The international comparison on laser power 2005 – 2007 EUROMET.PR-S2

Stefan Kück, PTB

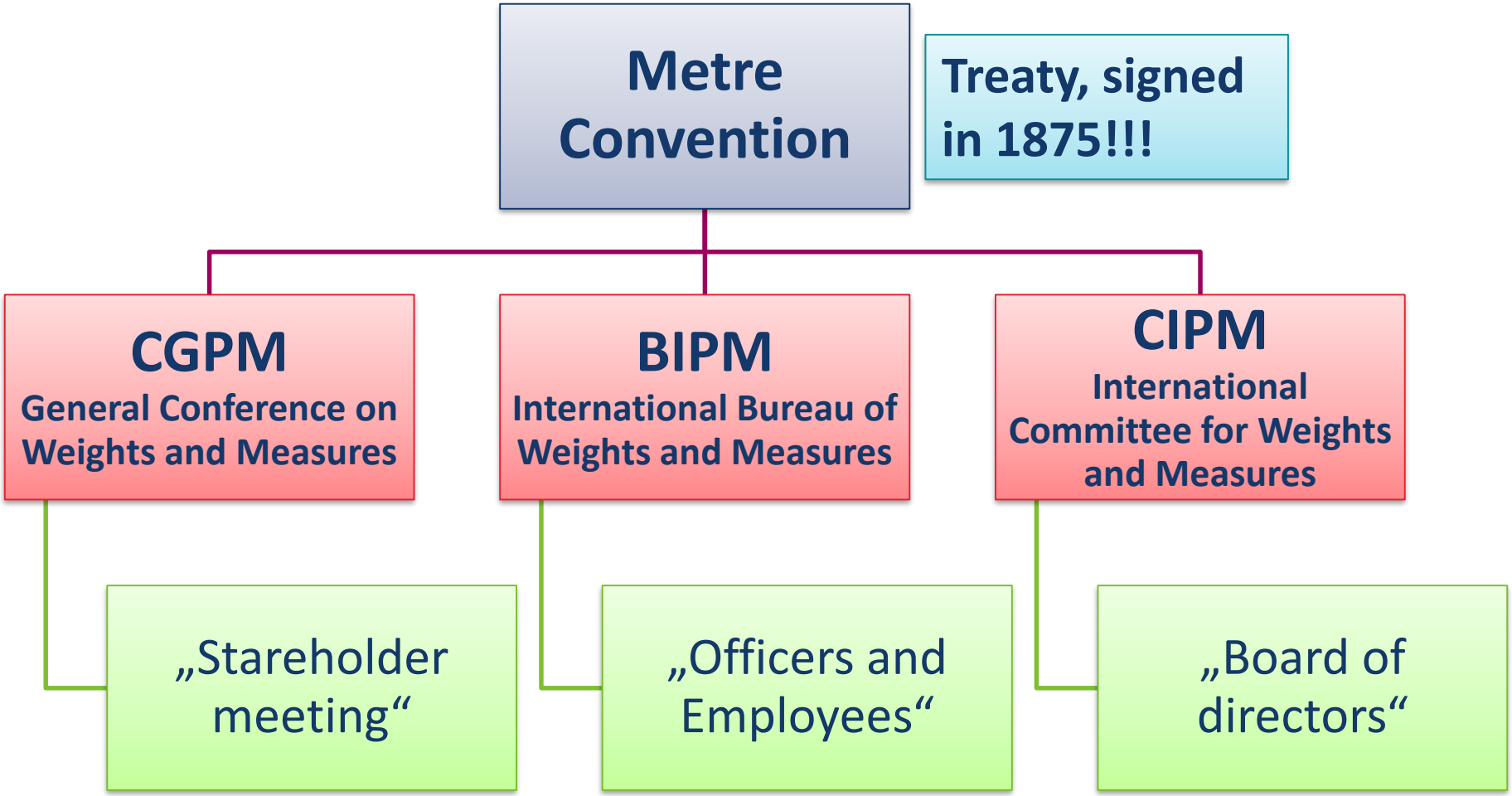
Motivation for EURAMET.PR-S2

1 General information on the comparison

1.1 Under the Mutual Recognition Arrangement (MRA)[1] the metrological equivalence of national measurement standards will be determined by a set of key comparisons (KCs) chosen and organised by the Consultative Committees of the CIPM working closely with the Regional Metrology Organisations (RMOs). This set of key comparisons has to be added by supplementary comparisons (SCs) organised by the RMOs.

A little bit of organisational stuff…

Metre Convention



Metre Convention - Member states and associates of the BIPM

As of 17 August 2016, there are 58 Member States of the BIPM, and 41 Associates of the General Conference

CIPM - International Committee for Weights and Measures

The CIPM currently has ten Consultative Committees:

- CCAUV: Consultative Committee for Acoustics, Ultrasound and Vibration
- CCEM: Consultative Committee for Electricity and Magnetism
- CCL: Consultative Committee for Length
- CCM: Consultative Committee for Mass and Related Quantities
- CCPR: Consultative Committee for Photometry and Radiometry
- CCQM: Consultative Committee for Amount of Substance: Metrology in Chemistry and Biology
- CCRI: Consultative Committee for Ionizing Radiation
  - > Section I | Section II | Section III |
- CCT: Consultative Committee for Thermometry
- CCTF: Consultative Committee for Time and Frequency
- CCU: Consultative Committee for Units

- The role of the Consultative Committees
- Criteria for membership of a Consultative Committee

- BIPM Forum Workspace (for registered user groups)

CCPR - Consultative Committee for Photometry and Radiometry

Consultative Committee for Photometry and Radiometry (CCPR)

CCPR | Mission | Members | Strategy | Publications | Photographs | Members' working area

CIPM Consultative Committee:

- **CCPR – Consultative Committee for Photometry and Radiometry** — **23 members**

CCPR Working Groups and Task Groups:

- CCPR Working Group on CMCs (WG-CMC) — **Calibration and measurement capabilities**
- CCPR Working Group on Key Comparisons (WG-KC)
- CCPR Working Group on Strategic Planning (WG-SP)

http://www.bipm.org/en/committees/cc/ccpr/

RMOs – Regional Metrology Organisations

MRA – Mutual Recognition Agreement

The CIPM Mutual Recognition Arrangement (CIPM MRA) is the framework through which National Metrology Institutes demonstrate the international equivalence of their measurement standards and the calibration and measurement certificates they issue. The outcomes of the Arrangement are the internationally recognized (peer-reviewed and approved) Calibration and Measurement Capabilities (CMCs) of the participating institutes. Approved CMCs and supporting technical data are publicly available from the CIPM MRA database (the KCDB).

