Internationale Durchflußmessung und Aktivitäten

D. Dopheide et al., PTB Braunschweig

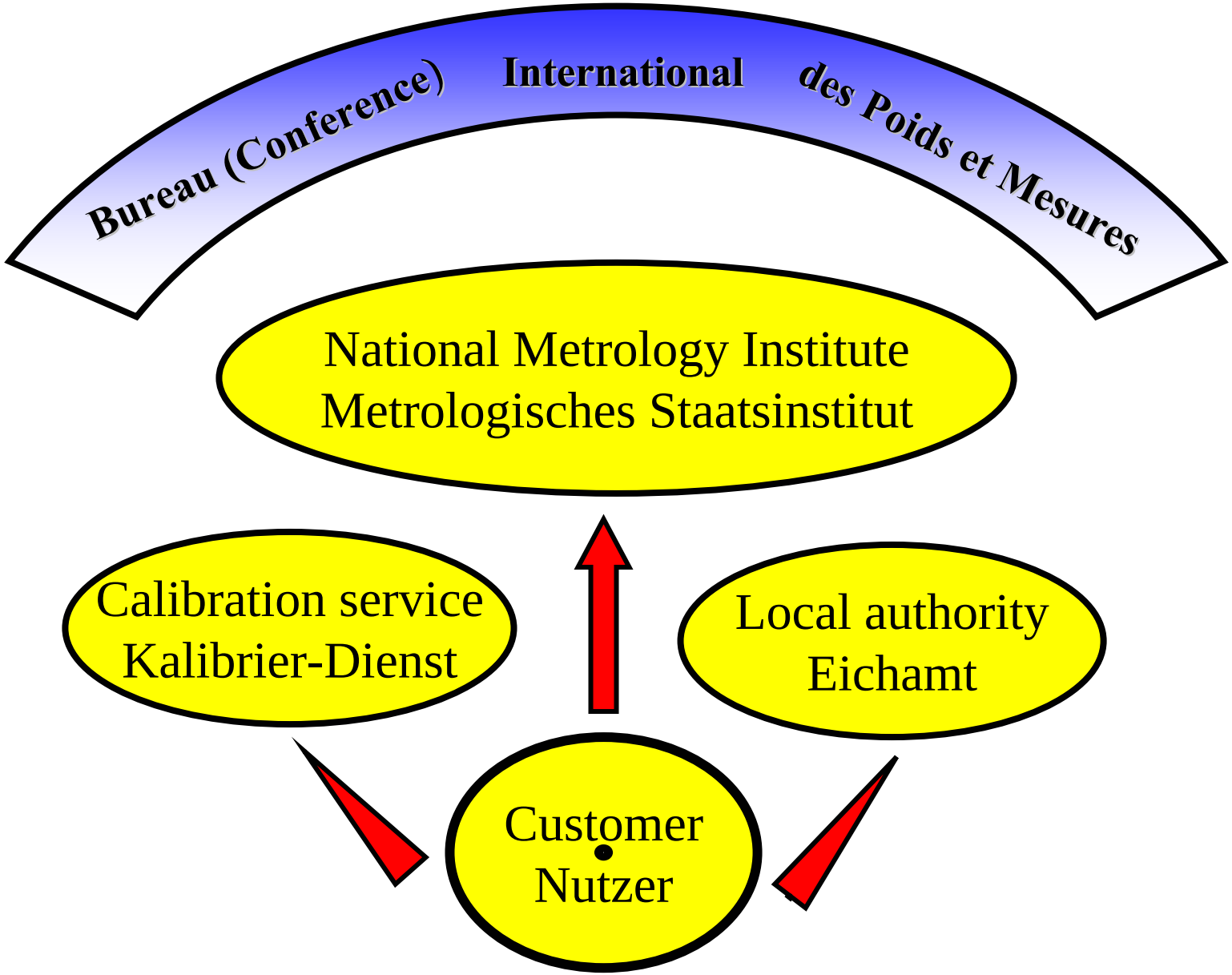
EMATEM Sommerschule
„Aktuelle Probleme der Wärememengen- und Durchflußmessung“

23-25 August 2005 Kloster Seeon

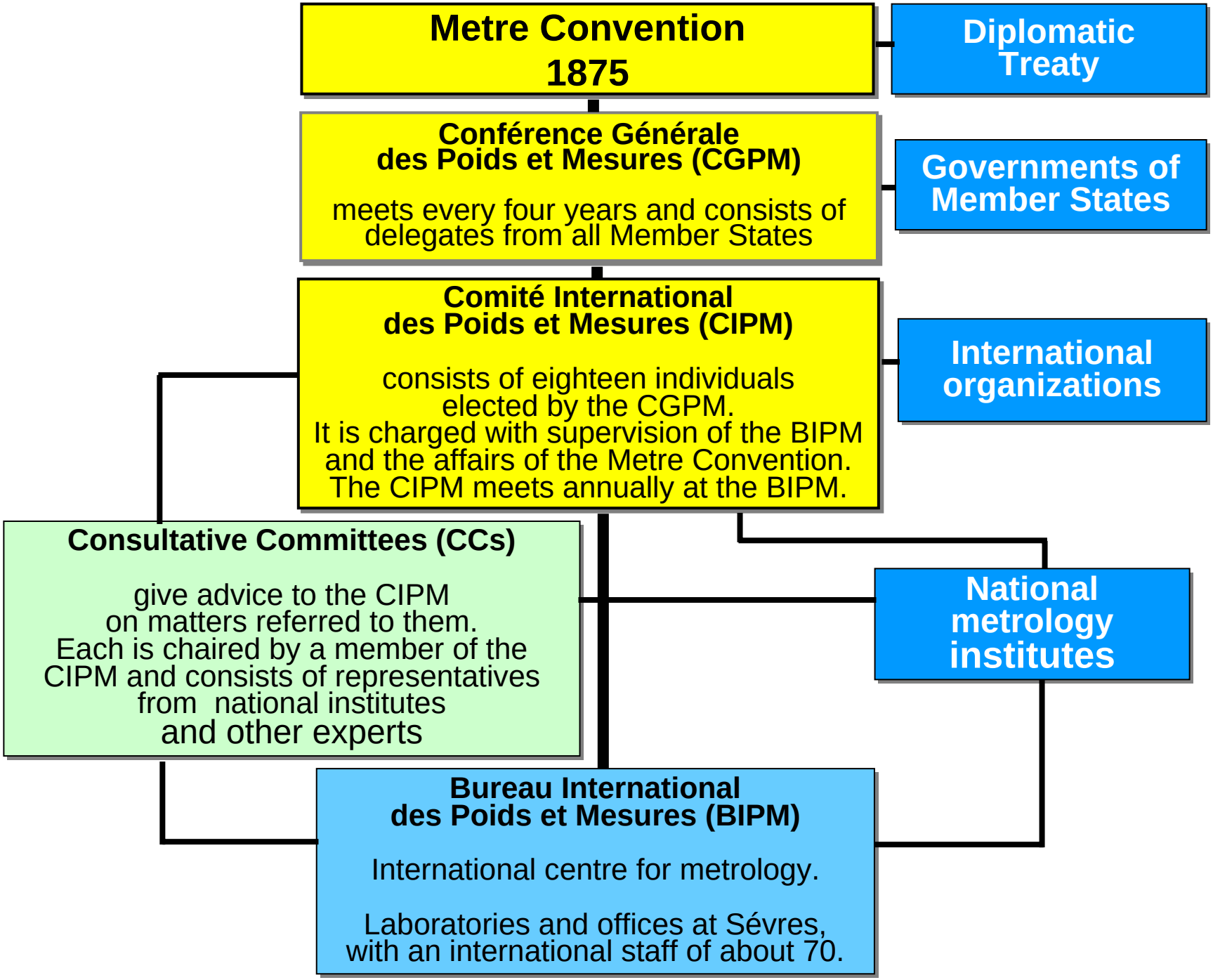
Inhalt:

Metrologie-Organisationen
BIPM/CIPM Initiativen
Mutual Recognition Arrangement (MRA)
Weltweite Ringvergleiche (Key Comparisons)
Calibration and Measuring Capabilities (CMCs)

Übersicht über weltweit vorhandene Kalibriereinrichtungen (NMIs)
Gas, Wasser, Öle etc.



Tracebility Chains for Measurements


Metre Convention
1875
Diplomatic Treaty
Conférence Générale des Poids et Mesures (CGPM)
meets every four years and consists of delegates from all Member States
Governments of Member States
Comité International des Poids et Mesures (CIPM)
consists of eighteen individuals elected by the CGPM.
It is charged with supervision of the BIPM and the affairs of the Metre Convention.
The CIPM meets annually at the BIPM.
International organizations
Consultative Committees (CCs)
give advice to the CIPM on matters referred to them.
Each is chaired by a member of the CIPM and consists of representatives from national institutes and other experts
National metrology institutes
Bureau International des Poids et Mesures (BIPM)
International centre for metrology.
Laboratories and offices at Sévres, with an international staff of about 70.

Mutual Recognition Agreement
CIPM-MRA

Acrobat-Dokument

Signed 1999

by about 60 countries, incl. China, USA, Russia etc

Supported by the WTO

MRA Signatories (50):

Argentina
Australia
Austria
Belgium
Brazil
Bulgaria
Canada
Chile
China
Cuba
Czech Republic
Denmark
Ecuador
Egypt
Finland
France
Germany
Greece
Hungary
Hong Kong
India
Ireland
Italy
Japan
Korea
Latvia
Lithuania
Malaysia
Malta
Mexico
Netherlands
New Zealand
Norway
Poland
Portugal
Romania
Russia
Singapore
Slovak Republic
South Africa
Spain
Sweden
Switzerland
Thailand
Turkey
UK
Uruguay
US

Int'l Orgs:

Int'l Atomic Energy Agency (IAEA)
Inst. for Refr. Matls and Msmts (IRMM)

Mutual Recognition Arrangement (MRA*)

...produced by CIPM under the authority of the Meter Convention for signature in 1999 by the directors of the NMIs of the Member States of the Convention.

Objectives:

- **to establish the degree of equivalence of *national measurement standards* maintained by the NMIs;**
- **to provide for the mutual recognition of *calibration and measurement certificates* issued by the NMIs;**
- **thereby to provide governments and other parties with a secure technical foundation for wider agreements related to international trade, commerce, and regulatory affairs.**

Process:

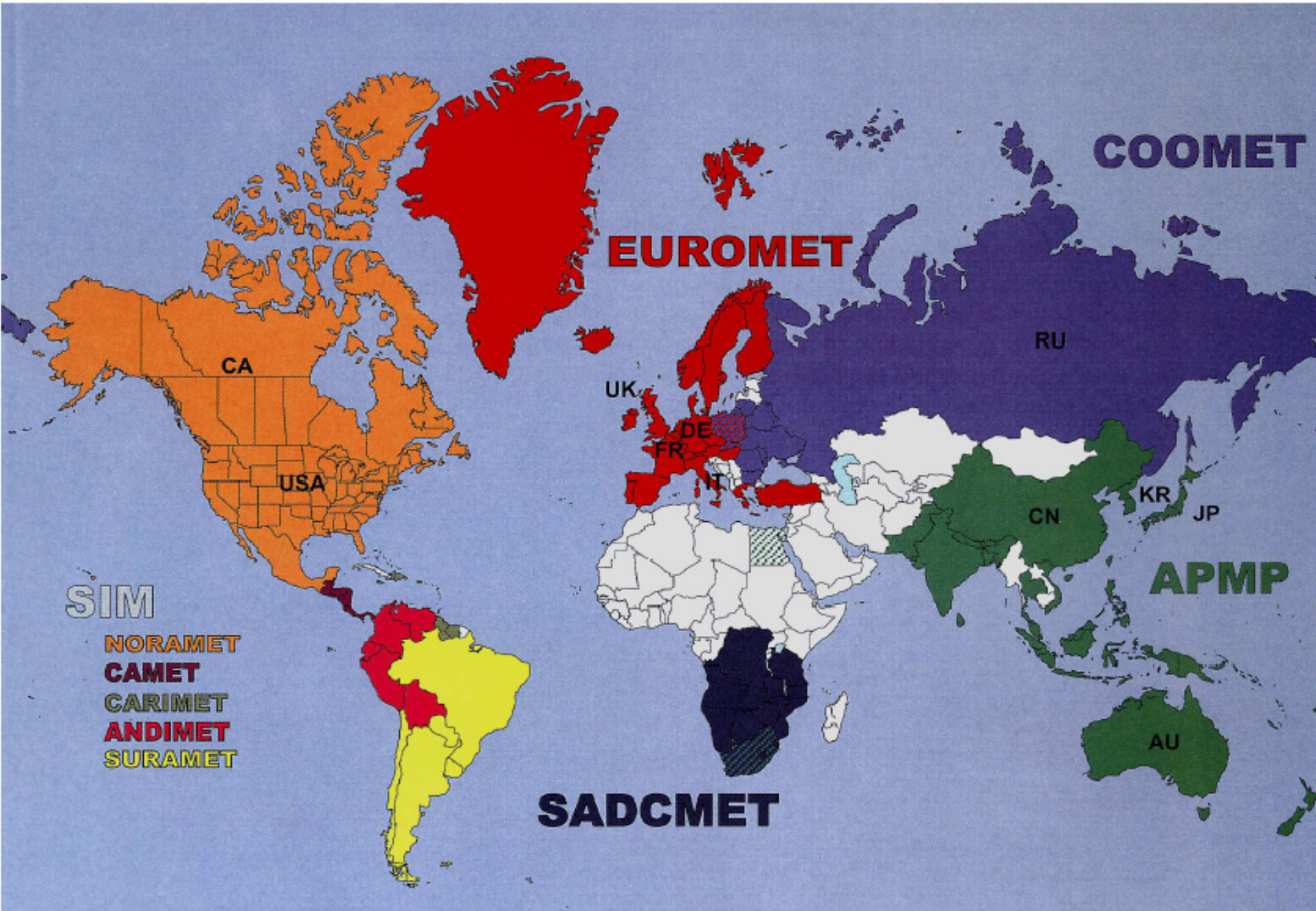
- **international comparisons ~ CIPM KCs,**
- **supplementary comparisons ~ Regional Metrology Organization (RMO) KCs, etc.**
- **quality systems and demonstrations of competence by NMIs.**

Outcome:

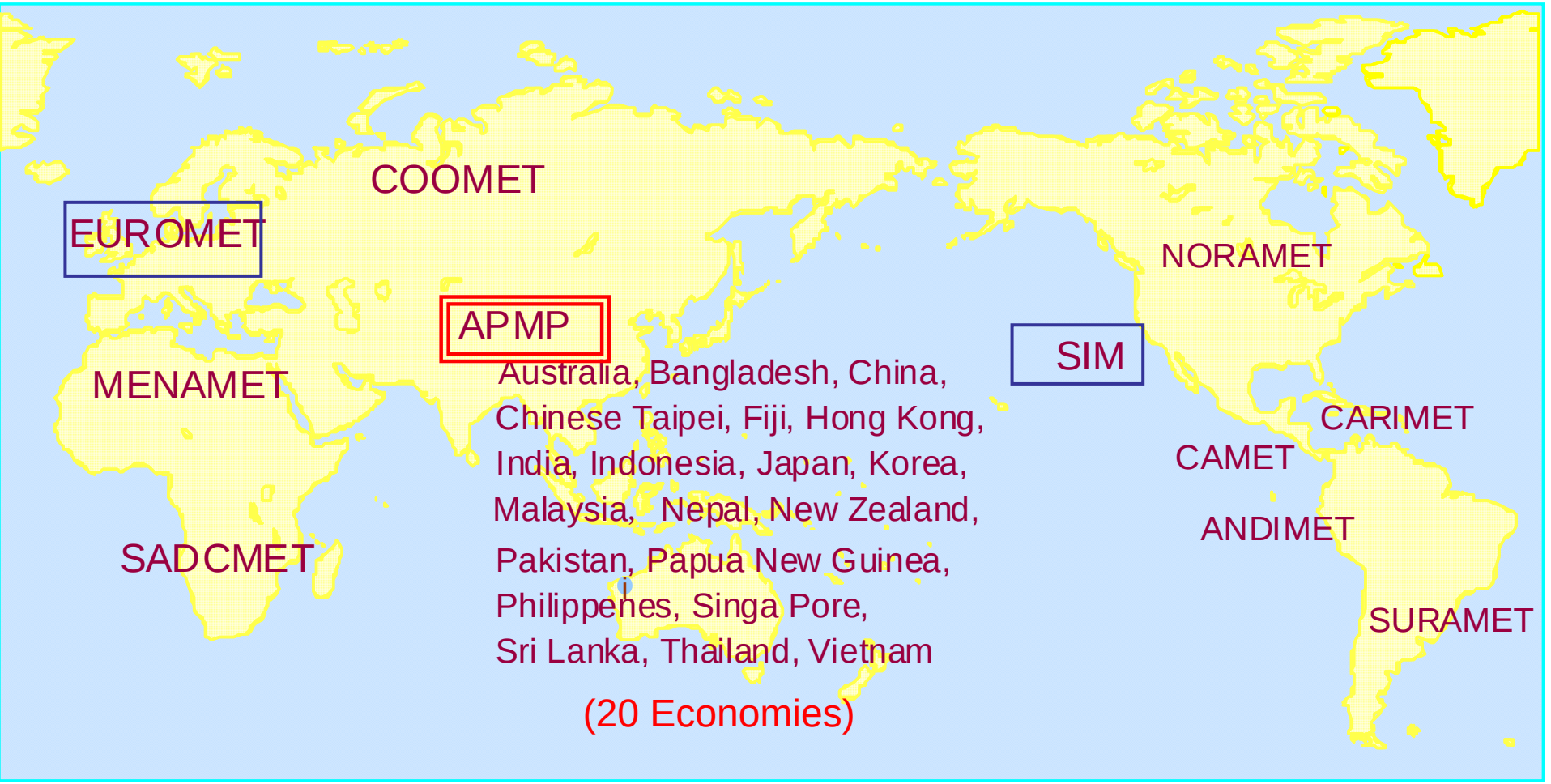
Statements of the measurement capabilities of each NMI in a data base maintained by the BIPM and publicly available on the Web.

*** See www.bipm.fr for details on the BIPM, CIPM, and the MRA.**

Regional Metrology Organizations

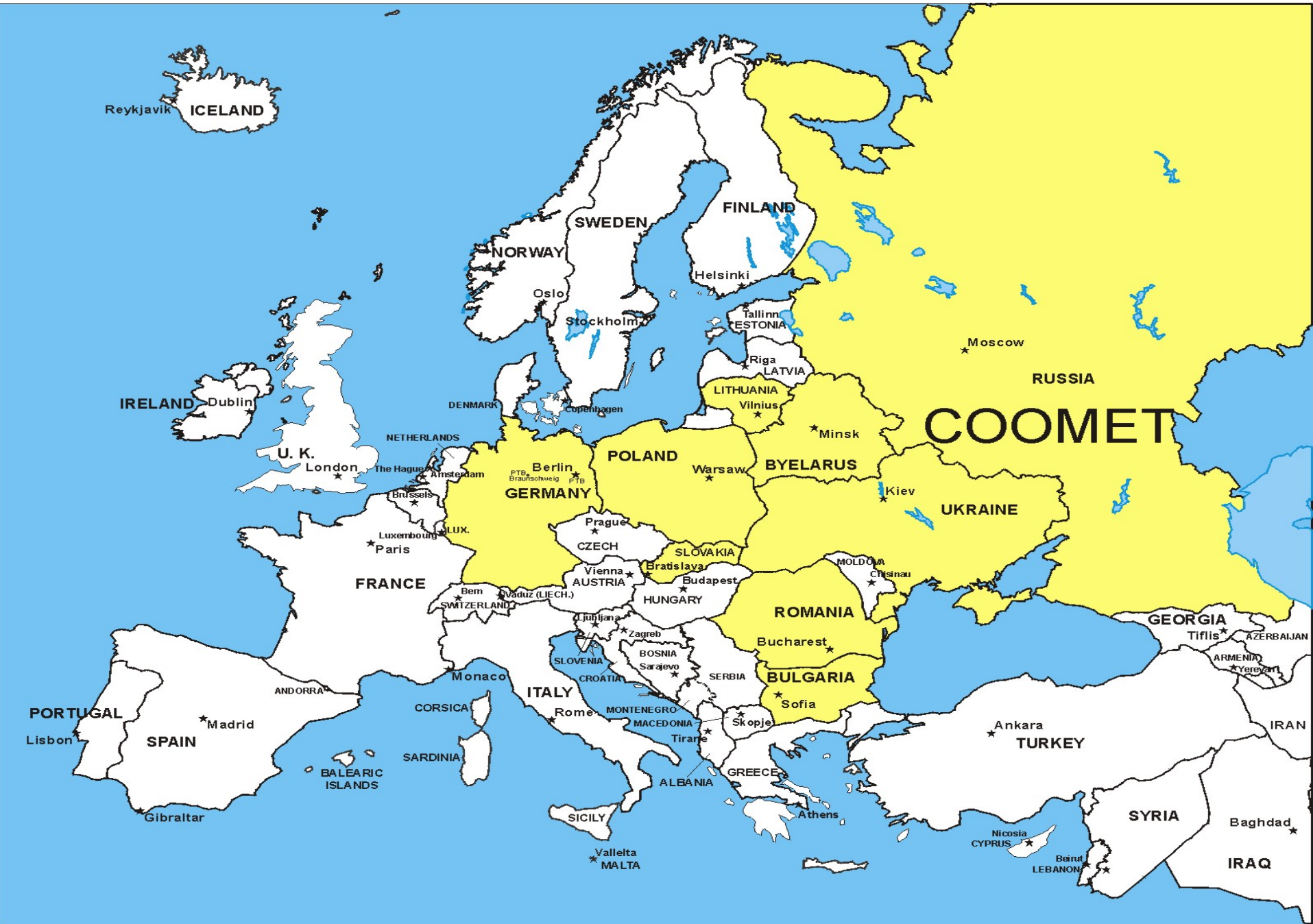


APMP and other RMOs

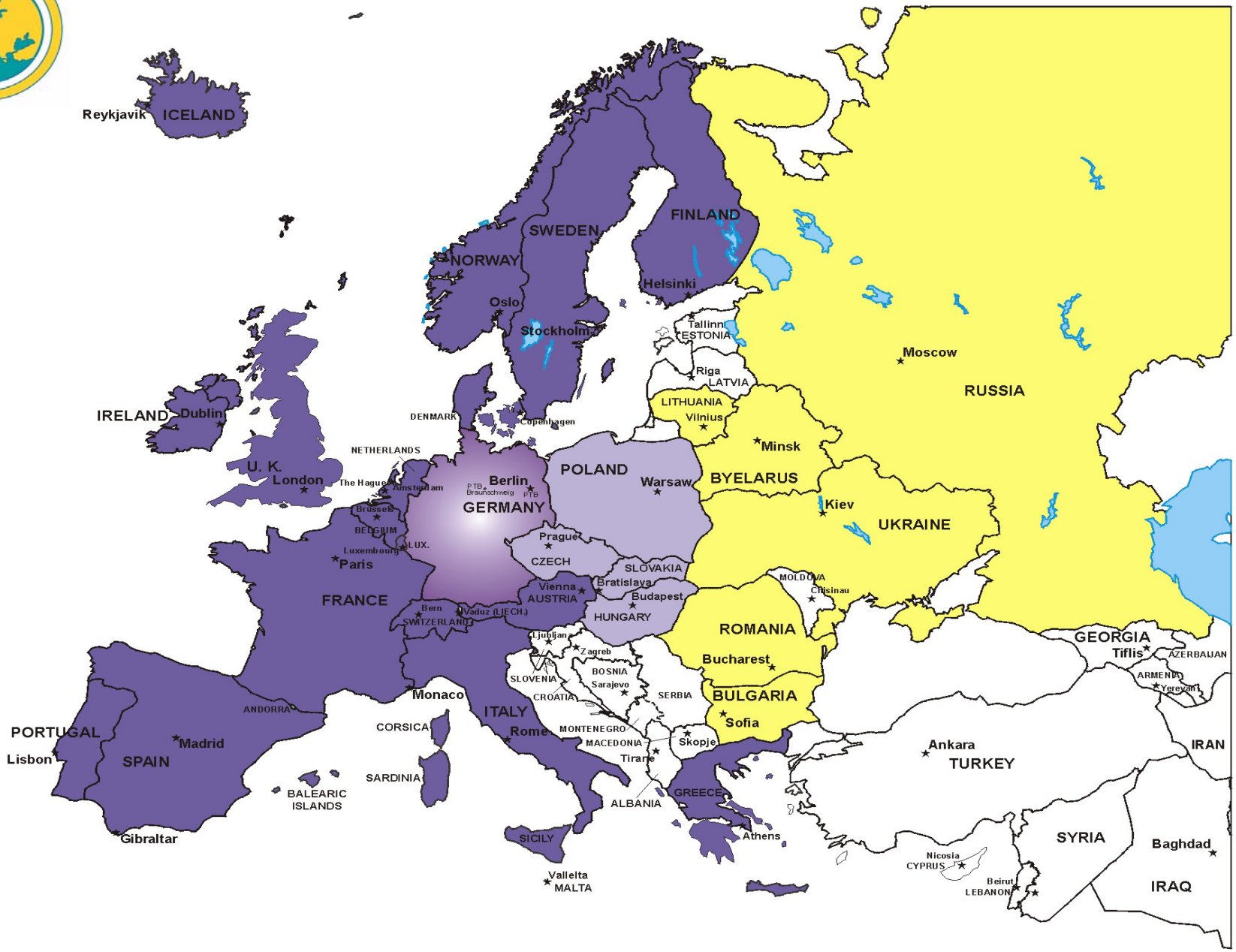


SIM Structure

Regional Metrology Organization COOMET



EUROMET + COOMET



EUROMET:
Its Objectives and Achievements

Membership and organisation

25 Full Members (Signatories)

EU 16 EFTA 3 PECO 5 other 1

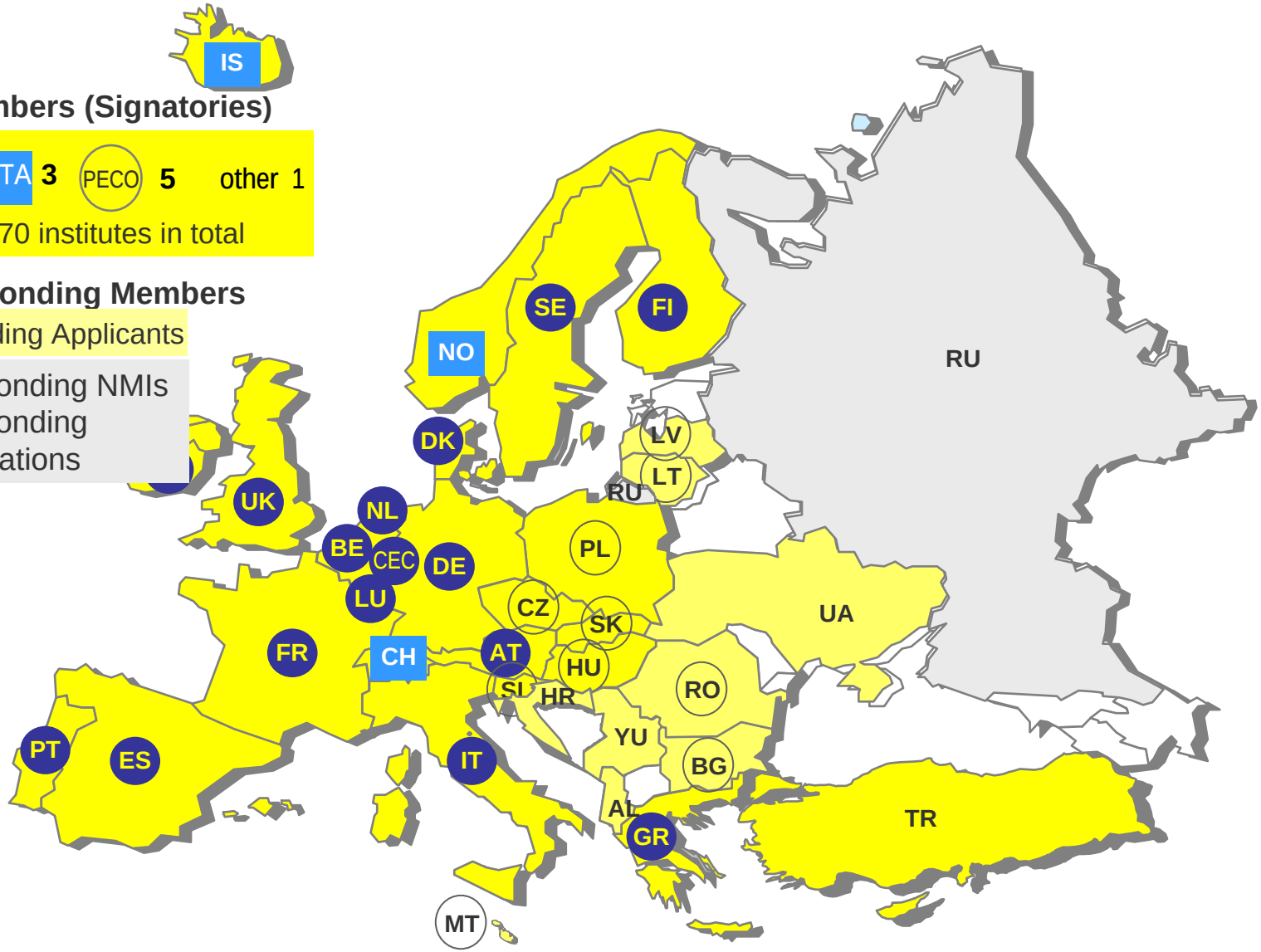
comprising ~70 institutes in total

25 Corresponding Members

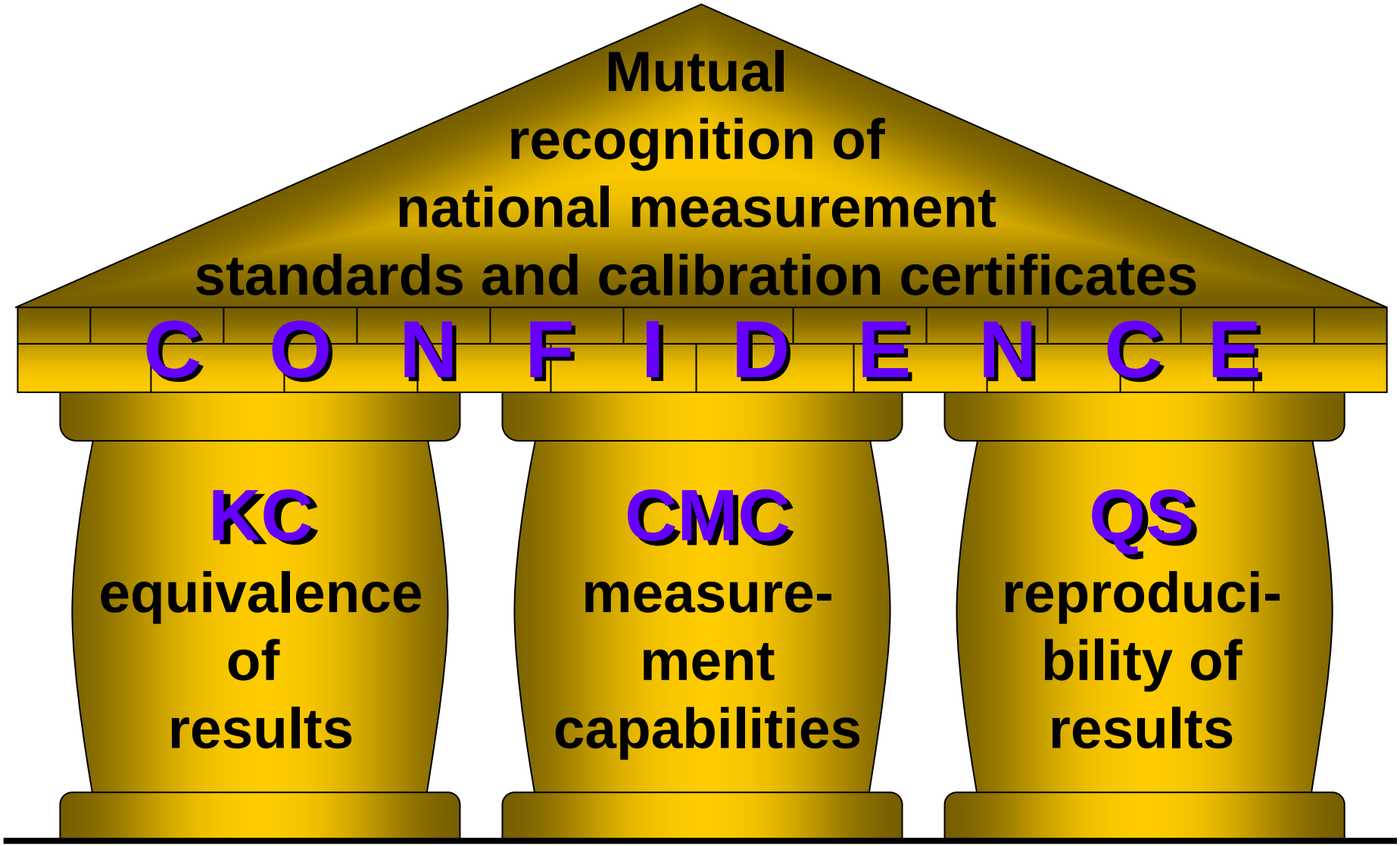
9 Corresponding Applicants

2 Corresponding NMIs

14 Corresponding Organisations



Implementation of MRA



Tasks of EUROMET for the MRA

KC: Coordinate EUROMET Key Comparisons, define and coordinate Supplementary Comparisons.

CMC: Review EUROMET CMCs, review samples of CMCs of other RMOs.

