RMO Key Comparison EUROMET.EM-K2
Comparison of Resistance Standards at 10 MΩ and 1 GΩ

FINAL REPORT

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Table of Contents

Annexes

1. Introduction

The technical basis of the Mutual Recognition Arrangement (MRA) is a set of results obtained in a course of time through key comparisons carried out by the Consultative Committees (CCs) of the CIPM, the BIPM and the Regional Metrology Organizations (RMOs). As part of this process, the CIPM Consultative Committee for Electricity and Magnetism (CCEM) carried out the key comparison CCEM-K2 of resistance standards at 10 MΩ and 1 GΩ. This comparison was piloted by the National Institute for Standards and Technology and approved by the CCEM for full equivalence in January 2002 [1, 2].

In order to link the National Metrology Institutes (NMI) organized in EUROMET to the key comparison CCEM-K2, the EUROMET Technical Committee for Electricity and Magnetism decided at its October 2004 meeting to carry out the corresponding RMO key comparison EUROMET.EM-K2. The Federal Office of Metrology (METAS) acted as pilot laboratory.

2. Participants and organisation of the comparison

2.1 Co-ordinator and members of the support group

The pilot laboratory for the comparison was the Federal Office of Metrology (METAS).

Co-ordinator:

Dr Beat Jeckelmann
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Support group, appointed by the EUROMET technical committee for electricity and magnetism:

Dr Bernd Schumacher, Physikalisch-Technische Bundesanstalt (PTB), DE;
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Dr Gert Rietveld, VSL, NL:
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2.2 List of participants

Twenty-two EUROMET NMIs and two non-EUROMET NMIs participated in the comparison. Six laboratories already participated in the key comparison CCEM.K2 and, thus, act as linking laboratories. CSIR-NML performed measurements but withdrew afterwards from the comparison before reporting results to the pilot laboratory.

No	Country	Institute	Acronym
1	Switzerland	Federal Office of Metrology	METAS*)
2	Germany	Physikalisch-Technische Bundesanstalt	PTB*)
3	Slovenia	Slovenian Institute of Quality and Metrology	SIQ
4	Slovakia	Slovak Institute of Metrology	SMU
5	Netherlands	VSL	VSL*)
6	Lithuania	State Metrology Service/ Semiconductor Physics Institute	VMT/ PFI
7	Finland	Centre for Metrology and Accreditation	MIKES
8	Hungary	National Office of Measures	OMH
9	Czech Re-	Czech Metrology Institute	CMI

No	Country	Institute	Acronym
	public		
10	Romania	National Institute of Metrology	INM
11	Poland	Central Office of Measures	GUM
12	Ireland	National Metrology Laboratory	NML
13	Norway	Norwegian Metrology and Accreditation Service	JV
14	Portugal	Instituto Nacional de Engenharia, Tecnologia e Inovação	INETI /LME
15	Latvia	Latvian National Metrology Centre	LNMC
16	United Kingdom	National Physical Laboratory	NPL*)
17	Belgium	Service de la Métrologie	SMD
18	Turkey	Ulusal Metroloji Enstitüsü	UME
19	France	Laboratoire National d'Essais	LNE*)
	South Africa	CSIR- National Metrology Laboratory	CSIR-NML**)
20	Greece	Hellenic Institute of Metrology	EIM
21	Austria	Bundesamt für Eich- und Vermessungswesen	BEV
22	Spain	Centro Español de Metrologia	CEM
23	Russia	D.I. Mendeleyev Institute for Metrology	VNIIM*)

Table 1: Participants

*) These laboratories participated in CCEM-K2 and assure the link to this CCEM key comparison.

**) CSIR-NML performed the measurements but withdrew from the comparison before reporting the measurement results.

2.3 Organisation and comparison schedule

The comparison was carried out in two parallel loops (loop A and loop B). The circulation of the standards started in July 2005 and was completed in July 2007. The detailed time schedule for the comparison is given in Table 2.

A period of four weeks was originally allowed for the measurements in each laboratory, including the time necessary for transportation. The standards were re-measured at certain intervals in the pilot laboratory to establish a drift rate for the standards and to detect resistance changes related to transport. Due to delays caused by participants and due to transport delays, the original schedule could not be kept. Several new arrangements were necessary in the course of the exercise. The lesson learnt from this is that a period of 4 weeks per participant is too tight.