CMCs – Calibration and Measurement Capabilities

Germany, PTB (Physikalisch-Technische Bundesanstalt)

Complete CMCs in Photometry and Radiometry for Germany (.PDF file)

Responsivity, laser, power. General detector. Measurand unit, **A/W, V/W, or reading/W**
Relative expanded uncertainty (k = 2, level of confidence 95%) in %: **0.3 to 1.0, varies with power level**
Comparison with standard detector linked to cryogenic radiometer
Wavelength: 10.6 µm
Power level: 0.1 W to 1500 W
Type of detector: laser power meter
Approved on 20 April 2017
Internal NMI service identifier: PTB_4.13-1

Responsivity, laser, power. General detector. Measurand unit, **A/W, V/W, or W/reading**
Relative expanded uncertainty (k = 2, level of confidence 95%) in %: **0.2 to 1.0, varies with power level**
Comparison with standard detector linked to cryogenic radiometer
Wavelengths: laser lines between 337 nm and 1064 nm
Power level: 100 µW to 120 W
Type of detector: laser power meter
Approved on 20 April 2017
Internal NMI service identifier: PTB_4.13_2

Proof for CMCs

- Successful participation in Key Comparisons (KCs): CCPR, RMOs only 6 quantities:
  - Spectral Irradiance
  - Spectral Responsivity
  - Luminous Intensity
  - Luminous Flux
  - Spectral Diffuse Reflectance
  - Spectral Regular Transmittance
- Successful participation in Supplementary Comparisons (SCs): RMOs
- Other evidence (publications etc.)

$\Rightarrow$ For High Power Laser Responsivity, EURAMET decided to carry out a Supplementary Comparison

EURAMET.PR-S2

EUROMET Comparison

Project No. 156

EUROMET.PR-S2

Responsivity of detectors for radiant power of lasers

Final Report

(in compliance with Draft B of "Radiant Power of High Power Lasers – Part 1")

Metrologia, 2010, **47**, *Tech. Suppl.*, 02003
EUROMET.PR-S2 Final Report, 2010, 216 pages

Motivation for EURAMET.PR-S2

1 General information on the comparison

1.1 Under the Mutual Recognition Arrangement (MRA)[1] the metrological equivalence of national measurement standards will be determined by a set of key comparisons (KCs) chosen and organised by the Consultative Committees of the CIPM working closely with the Regional Metrology Organisations (RMOs). This set of key comparisons has to be added by supplementary comparisons (SCs) organised by the RMOs.

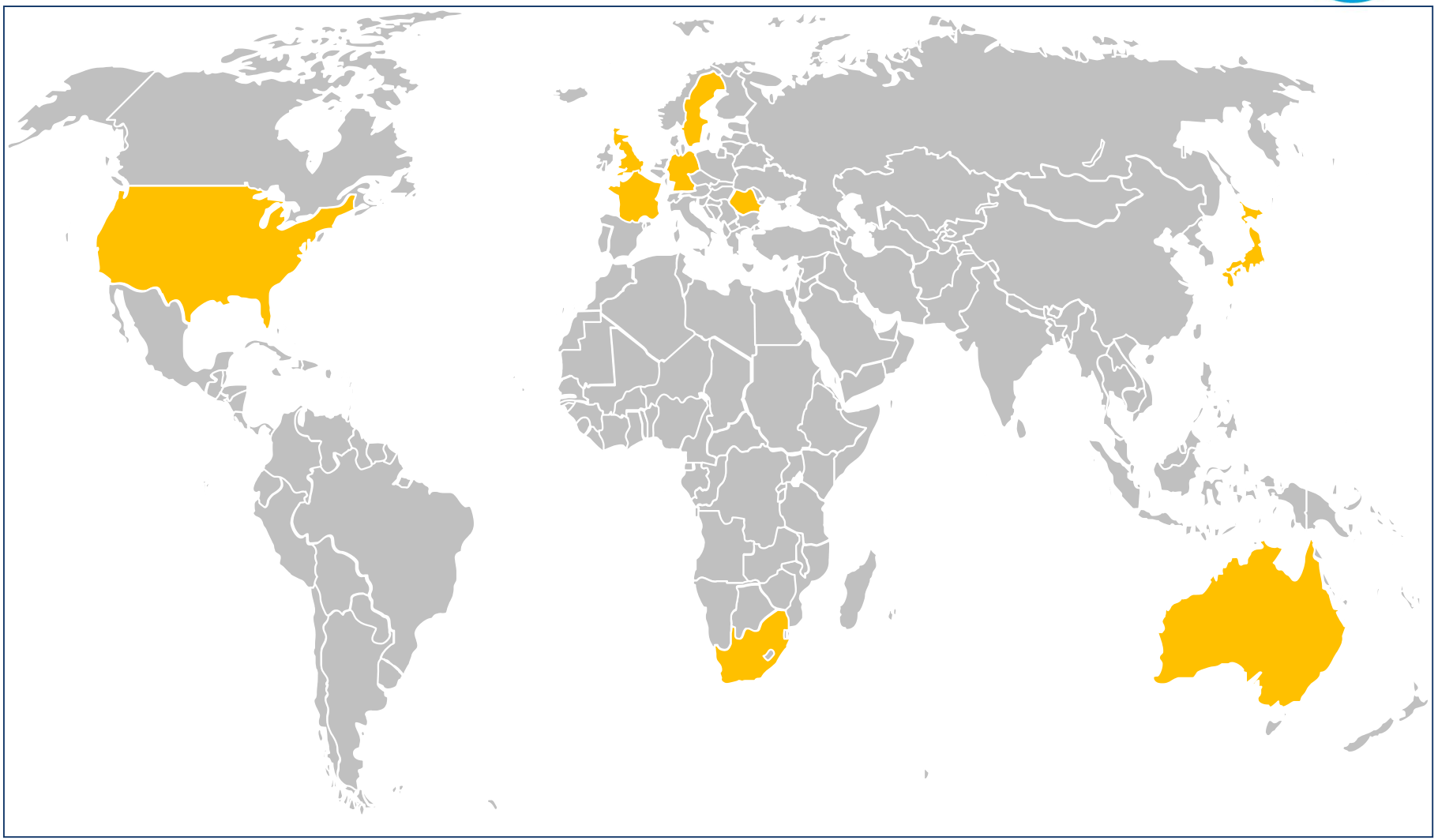
1.2 At their meeting in Delft in April 12.-13. 1999, the EUROMET Photometry and Radiometry contact persons decided to start a supplementary comparison on radiant power of high power lasers (EUROMET project 156). The PTB was assigned to act as a pilot laboratory. This comparison was split into two parts. The first part, starting in January 2005, covers the following lasers, wavelengths and power levels: Laser Wavelength Power

Argon ion	514.5 nm	1 W
Nd:YAG	1064 nm	1 W
Nd:YAG	1064 nm	10 W
CO2	10.6 µm	1 W
CO2	10.6 µm	5 W

Although this SC is organized within a EUROMET project, it is a global comparison carried out worldwide.