QS: Review QS of EUROMET Members

Collaboration types of EUROMET

Cooperation
in research

Comparison
of measurement standards

Consultation
on facilities

Traceability
projects

EUROMET Organisation

EUROMET Committee
25 Delegates

Executive Committee
8 Members
incl. Chairman &
past Chairman or
Chairman elect

EUROMET Chairman
with
Secretary

11 Technical Committees
of
11 Subject Fields
chaired by
11 TC Chairmen

Subject Fields of EUROMET

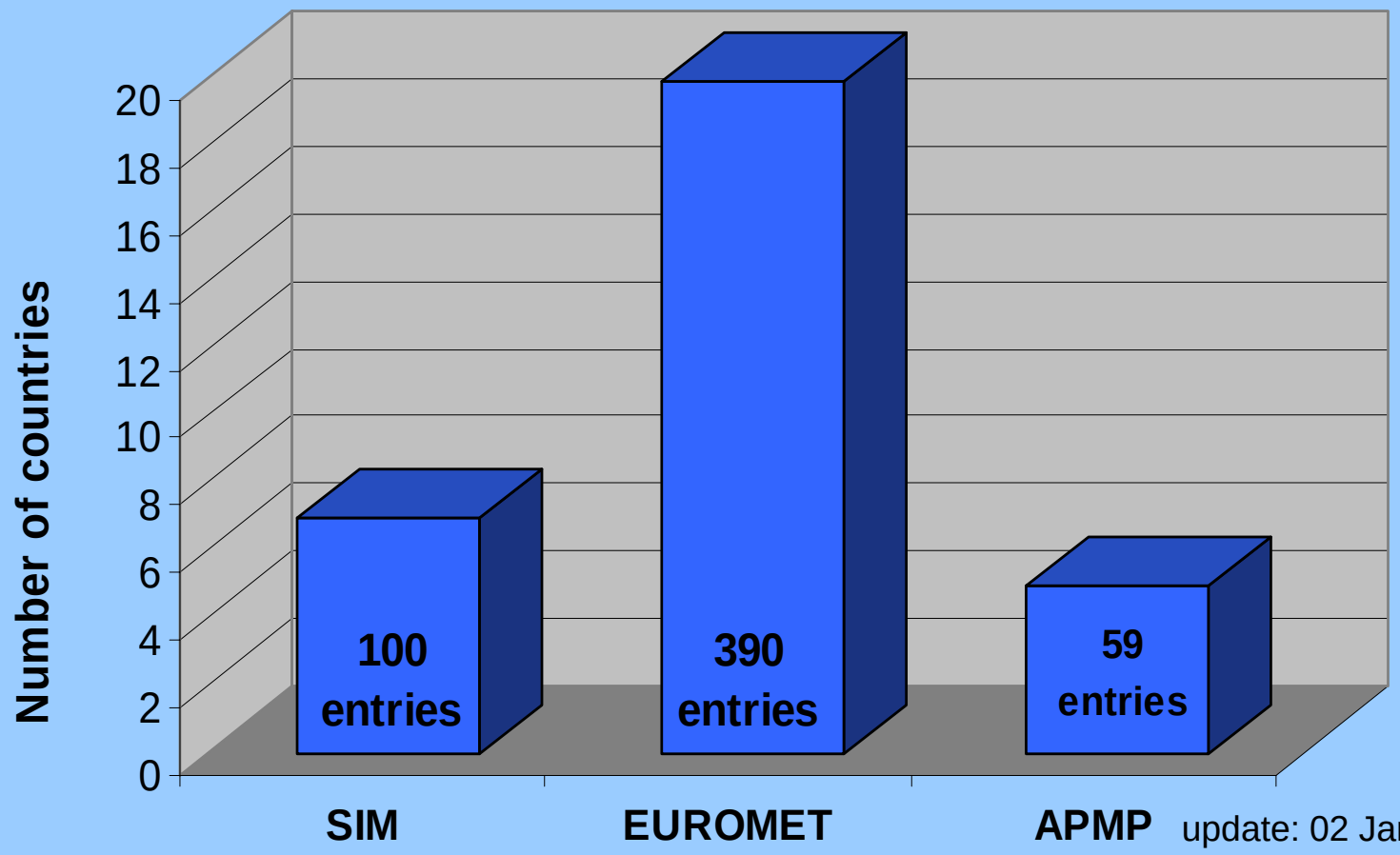
- **Acoustics, ultrasound and vibration**
- **Electricity and magnetism**
  - DC and quantum metrology
  - Low frequency
  - Radiofrequency and microwaves
- **Flow**
- **Interdisciplinary metrology**
- **Ionising radiation**
  - Photon dosimetry
  - Radioactivity
  - Neutron measurements

Subject Fields of EUROMET

- <u>Length</u>
- <u>Mass and related quantities</u>
  - Force
  - Pressure
  - Mass
- <u>Metrology in chemistry</u>
  - Gas
  - Organic
  - Inorganic
  - Electrochemistry
- <u>Photometry and radiometry</u>
- <u>Thermometry</u>
- <u>Time and frequency</u>

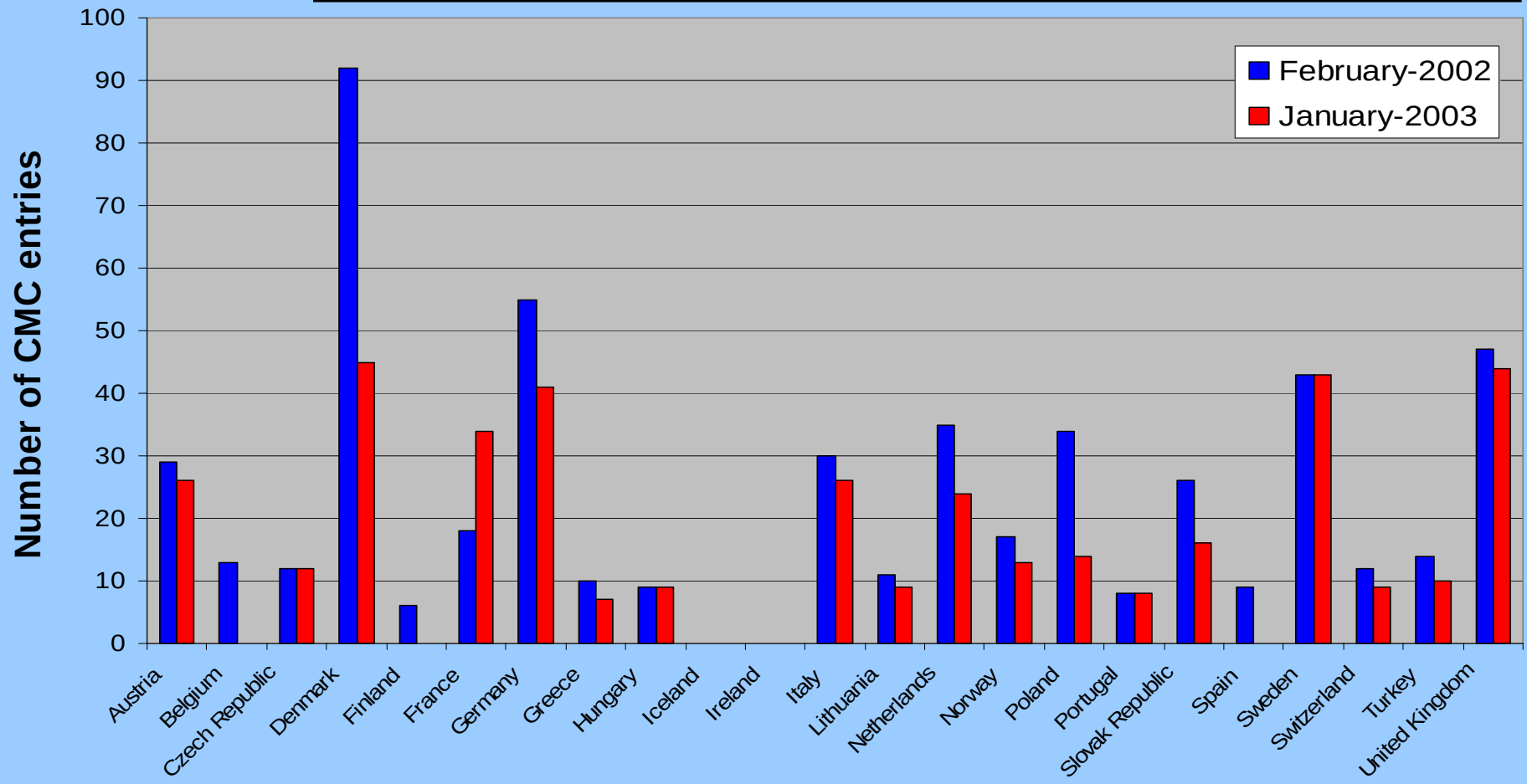
Flow Section: EUROMET 2003

Number of participating countries and CMC flow entries per RMO



update: 02 January 2003

EUROMET-Flow Section: 2003



update: 02 January 2003

Calibration and Measuring Capabilities (CMCs) of all NMIs in different Regional Metrology Organizations (RMOs)

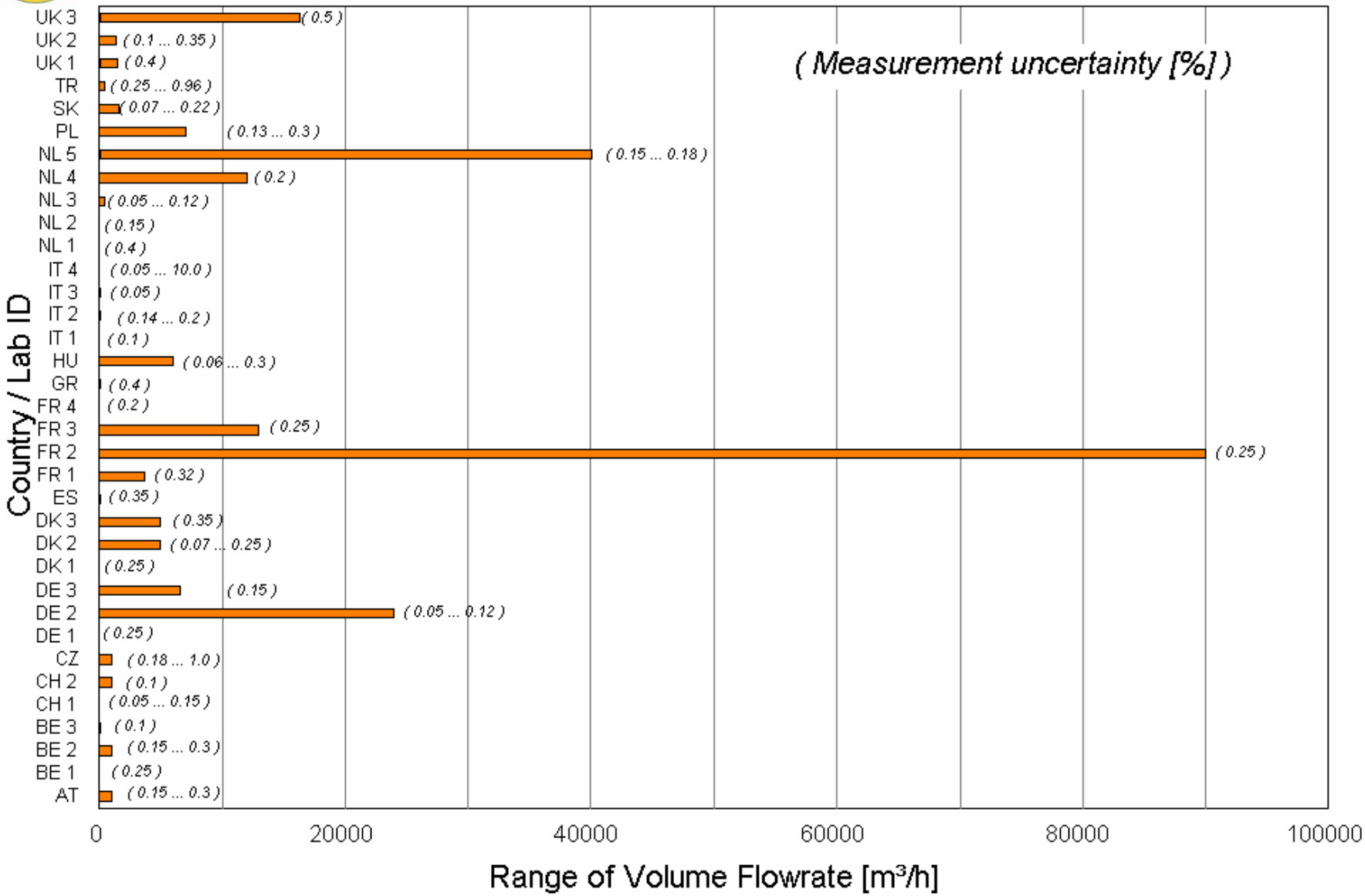
NMI = National Metrology Institute

CMCs of European NMI for gas

European NMIs' Calibration Facilities

Test fluid: Gas(es)

Euromet Flow Rapporteur

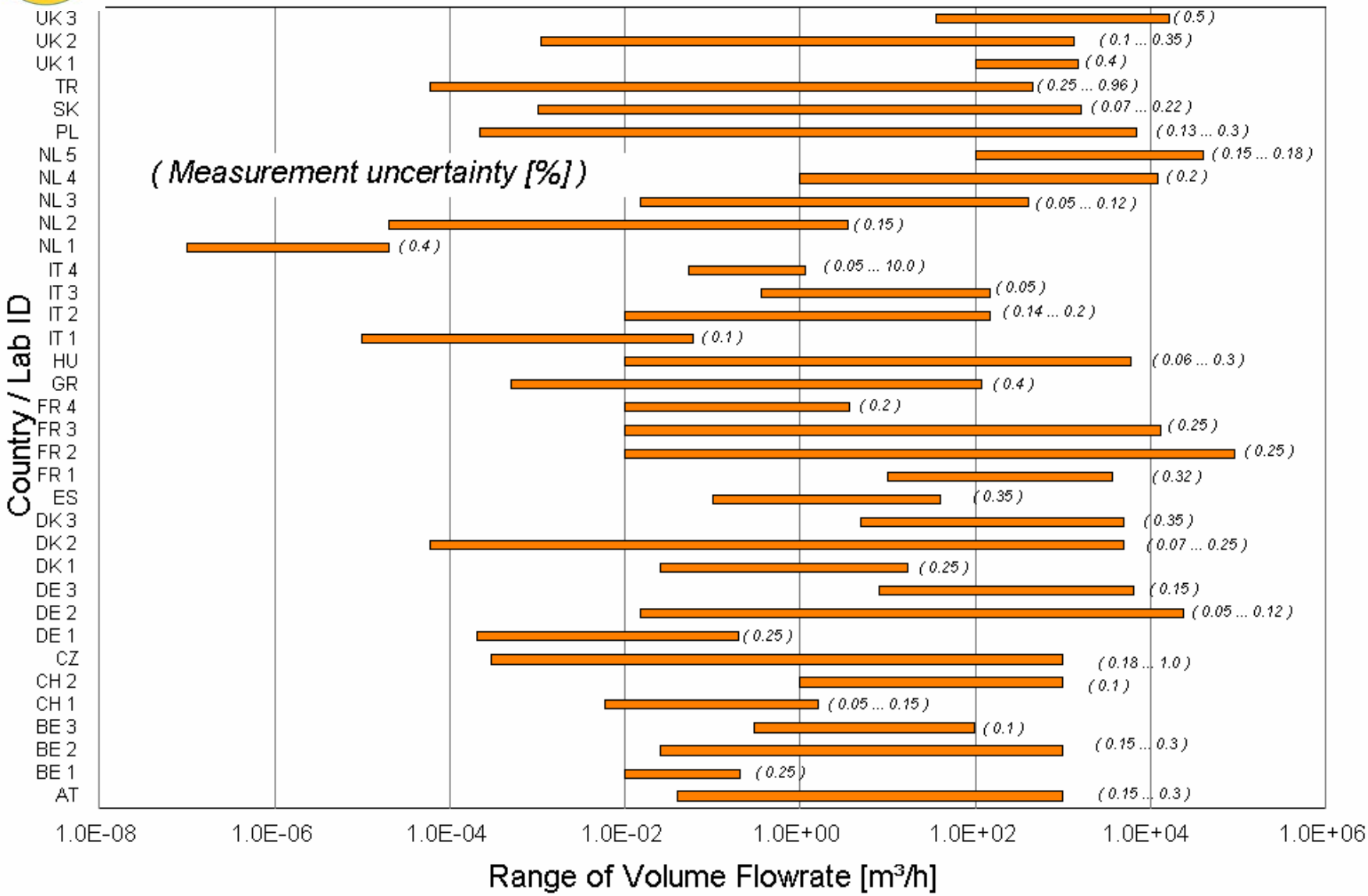


Update: Dopheide 2001-March-9

European NMIs' Calibration Facilities

Test fluid: Gas(es)

Euromet Flow Rapporteur

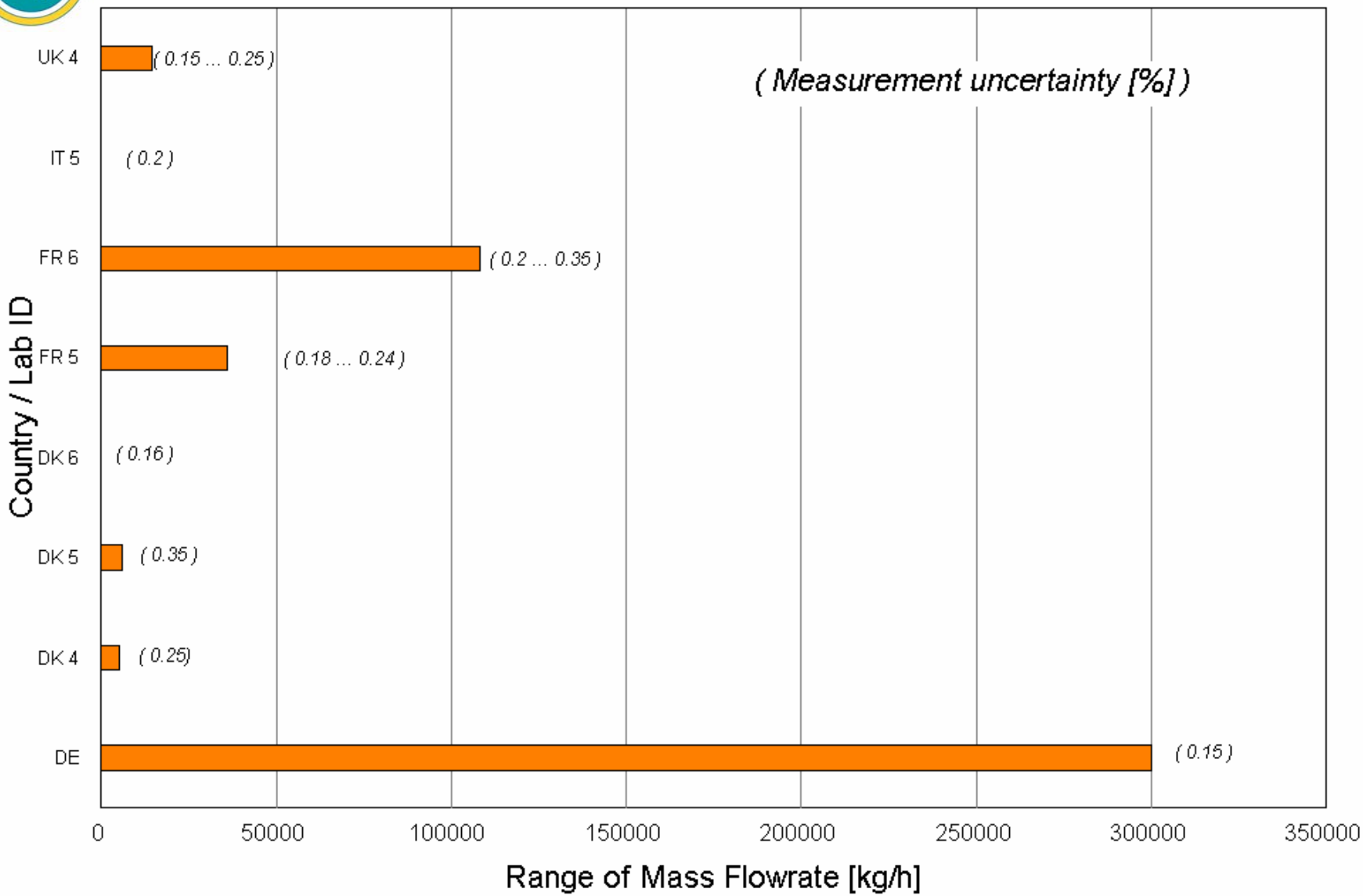


Update: Dopheide 2001-March-9

European NMIs' Calibration Facilities

Test fluid: Gas(es)

Euromet Flow Rapporteur

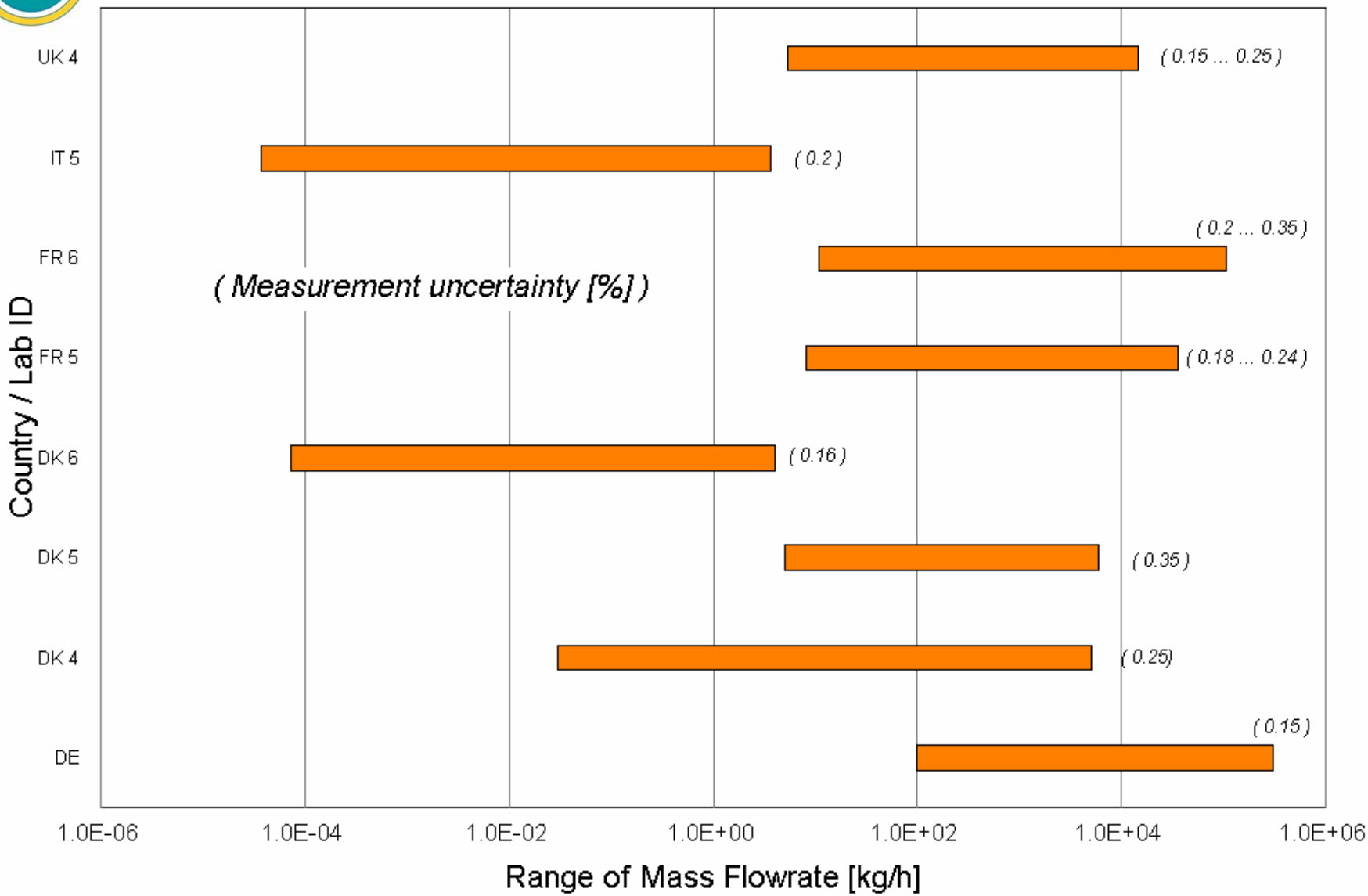


Update: Dopheide 2001-March-9

European NMIs' Calibration Facilities

Test fluid: Gas(es)

Euromet Flow Rapporteur

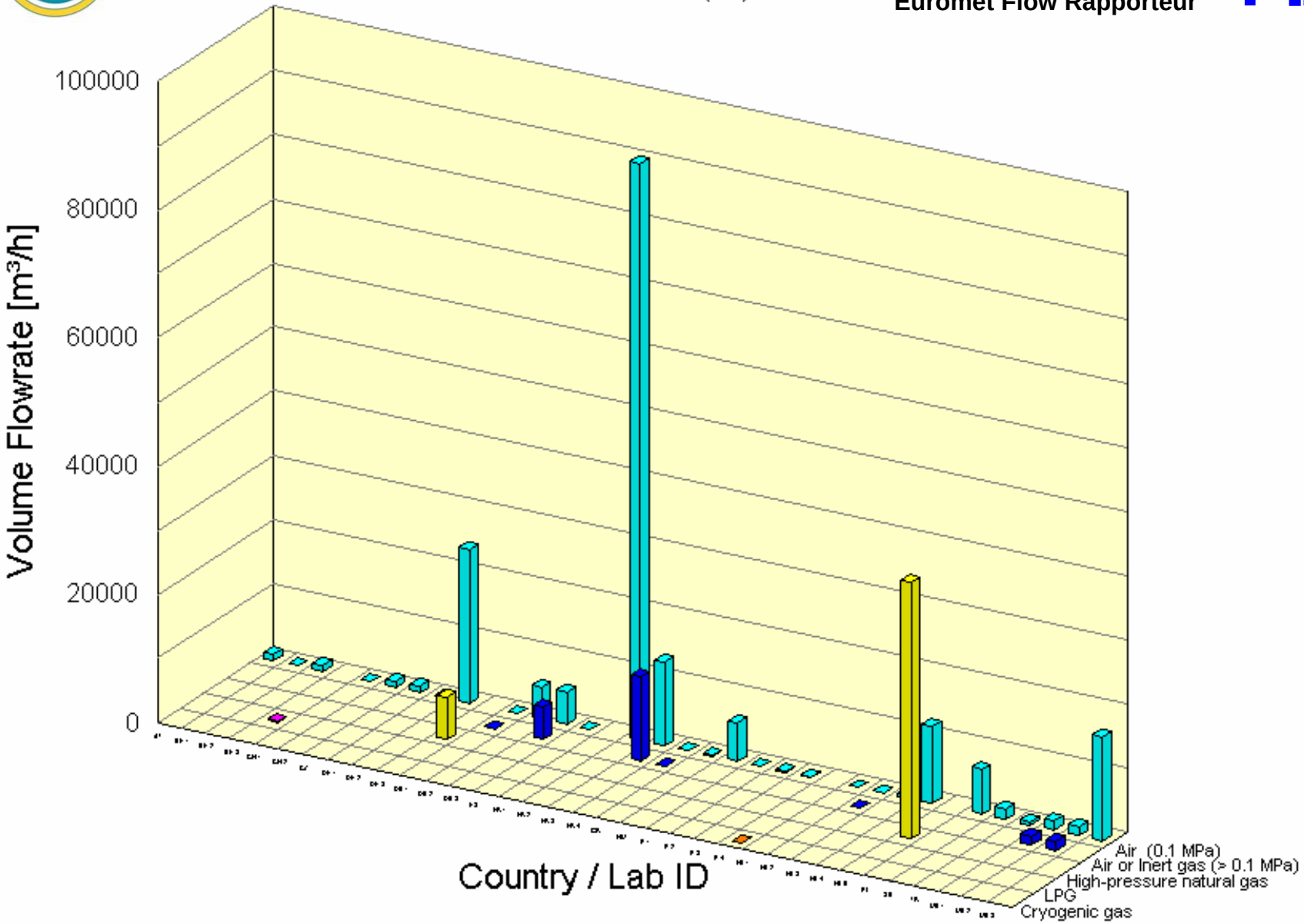


Update: Dopheide 2001-March-9

European NMIs' Calibration Facilities

Test fluid: Gas(es)

Euromet Flow Rapporteur

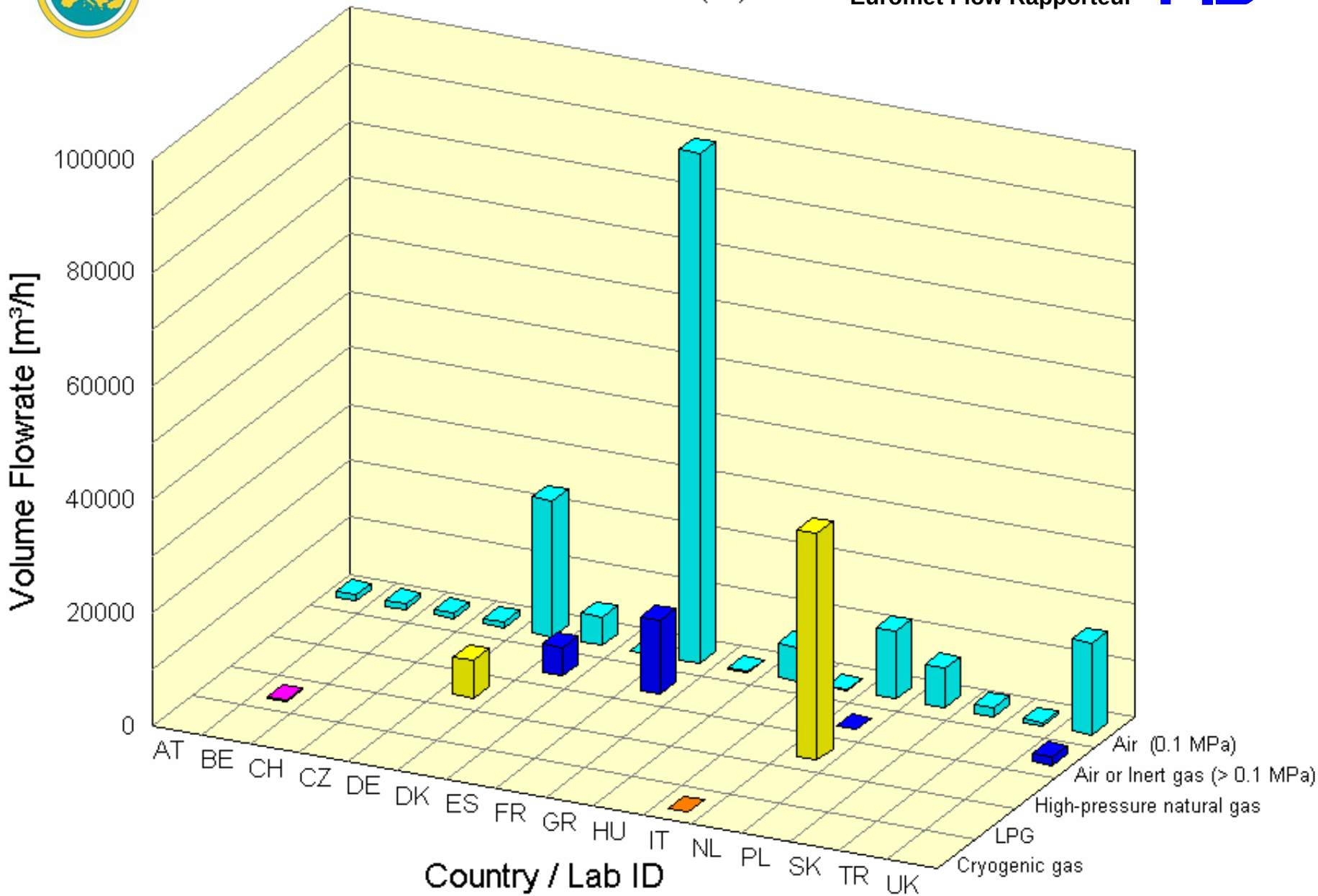


Update: Dopheide 2001-March-9

European NMIs' Calibration Facilities

Test fluid: Gas(es)

Euromet Flow Rapporteur

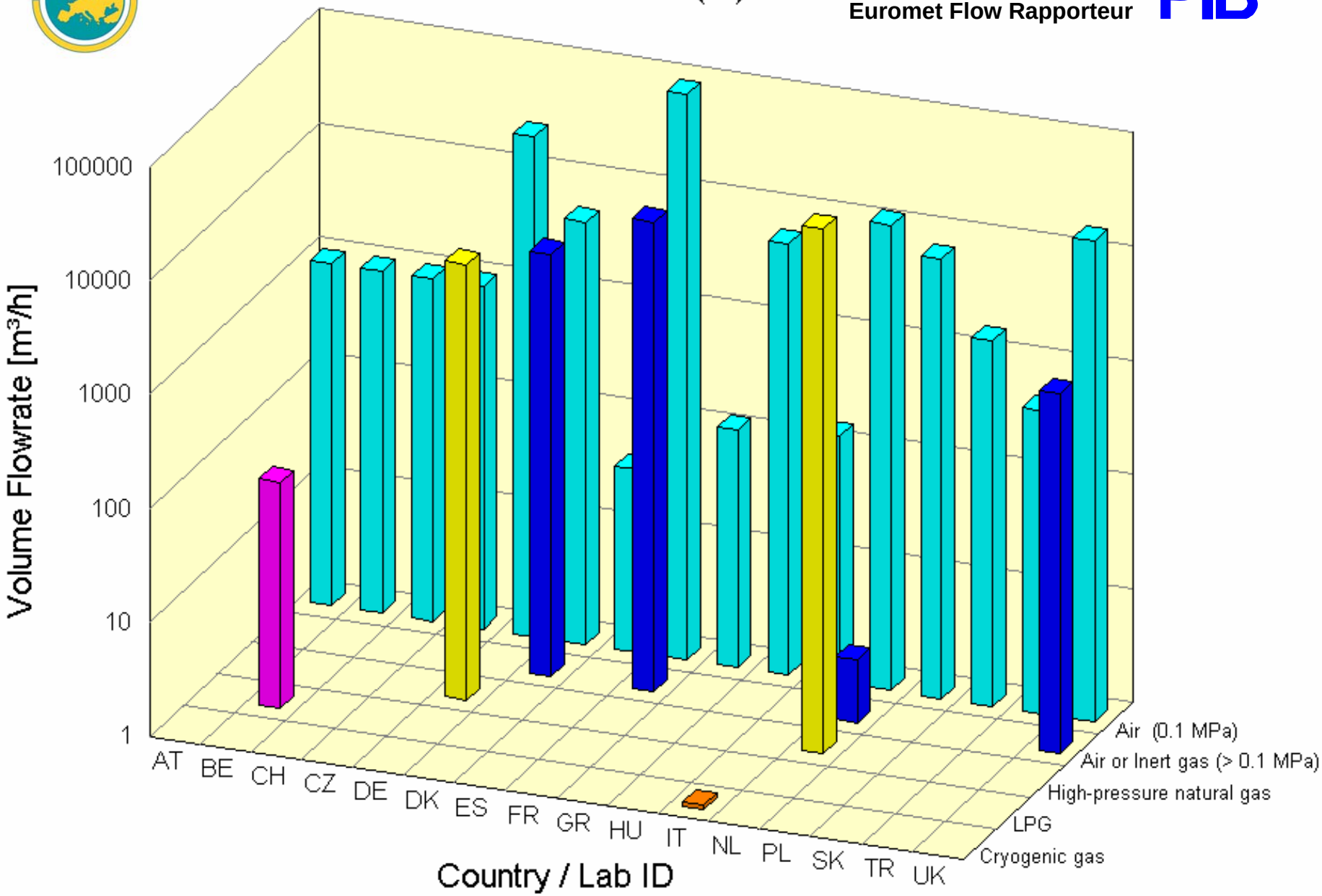


Update: Dopheide 2001-March-9

European NMIs' Calibration Facilities

Test fluid: Gas(es)