Two participants (INM and GUM) asked for a second measurement slot. Both laboratories sent results only for this second measurement period.

Loop A

Institute	Country	Mean date of measurements	Time for measurements and transport (weeks)
Pilot (METAS)	Switzerland		
PTB	Germany	10.08.05	5.9
SIQ	Slovenia	20.09.05	4.4
SMU	Slovak Republic	21.10.05	5.6
VSL	Netherlands	29.11.05	5.7
Pilot (METAS)	Switzerland	08.01.06	
VMT/PFI	Lithuania	13.02.06	4.9
MIKES	Finland	19.03.06	3.1
OMH	Hungary	09.04.06	5.4
CMI	Czech Republic	17.05.06	
GUM	*Poland*	June 2006	
INM	*Romania*	July 2006	
CSIR-NML	*South-Africa*	*August 2006*	
INM (2nd measurement)	Romania	21.10.06	4.6
GUM (2nd measurement)	Poland	22.11.06	9.5
Pilot (METAS)	Switzerland		

Loop B

Institute	Country	Mean date of measurements	Time for measurements and transport (weeks)
Pilot (METAS)	Switzerland		
NML	Ireland	13.08.05	4.6
JV	Norway	14.09.05	5.6
INETI/LME	Portugal	23.10.05	4.5
LNMC	Latvia	24.11.05	3.2
Pilot (METAS)	Switzerland	16.12.05	
NPL	United Kingdom	26.01.08	6.4
SMD	Belgium	11.03.06	10.3
UME	Turkey	22.05.06	6.2
LNE	France	05.07.06	11.9
EIM	Greece	26.09.06	5.9
BEV	Austria	06.11.06	2.8
Pilot (METAS)	Switzerland	25.11.06	
CEM	Spain	01.02.07	11.3
VNIIM	Russia	21.04.07	11.1
Pilot (METAS)	Switzerland		

Table 2: Comparison schedule

2.4 Unexpected incidents

Beside the long transit times between laboratories, no major problem was reported.

3. Travelling standard and measurement instructions

The travelling standards for this comparison were kindly supplied by the National Institute of Standards and Technology (NIST), Gaithersburg, USA and Measurements International (MI), Prescott, CA.

3.1 Description of the standards

10 MΩ

Two different types of travelling standards (three resistors each) were used:

1. NIST type wire-wound resistors. The resistance elements are hermetically sealed in metal containers. The two resistor terminations of the standards are coaxial BPO connectors mounted on grooved PTFE circular plates on the top panel of the enclosures. The resistor containers are electrically isolated from the enclosures and electrically connected to the shield of one of the coaxial connectors. This allows the resistor container of the standard to be operated either in floating mode, a grounded mode, or driven at a guard potential.
2. Standards manufactured by Measurements International (CA), Model 9331. The resistance elements are hermetically sealed in metal containers. The four resistor terminations of the standards are tellurium copper binding posts. A separate ground terminal is included for screening.

1 GΩ

Two different types of travelling standards (three resistors each) were used:

1. NIST film-type resistors. The mounting of the resistance elements is the same as for the 10 MΩ standards.
2. Standards manufactured by Measurements International (CA), Model 9331S (based on NIST design). The resistance elements are housed in a double shielded enclosure. The two resistor terminations of the standards are BPO coaxial connectors mounted directly on the outer enclosure. The inner enclosure containing the resistive element is isolated from the external enclosure. It is connected to the guard terminal and may be operated either in floating mode, a grounded mode, or driven at a guard potential.

In each of the two measurement loops, three 10 MΩ and three 1 GΩ standards were circulated (see Table 3).