Metrologia, 2010, **47**, *Tech. Suppl.*, 02003
EUROMET.PR-S2 Final Report, 2010, 216 pages

Participants



Participants ans Measurands

	Argon 1 W	Nd:YAG 1 W	Nd:YAG 10 W	CO_2 1 W	CO_2 10 W
D	X	X	X	X	X
S	X			X	X
USA	X	X	X	X	X
F	X	X	X	X	X
ZA	X	X	X	X	X
J	X	X	X	X	X
UK		X	X	X	X
ROM	X	X			
AUS		X	X		

Timeline

Country	Receipt Confirmation	Damage	Completion Confirmation	Damage/ Remarks	Record of exposure	Description of facility	Results
DE	1.1.05	No	7.2.05	No	21.2.05	21.2.05	21.2.05
SE	16.2.05	No	15.3.05	No	5.5.05	5.5.05	5.5.05
US	8.4.05	No	11.7.05	No	11.7.05	11.7.05	11.7.05
FR	19.5.05	No	6.6.05	No	13.7.05	13.7.05	13.7.05
DE	16.6.05	No	14.7.05	No	13.7.05	13.7.05	13.7.05
ZA	12.8.05	No	13.10.05	No	13.10.05	13.10.05	13.10.05
AU	24.11.05	No	30.1.06	Yes / Molectron	-	-	shift to end
NL	-	-	-	-	-	-	withdrawn
DE	25.4.06	No	2.5.06	Molectron repaired	3.5.06	3.5.06	3.5.06
JP	1.6.06	No	4.7.06	No	9.8.06	9.8.06	9.8.06
UK	10.7.06	No	15.8.06	No	13.11.07	13.11.07	13.11.07
RO	6.10.06	No	31.1.07	No	24.1.07	24.1.07	24.1.07
DK	-	-	-	-	-	-	withdrawn
DE	22.1.07	No	9.2.07	No	20.2.07	20.2.07	20.2.07
AU	19.3.07	No	14.6.07	No	5.11.07	5.11.07	5.11.07
UA	-	-	-	-	-	-	withdrawn
DE	2.7.07	No	13.9.07	No	13.9.07	13.9.07	13.9.07

> 2.5 years of measurements, acceptance of final report: 2009-10-02

Method for establishing the Supplementary Comparison Reference Value (SCRV) and the Degrees of Equivalence

Stability of transfer detectors

Performance of the transfer detectors

It was agreed in the pre-Draft A (see page 17, "Performance of the transfer detectors" and tables 9 – 11 in the pre-Draft A) that the change of the responsivity over time is taken into account by a linear interpolation based on the measurements carried out at the pilot lab (PTB):

$$s^{*}_{\mathrm{NMI}} = s_{\mathrm{NMI}} \cdot \left(1 + \left(s(\mathrm{PTB})_{n+1} - s(\mathrm{PTB})_{n} \right) \frac{\Delta N_{\mathrm{NMI}}}{\Delta N} \right) = s_{\mathrm{NMI}} \cdot (1 + \Delta s)$$

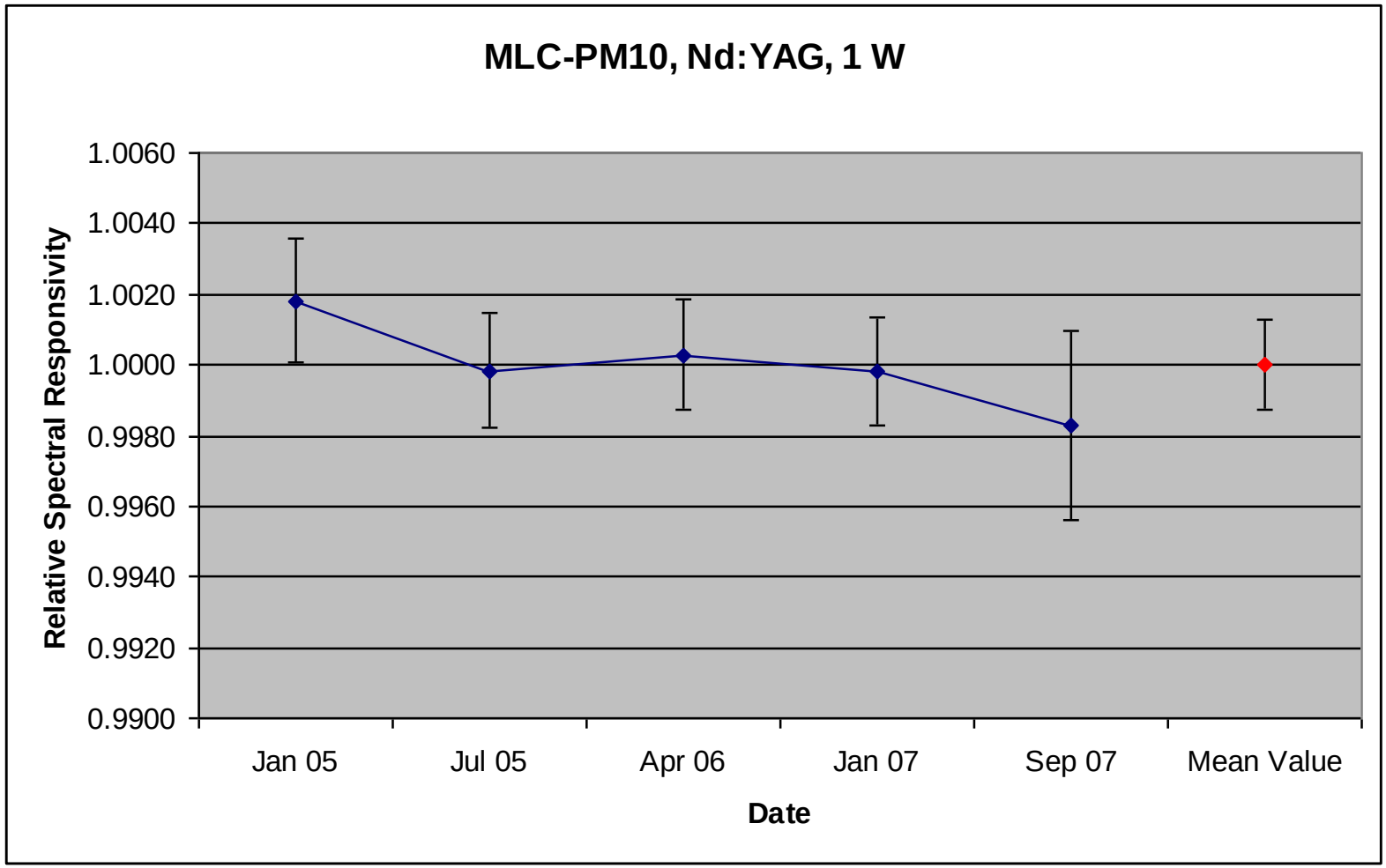
where s^{*}_{NMI} (s_{NMI}) is the corrected (submitted) spectral responsivity for each participating laboratory, $s(\mathrm{PTB})_{n+1}$ and $s(\mathrm{PTB})_{n}$ are the normalized spectral responsivities measured at PTB before and after the individual measurement of the NMI, respectively, ΔN is the number of measurements between the two PTB measurements + 1, and ΔN_{NMI} is the number of the measurement for the individual NMI between two PTB measurements.