Euromet Flow Rapporteur

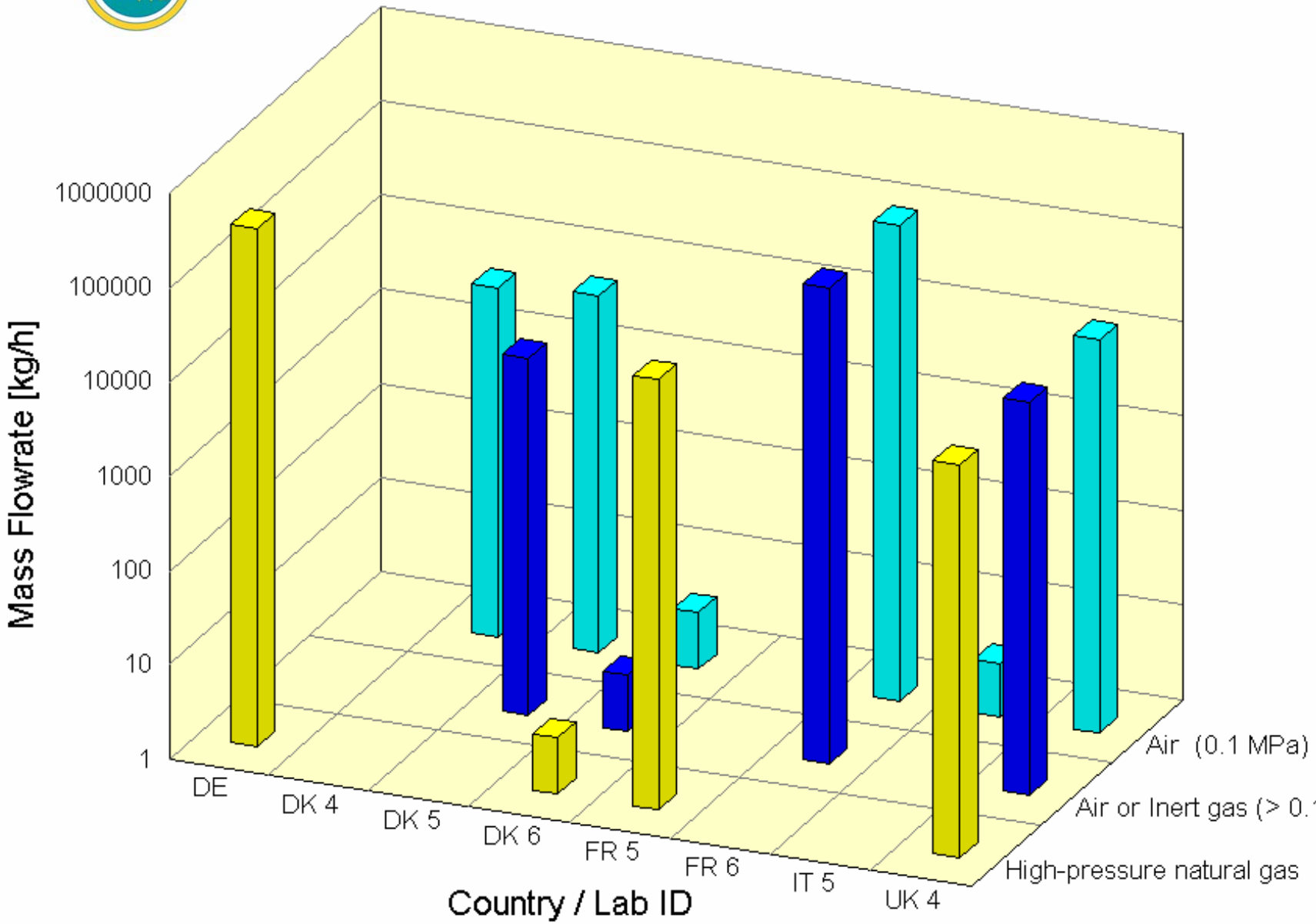


Update: Dopheide 2001-March-9

European NMIs' Calibration Facilities

Test fluid: Gas(es)

Euromet Flow Rapporteur

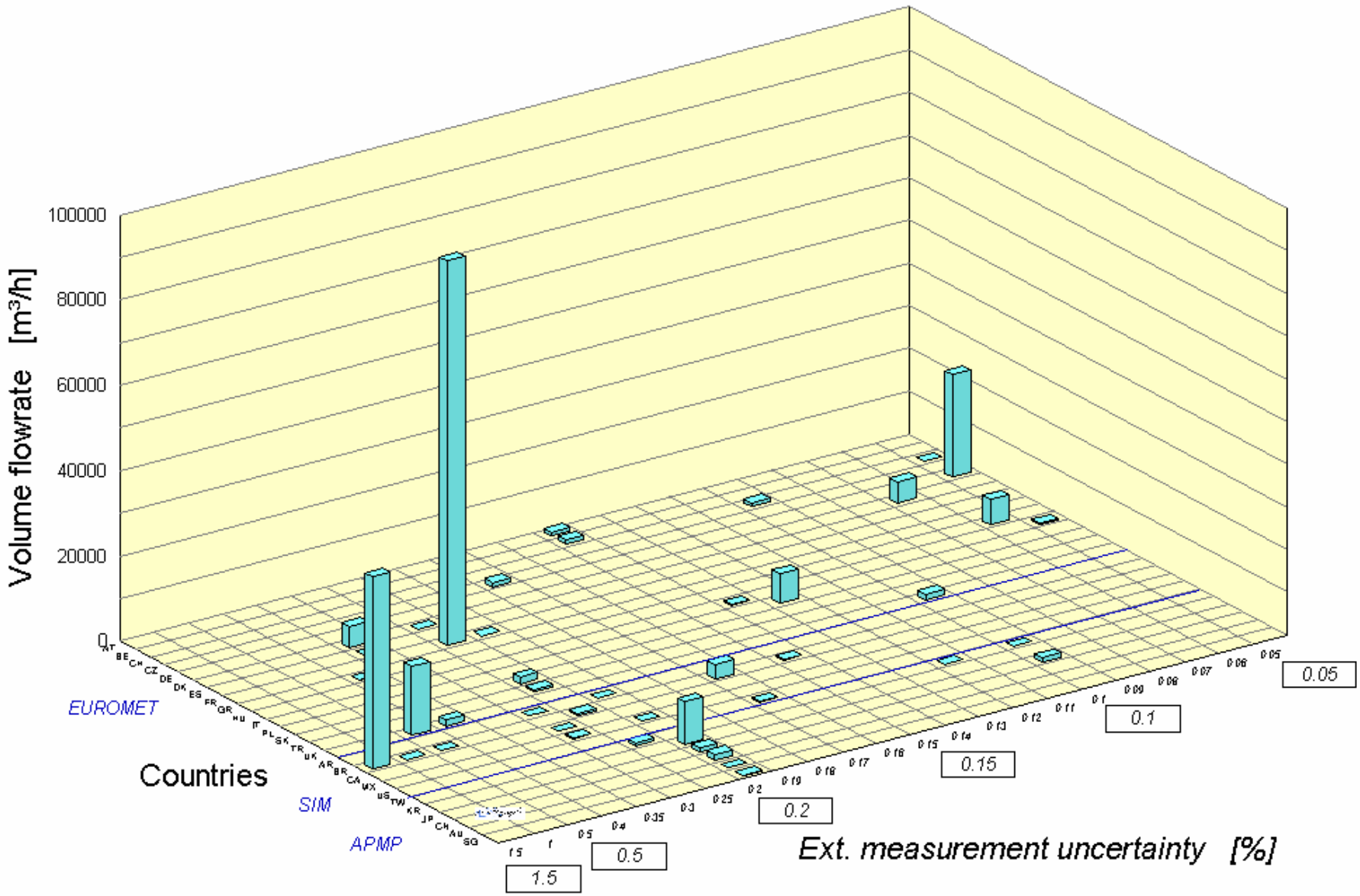


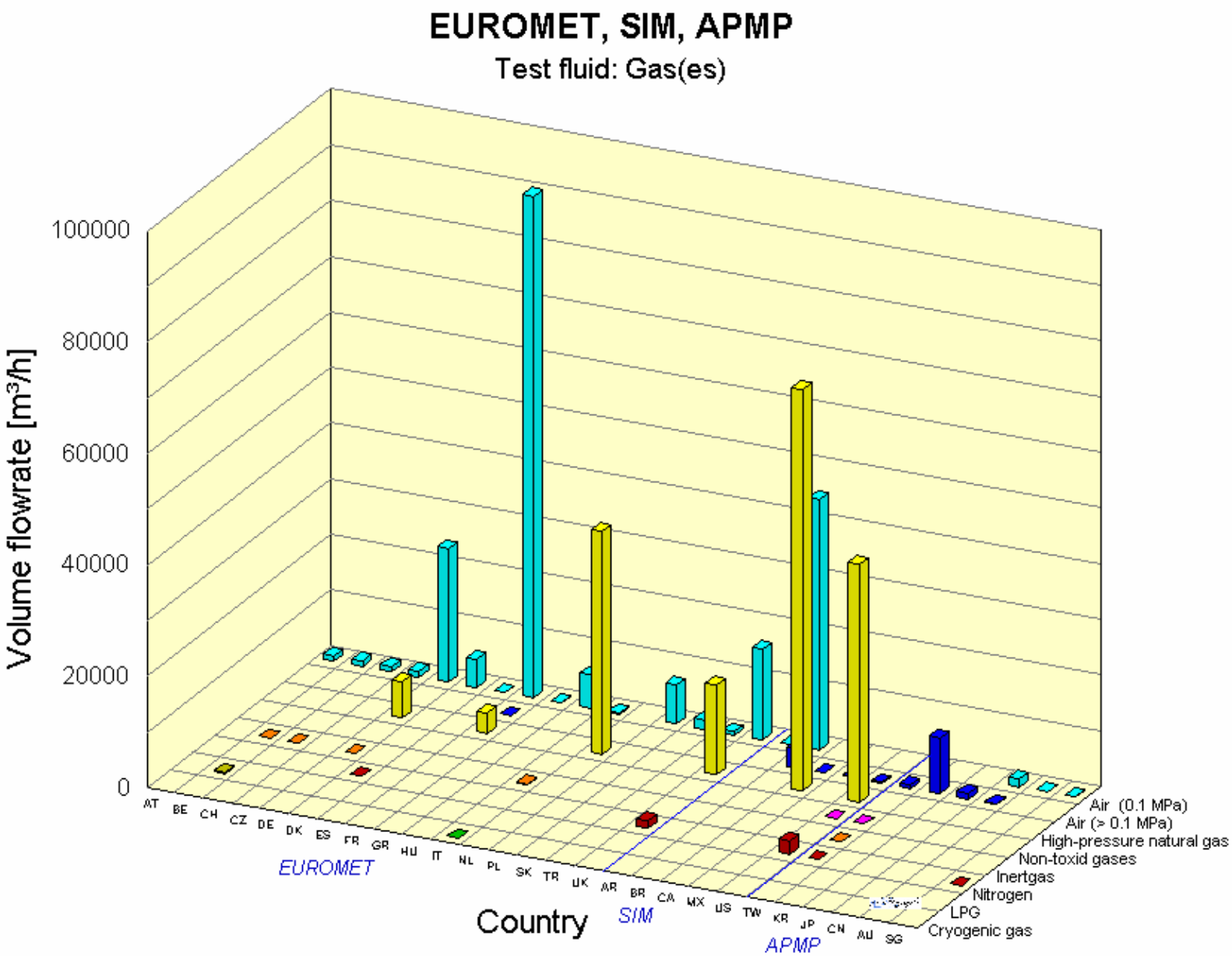
Update: Dopheide 2001-March-9

CMCs of all EUROMET; SIM and APMP for air

EUROMET, SIM, APMP

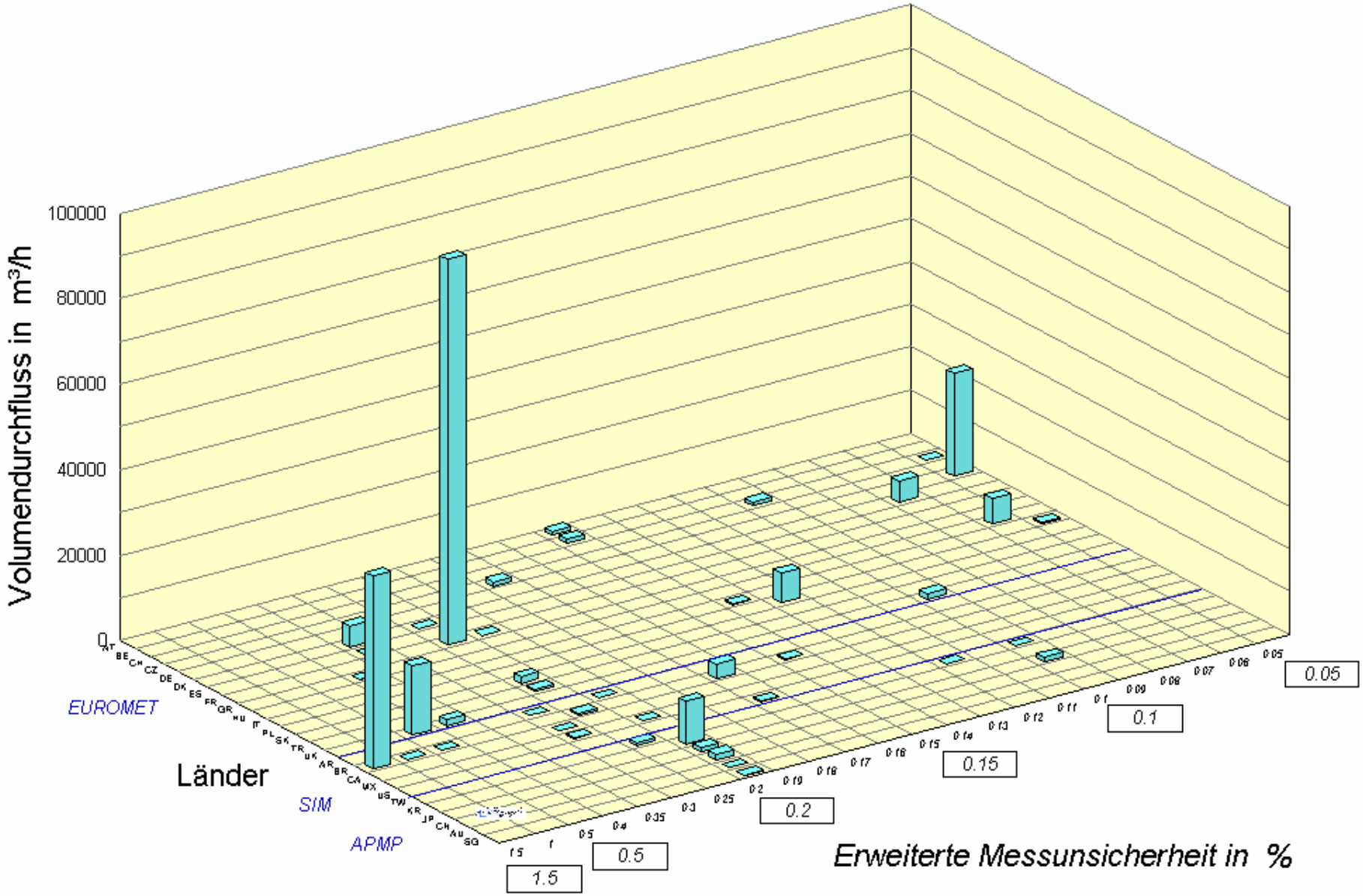
CMCs for air




EUROMET, SIM, APMP
Test fluid: Gas(es)
Volume flowrate [m³/h]
100000
80000
60000
40000
20000
0
AT BE CH CZ DE DK ES FR GR HU IT NL PL SK TR UK AR BR CA MX US TW KR JP CN AU SG
EUROMET
SIM
APMP
Country
Air (0.1 MPa)
Air (> 0.1 MPa)
High-pressure natural gas
Non-toxid gases
Inertgas
Nitrogen
LPG
Cryogenic gas

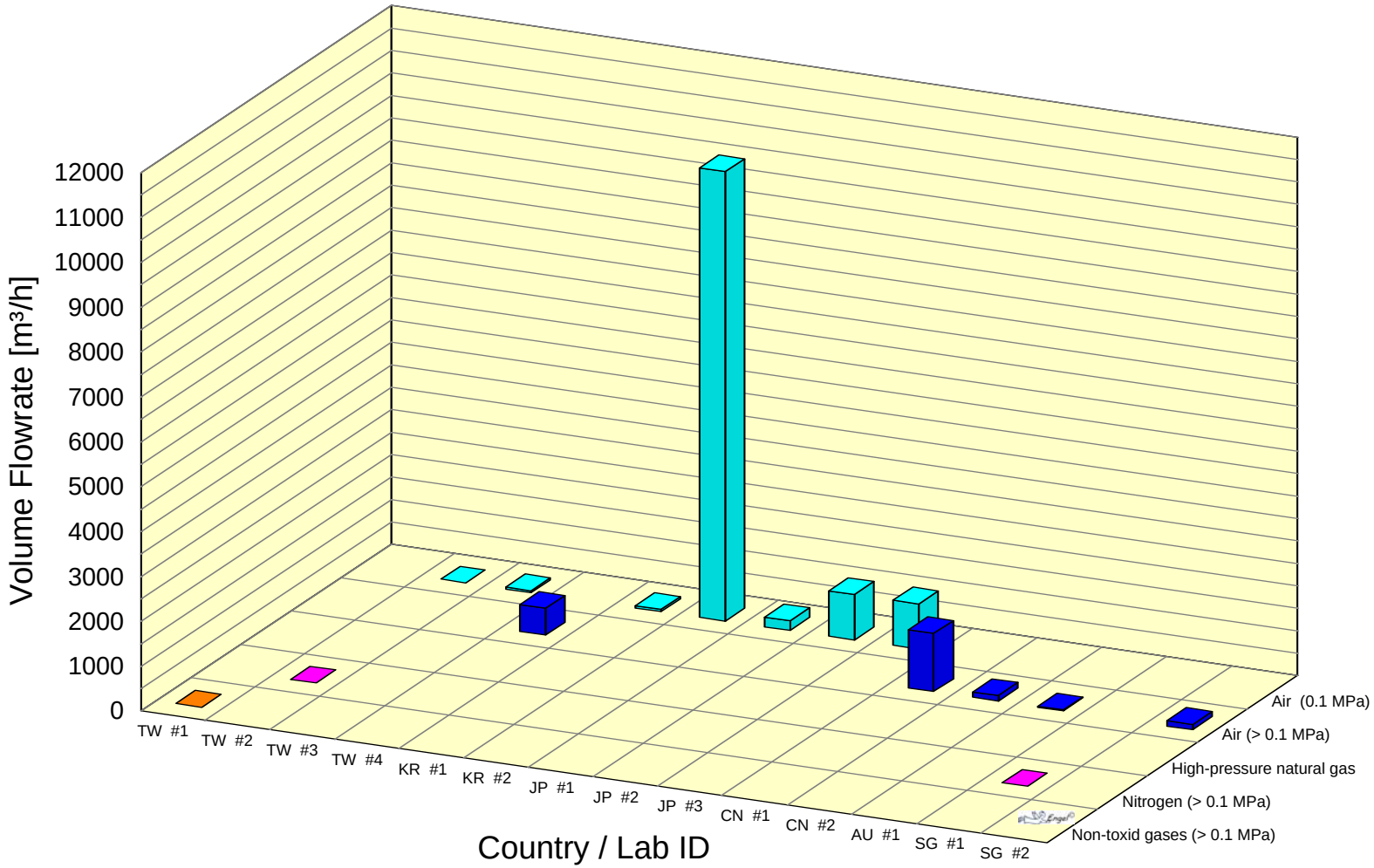
EUROMET, SIM (Amerika), APMP (Asien)

Kalibriermöglichkeiten für Luft



APMP - NMIs' Calibration Facilities

Test fluid: Gas(es)

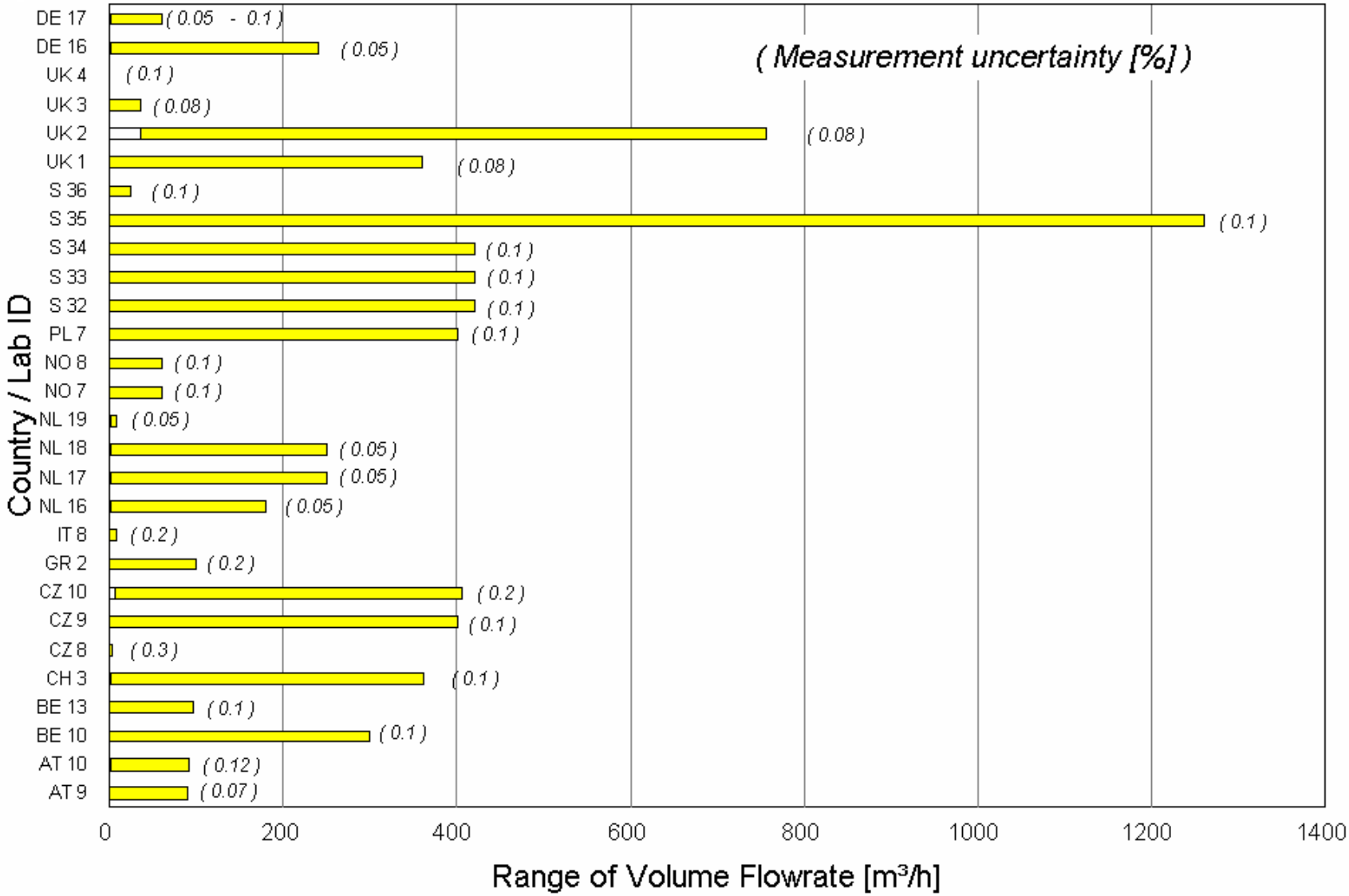


Facilities for oil, pipettes etc.