Loop	R	Std-ind. *a*	Standards
A	10 MΩ	1	NIST, SN HR 7550
		2	NIST, SN HR 7552
		3	MI 9331, SN 1050109
	1 GΩ	7	NIST, SN HR 9106
		8	MI 9331S, SN 1100036
		9	MI 9331S, SN 1100037
B	10 MΩ	4	MI 9331, SN 1050110
		5	MI 9331, SN 1050111
		6	NIST SN HR 7551
	1 GΩ	10	NIST, SN HR 9101
		11	NIST, SN HR 9102
		12	MI 9331S, SN 1100035

Table 3: List of travelling standards

3.2 Quantities to be measured and conditions of measurement

- Resistance of the 10 MΩ standards at the following conditions:
  test voltage: $V_{\text{test}} \leq 100$ V; preferably 10 V
  ambient temperature: (23 ± 0.2) °C
  relative humidity: (50 ± 10) %

- Resistance of the 1 GΩ standards at the following conditions:
  test voltage: $V_{\text{test}} \leq 100$ V; preferably 100 V
  ambient temperature: (23 ± 0.2) °C
  relative humidity: (50 ± 10) %

If an ambient temperature of 23 °C could not be achieved, the measurements could also be performed at an ambient temperature of (20 ± 0.2) °C. In such a case, the results were corrected to 23 °C using the temperature coefficients determined by the pilot laboratory.

3.3 Measurement instructions

Pre- conditioning:	The standards were to be installed in a thermostatic air bath, regulated at the chosen working temperature, at least 24 h before starting the measurements.
Measurements:	It was expected that the measurements would be repeated several times during the whole period allocated to the participating laboratory.
Method:	The measurement method was not specified. It was assumed that every participant uses its normal measurement method. The method and the traceability

scheme had to be described in the measurement report.
The choice of the ground/guard configuration was left to the participants.

3.4 Deviations from the protocol

The comparison was carried out as described in the protocol. Except to the modifications in the comparison schedule, no adjustments of the protocol were necessary.

4. Methods of measurement

A short description of the methods of measurement and the step-up procedures used by each participant is given in Annex B.

For the **10 MΩ *measurements***, a potentiometric resistance bridge was used by the majority of the participants. The schematic of such a bridge is shown in Figure 1.

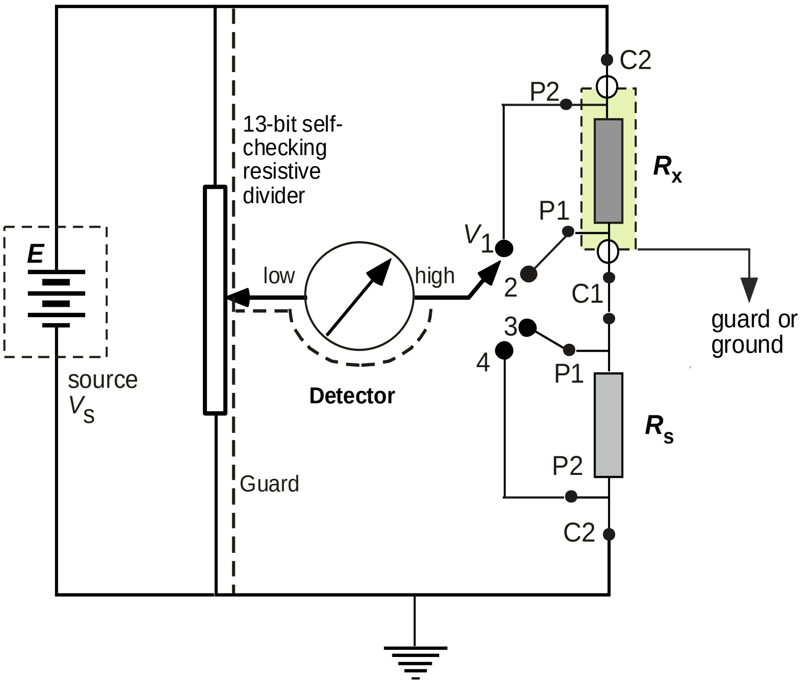


Figure 1: Schematic of the potentiometric measurement bridge, used by the majority of the participants for the 10 MΩ measurements. The bridge equation is given by:

$$\frac{R_x}{R_s} = \frac{(V_1 - V_2)}{(V_3 - V_4)}$$

Beside the potentiometric method, the following measurement set-ups were used:

- DC current comparator bridge: MIKES, BEV
- Capacitance resistance transfer method by RC time measurement (Teraohmmeter): INM
- Wheatstone bridge (active arm or traditional): INETI/LME, UME, EIM, VNIIM
- Cryogenic current comparator: NPL
- Substitution against a 10 MΩ reference (traceable to another NMI) using a DMM: LNMC

For the **1 GΩ *measurements***, an active arm Wheatstone bridge was used by most participants. The schematic of such a bridge is shown in Figure 2.