Maximum corrections $\Delta s_{\max}$ are

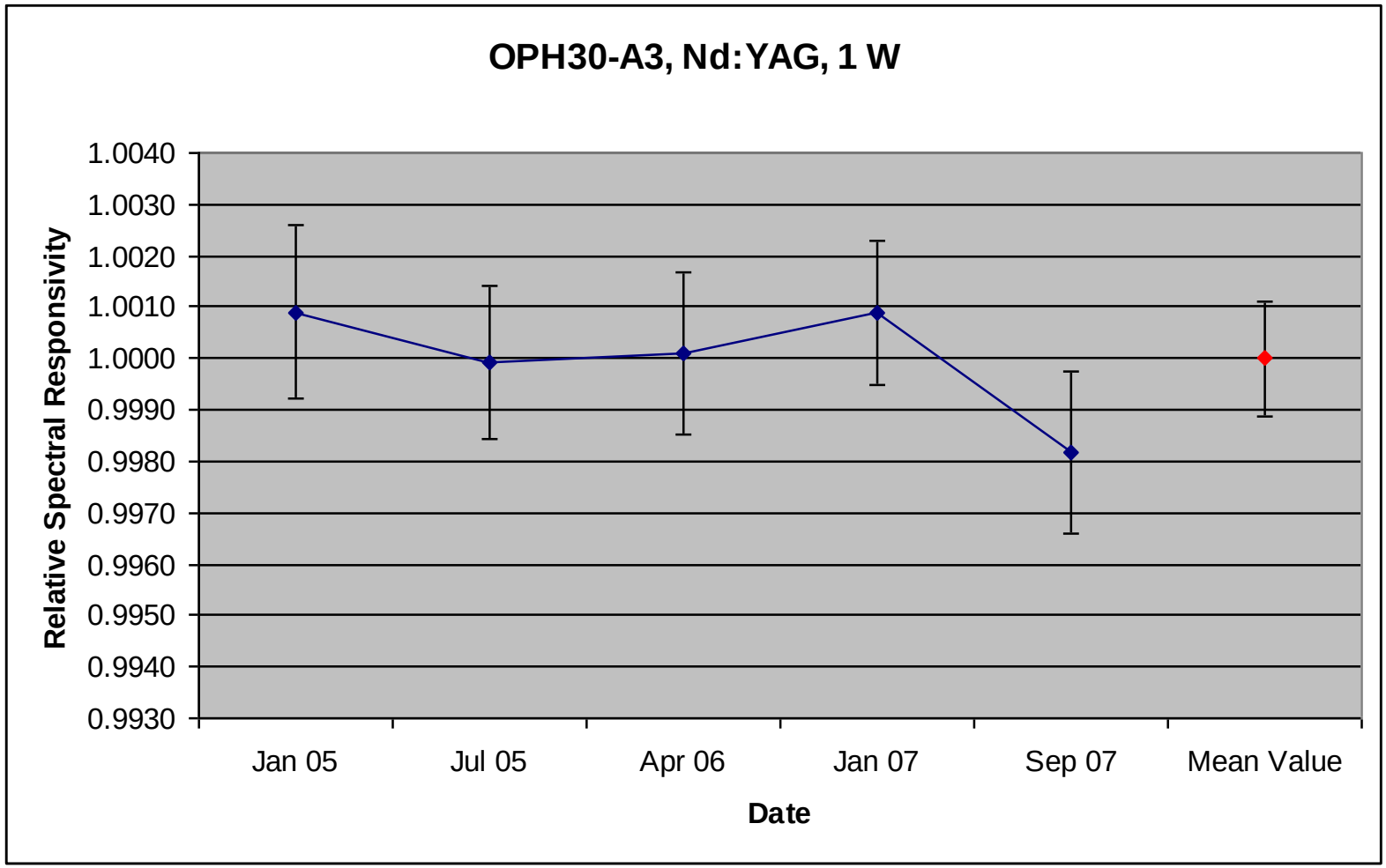
for the Ophir 30–A3: $\Delta s_{\max} = +0.00143$, $1 + \Delta s_{\max} = 1.00143$,

for the Molectron PM10: $\Delta s_{\max} = -0.00153$, $1 + \Delta s_{\max} = 0.99847$.

Stability of transfer detectors



Stability of transfer detectors



Uncertainties – Cut-off

Determination of the cut-off, the SCRV and the Degrees of Equivalence

The weighted mean of the spectral responsivity values of all NMIs represent the SCRV. Following the Guidelines for CCPR Comparison Report Preparation the weight is calculated with cut-off, which is calculated as the average of the NMIs uncertainties which are less than or equal to the median of the uncertainties of all NMIs. The cut-off uncertainty $u_{\text{cut-off}}$ is then average of the four institutes stating the lowest uncertainties:

$$u_{\text{cut-off}} = \frac{1}{4}\sum_{1=1}^{4} u_{\text{rel}}(s_i) \text{ for } u_{\text{rel}}(s_i) \leq median\left\{u_{\text{rel}}(s_k)_{k=1\ldots7\,(8)}\right\}$$

where $u_{rel}(s_i)$ is the relative uncertainty stated by the participant i and the median is calculated from the seven (eight for Nd:YAG, 1 W) participants.

In Table 10 the relative uncertainties of all participants for each measurand are listed together with the mean value, the cut-off value and adjusted uncertainties. In Figure 4 and Figure 5 the results, i.e. the standard uncertainty for each participant as well as the median and the cut-off value, are shown graphically.

Uncertainties, Weights, SCRV

For each participant, the relative uncertainty for the NMI representative value $u_{rel}(s_i)$ is then adjusted by the cut-off, see also Table 10:

$$u_{adj}(s_i) = \begin{cases} u_{rel}(s_i) \text{ for } u_{rel}(s_i) \geq u_{cut-off} \\ u_{cut-off} \text{ for } u_{rel}(s_i) < u_{cut-off} \end{cases}$$

The weight w_i for the participant i is then calculated as

$$w_i = \frac{u_{adj}(s_i)^{-2}}{\sum_{i=1}^{7,8} u_{adj}(s_i)^{-2}}$$

and shown graphically in Figure 6 and Figure 7. The SCRV of the comparison is calculated as

$$s_{SCRV} = \sum_{i=1}^{7,8} w_i s_i$$

with the relative standard uncertainty

$$u_{rel}(s_{SCRV}) = \sqrt{\frac{1}{\sum_{i=1}^{7,8} u_{adj}(s_i)^{-2}}}.$$

Ophir30 -A3	Nd:YAG 1 W			Nd:YAG 10 W		
	$u_{rel}(s_i)$	$u_{adj}(s_i)$	w_i	$u_{rel}(s_i)$	$u_{adj}(s_i)$	w_i
DE	0.13%	0.36%	0.2310	0.14%	0.38%	0.2516
SE						
US	0.44%	0.44%	0.1538	0.53%	0.53%	0.1283
FR	0.44%	0.44%	0.1538	0.44%	0.44%	0.1876
ZA	2.02%	2.02%	0.0073	1.98%	1.98%	0.0092
JP	0.47%	0.47%	0.1352	0.47%	0.47%	0.1641
GB	0.43%	0.43%	0.1605	0.62%	0.62%	0.0932
RO	1.12%	1.12%	0.0236			
AU	0.47%	0.47%	0.1348	0.47%	0.47%	0.1661
Median	0.45%		1.0	0.47%		1.0
Cut-off	**0.36%**			**0.38%**		
Number	8			7		