European NMIs' Calibration Facilities

Test fluid: Petroleum products

Euromet Flow Rapporteur

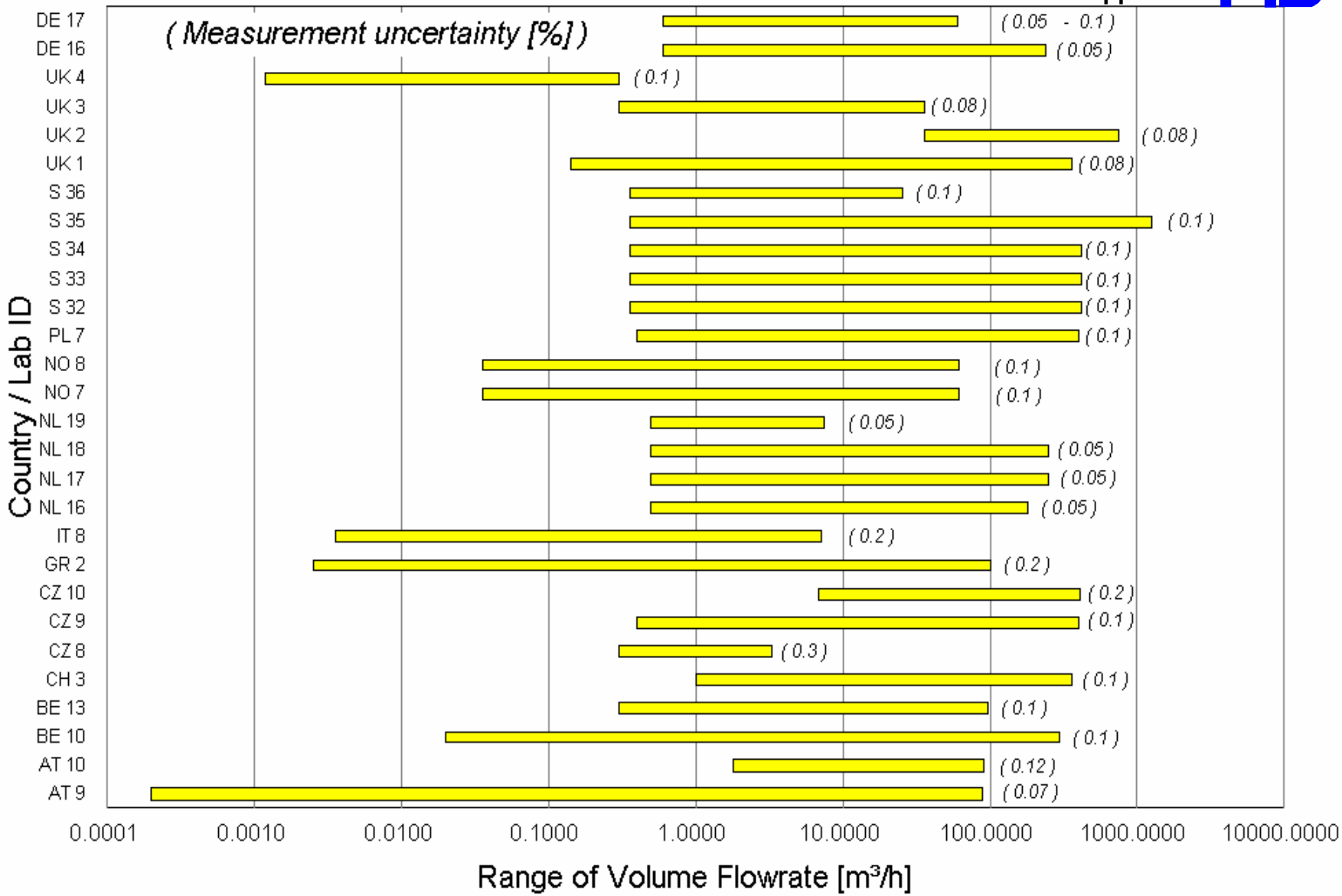


Update: Dopheide 2001-March-9

European NMIs' Calibration Facilities

Test fluid: Petroleum products

Euromet Flow Rapporteur

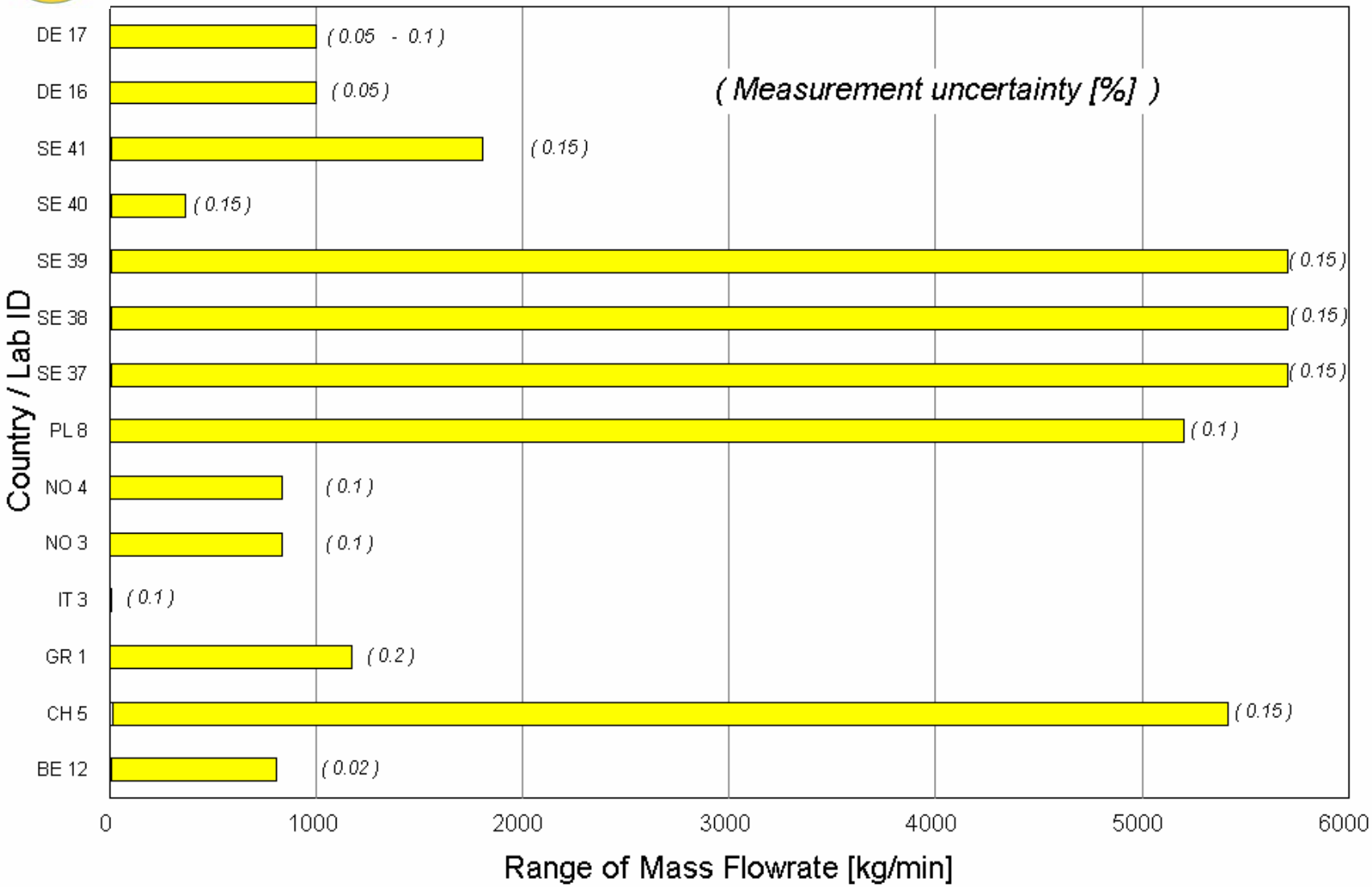


Update: Dopheide 2001-March-9

European NMIs' Calibration Facilities

Test fluid: Petroleum products

Euromet Flow Rapporteur

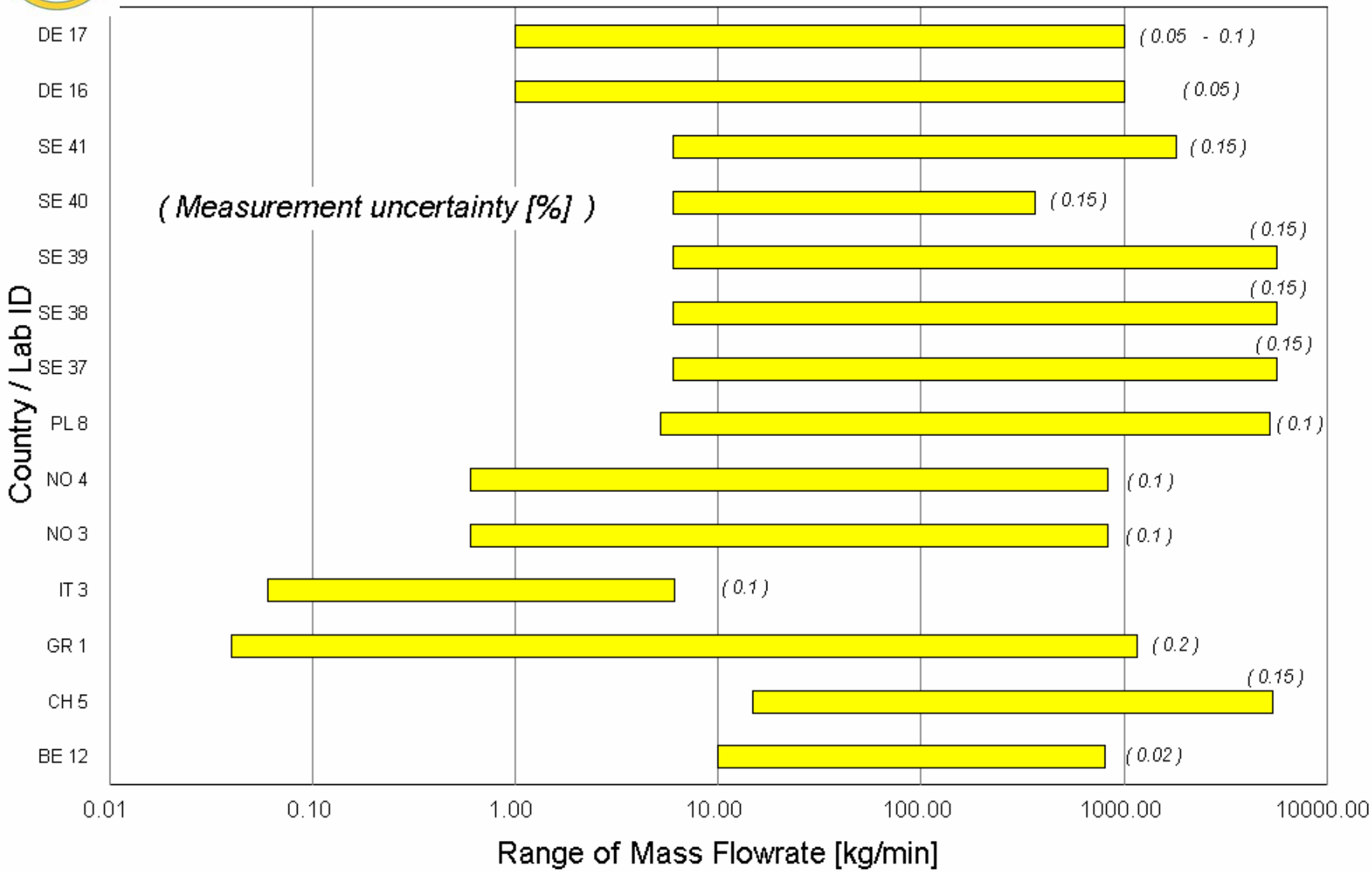


Update: Dopheide 2001-March-9

European NMIs' Calibration Facilities

Test fluid: Petroleum products

Euromet Flow Rapporteur

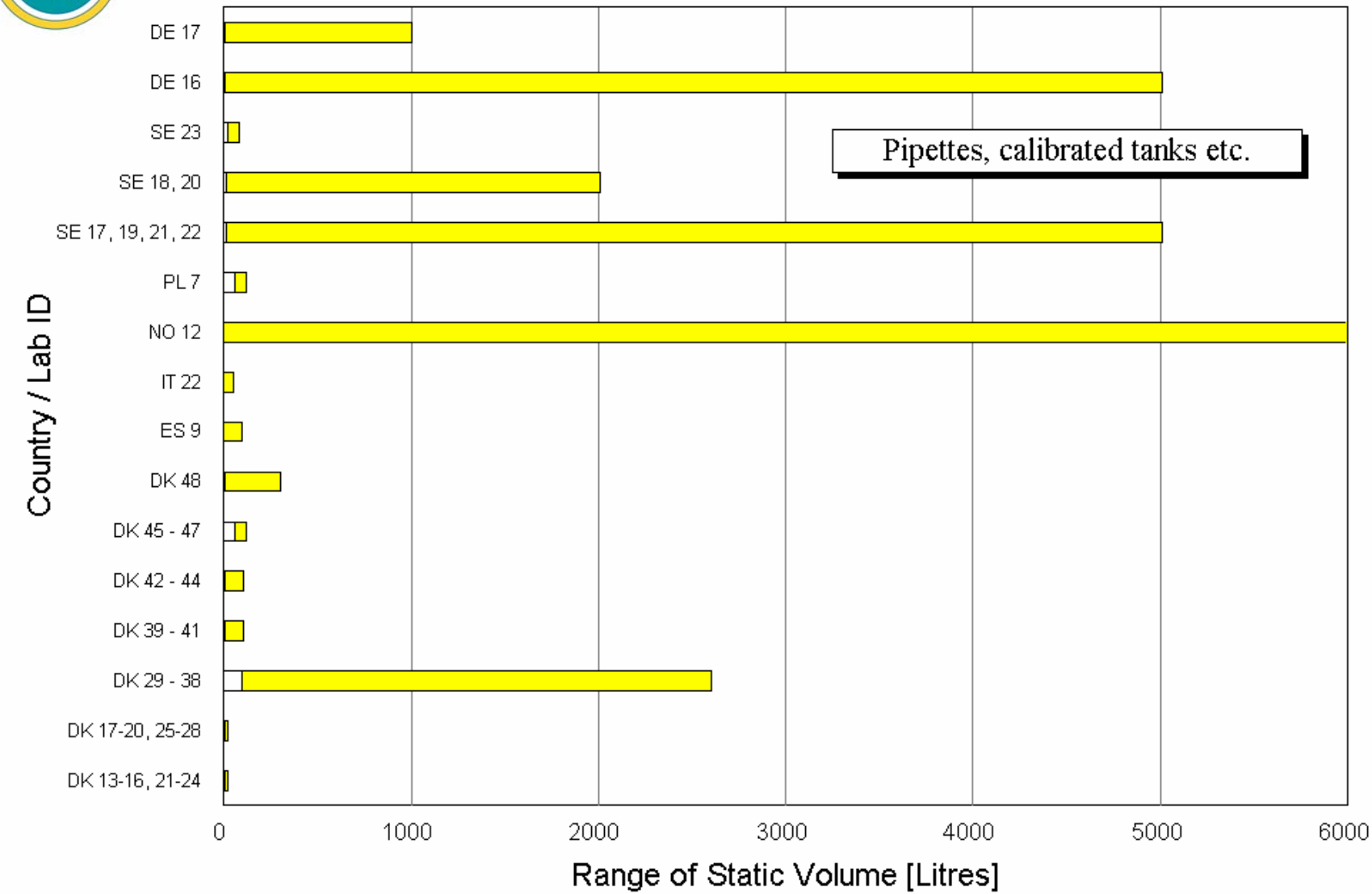


Update: Dopheide 2001-March-9

European NMIs' Calibration Facilities

Test fluid: Petroleum products

Euromet Flow Rapporteur

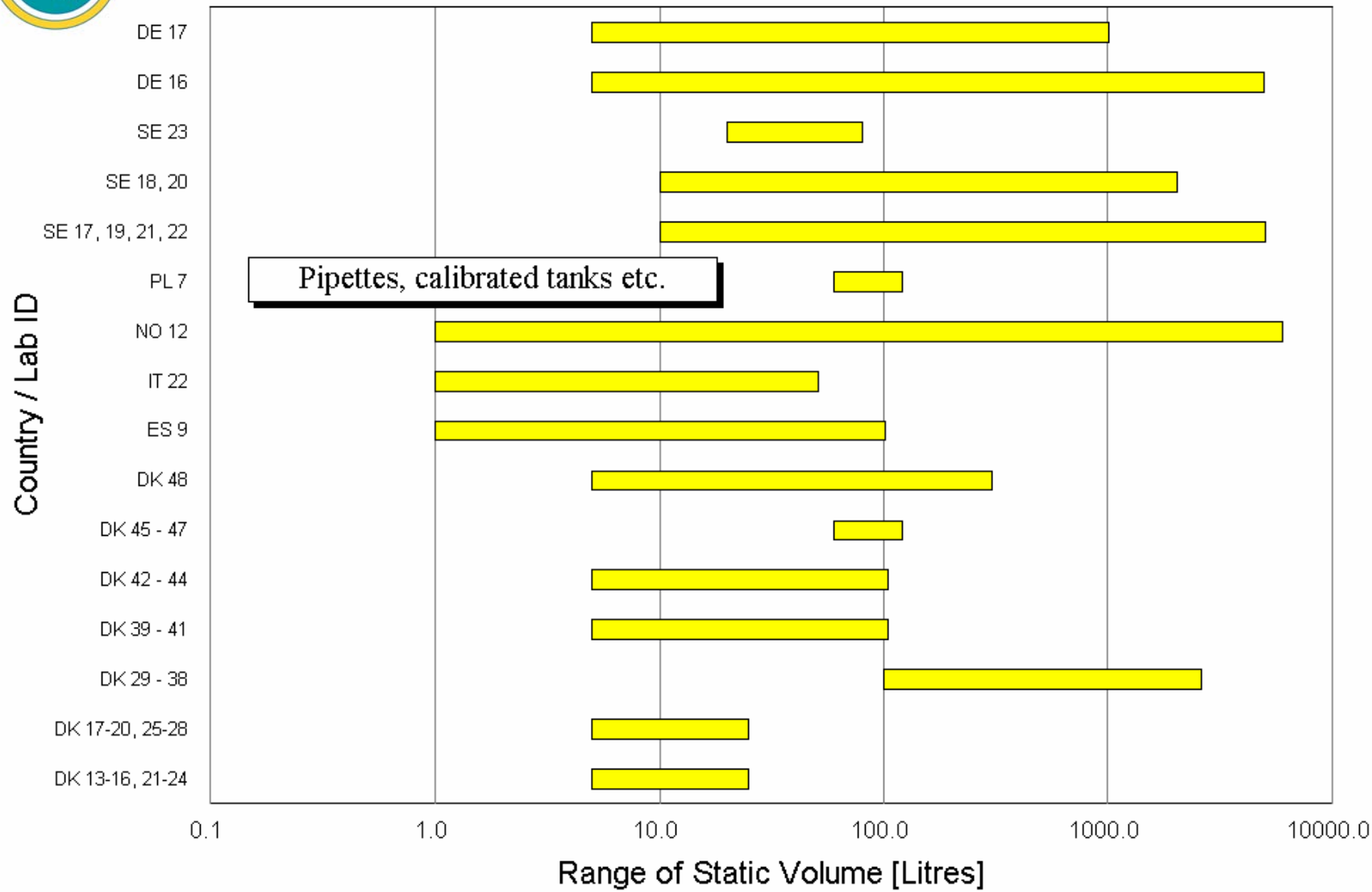


Update: Dopheide 2001-March-9

European NMIs' Calibration Facilities

Test fluid: Petroleum products

Euromet Flow Rapporteur



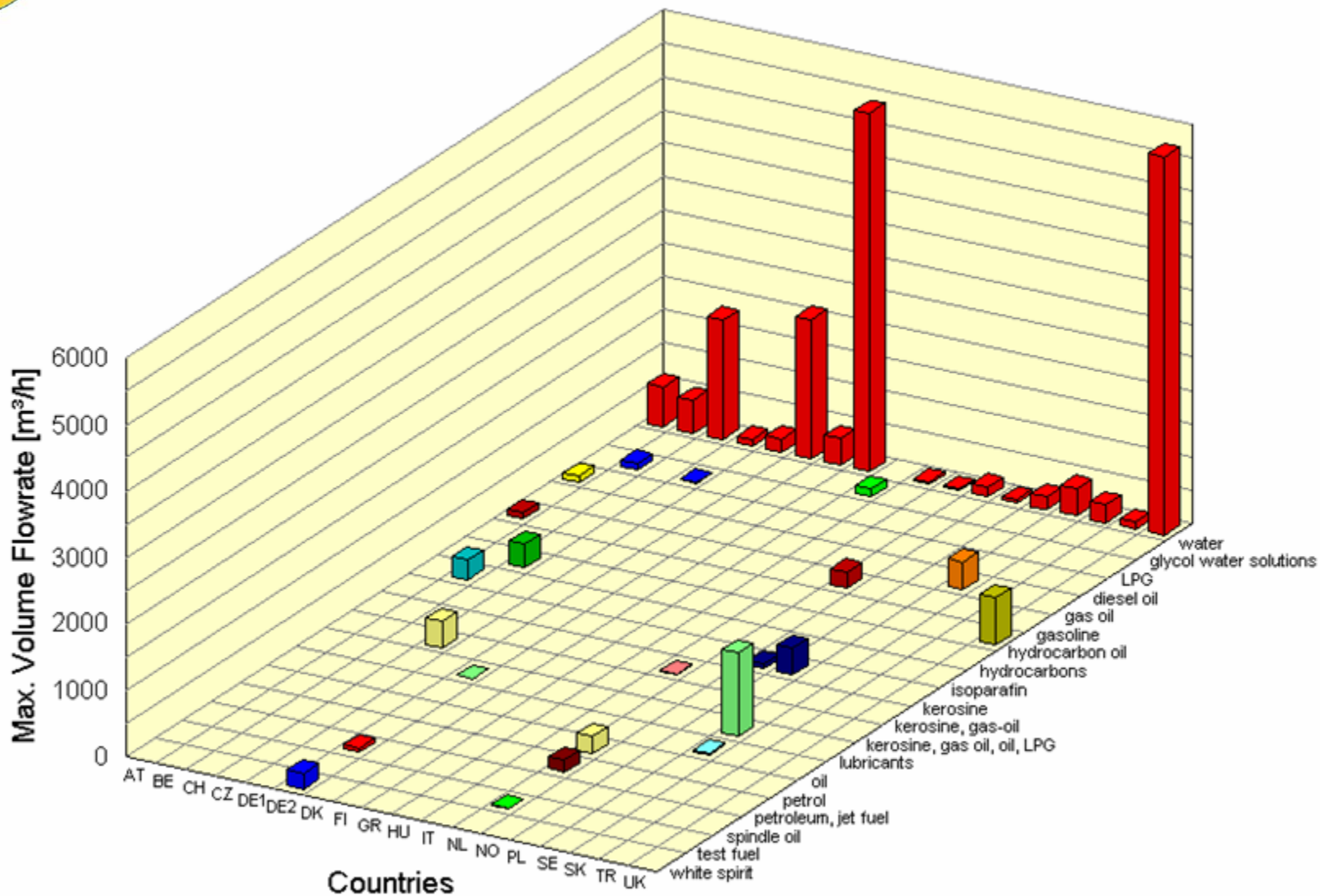
Update: Dopheide 2001-March-9

All liquids

European NMIs' Calibration Facilities

Water and liquids other than water

Euromet Flow Rapporteur



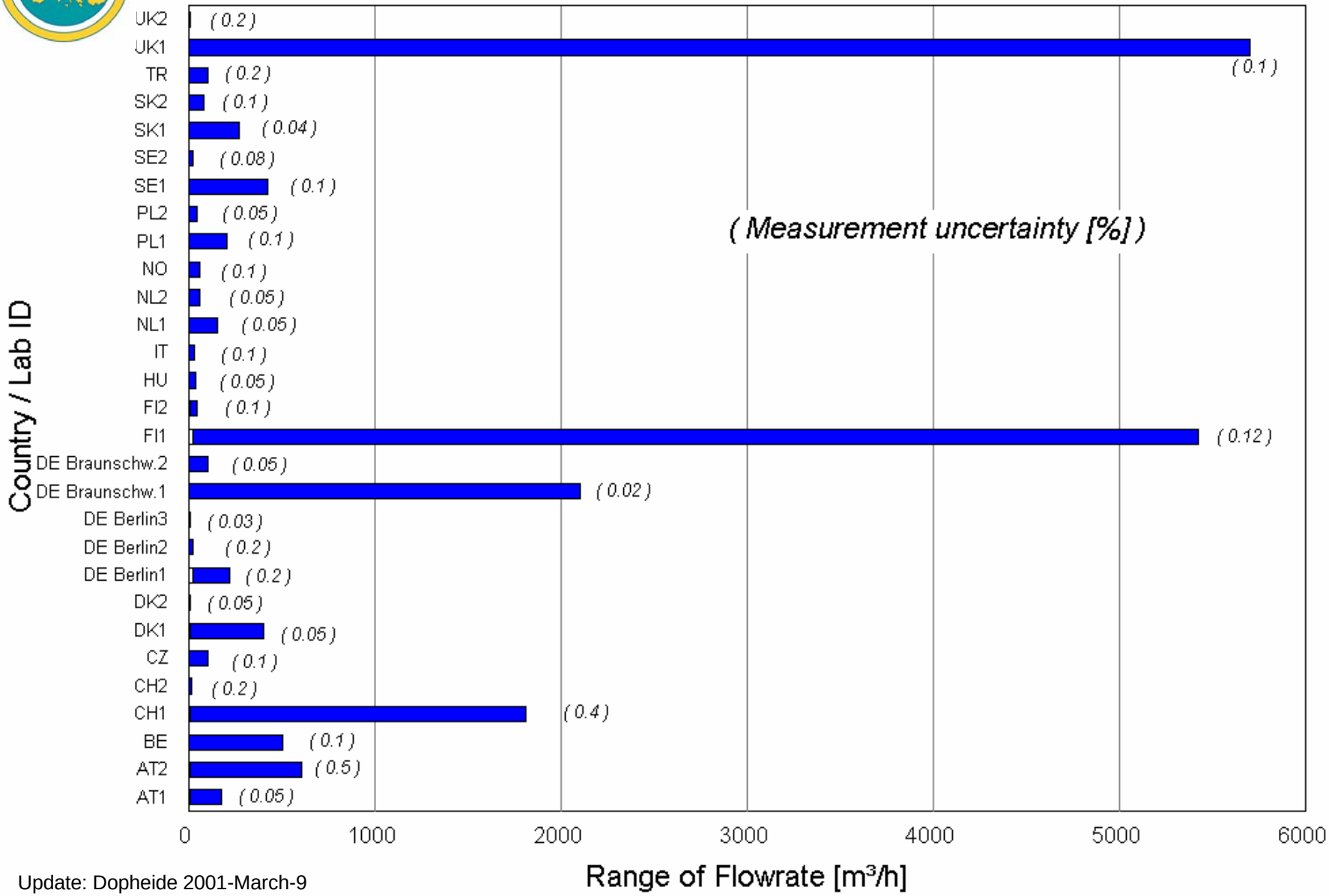
Update: Dopheide 2001-March-9

Water facilities

European NMIs' Calibration Facilities

Test fluid: Water

Euromet Flow Rapporteur

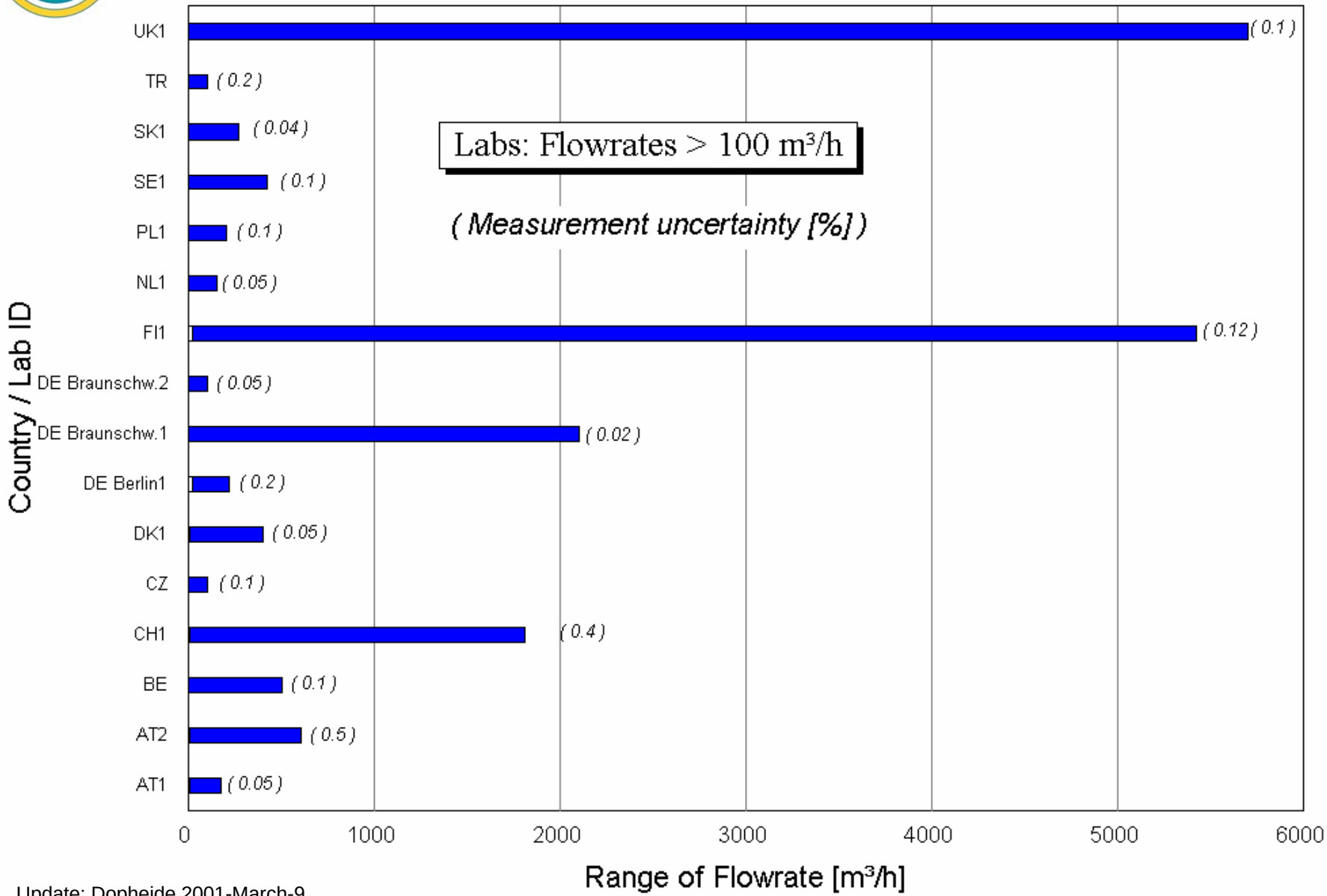


Update: Dopheide 2001-March-9

European NMIs' Calibration Facilities

Test fluid: Water

Euromet Flow Rapporteur

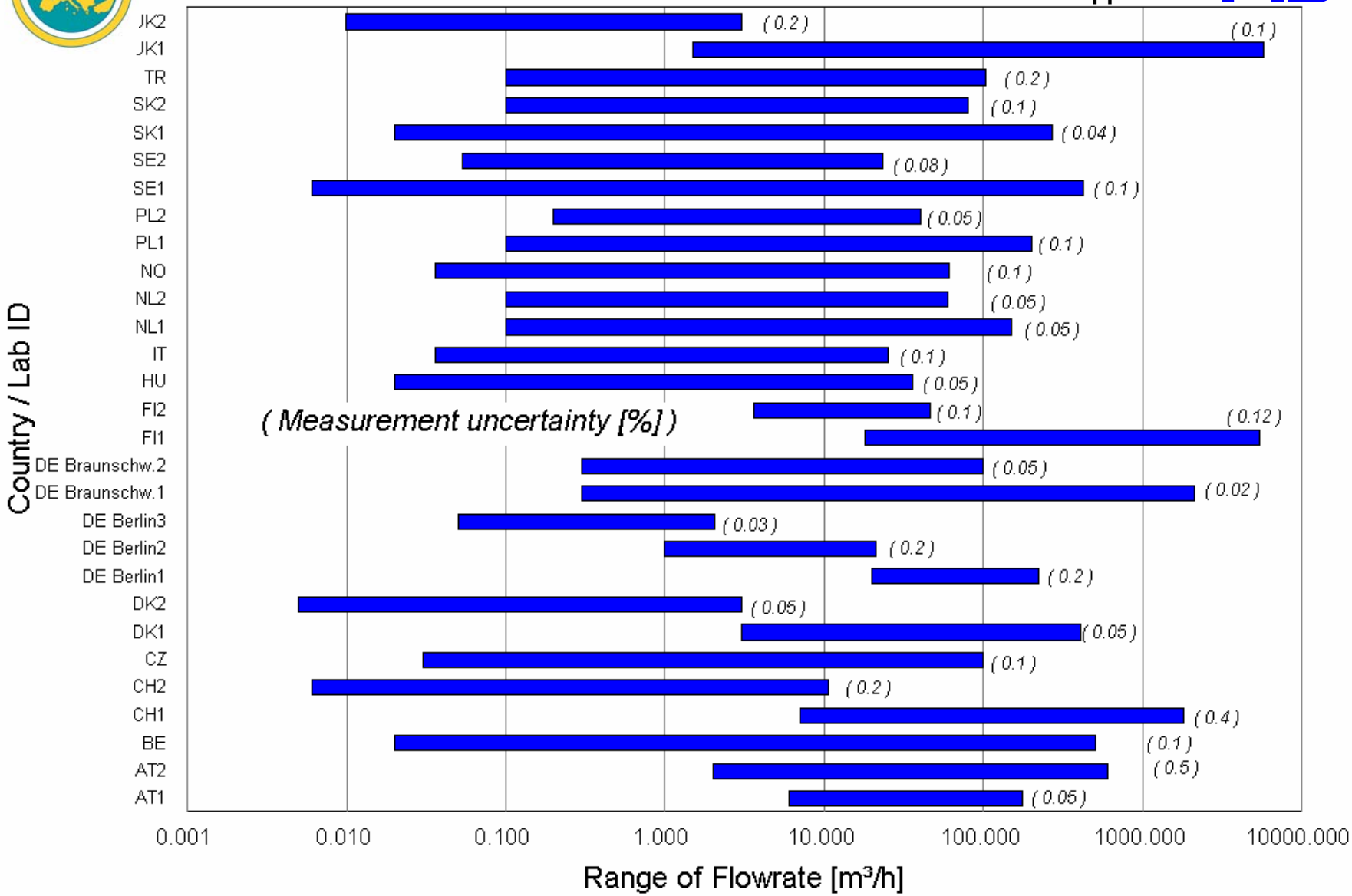


Update: Dopheide 2001-March-9

European NMIs' Calibration Facilities

Test fluid: Water

Euromet Flow Rapporteur

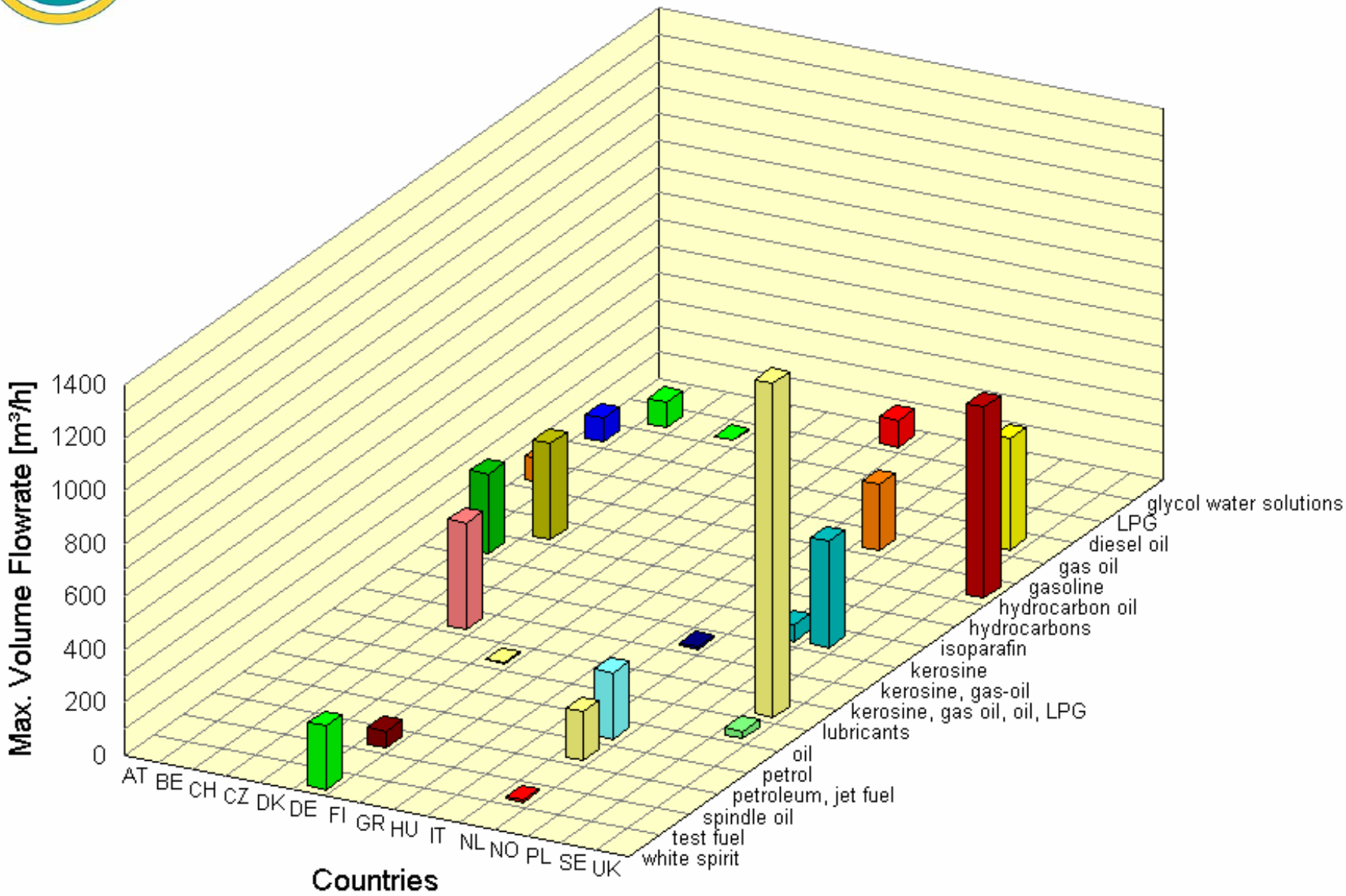


Liquids other than water

European NMIs' Calibration Facilities

