs. The high degree of equivalence is quite obvious, as all error bars are overlapping very well with all partners and with the KCRV.

From Fig. 6 the following conclusions can be drawn:
All NMIs are equivalent to each other within their claimed uncertainties, as all uncertainty bars are overlapping very nicely.
The degree of equivalence of all three NMIs with the KCRV couldn't be much better. The KCRV is considered to be the best available realization of the Natural gas cubic meter (flow) at high pressure. As mentioned before, this KCRV is identical with the Harmonized European Reference Level or Gas Cubic Meter. This is, because the European NMIs and their calibration facilities do disseminate the KCRV itself since May 4th 2004.

Fig. 7 presents similar Key Comparison results using ultrasonic meter at 47 bar.

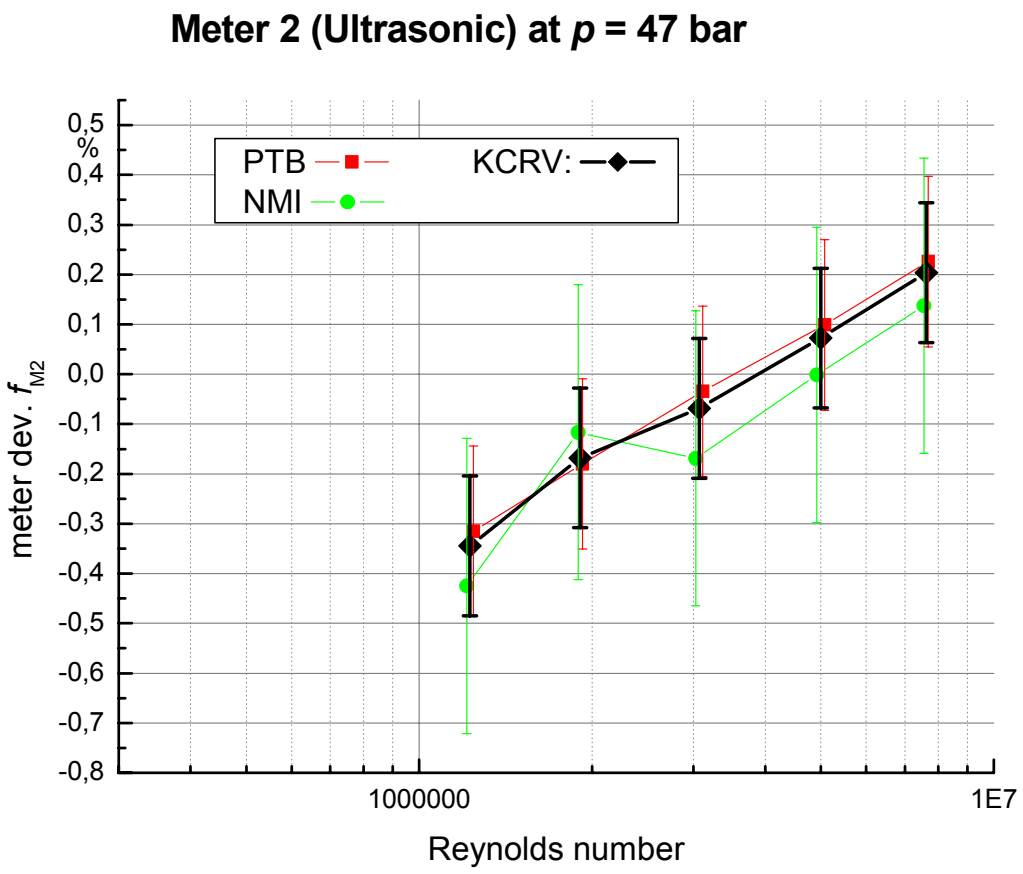

Fig.7: Calibration of an ultrasonic meter (Instromet G1000) turbine transfer standard at PTB and NMi at 47 bar during the CIPM KCs. The high degree of equivalence is obvious, as all error bars are overlapping very well with all partners and with the KCRV. LNE could not participate here, compare Fig. 2.

The black lines in Fig. 6 and Fig. 7 visualize the KCRV function of the facilities and represent the best available realization of the natural gas cubic meter for natural gas at high pressure. The uncertainties of this KCRV function have also been shown in Figs. 6 and 7 in order to demonstrate that the KCRV is associated with an adherent smaller uncertainty than the participating facilities actually have. It has been proven, that PTB, NMi-VSL and LNE claim realistic and reliable uncertainties, namely 0,16% for PTB-*pigsar*, 0,30 % for LNE and 0,23 % -0,28 % for NMi-VSL.

This is actually the big advantage for metrological applications, as the European facilities do disseminate this (black) KCRV function. This KCRV function has been marked in blue in Fig. 3. Therefore, the Harmonized European Gas Cubic Meter can claim a small uncertainty and shows – this is the most important fact – a very time-independent stability over years; compare the prerequisites for the harmonization procedure. The latter property is extremely important for companies to get their gas balance.
The last important benefit for the customer and metrology is, that the users can't divide the market and more into a seller and buyer market by making use of even small differences between calibration facilities.

The positive outcome for the customer is, that he gets always the same calibration in Germany and the Netherlands (as well as in France) at any test facility and he can enjoy the benefit of a very stable and small uncertainty of the harmonized reference value. In the meantime, this Harmonized European Gas Cubic Meter has been accepted in nearly all West European countries.

This Harmonized European Natural Gas Cubic Meter will be disseminated towards all countries and all facilities in Europe (West and East). In the meantime it has already been accepted by the Canadian NMI, the NRC in Canada. In the meantime nearly all European calibration facilities and authorties have accepted this reference value, which is highly acknowledged by all gas companies.

At last it shall be pointed out here, that the full report on the CIPM Key Comparisons is available on the internet at the BIPM website and has been published online at the international journal Metrologia as mentioned in ref. [1].

5. REFERENCES

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Results for natural gas comparisons available at:
http://kcdb.bipm.org/AppendixB/KCDB_ApB_search.asp
and then search for **CCM.FF-K5.a** to get access to all KC data including the full report. Click on CCM.FF-K5.a Final Report. to get the final report on the CIPM Key Comparisons for Natural gas at high pressure.

or

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