PM10	Nd:YAG 1 W			Nd:YAG 10 W		
	$u_{rel}(s_i)$	$u_{adj}(s_i)$	w_i	$u_{rel}(s_i)$	$u_{adj}(s_i)$	w_i
DE	0.24%	0.39%	0.2075	0.17%	0.38%	0.2423
SE						
US	0.44%	0.44%	0.1592	0.53%	0.53%	0.1242
FR	0.43%	0.43%	0.1652	0.39%	0.39%	0.2268
ZA	2.01%	2.01%	0.0077	2.03%	2.03%	0.0085
JP	0.47%	0.47%	0.1387	0.47%	0.47%	0.1571
GB	0.43%	0.43%	0.1645	0.62%	0.62%	0.0915
RO	1.14%	1.14%	0.0237			
AU	0.48%	0.48%	0.1335	0.48%	0.48%	0.1496
Median	0.46%		1.0	0.48%		1.0
Cut-off	**0.39%**			**0.38%**		
Number	8			7		

Uncertainties

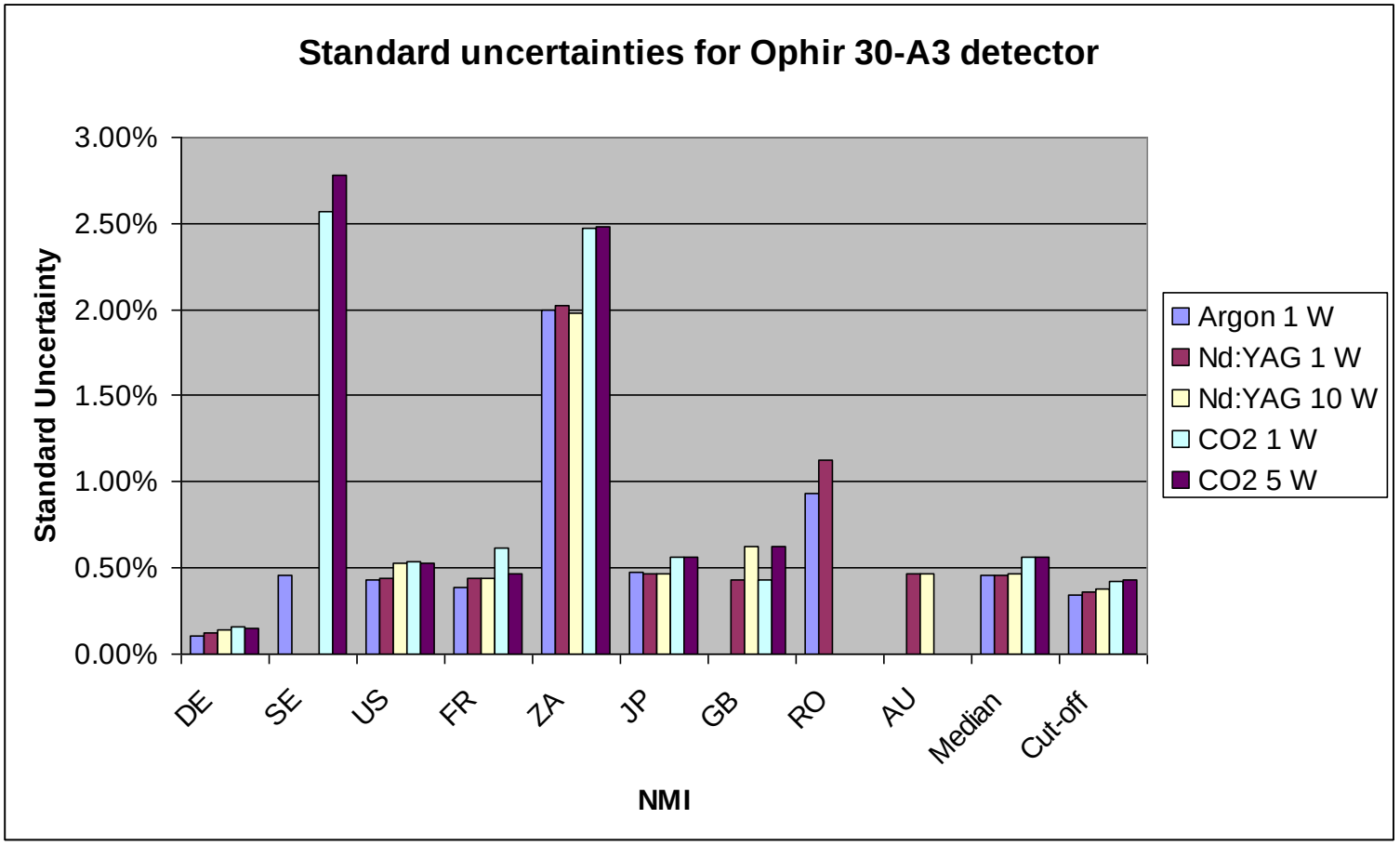


Figure 4. Relative standard uncertainties, median and cut-off for the Ophir 30-A3 transfer detector.