Fluids: Liquids other than water

Euromet Flow Rapporteur

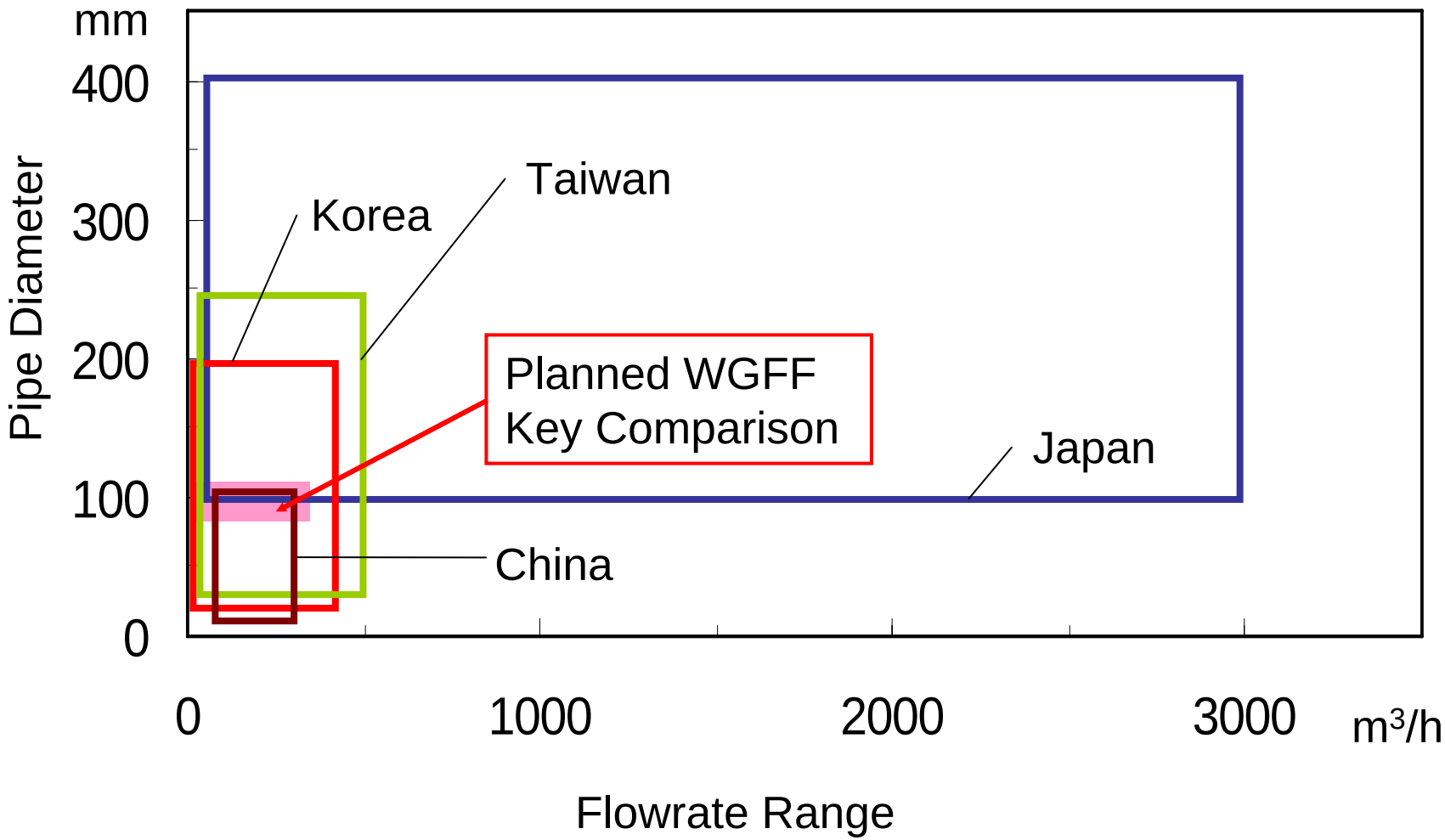


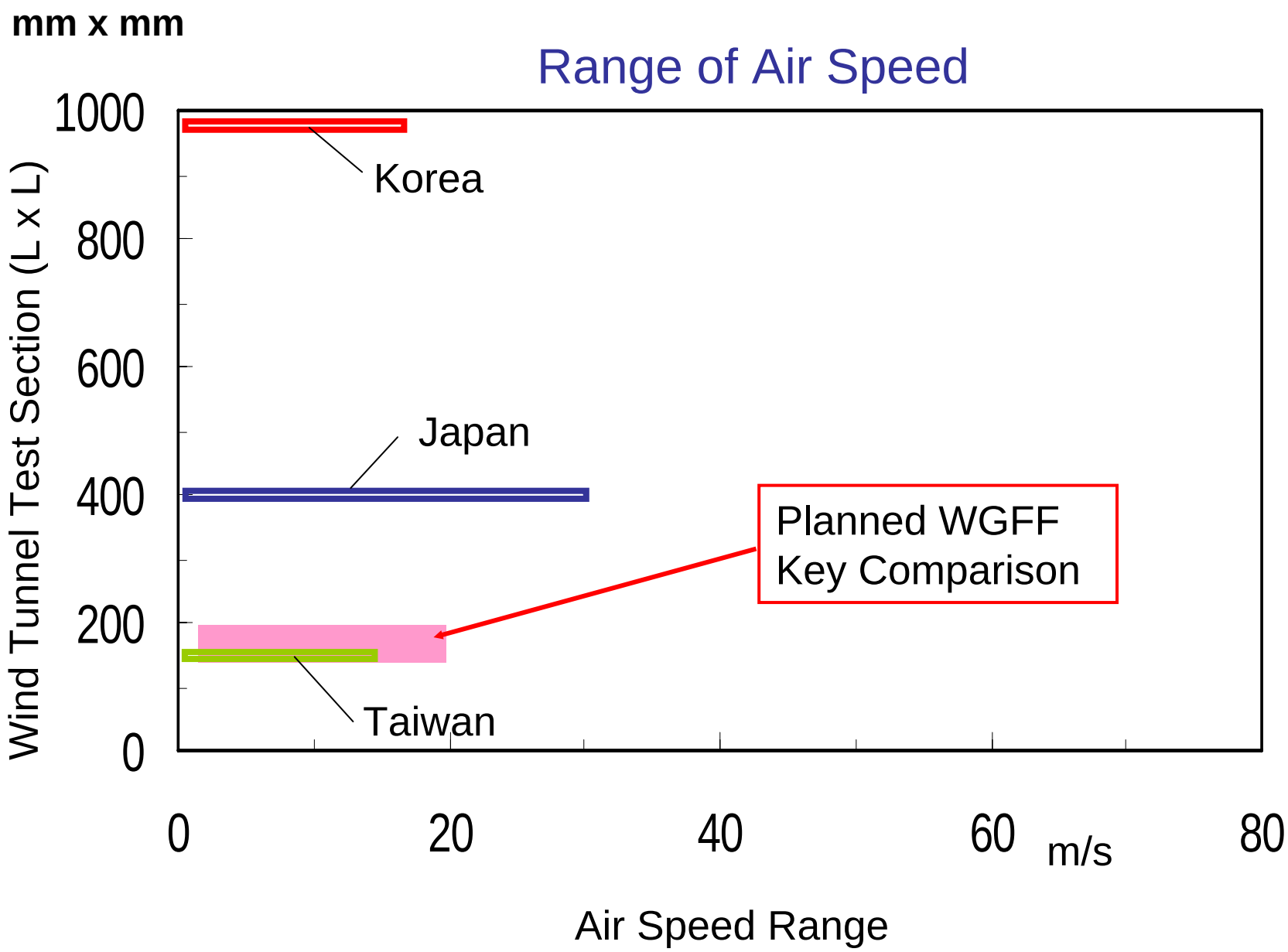
Update: Dopheide 2001-March-9

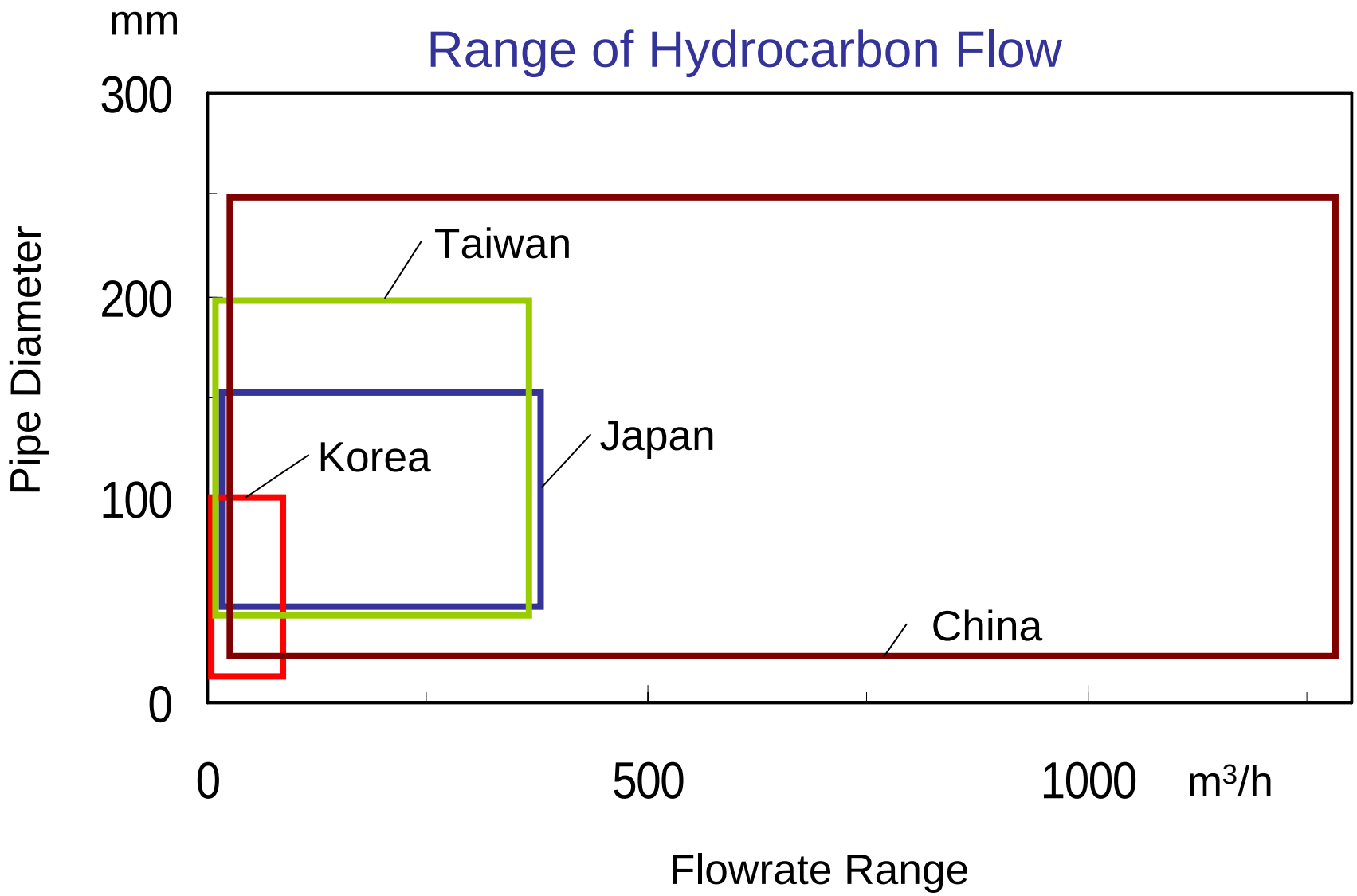
CMCs of APMP

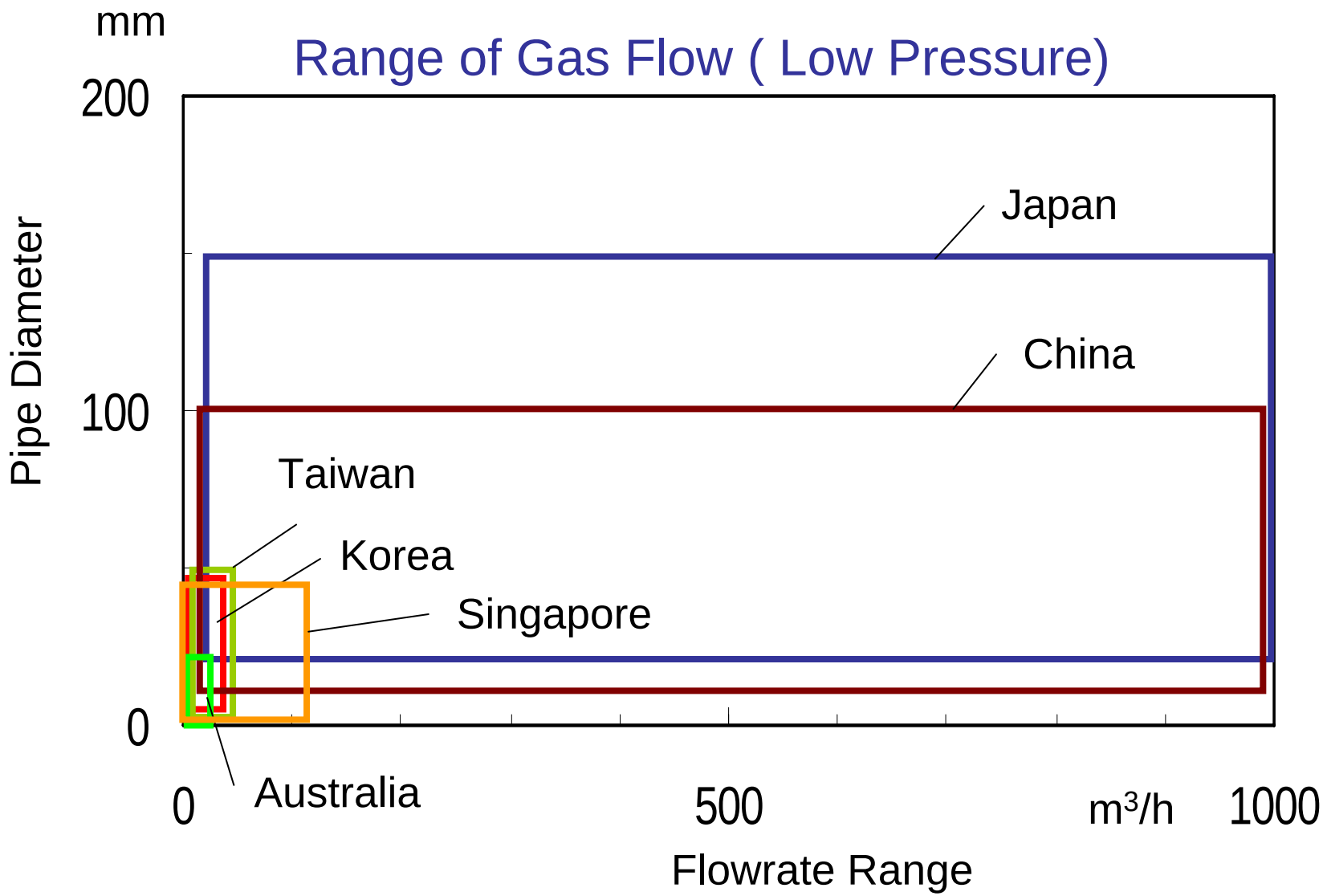
CMCs of APMP Members

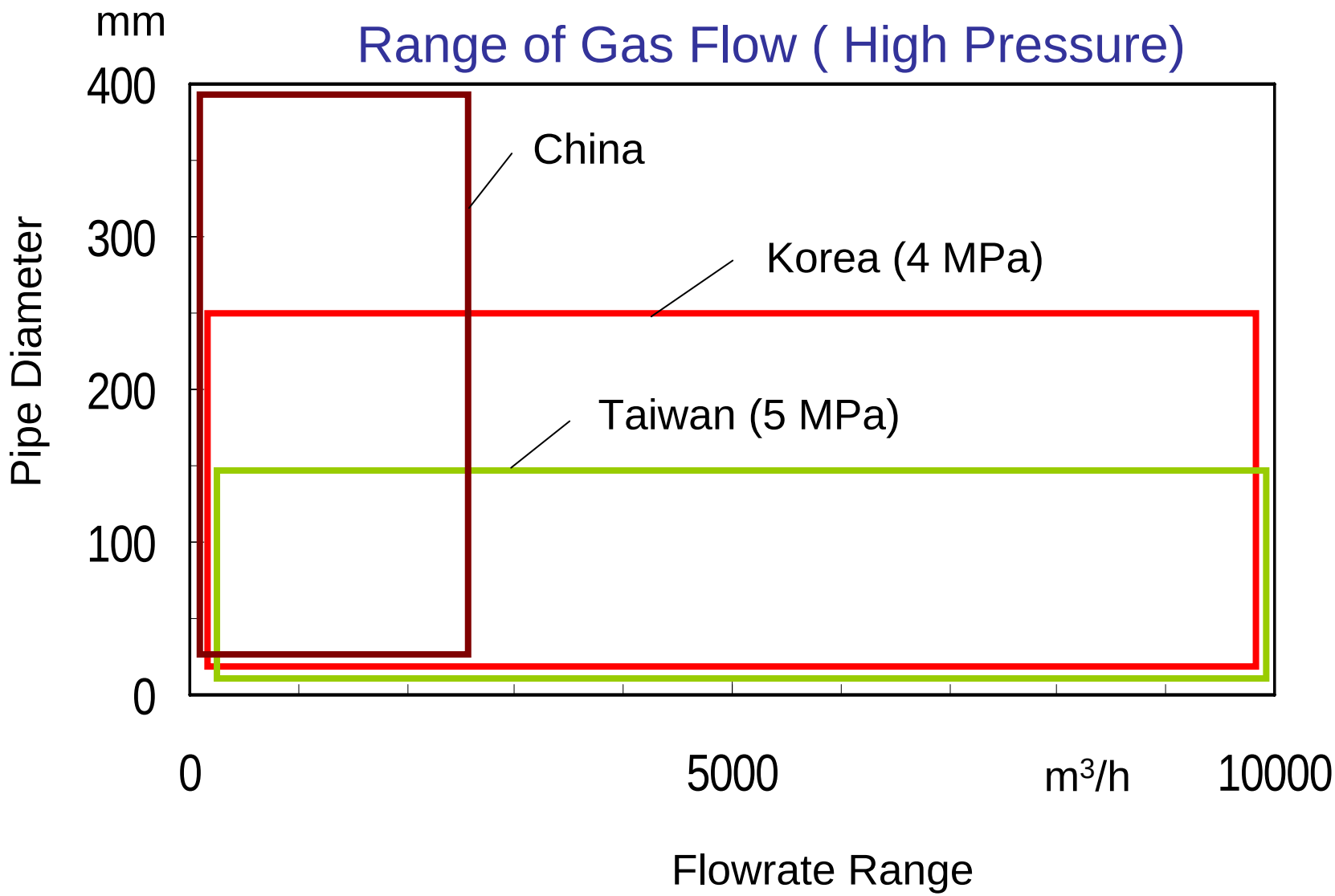
Range of Water Flow



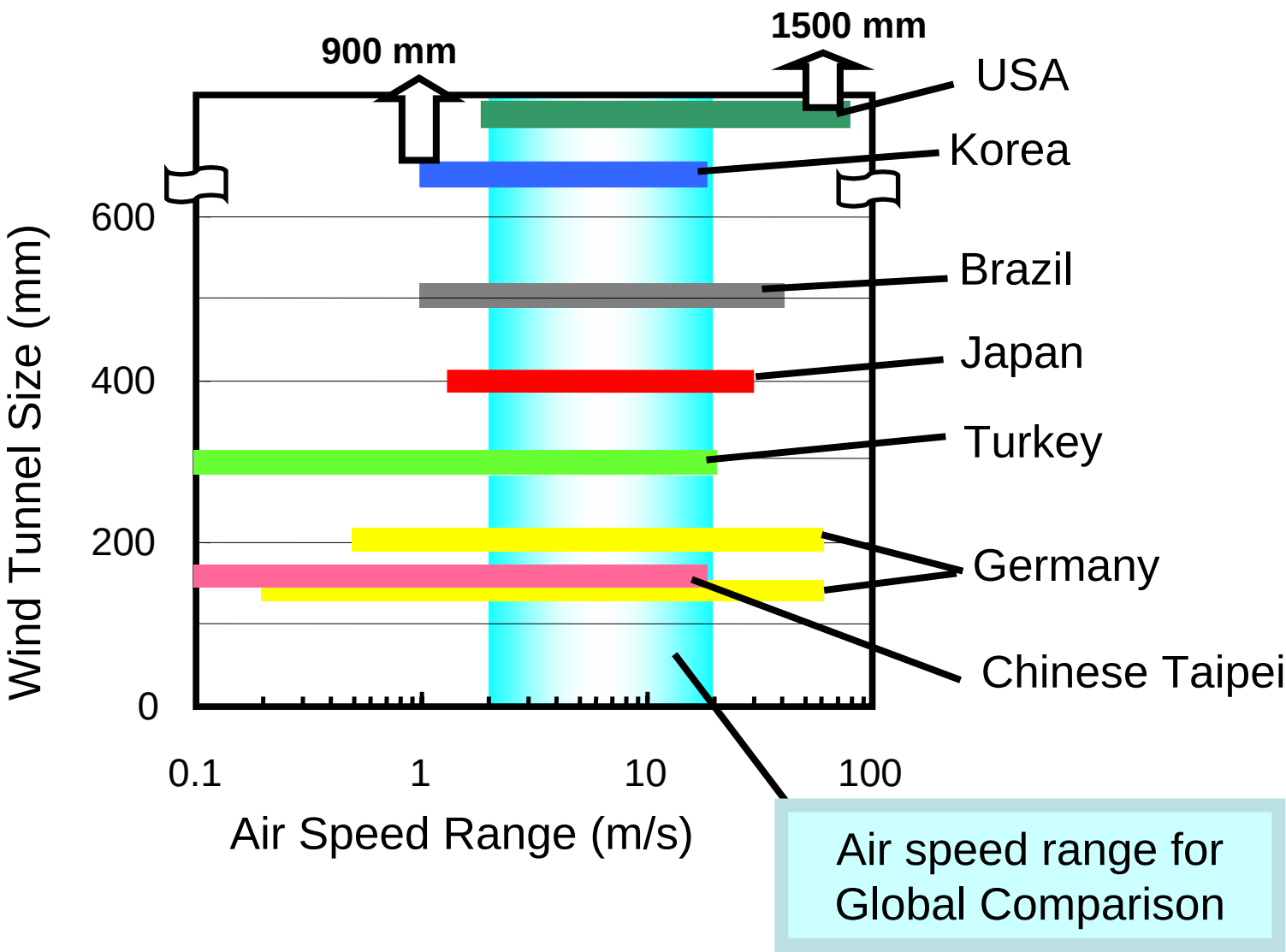

mm x mm
Range of Air Speed
1000
800
600
400
200
0
Wind Tunnel Test Section (L x L)
Korea
Japan
Taiwan
Planned WGFF
Key Comparison
0
20
40
60
m/s
80
Air Speed Range


Range of Hydrocarbon Flow
mm
300
200
100
0
Pipe Diameter
Taiwan
Japan
Korea
China
0
500
1000
m³/h
Flowrate Range


Range of Gas Flow (Low Pressure)
mm
200
100
0
Pipe Diameter
Japan
China
Taiwan
Korea
Singapore
Australia
0
500
m³/h
1000
Flowrate Range


Range of Gas Flow (High Pressure)
mm
400
300
200
100
0
Pipe Diameter
China
Korea (4 MPa)
Taiwan (5 MPa)
0
5000
m3/h
10000
Flowrate Range

Speed range and wind tunnel size of NMIs



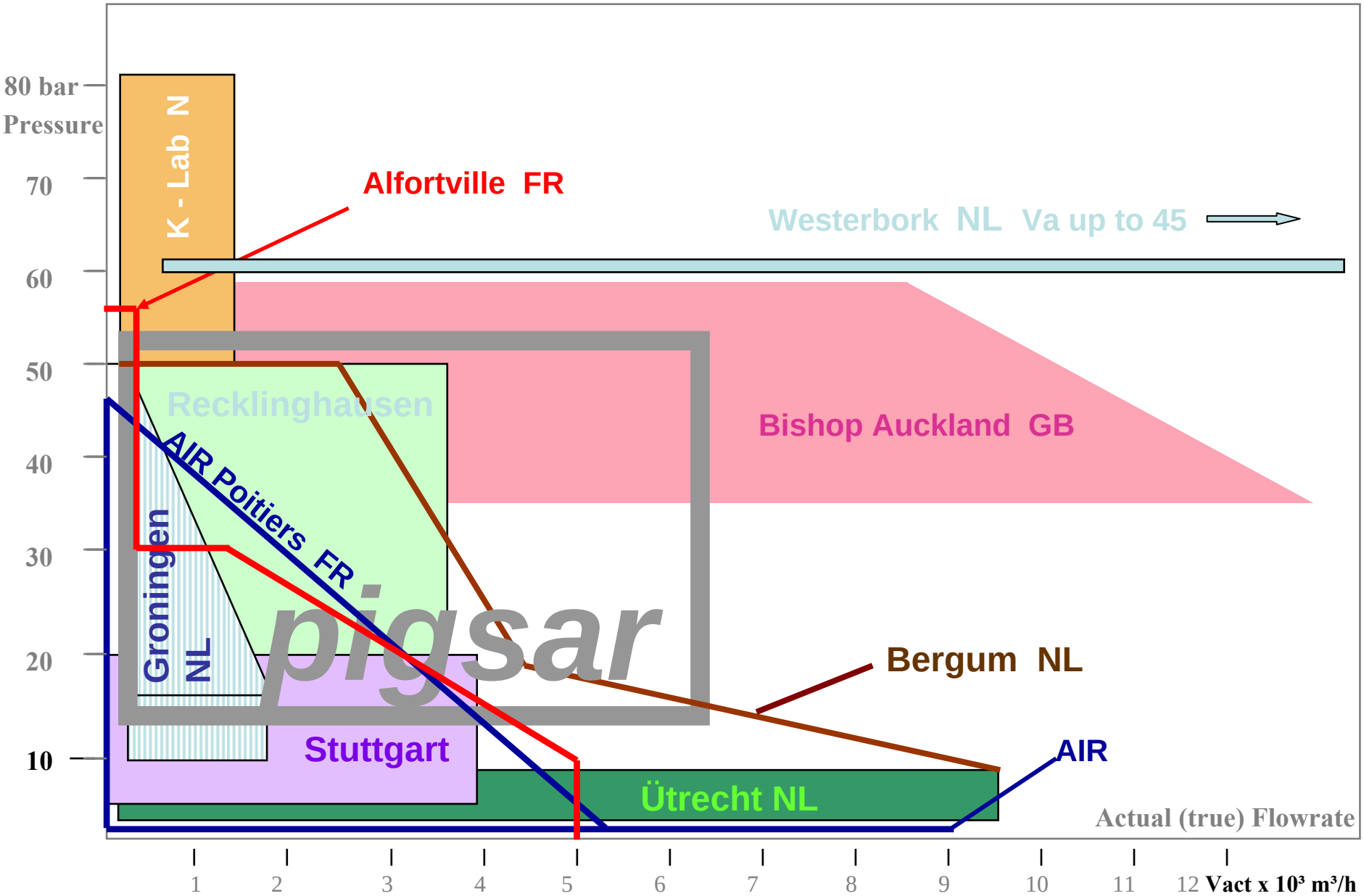
No CMCs for SIM and COOMET available on August 2005

Natural gas at high-pressure

Calibration measuring capabilities of European test rigs similar to *pigsar*

PTB

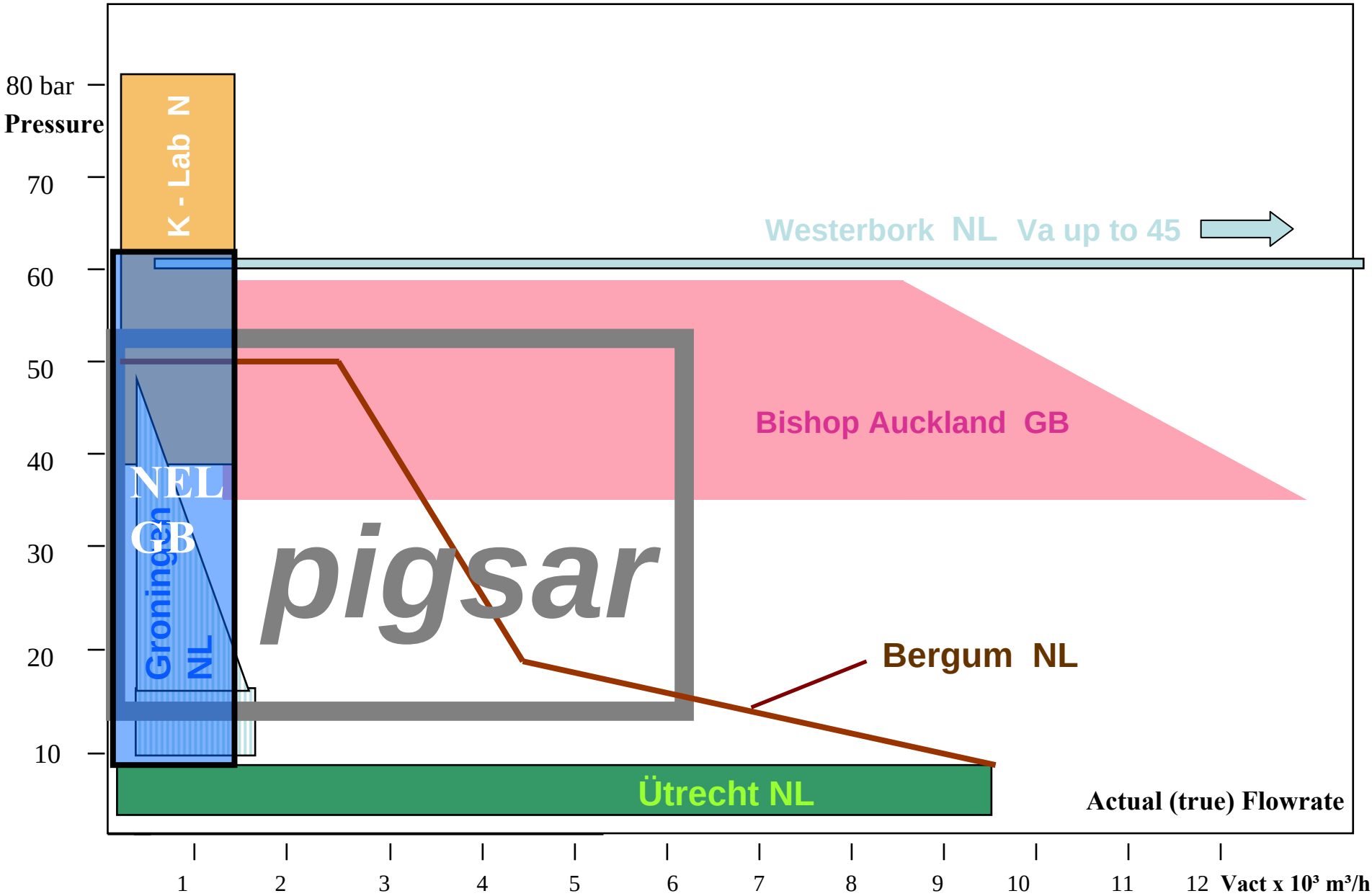
Update 10 March 2001
Dopheide



Calibration measuring capabilities of European test rigs similar to *pigsar, NEL-Nitrogen*

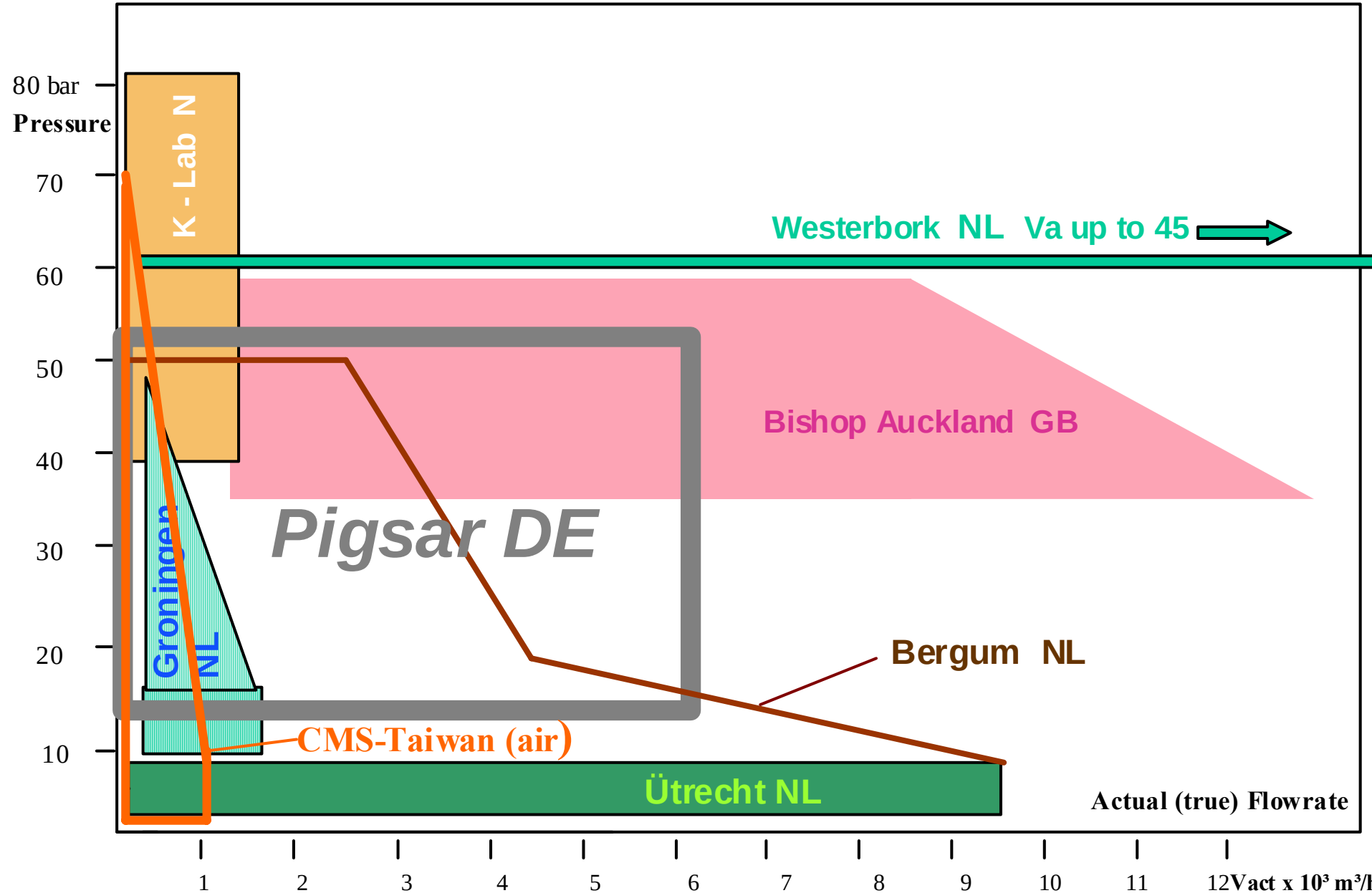
PTB

Update 10 March 2001
Dopheide



Calibration measuring capabilities of European test rigs similar to *pigsar, CMC-Taiwan*

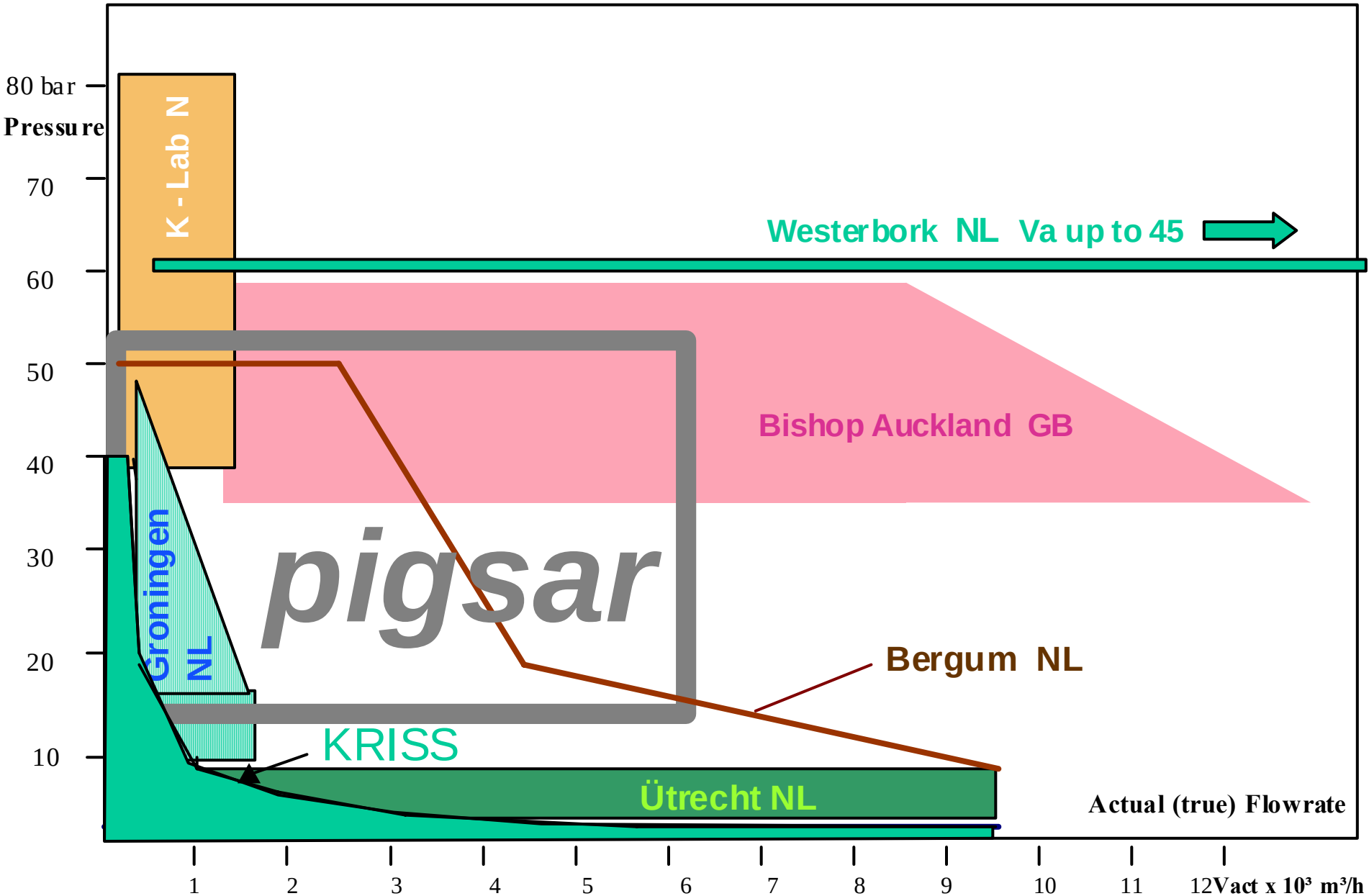
Update 17 April 2001
Dopheide



Calibration measuring capabilities of European test rigs similar to *pigsar, CMC-KRISS for Air*