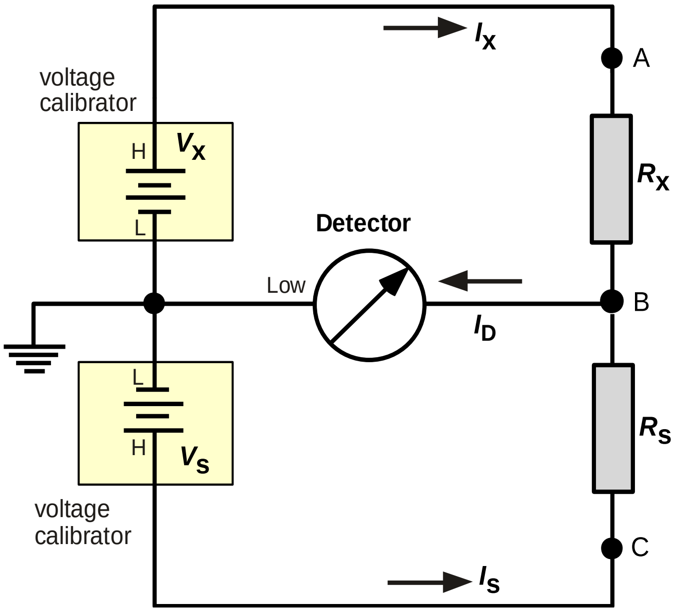


Figure 2: Schematic of the double source Wheatstone bridge, used by the majority of the participants for the 1 GΩ measurements. The bridge equation is given by:

$$I_D = 0 \Rightarrow R_x = -\frac{V_x}{V_s} \cdot R_s$$

Beside the Wheatstone method, the following measurement set-ups were used:

- Potentiometric bridge (see Fig. 1): SIQ, SMU, VMT/PFI, OMH, CMI, JV, SMD, CEM
- Classical Wheatstone bridge: LNE, VNIIM
- Capacitance resistance transfer method by RC time measurement (Teraohmmeter): INM
- Cryogenic current comparator: NPL
- Substitution against Hamon network using a DMM: NML; or using an electrometer: MIKES

5. Repeated measurements of the pilot institute, behaviour of the travelling standards

5.1 Temperature and voltage dependence

Before starting the measurement loops, the temperature and voltage dependence of the travelling standards were determined at the pilot laboratory. The temperature was varied between 20 °C and 23 °C. The voltage was varied between 5 V and 81 V for the 10 MΩ standards and between 10 V and 200 V for the 1 GΩ standards respectively.

The temperature (T) and voltage (V) dependence can be described by the following model:

$$R_a(T,V) = R_a(T_{nom},V_{nom}) \cdot \left(1 + \alpha_a (T - T_{nom}) + \beta_a (T - T_{nom})^2 + \gamma_a (V - V_{nom})\right), \tag{5.1}$$

where a is the index for the standard.

The temperature coefficients (α and β) and the voltage coefficient (γ) were determined by a least-squares fit to the data. The fit results are listed in Table 4.

Standard Index a		T_{nom} (°C)	α_a (ppm/K)	β_a (ppm/K^2)	V_{nom} (V)	γ_a (ppm/V)
10 MΩ						
1	HR 7550	23	1.10 ± 0.20	0	10	$-(0.1 \pm 2.7)\ 10^{-3}$
2	HR 7552		1.60 ± 0.20	0		$-(0.9 \pm 2.7)\ 10^{-3}$
3	MI 1050109		0.85 ± 0.05	-0.010 ± 0.017		$+(0.4 \pm 2.7)\ 10^{-3}$
4	MI 1050110		-1.24 ± 0.21	-0.78 ± 0.07		$-(2.5 \pm 3.9)\ 10^{-3}$
5	MI 1050111		0.41 ± 0.10	-0.125 ± 0.036		$-(2.1 \pm 2.7)\ 10^{-3}$
6	HR 7551		3.00 ± 0.20	0		$-(1.0 \pm 2.7)\ 10^{-3}$
1 GΩ						
7	HR 9106	23	-23.6 ± 1.0	0.85 ± 0.36	100	$-(3 \pm 9)\ 10^{-3}$
8	MI 1100036		-0.21 ± 0.25	1.05 ± 0.26		$+(2 \pm 18)\ 10^{-3}$
9	MI 1100037		-23 ± 9	-5.4 ± 3.0		$-(2 \pm 8)\ 10^{-3}$
10	HR 9101		-25.7 ± 1.0	1.28 ± 0.34		$-(5 \pm 9)\ 10^{-3}$
11	HR 9102		-29.6 ± 0.6	0.45 ± 0.22		$+(3 \pm 7)\ 10^{-3}$
12	MI 1100035		-1.1 ± 0.5	-1.25 ± 0.18		$+(10 \pm 14)\ 10^{-3}$