Uncertainties

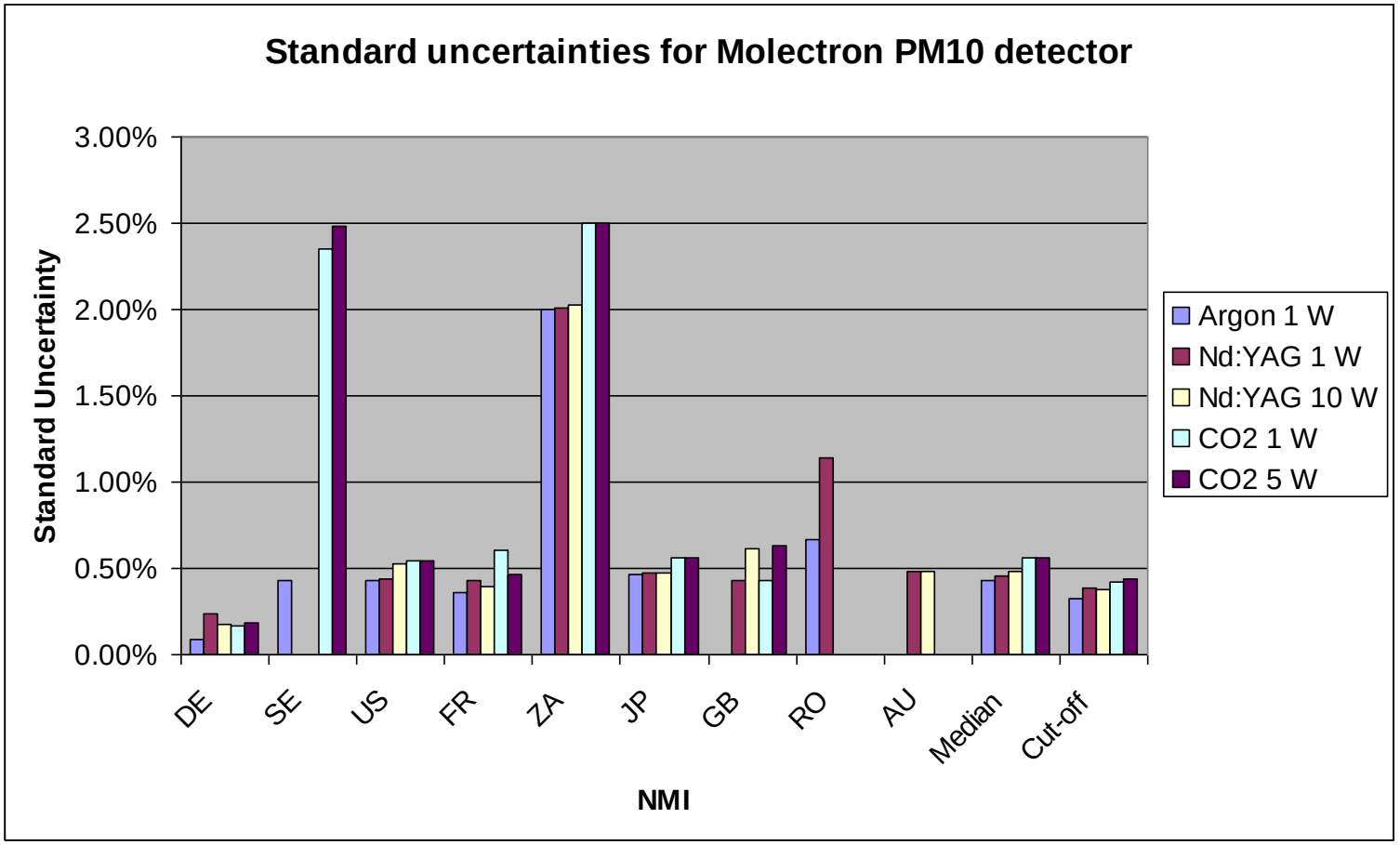


Figure 5. Relative standard uncertainties, median and cut-off for the Molectron PM10 transfer detector.

Weights

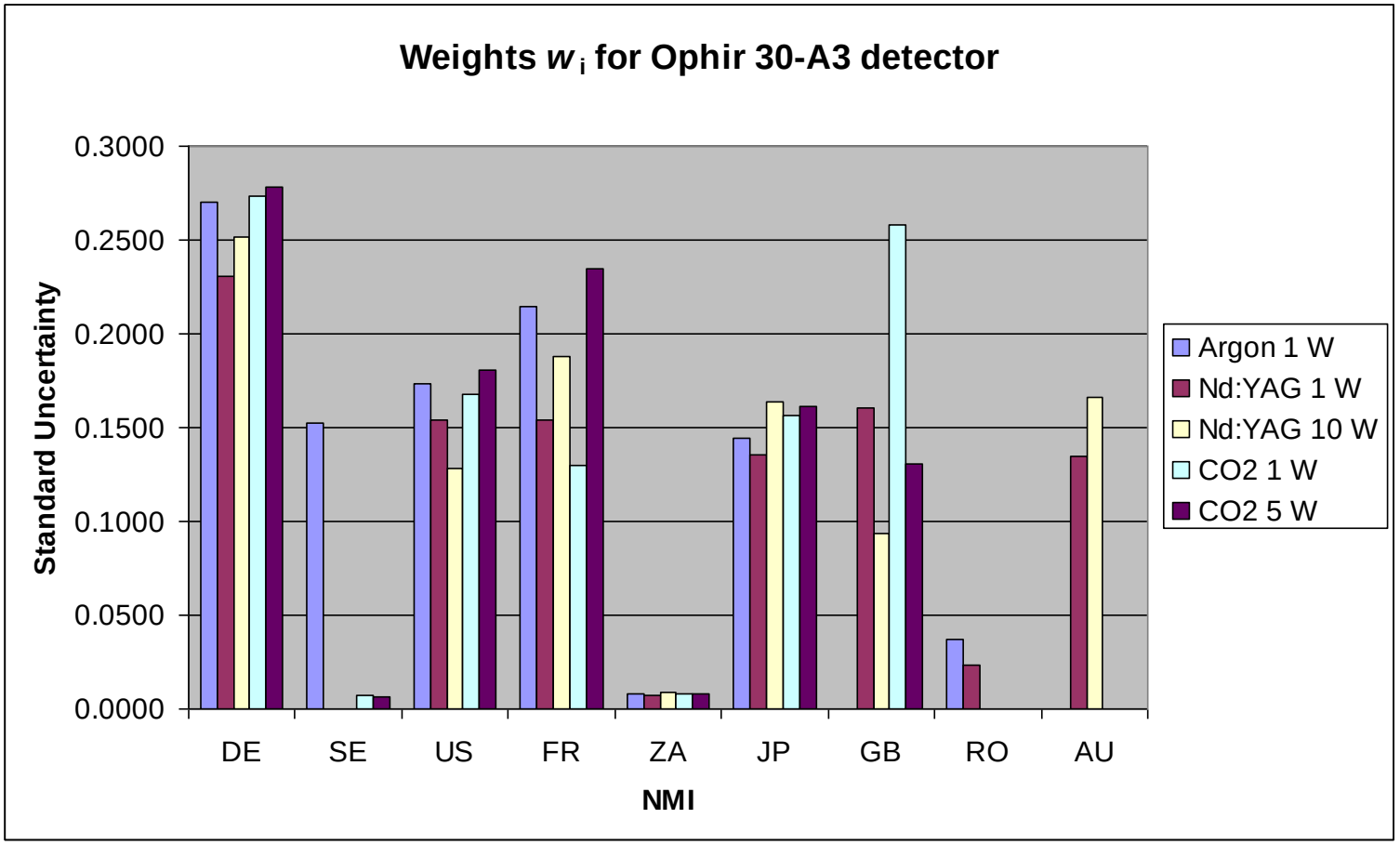


Figure 6. Weights for the Ophir 30-A3 detector.