PTB

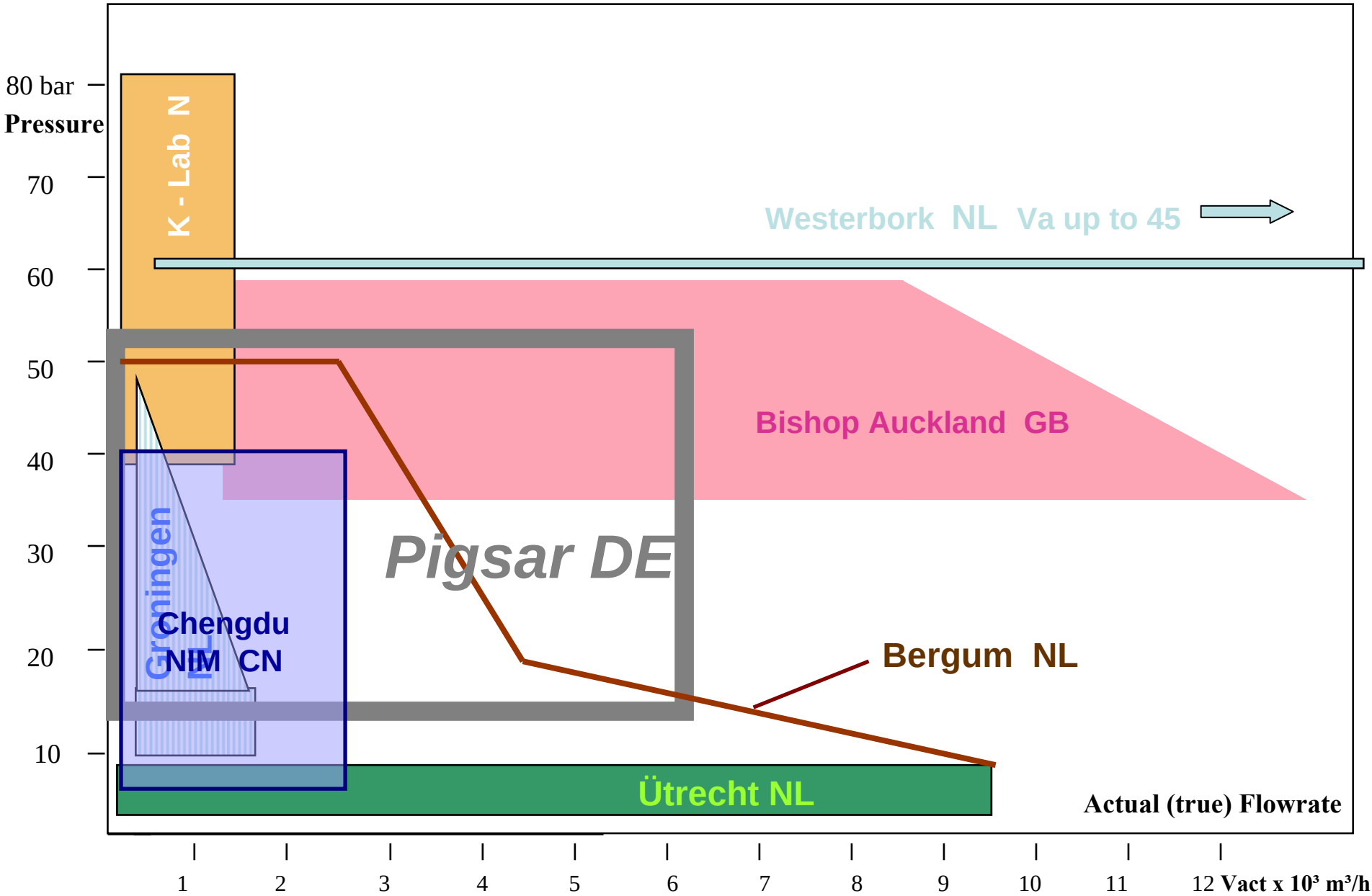
Update 17 April 2001
Dopheide

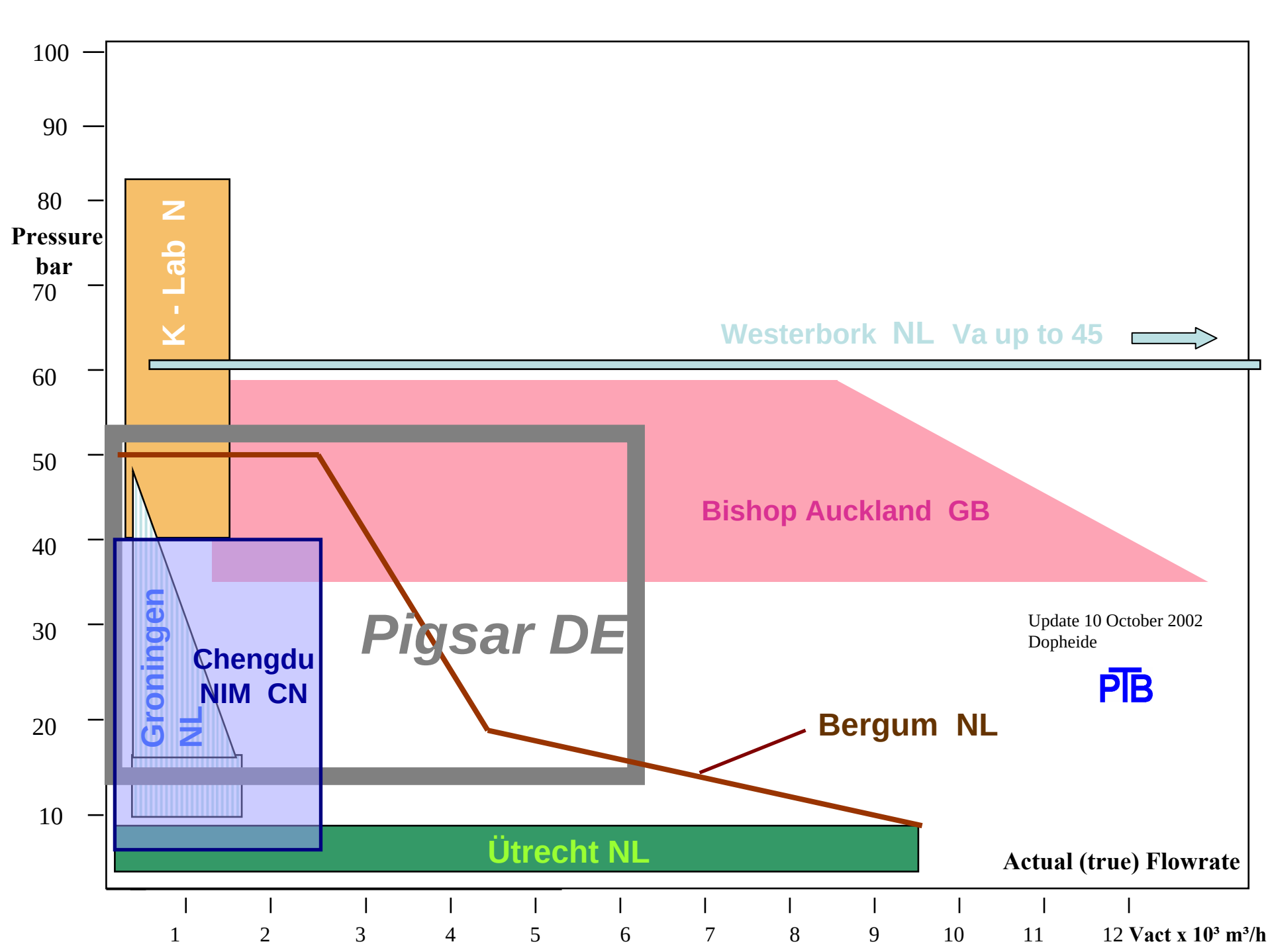


Calibration measuring capabilities of European test rigs similar to *pigsar, NIM China, Chengdu*

PTB

Update 10 March 2001
Dopheide

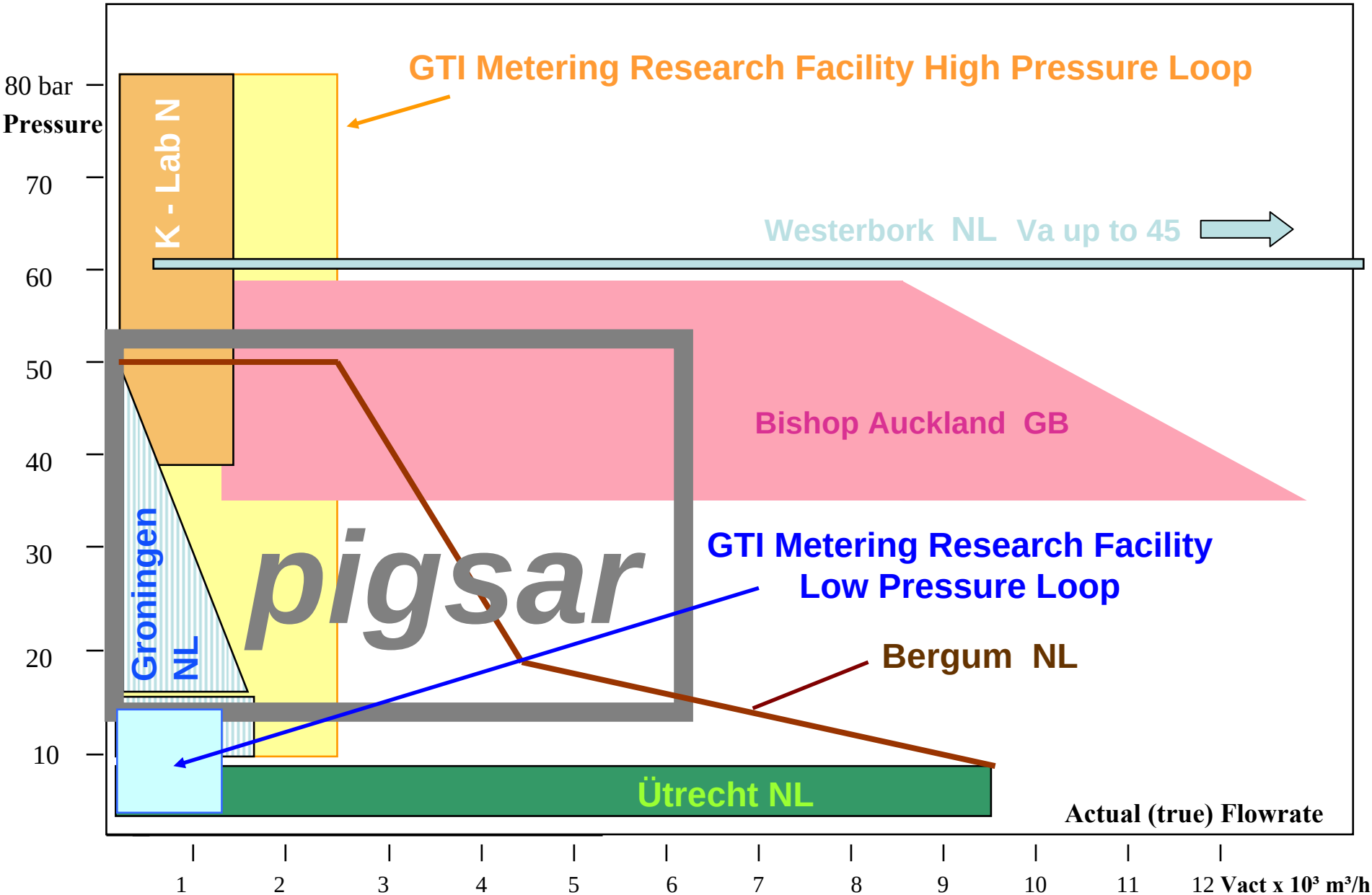



100
90
80
Pressure
bar
70
60
50
40
30
20
10
K - Lab N
Westerbork NL Va up to 45
Bishop Auckland GB
Pigsar DE
Groningen
NL
Chengdu
NIM CN
Update 10 October 2002
Dopheide
PTB
Bergum NL
Ütrecht NL
Actual (true) Flowrate
1
2
3
4
5
6
7
8
9
10
11
12 Vact x 10³ m³/h

Calibration measuring capabilities of European test rigs similar to *pigsar, GTI-SwRI high and low pressure*

PTB

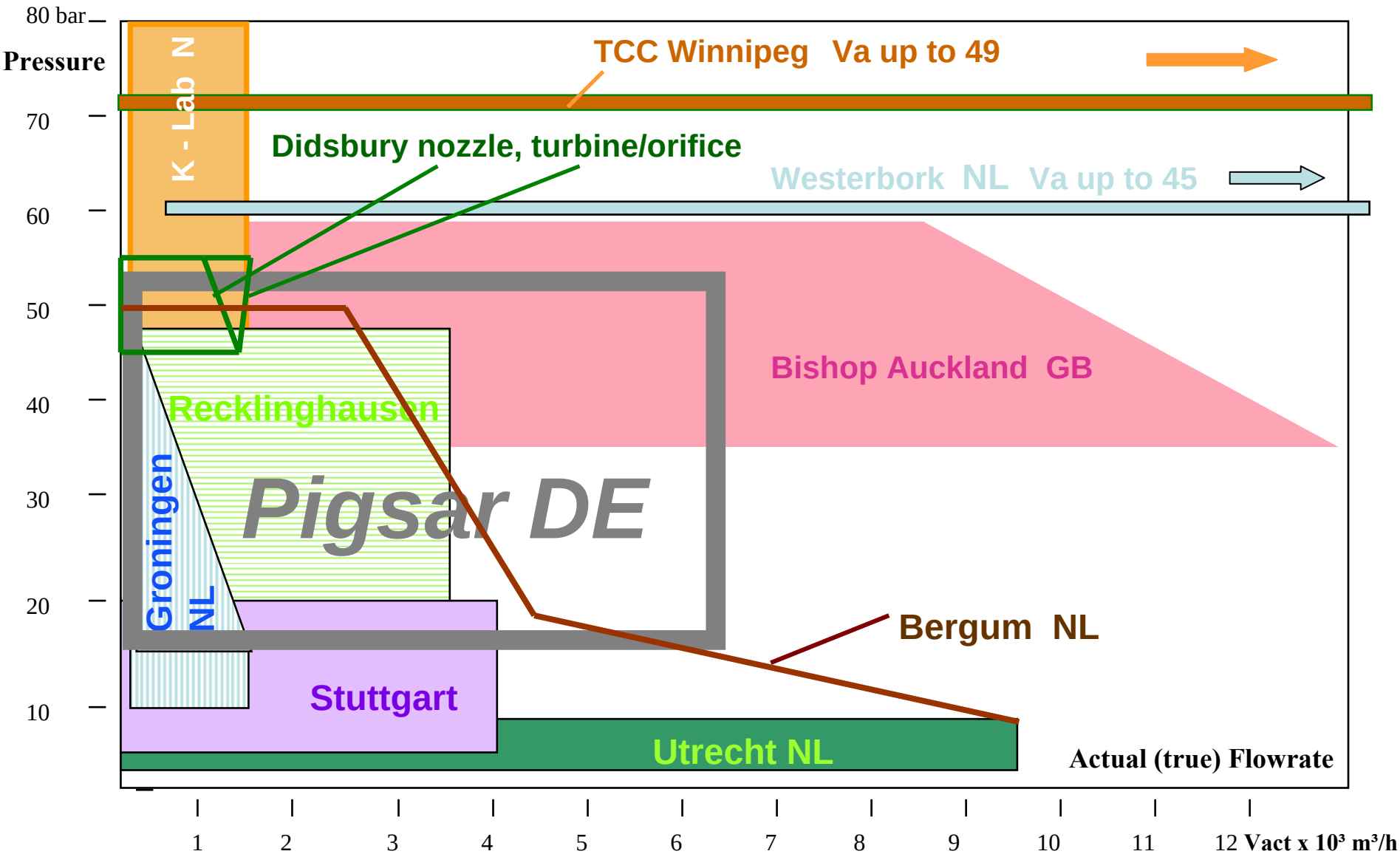
Update 10 March 2001
Dopheide



Calibration measuring capabilities of European test rigs similar to *pigsar*, TransCanada

PTB

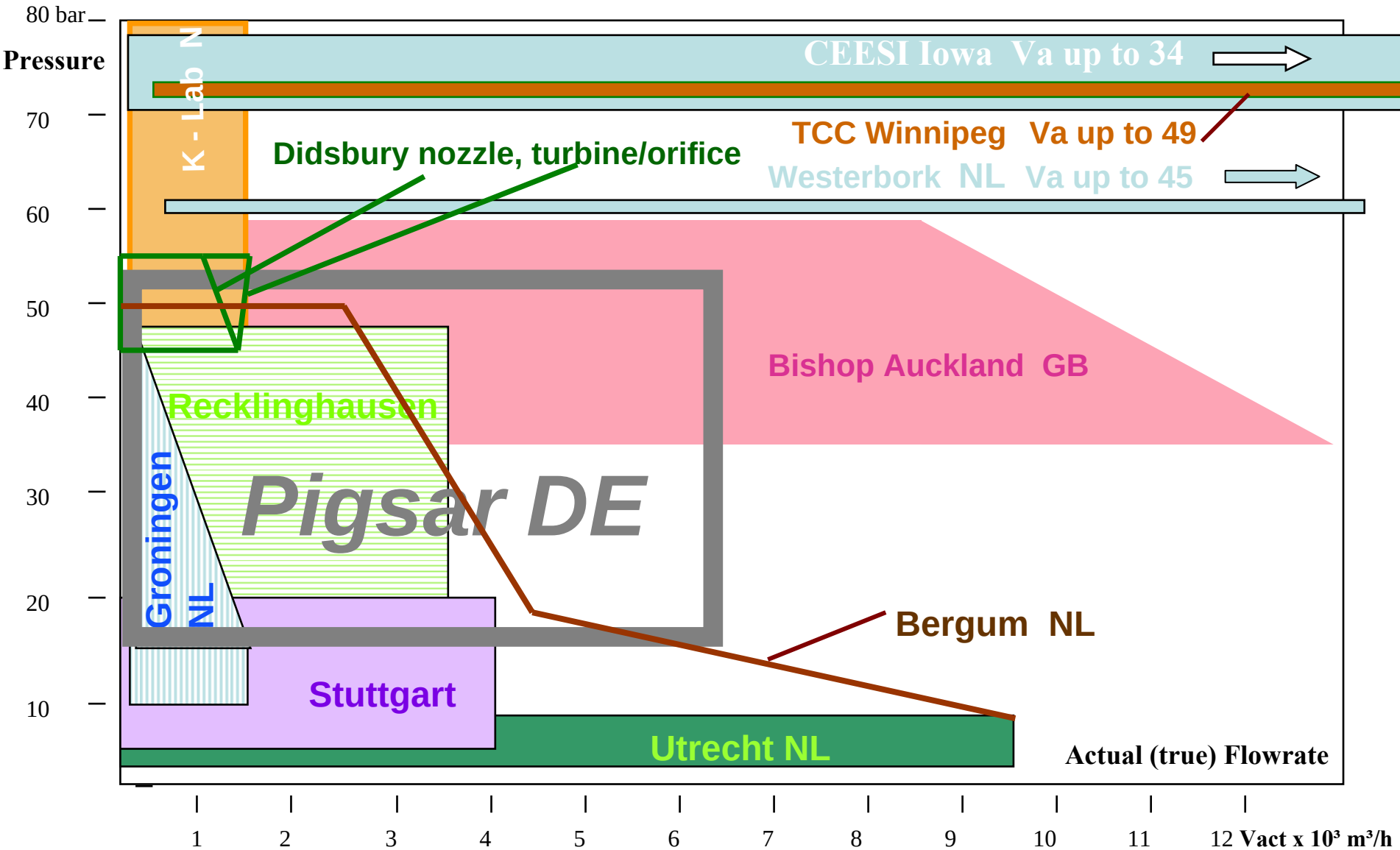
Update 10 March 2001
Dopheide



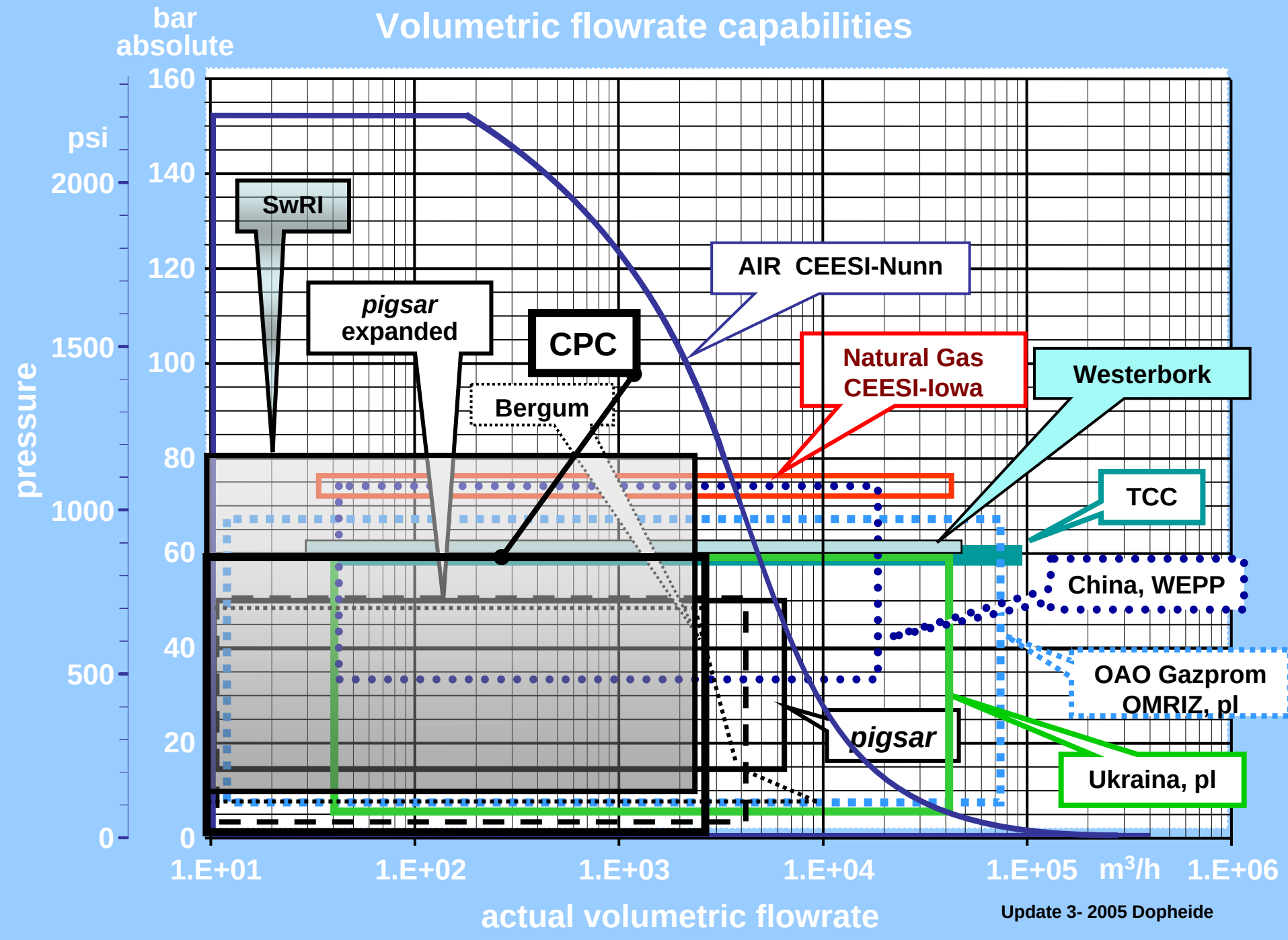
Calibration measuring capabilities of European test rigs similar to *pigsar,* TTC, CEESI

PTB

Update 10 March 2001
Dopheide

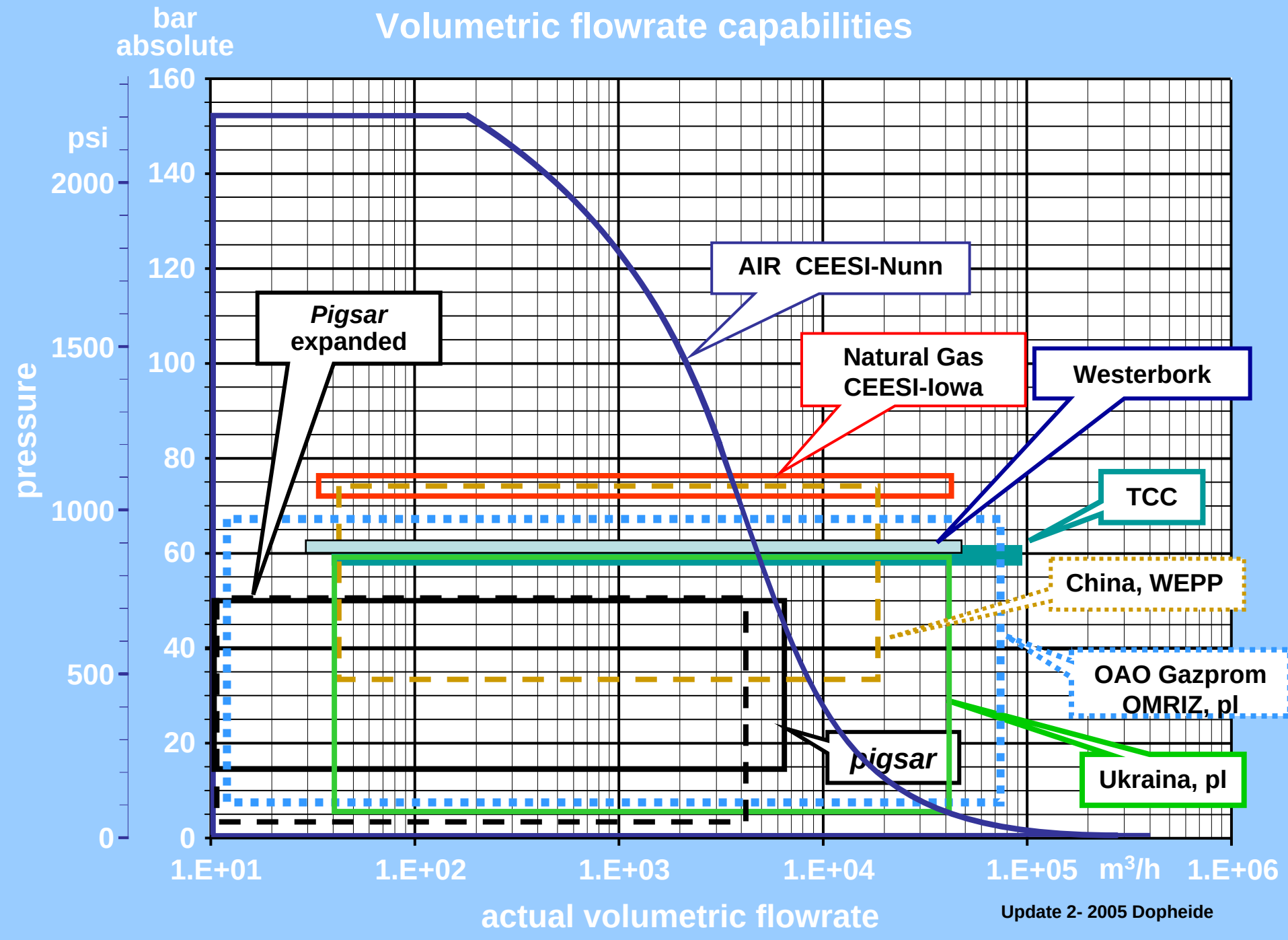


Volumetric flowrate capabilities



Update 3- 2005 Dopheide

Volumetric flowrate capabilities



Update 2- 2005 Dopheide

The BIPM / CIPM Key Comparisons

CIPM Consultative Committees (CCs):

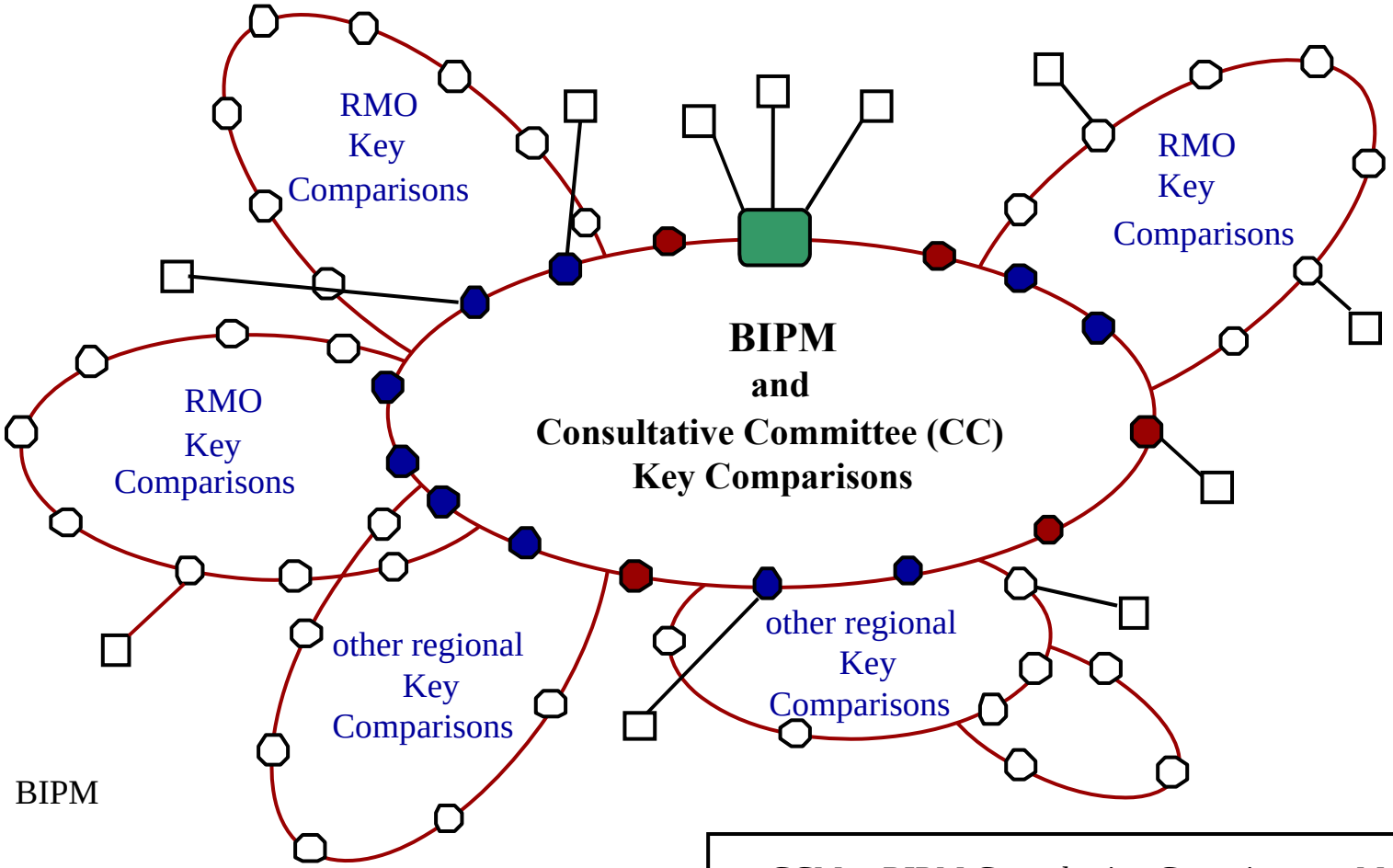
1. CCAUV-Acoustics, Ultrasound, and Vibration
2. CCEM-Electricity and Magnetism
3. CCL-Length
4. CCM-Mass and Related Quantities
5. CCPR-Photometry and Radiation
6. CCQM-Amount of Substance
7. CCRI-Ionizing Radiation
8. CCT-Thermometry
9. CCTF-Time and Frequency
10. CCU-Units

Working Groups:

1. Density
2. Mass
3. Force (WGF)
4. Pressure
5. Avogadro's Const.
6. Hardness
7. Fluid Flow (WGFF)
   a. Water Flow
   b. Hydrocarb. Liq. Flow
   c. Air Speed
   d. Liquid Volume
   e. Hi-Press Gas Flow
   f. Lo-Press Gas Flow

Responsibilities for runnig Global Comparison

Measurand	(Pilot Lab) Initiating Country	Assisting Country	Assisting Country
Water Flow	Korea	UK	Mexico
Hydrocarbon Liquid Flow	UK	Japan	US
Air Flow (Low P)	US	UK	Korea
Gas Flow (High P)	Germany	NL	Korea
Air Speed	Japan	Brazil	Netherlands
Volume	Mexico	Australia	Sweden



BIPM

NMI participating in BIPM/CC Key Comparisons

NMI participating in BIPM/CC Key Comparisons and in RMO Key Comparisons

NMI participating in regional Key Comparisons

NMI participating in neither BIPM/CC nor regional Key Comparisons but making bilateral comparisons directly with BIPM or with NMIs in categories , , or

CCM = BIPM Consultative Committee on Mass and Related Quantities

RMOs = Regional Metrology Organizations

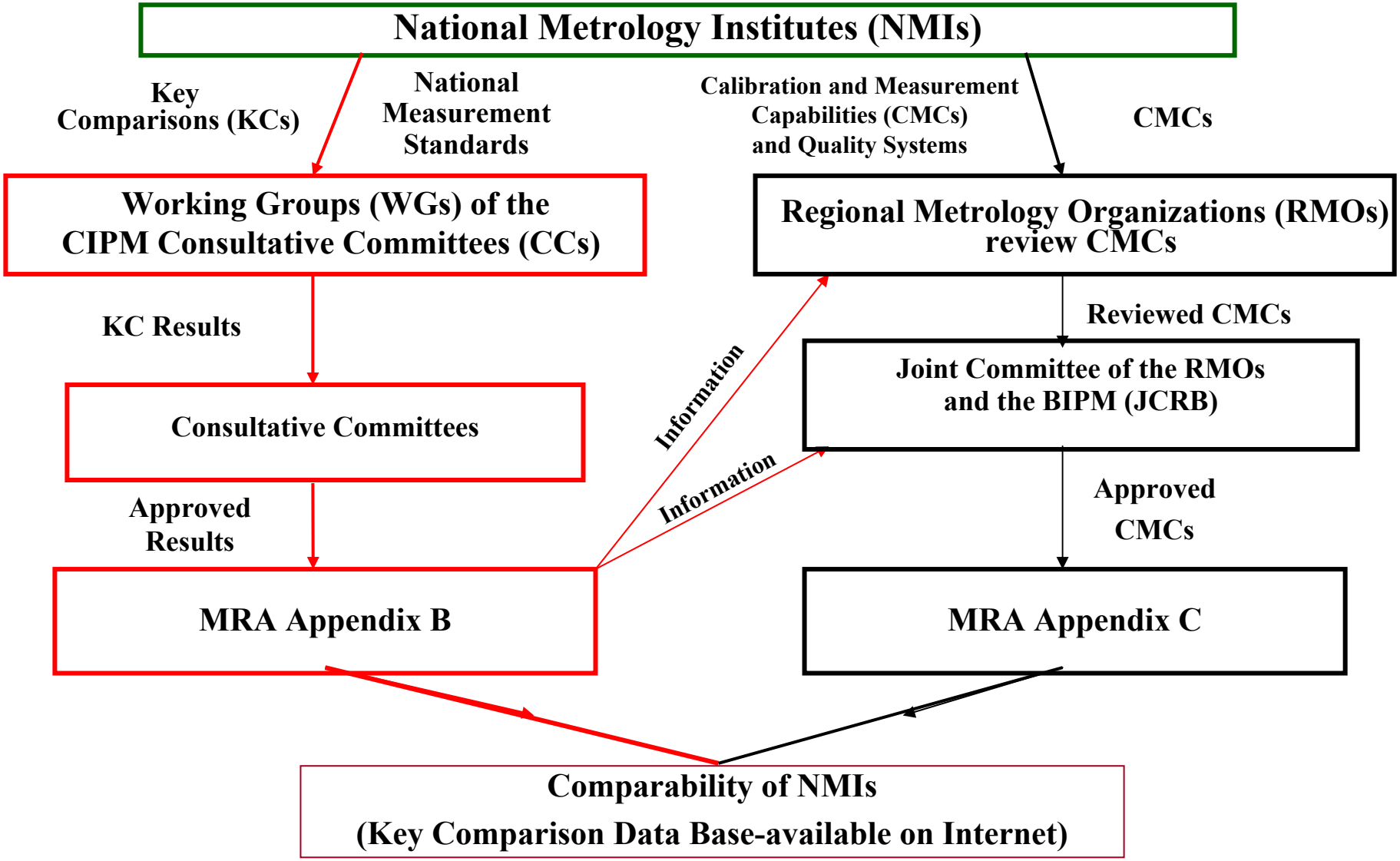
NMI = National Metrology Institution

SIM = Systema Interamericano Metrologia

APMP = Asian-Pacific Metrology Program

EUROMET = Metrology Organization of the European Union

The MRA (Mutual Recognition Arrangement):



WGFF Membership:

- **NMIs of the Member States of the Meter Convention that have signed the MRA, or**
- **Delegates of NMIs that have signed the MRA, in respective areas of measurement.**

WGFF Strategy:

In accord with the BIPM/CIPM MRA*:

1. Review and assess the Calibration and Measurement Capabilities (CMCs) of the NMIs participating in the WGFF measurement areas,

2. Design and conduct the CIPM Key Comparisons (KCs) and related activities needed to quantify the equivalency (i.e., the "horizontal comparability")** of the national standards for fluid measurements among the NMIs that participate in the MRA,

3. Report results,

4. As needed, maintain or expand CIPM KCs.

---

*See: www.bipm.fr for details on the BIPM, CIPM, and the Mutual Recognition Arrangement (MRA).

**Note: Establishment of:
(a) the "horizontal comparability" of flow standards among the world's NMIs and
(b) the domestic "vertical traceability" to the local NMI
should eliminate measurement-based barriers to international trade.

Results of first BIPM/CIPM Key Comparison
Natural gas at high pressure

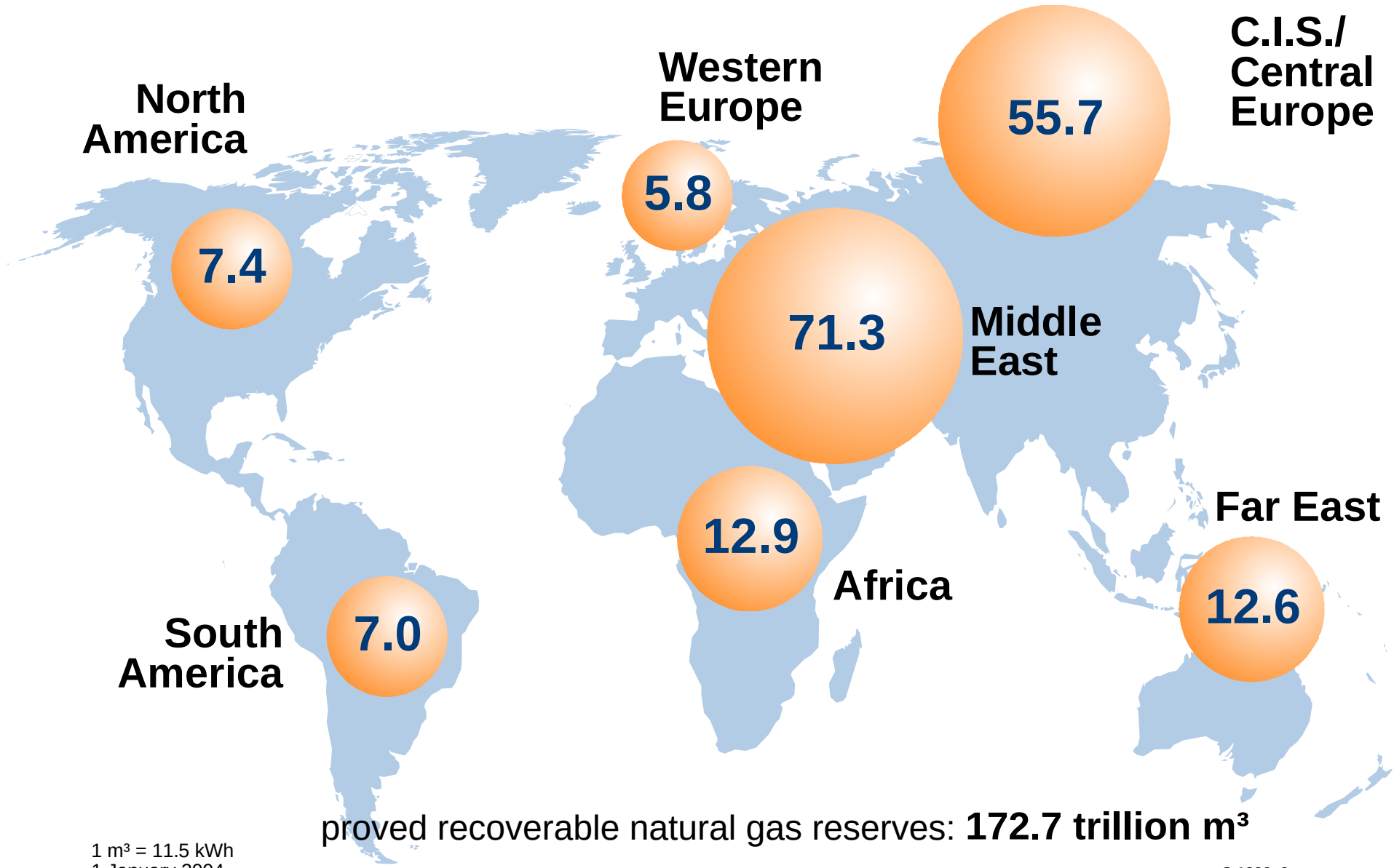
National Standard of Germany for flow rate of high-pressure natural gas

The international BIPM/CIPM Key Comparisons for high-pressure natural gas and the Key Comparison Reference Value (KCRV): its meaning for metrology and international trade as well as for the Mutual Recognition Agreement (MRA).

D. Dopheide, B. Mickan, R. Kramer, H.-J. Hotze
Physikalisch-Technische Bundesanstalt (PTB)
and ***pigsar, National Lab***

Gas Pipeline Systems in Europe including Supply Areas of CIS States

World Gas Reserves



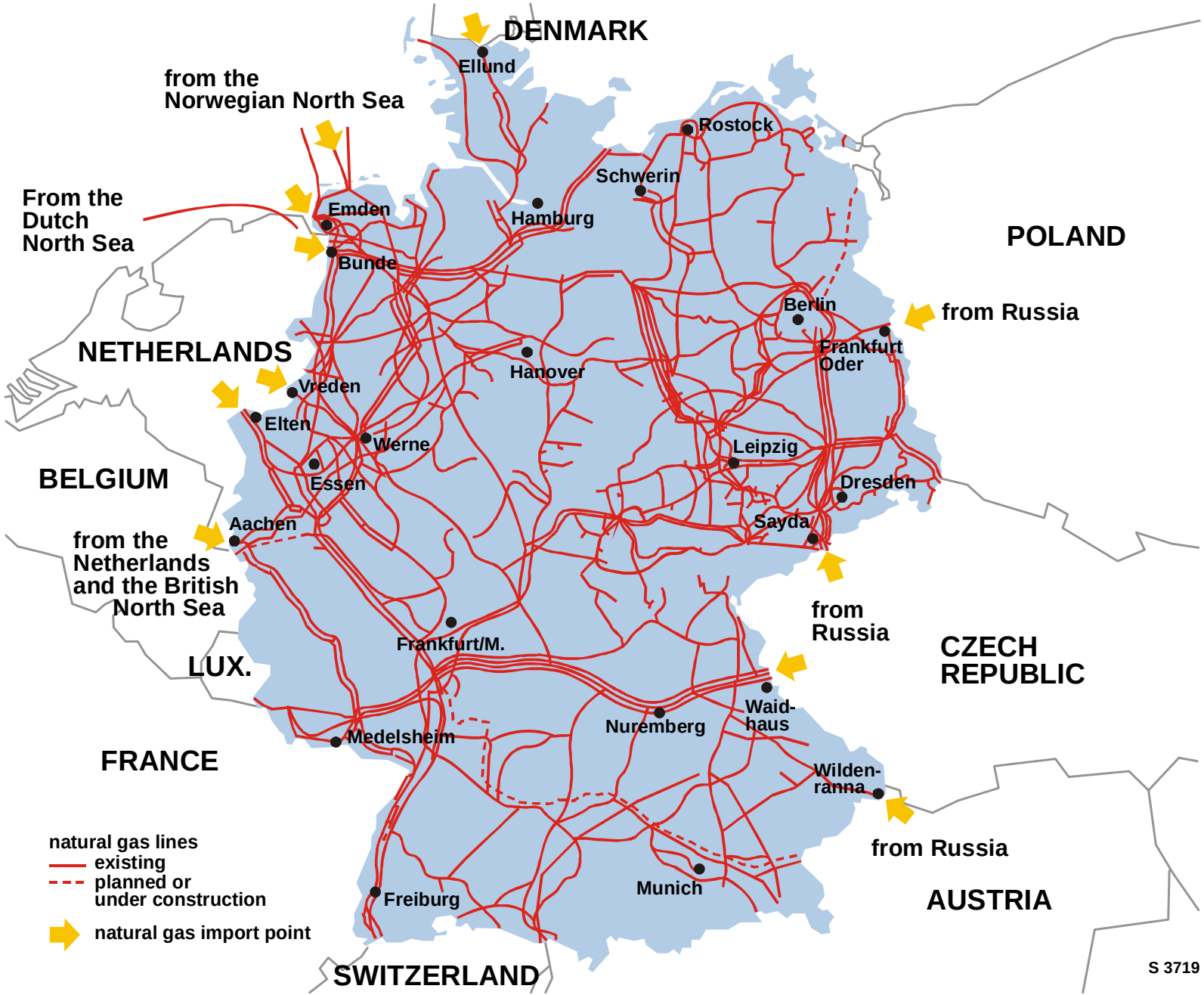
proved recoverable natural gas reserves: **172.7 trillion m³**

1 m³ = 11.5 kWh
1 January 2004

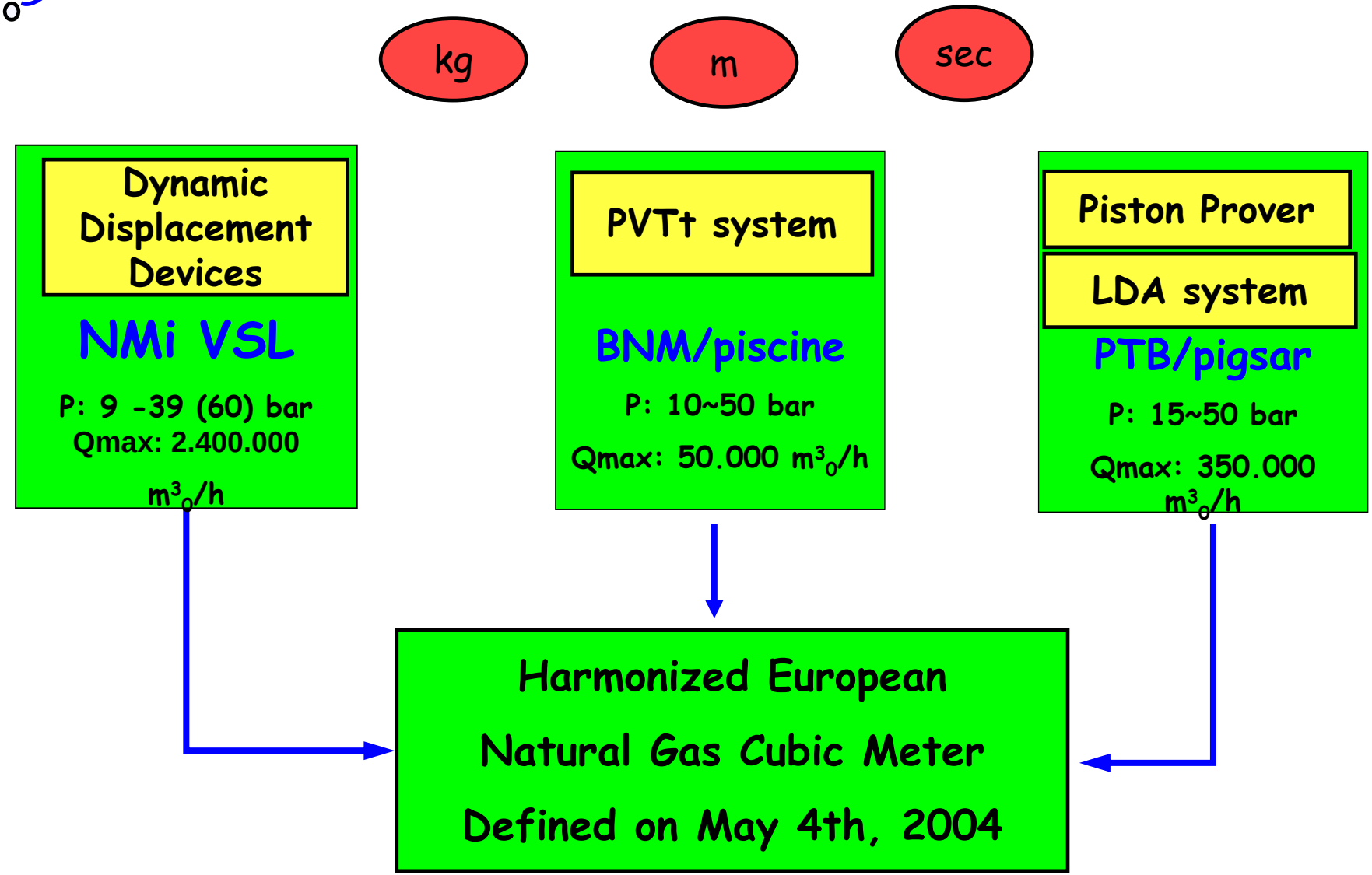
S 1832_3


RUSSIAN FEDERATION
Surgut
Nizhnevartovsk
Baykit
Sredne-Viluyskoye
SAKHA REPUBLIC
Aldan
Sredne-Botubinskoye
Chayandinskoye
Talakanskoye
From Western Siberia
Tomsk
Kovyktinskoye
Novokuznetsk
Skovorodino
Okha
Astana
Irkutsk
Chita
Ulan-Ude
Komsomolsk -na-Amur
Zabaykal'sk
Erdenet
From Kazakhstan
Ulan Bator
Eastern Route
Khabarovsk
MONGOLIA
Harbin
Western Route
Dal'nerechensk
Almaty
Urumqi
Shanshan
From Turkmenistan
Vladivostok
KYRGYZSTAN
Lunnan
Korla
West-East Pipeline
Beijing
Yumen
Yinchuan
TAJIKISTAN
Seoul
JAPAN
CHINA
Golmud
Qingdao
Lanzhou
Tokyo
Islamabad
Xi'an
Nantong
Shanghai
Chengdu
Wuhan
New Delhi
Chongqing
NEPAL
BHUTAN
INDIA
Qili
Jagdishpur
BANGLADESH
TAIWAN
Hong Kong
MYANMAR
LAOS
Pipelines
Existing
Under Construction
Gas Fields

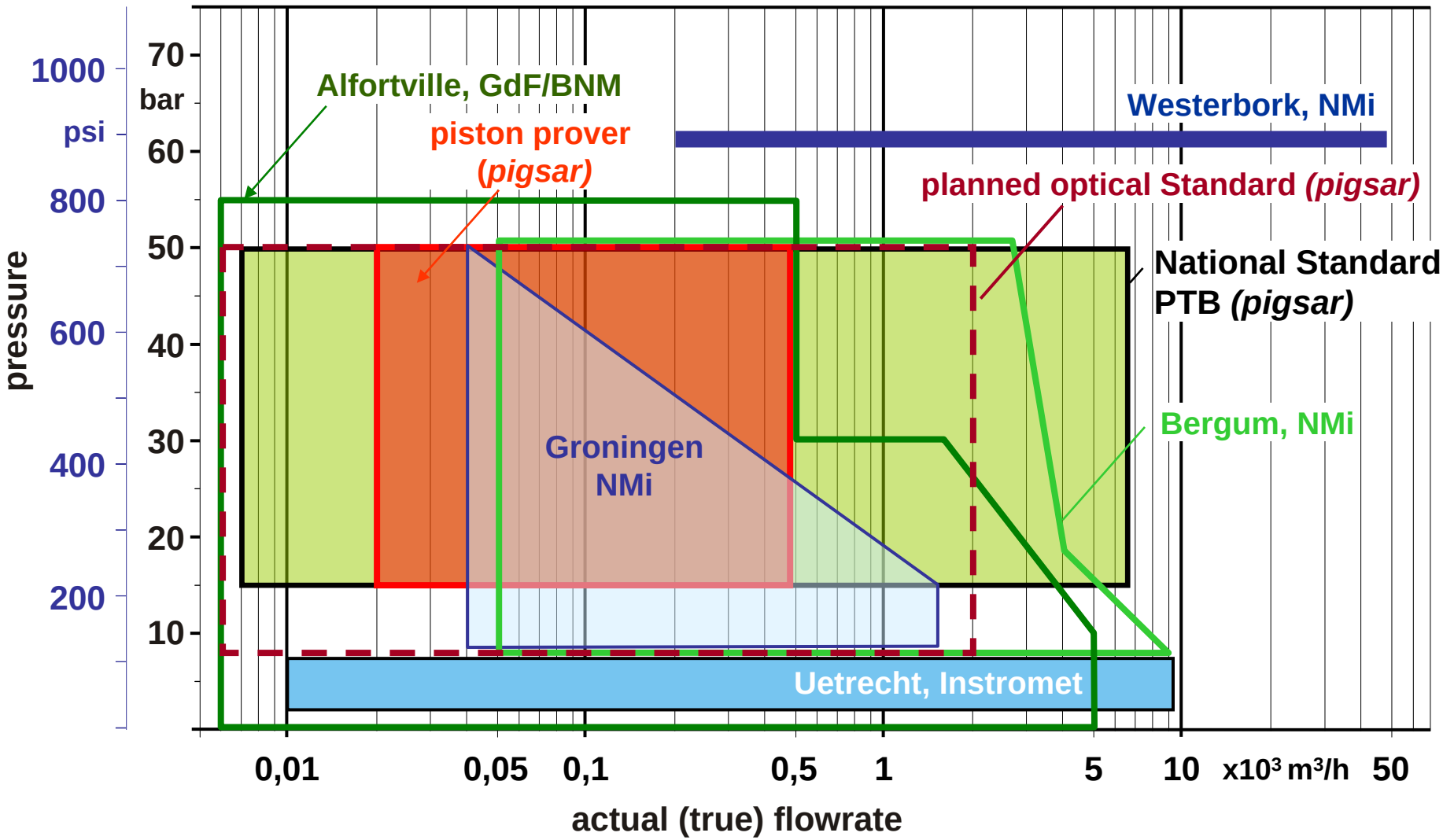
Natural Gas Lines in Germany



Interaction between the traceability chains



Calibration and measuring capabilities of facilities participating in the Harmonization process of natural gas



Suggestions for defining a KCRV

Median

J.W. Müller, *Possible Advantages of a Robust Evaluation of Comparison*
J. Res. Nat. Stand. Technol. 105, 551 (2000)

Arithmetic mean, Weighted mean

M.Cox, *The evaluation of key comparison data,*
Metrologia, 2002, 39, 589-595

Least square estimates

L.Nielsen, *Evaluation of measurement intercomparisons*
***by the method of least squares*, DFM-99-R39 (2000)**

The weighted mean

Procedure A suggested by BIPM for the KC Reference Value:

KCRV = weighted mean *y*

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

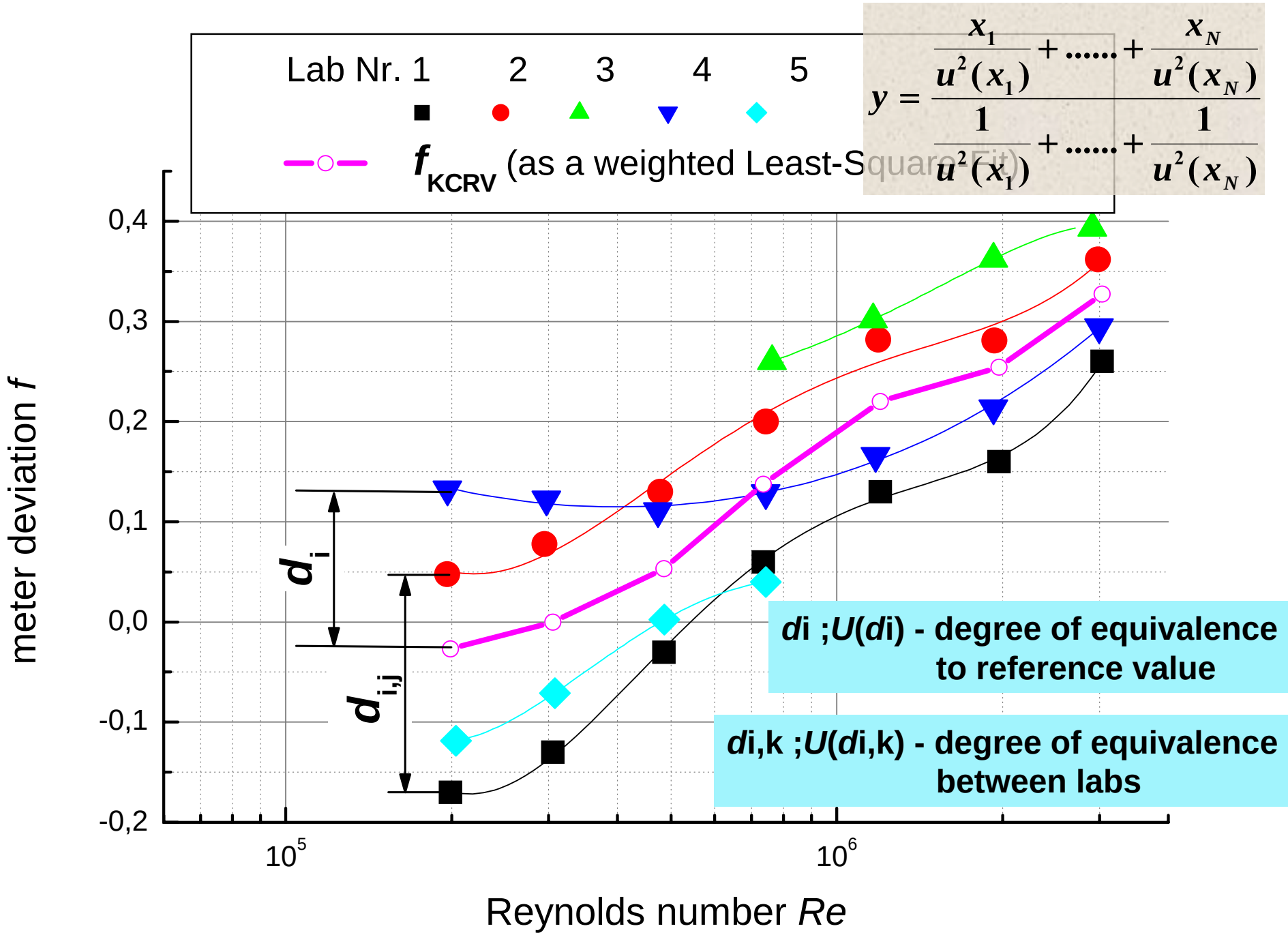
Variance associated with *y*

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

To check the outcome:

Chi-squared test $\chi^2_{obs} = \dfrac{(x_1 - y)^2}{u^2(x_1)} + \ldots\ldots + \dfrac{(x_N - y)^2}{u^2(x_N)}$ **on observed values**

If Pr $\left\{\chi^2(v) \,|\, > \chi^2_{obs}\right\} > 0{,}05$ **accept** $x_{ref} = y = KCRV$


Lab Nr. 1 2 3 4 5
f_{KCRV} (as a weighted Least-Square Fit)
$y = \frac{\frac{x_1}{u^2(x_1)} + \ldots\ldots + \frac{x_N}{u^2(x_N)}}{\frac{1}{u^2(x_1)} + \ldots\ldots + \frac{1}{u^2(x_N)}}$
meter deviation f
0,4
0,3
0,2
0,1
0,0
-0,1
-0,2
d_i
$d_{i,j}$
10^5
10^6
Reynolds number Re
d_i ;$U(d_i)$ - degree of equivalence to reference value
$d_{i,k}$;$U(d_{i,k})$ - degree of equivalence between labs

Uncertainty in HRV:

Uncertainty analyses, example

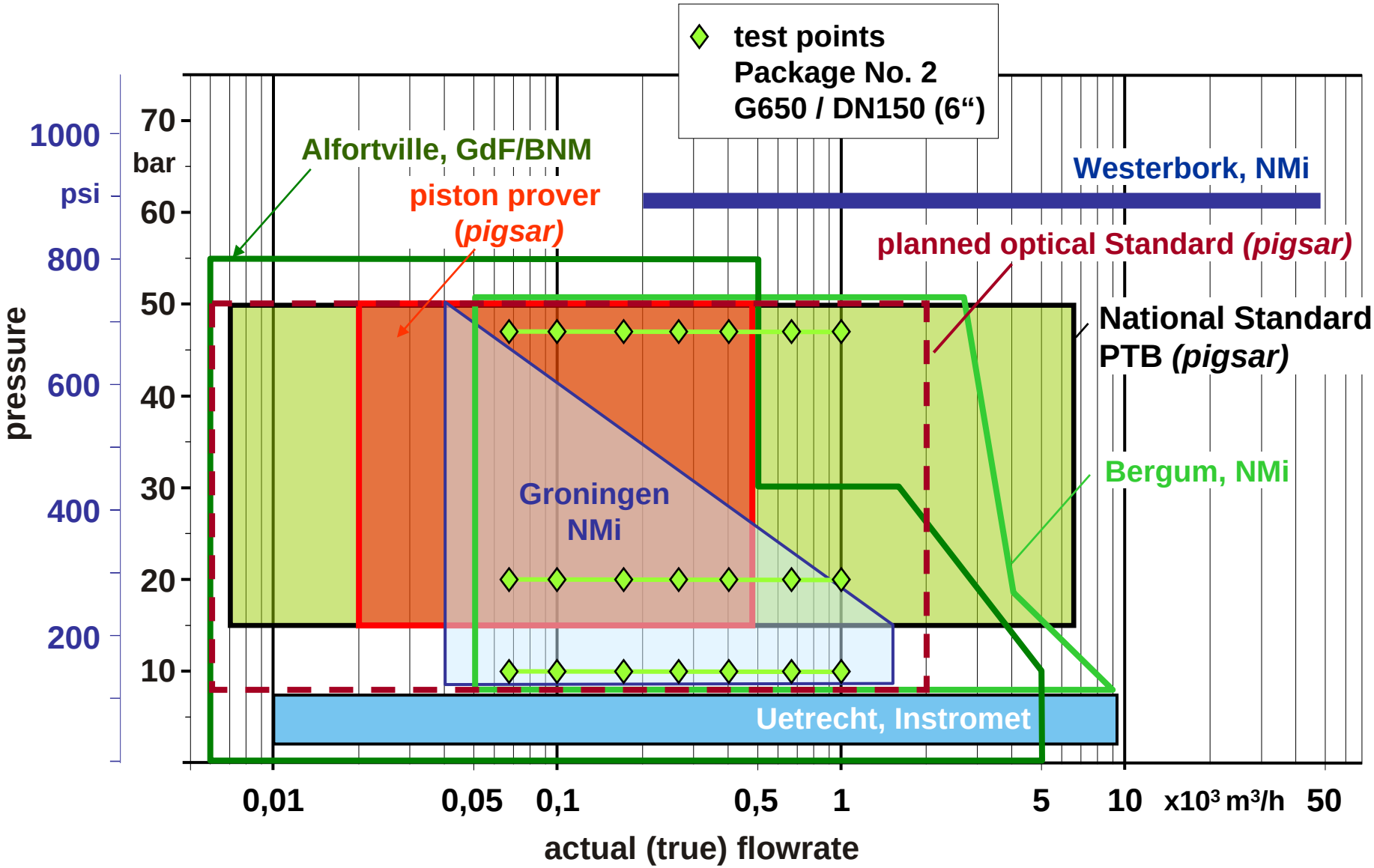
$$U_{harmonized} = \sqrt{W_1 * U_1^2 + W_2 * U_2^2 + U_{comparison}^2}$$

$$U_{harmonized} = \sqrt{0{,}5^2 * U^2 + 0{,}5^2 * U^2 + U_{comparison}^2}$$

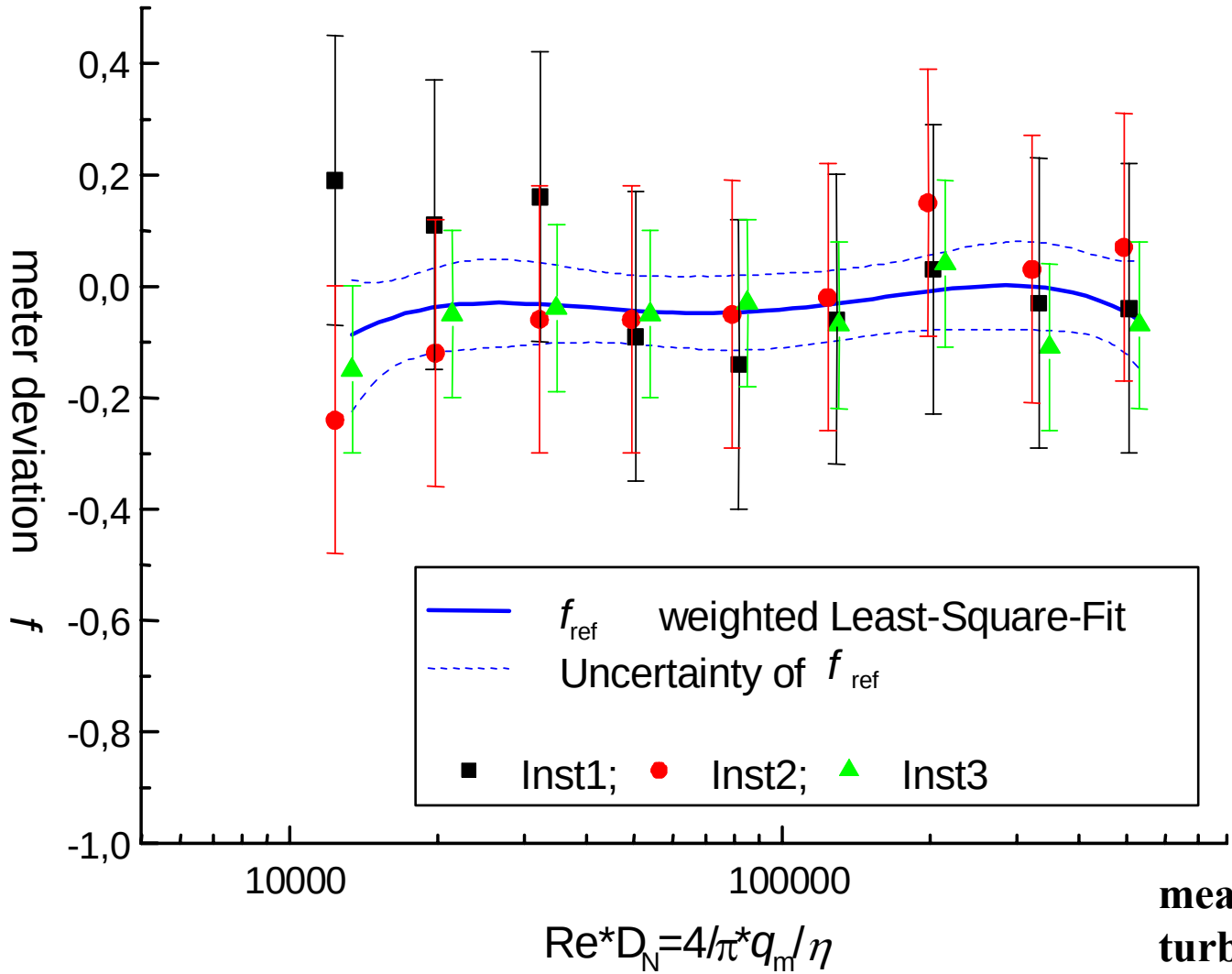
$$= \sqrt{\frac{0{,}5^2}{2} + U_{comparison}^2}$$

N-number of traceability chains!