Weights

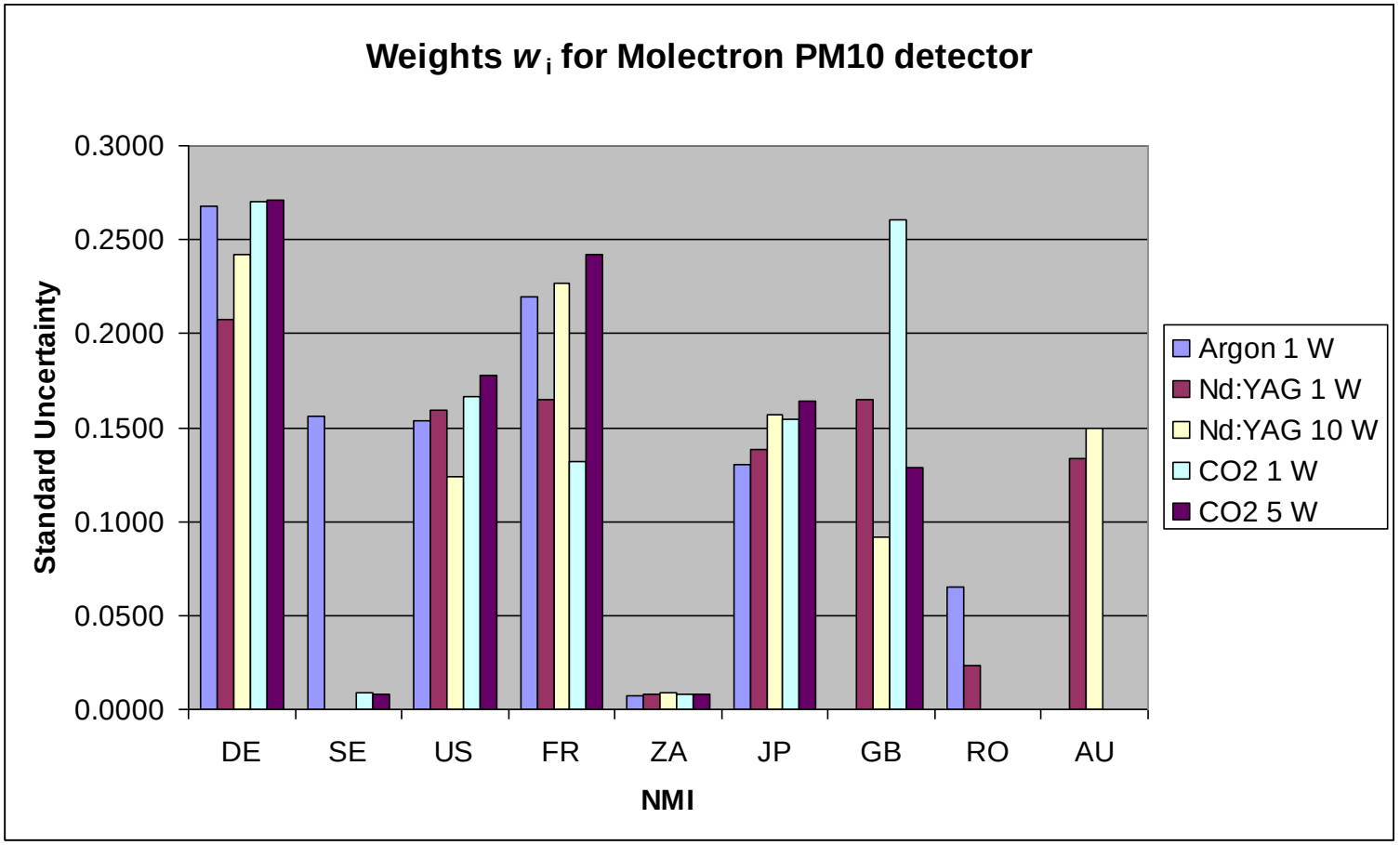


Figure 7. Weights for the Molectron PM10 detector.

DoEs – Degrees of Equivalence

These results directly lead to the unilateral and bilateral Degrees of Equivalence (DoE). The unilateral DoE of NMI *i* is given by

$$D_i = \frac{s_i - s_{SCRV}}{s_{SCRV}}$$

with its expanded uncertainty

$$U_i = k\sqrt{u_{rel}(s_{SCRV})^2 + u_{rel}(s_i)^2}\ ;\ k = 2.$$

In the same way the bilateral DoE of NMI *i* to NMI *m* is calculated as

$$D_{i,m} = D_i - D_m = \frac{s_i - s_m}{s_{SCRV}}$$

with

$$U_{i,m} = k\sqrt{u_{rel}(s_i)^2 + u_{rel}(s_m)^2 + u_{rel}(s_{SCRV})^2}\ ,\ k = 2.$$

This definition follows the convention for the analysis of Key Comparisons and provides bilateral DoEs that are symmetrical and consistent with the unilateral DoEs.

The simple data analysis presented here and the resulting parameters give satisfactory information to compare the participants' abilities in calibrating laser power meters in terms of spectral responsivity.

Outliers

7 Identification of Outliers

The CCPR has not agreed a formal policy on outliers. However, if a reference value is involved, care has to be taken that outliers do not skew the reference value. The currently favoured limit is three standard deviations from the reference value produced without the proposed outliers, using their adjusted standard uncertainty value. In this comparison, the following procedure was used: the deviations from the weighted mean value for each participant were listed and graphically shown. The data were made anonymous and send to all participants on March 30th (file: "Method for establishing the Supplementary Comparison Reference Value"). All participants were ask to propose outliers. If outliers are proposed, the pilot lab would have to recalculate the weighted mean value without the value of the proposed outlier and in case the deviation of the value from the proposed outlier is more than three adjusted standard deviations from the new calculated weighted mean with cut-off value, this participant will be removed for this measurand from the comparison. The cut-off value, the weighted mean and the Degrees of Equivalence would have to be recalculated for all measurands, for which outliers are proposed.

Based on the distributed data, outliers were not proposed by any participant. This means, that all results contribute to the calculation of the SCRV.

Degrees of Equivalence

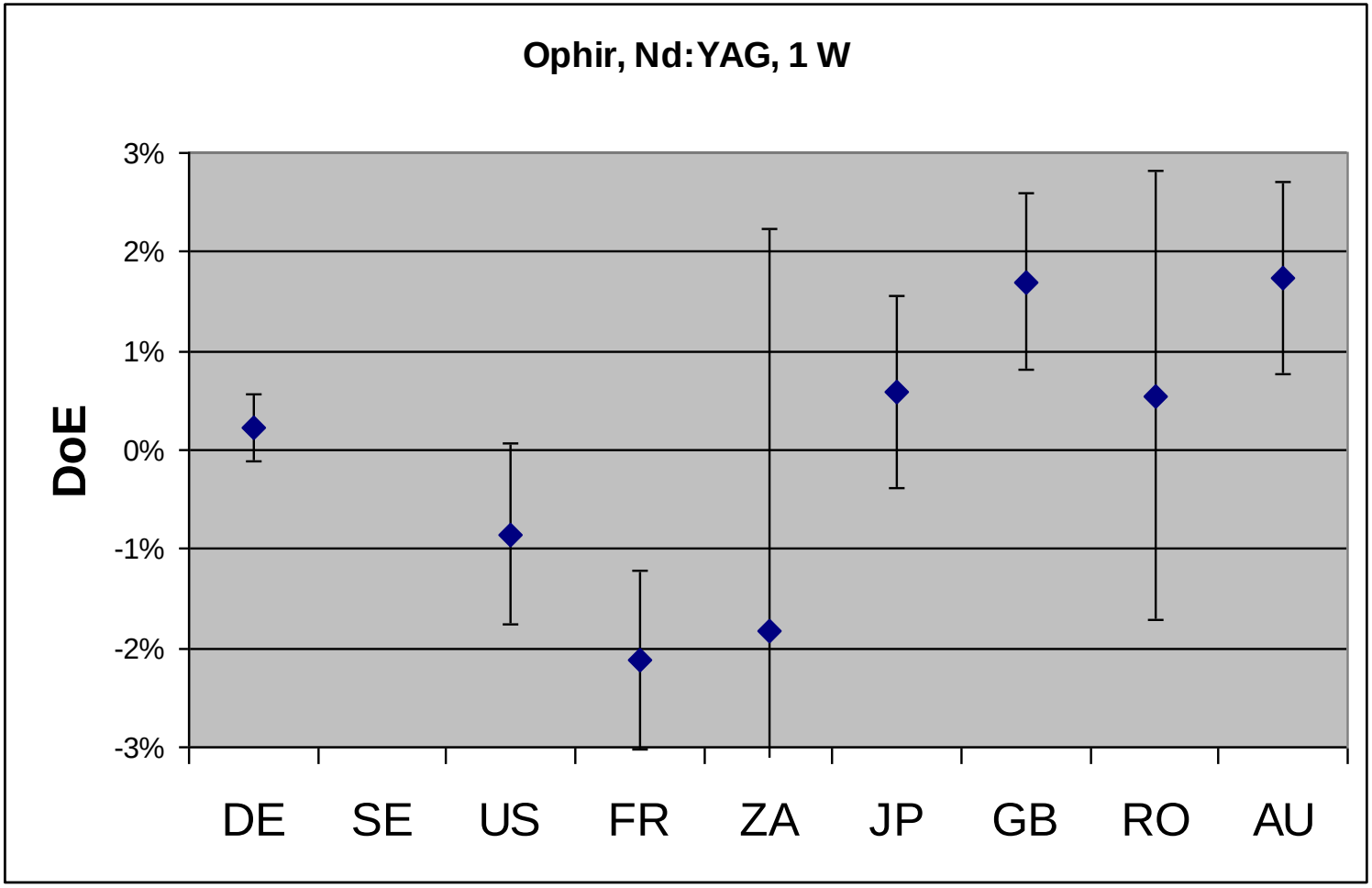


Figure 9: Unilateral Degree of Equivalence (DoE) for each participant and each measurand for the Ophir transfer detector.