Calibration and Measuring Capabilities of European Facilities



Spring 2004: Establishing the Harmonized Cubic Meter of PTB, NMi-VSL, BNM

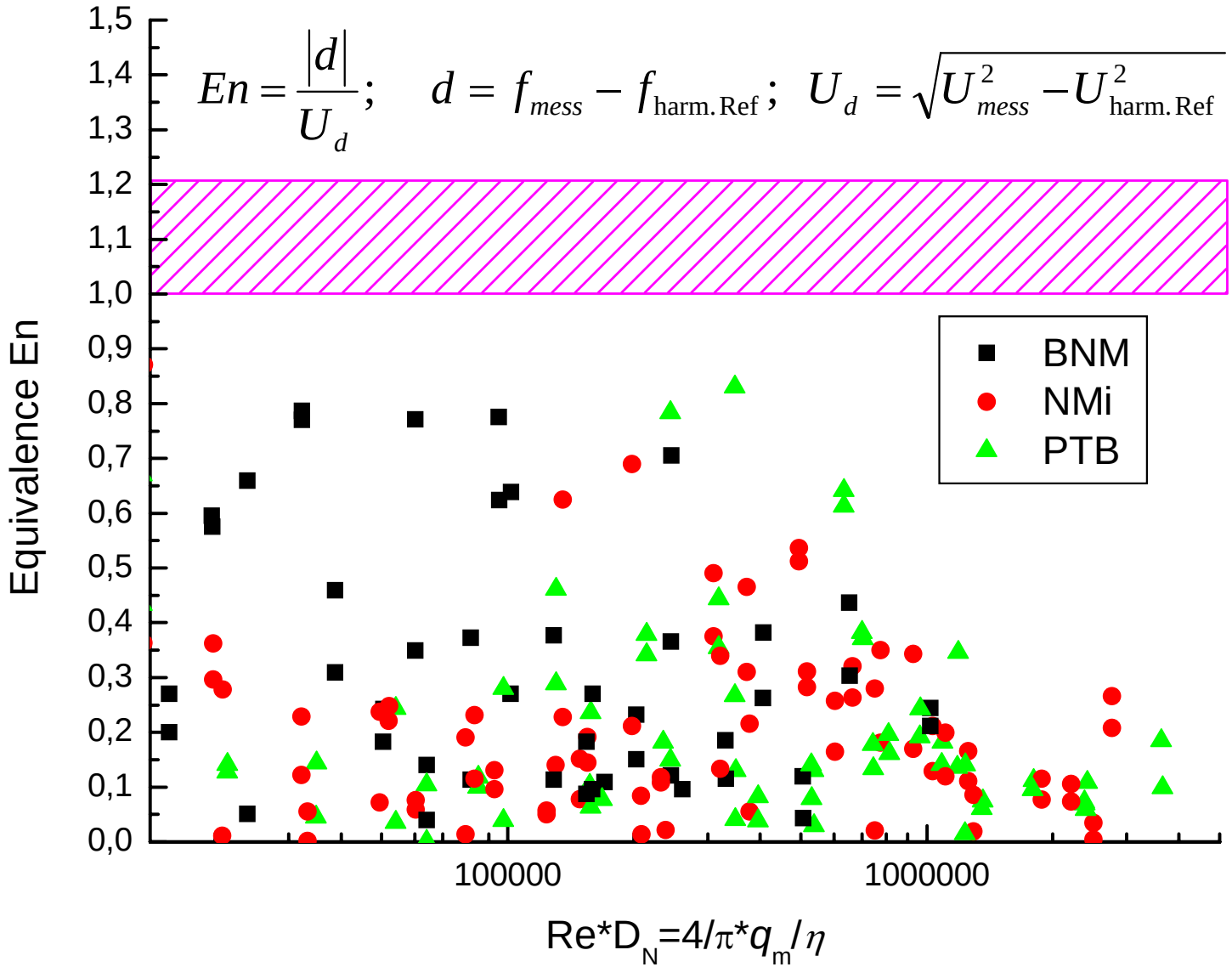


measured at 20 bar
turbine DN 150
second meter

Data of the Harmonization process for a <u>single</u> turbine meter at fixed pressure

Degree of Equivalence using En-criterium

$$En = \frac{|d|}{U_d}; \quad d = f_{mess} - f_{\text{harm.Ref}}; \quad U_d = \sqrt{U_{mess}^2 - U_{\text{harm.Ref}}^2}$$



Benefit of Harmonization Procedure:

- Smaller / lower uncertainty of Harmonized Reference Value

- Extremely stable reference value over time.
  This is considered to be most important for all energy / gas trading companies in order to balance input and output

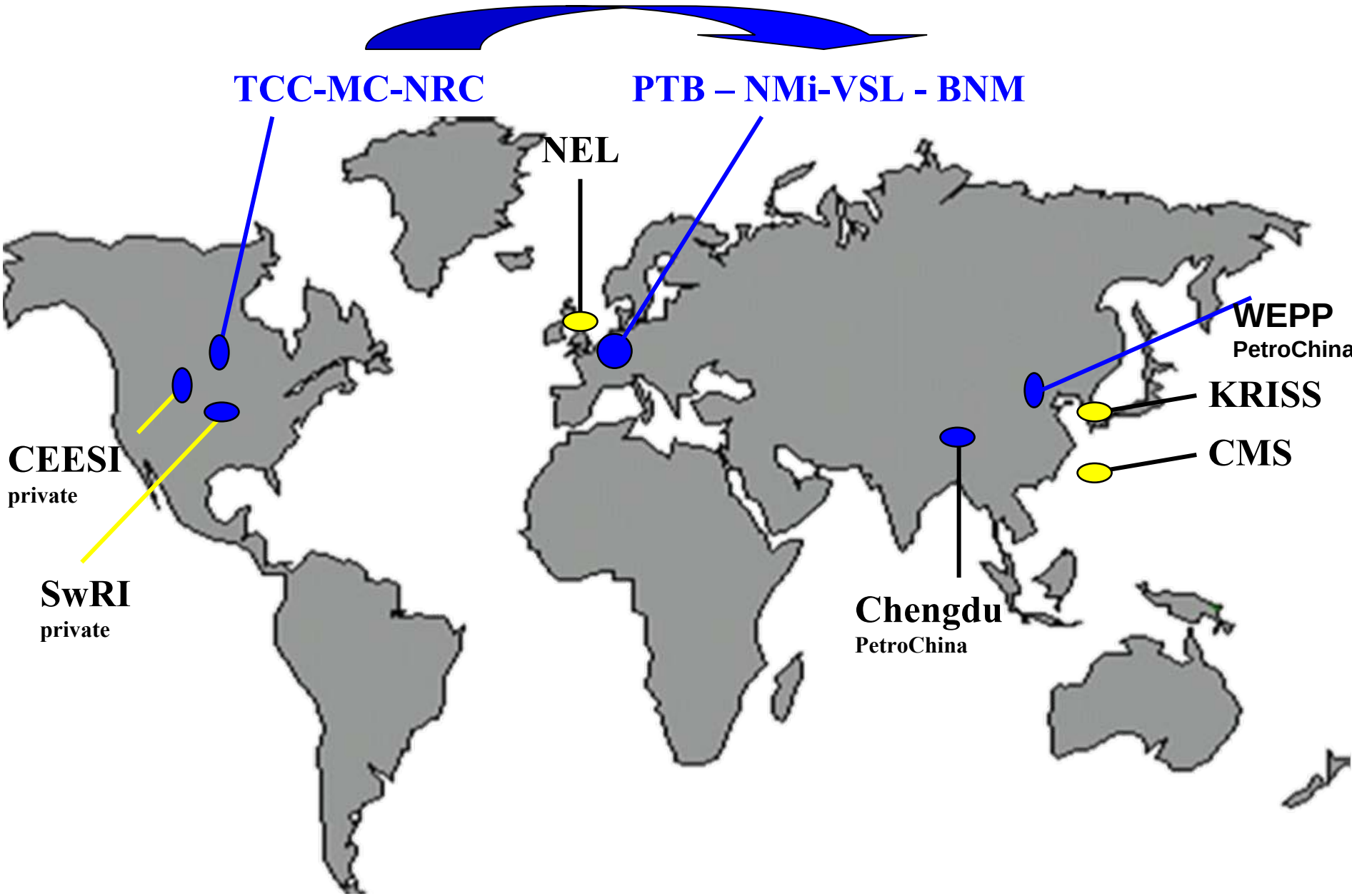
The BIPM / CIPM Key Comparisons

The Key Comparison Reference Value (KCRV)
can be consieed as the world-wide best available
realization of the natural gas cubic meter for natural gas

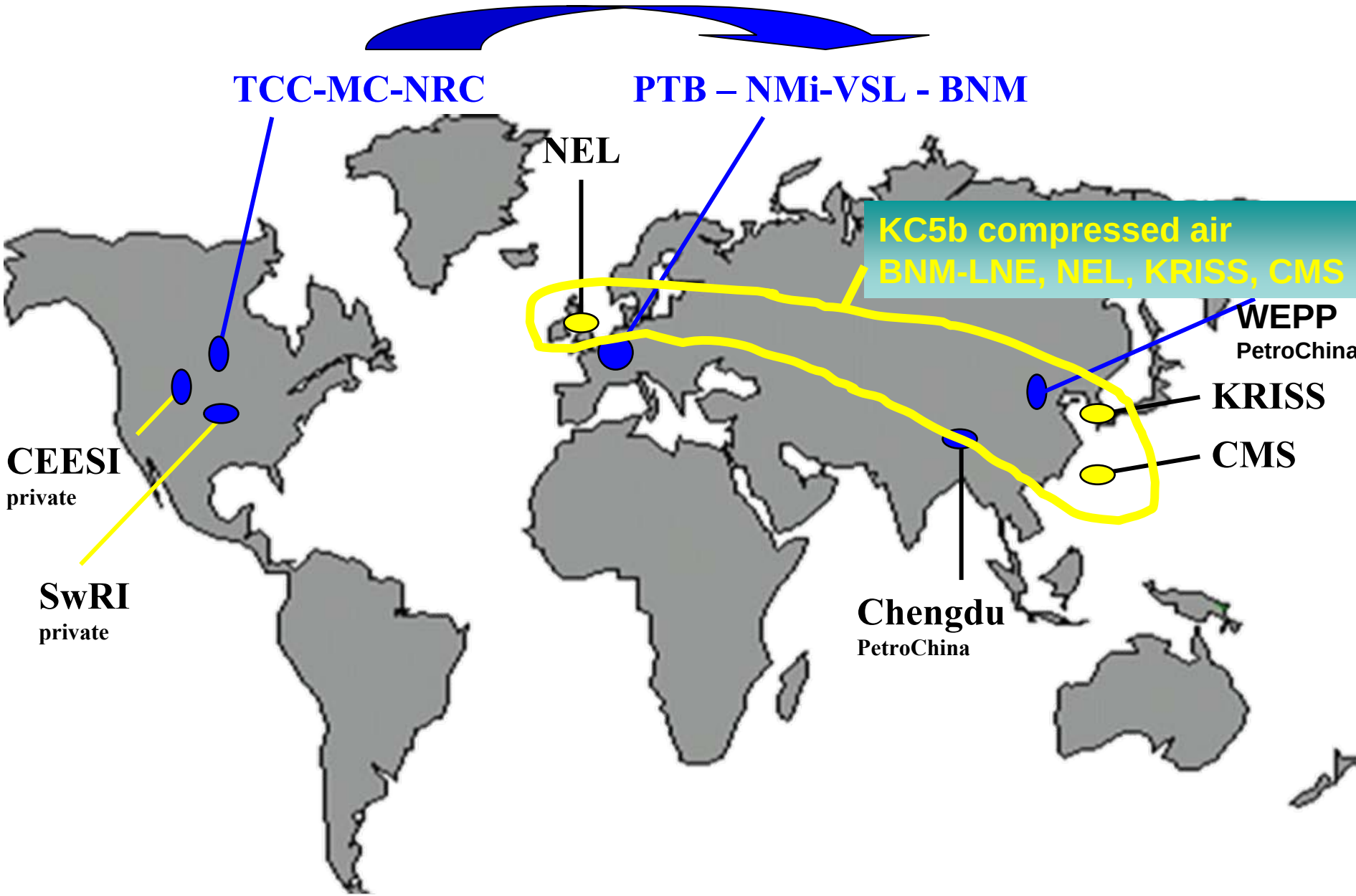
This KCRV is identical with the European Harmonized Reference Level
Europan Harmonized Gas Cubic Meter for Natural Gas
which is in use since May 4th, 2004

All other existing facilities refrained from participating in BIPM / CIPM KCs:
NIST, CEESI, SwRI, NRC-MC, TCC, NIM-AQSIQ/CSBTS

High-press natural gas calibration facilities and BIPM/CIPM Key Comparisons

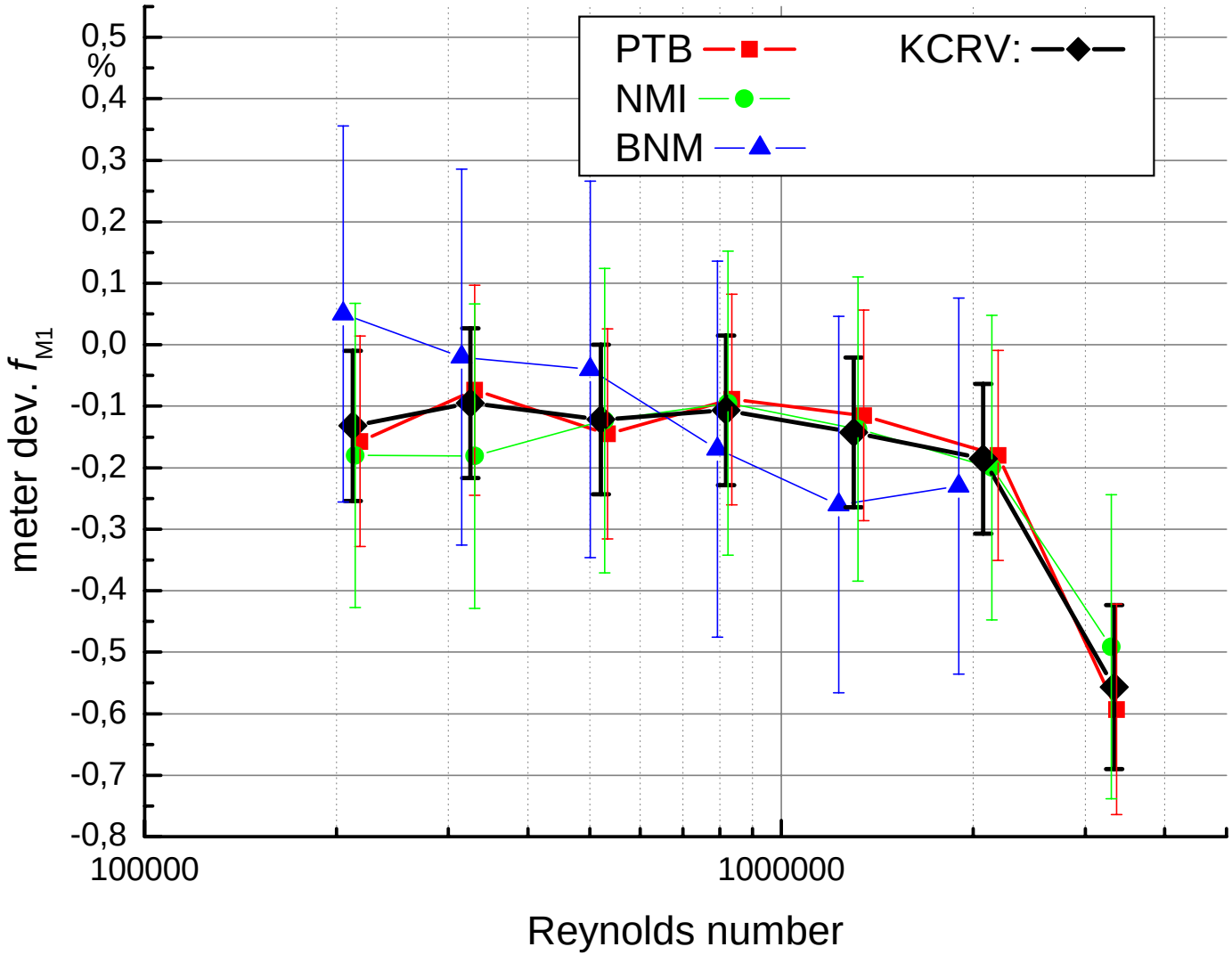


High-press natural gas BIPM/CIPM Key Comparisons 2004 / 2005

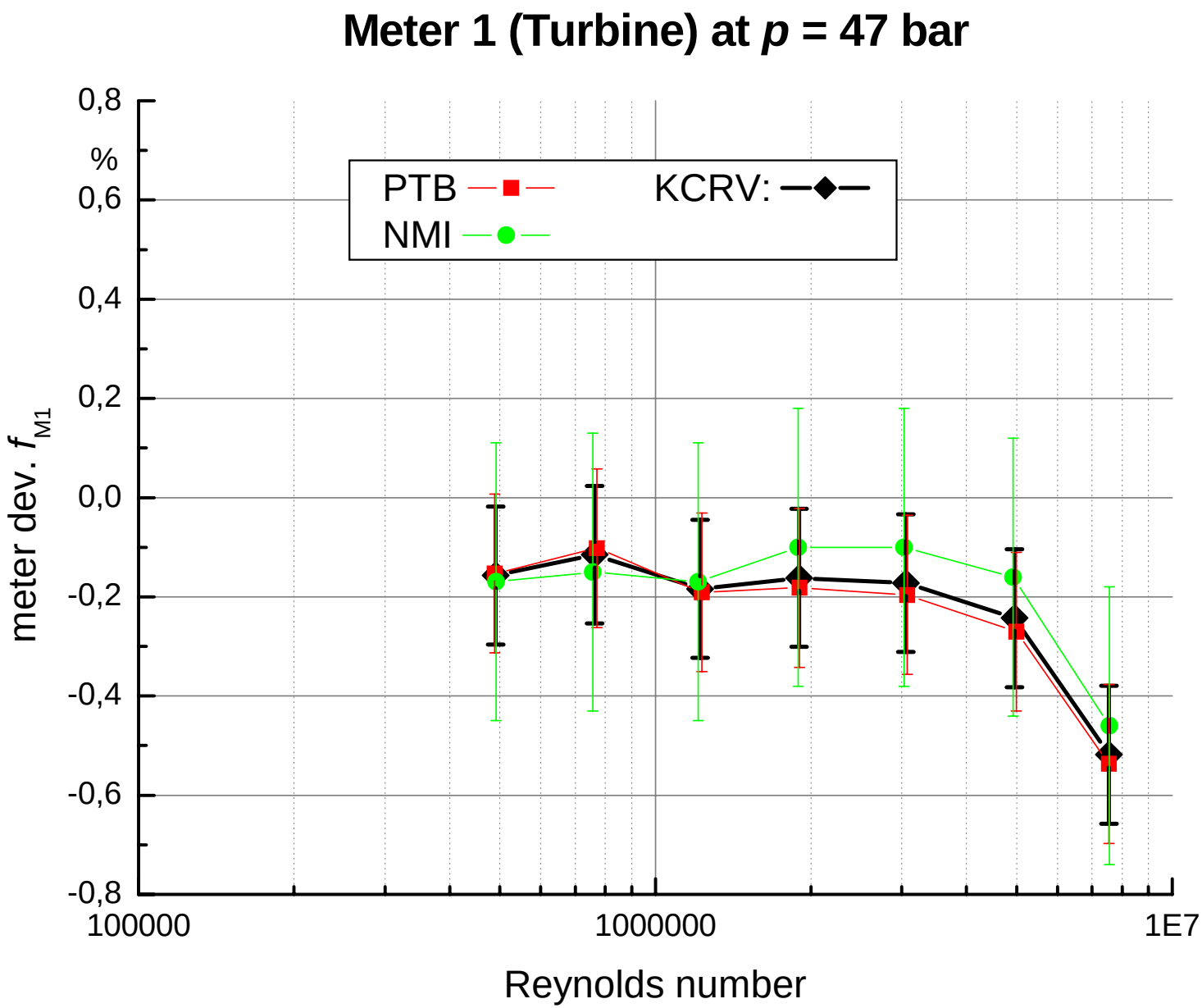


Key Comparison results for high-press natural gas

Meter 1 (Turbine) at *p* = 20 bar

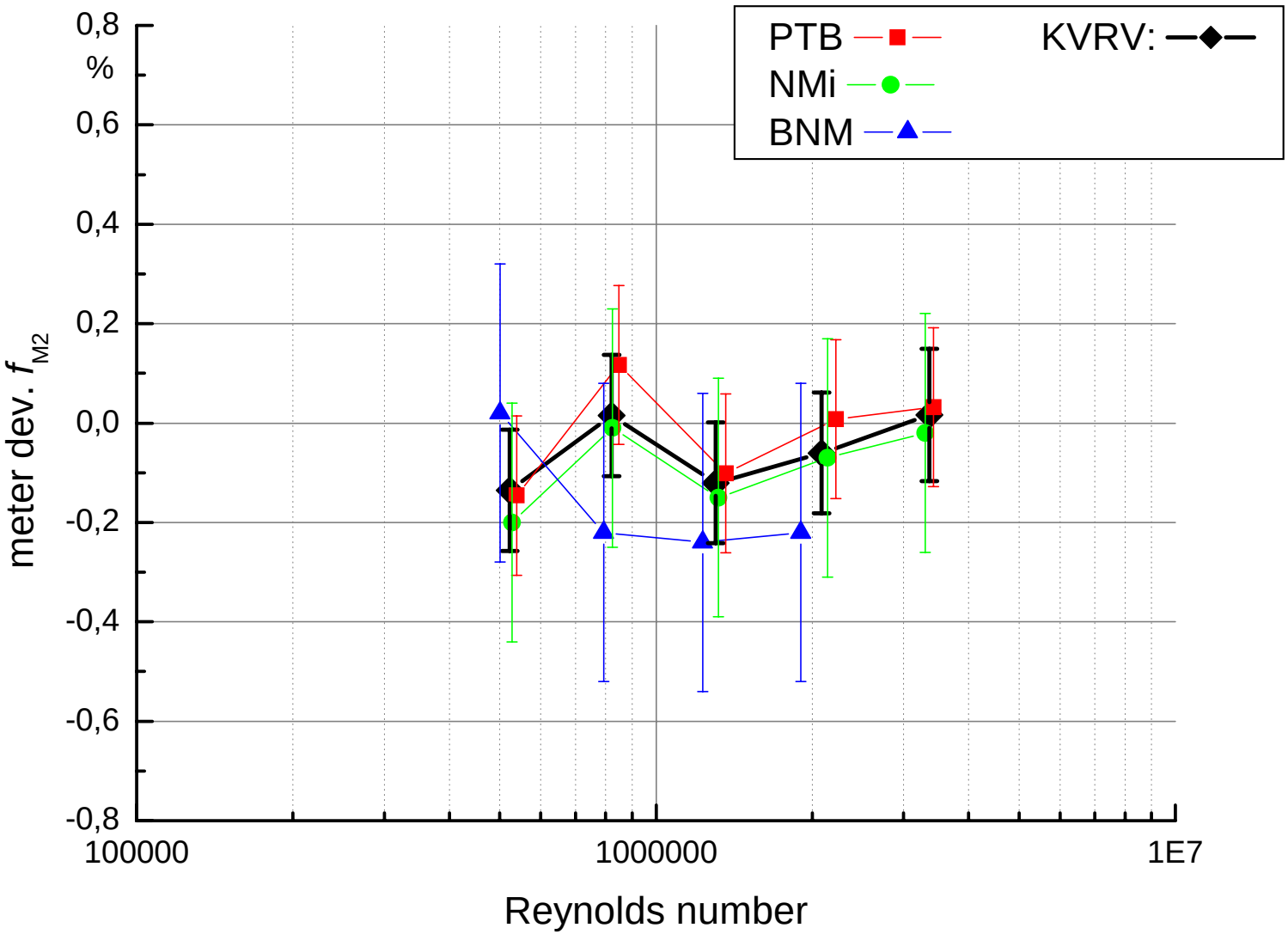


Key Comparison results for high-press natural gas



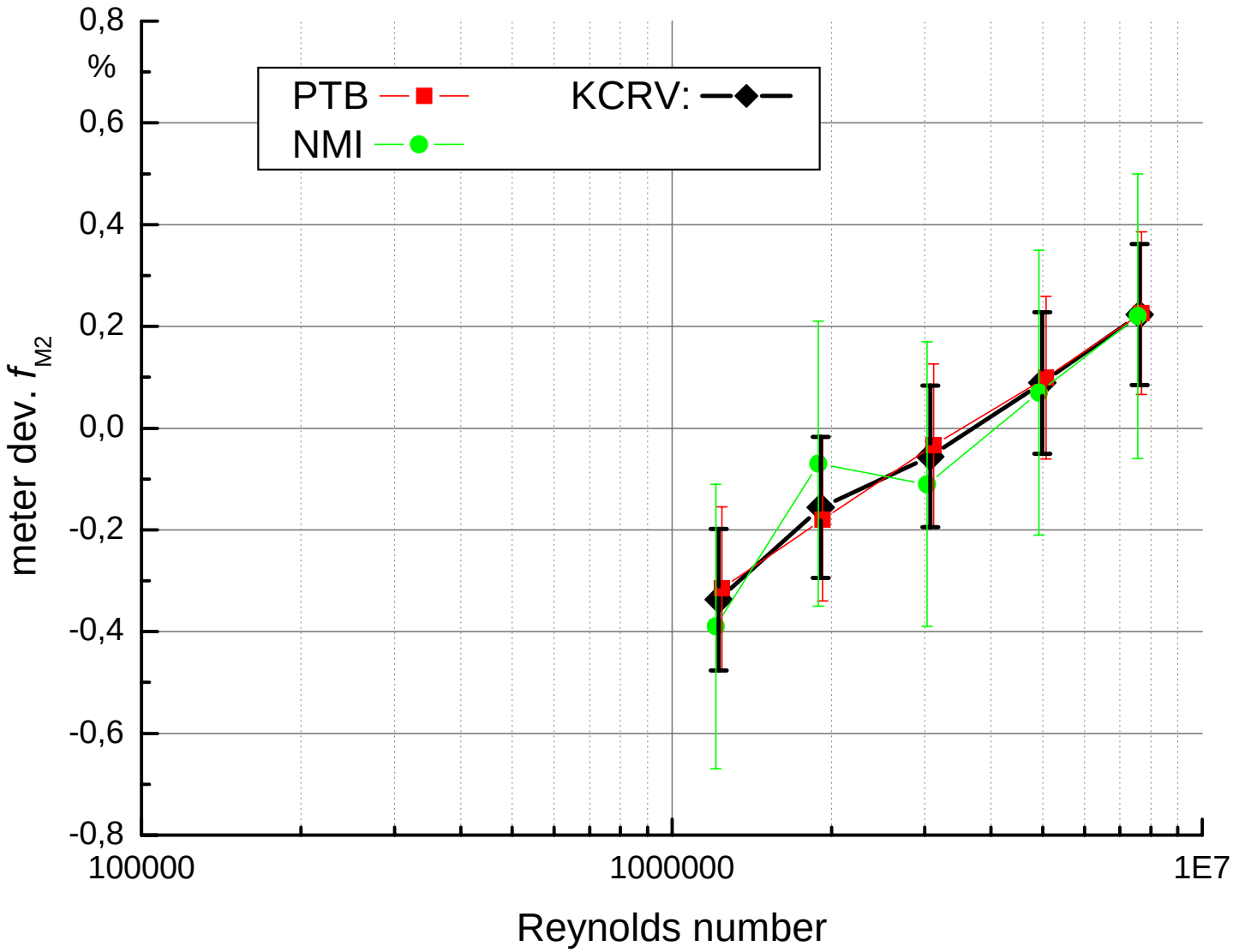
Key Comparison results for high-press natural gas

Meter 2 (Ultrasonic) at *p* = 20 bar



Key Comparison results for high-press natural gas

Meter 2 (Ultrasonic) at *p* = 47 bar



Summary of the KCRVs for natural gas I:

* All participating facilities are equivalent to each other

* All claimed uncertainties agree and overlap with each other

* All claimed uncertainies agree with the KCRV

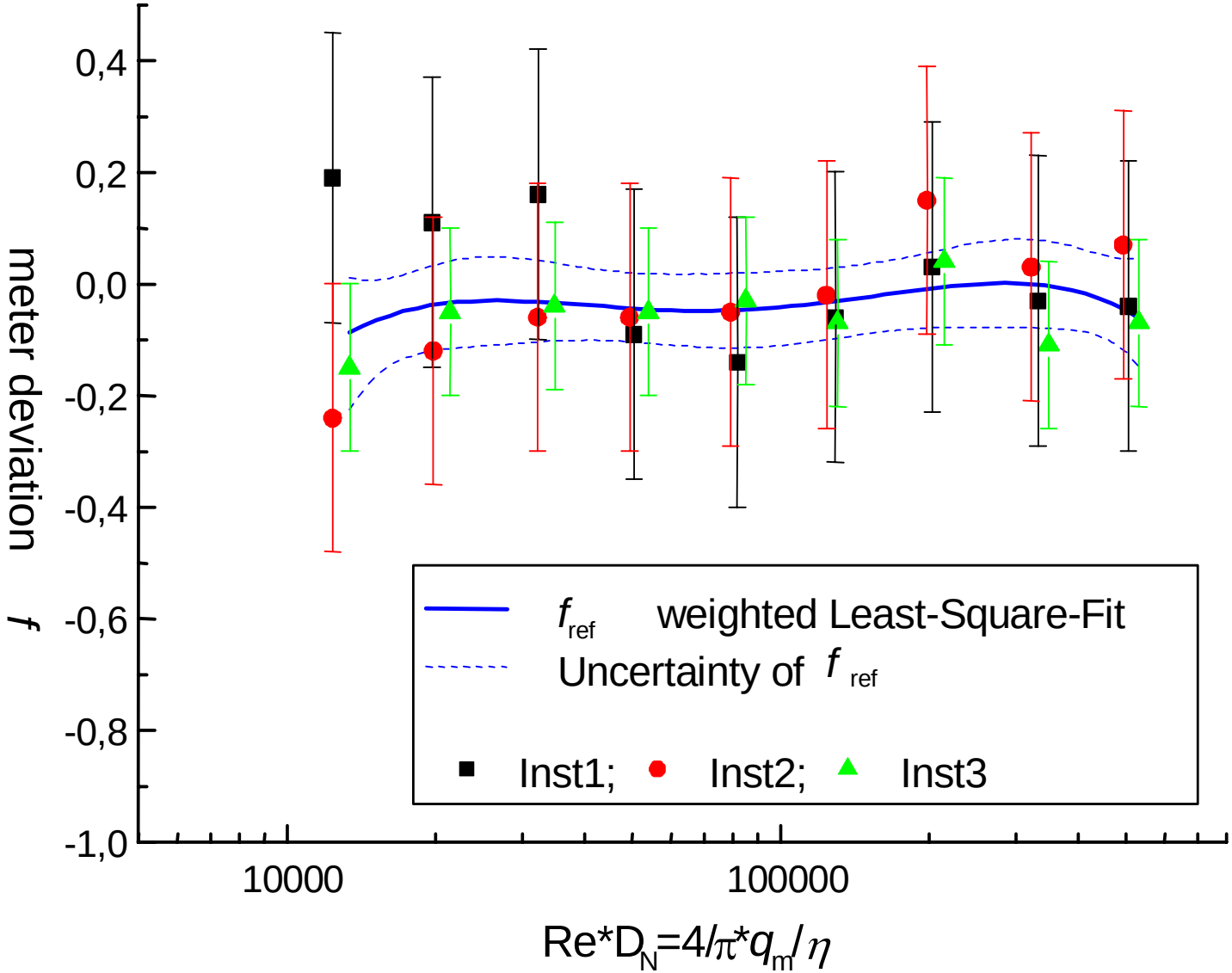
PTB-*pigsar*™	= 0,16 %
NMi-VSL	= 0,18 – 0,22 %
BNM-LNE	= 0,33 %

Summary of the KCRVs for natural gas II:

- **If one disseminates the KCRV, a smaller uncertainty level can be claimed, if reprocucibility is small**
- **A bias can be suppressed in this case**
- **If a facility has a bias and extremely good reproducibility, this facility benefits most**

In Europe all 3 NMIs disseminate the KCRV only:
This is what we call Harmonization since 1999

Spring 2004: Establishing the Harmonized Cubic Meter of PTB, NMi-VSL, BNM



Turbine 20 bar

1 = BNM
2 = NMi-VSL
3 = PTB-pigsar

The BIPM / CIPM Key Comparisons

The Key Comparison Reference Value (KCRV)
can be considered to be the world-wide best available
realization of the natural gas cubic meter for natural gas

This KCRV is identical with the European Harmonized Reference Level
Europan Harmonized Gas Cubic Meter for Natural Gas
which is in use since May 4th, 2004