Degrees of Equivalence

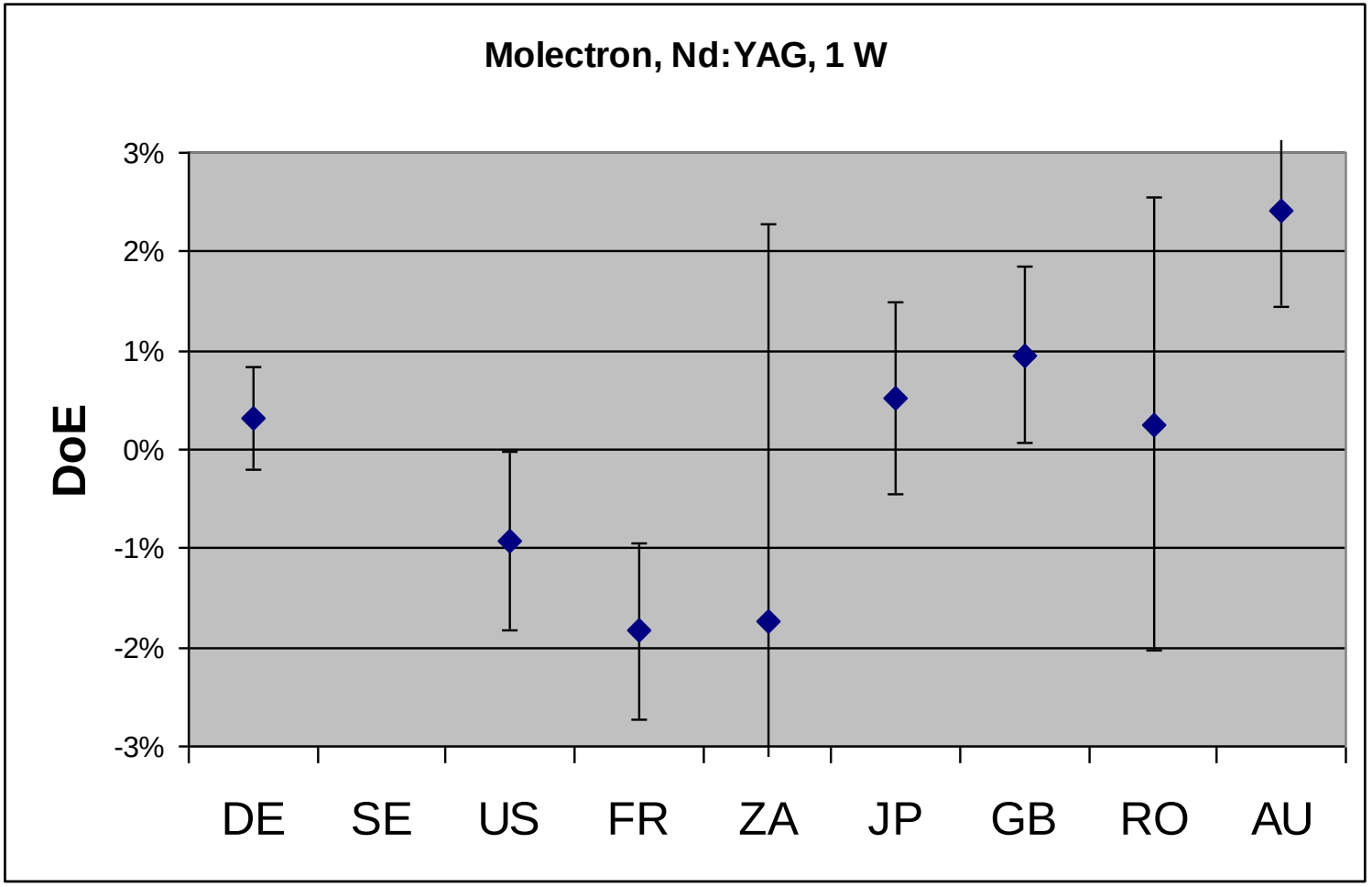


Figure 11: Unilateral Degree of Equivalence (DoE) for each participant and each measurand for the Molectron transfer detector.

Conclusions

9 Conclusions

The EUROMET.PR-S2 intercomparison of Radiant Power of High Power Lasers for five measurands was carried as a combined round-robin / star type comparison. In total 9 participants took part, 5 from Europe (National Metrology Institutes of France, Germany (pilot), Great Britain, Romania, Sweden) and 4 outside Europe (National Metrology Institutes of Australia, Japan, South Africa and The United States of America). Therefore, this comparison can be considered as a worldwide one. The measurements took place from January 2005 to September 2007.

All participants supplied detailed reports of their measurements including full uncertainty statements. All measurement results reported by the participants were be used for the intercomparison and no measurement was subject of rejection. The analysis method introduced in section 6 follows the Guidelines for CCPR Comparison Report Preparation and has been accepted by all participants.

For the calculation of the supplementary key comparison reference value no participant had to be excluded and the used weighted mean with cut-off has been supported by all participants.

The unilateral Degrees of Equivalence (DoE) calculated for each participant are in approx. 63 % consistent with their uncertainties at the $k = 2$ level and in approx. 81 % consistent within $k = 3$.

Information on EURAMET.PR-S2

Bureau International des Poids et Mesures

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Home > Comparisons Search > Results of the search > Information

Key and supplementary comparisons - Information KCDB

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EUROMET.PR-S2

Information

Metrology area, branch	Photometry and Radiometry, Radiometry
Description	Responsivity of detectors for radiant power of lasers
Time of measurement	2005 - 2007
Status	Approved and published
Reference(s)	*Metrologia*, 2010, **47**, *Tech. Suppl.*, 02003 EUROMET.PR-S2 Final Report, 2010, 216 pages
Measurand	Spectral responsivity
Transfer device(s)	-
Comparison type	Supplementary comparison
Consultative Committee	CCPR (Consultative Committee for Photometry and Radiometry)
Conducted by	EURAMET (formerly EUROMET) (European Association of National Metrology Institutes)
Other designation(s)	EUROMET Project No 156
Comments	The following lasers, wavelengths and power levels are covered: Argon ion (514.5 nm, 1 W), Nd:YAG (1064 nm, 1 W), Nd:YAG (1064 nm, 10 W), CO_2 (10.6 µm, 1 W), CO_2 (10.6 µm, 5 W)

Metrologia, 2010, **47**, *Tech. Suppl.*, 02003

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Thank you for your attention!