Table 4: Temperature and voltage coefficients of the travelling standards. The uncertainties are one-standard-deviations.

5.2 Drift behaviour of the standards

The measurements carried out at the pilot laboratory before starting the comparison, in the middle of the loops and at the end were used to establish the drift behaviour of the standards.

Due to relaxation effects in the metal used to fabricate a standard, its resistance value changes in time. Step-like resistance changes are observed after temperature shocks or mechanical shocks. These step changes usually decay exponentially as a function of time. For this reason, an exponential component can often been observed in the drift behaviour shortly after the fabrication of a standard. After a long stabilization time and over short or medium-term time periods, a polynomial fit up to order two is usually sufficient to describe the resistance change over time.

Following these considerations, two models were used to fit the measurements:

Model 1

$$R_a(t) = R_{nom}\left(1 + p_{a,0} + p_{a,1}(t - t_0) + p_{a,2}\exp\left(-p_{a,3}(t - t_0)\right)\right) = R_{nom}\left(1 + f_1(t)\right) \tag{5.2}$$

$p_{a,i}$, $i = 0$ to 3 are the fit parameters for artefact a. This model was used when a clear exponential component was observed in the data which could not be satisfactorily described by a polynomial model.

Model 2

$$R_a(t) = R_{nom}\left(1 + p_{a,0} + p_{a,1}(t - t_0) + p_{a,2}(t - t_0)^2\right) = R_{nom}\left(1 + f_2(t)\right) \tag{5.3}$$

For both models, the reference date t_0 was chosen as 1 February 2005, 00:00 h. The fit results are listed in Table 5 and plotted in Figures 3 and 4. With one exception (10 MΩ standard no 4), the fit residuals are randomly distributed and the scatter around zero corresponds well with the type A standard deviation attributed to the individual measurement points.

Standard Index a		Model	$P_{a,0}$ (ppm)	$P_{a,1}$ (ppm/y)	$P_{a,2}$ (ppm)* (ppm/y^2)**	$P_{a,3}$ (/y)
10 MΩ						
1	HR 7550	2	45.111 ± 0.050	4.42 ± 0.11	-0.391 ± 0.041	
2	HR 7552	2	38.59 ± 0.10	9.98 ± 0.21	-3.117 ± 0.090	
3	MI 1050109	1	11.71 ± 0.25	3.20 ± 0.10	-15.77 ± 0.30	1 fix
4	MI 1050110	1	34.0 ± 2.9	1.8 ± 1.1	-23.5 ± 2.5	1.71 ± 0.31
5	MI 1050111	2	-0.479 ± 0.083	17.80 ± 0.22	-3.375 ± 0.084	
6	HR 7551	2	13.900 ± 0.042	1.998 ± 0.091	-0.144 ± 0.033	
1 GΩ						
7	HR 9106	2	777.30 ± 0.28	1.79 ± 0.20	0 fix	
8	MI 1100036	1	-14.7 ± 1.1	0.70 ± 0.50	17.92 ± 0.94	2.81 ± 0.34
9	MI 1100037	1	-1.2 ± 2.4	-8.8 ± 1.2	128 ± 18	4.71 ± 0.67
10	HR 9101	2	49.59 ± 0.40	-1.3 ± 1.2	0.75 ± 0.42	
11	HR 9102	1	-63.33 ± 0.33	2.10 ± 0.20	480 ± 720	24.2 ± 7.4
12	MI 1100035	1	-16.3 ± 1.0	-0.27 ± 0.44	14.85 ± 0.89	2.69 ± 0.36

Table 5: Fit parameters describing the drift behaviour of the travelling standards
* Model 1, ** Model 2. Reference date t_0: 1 February 2005, 00:00 h

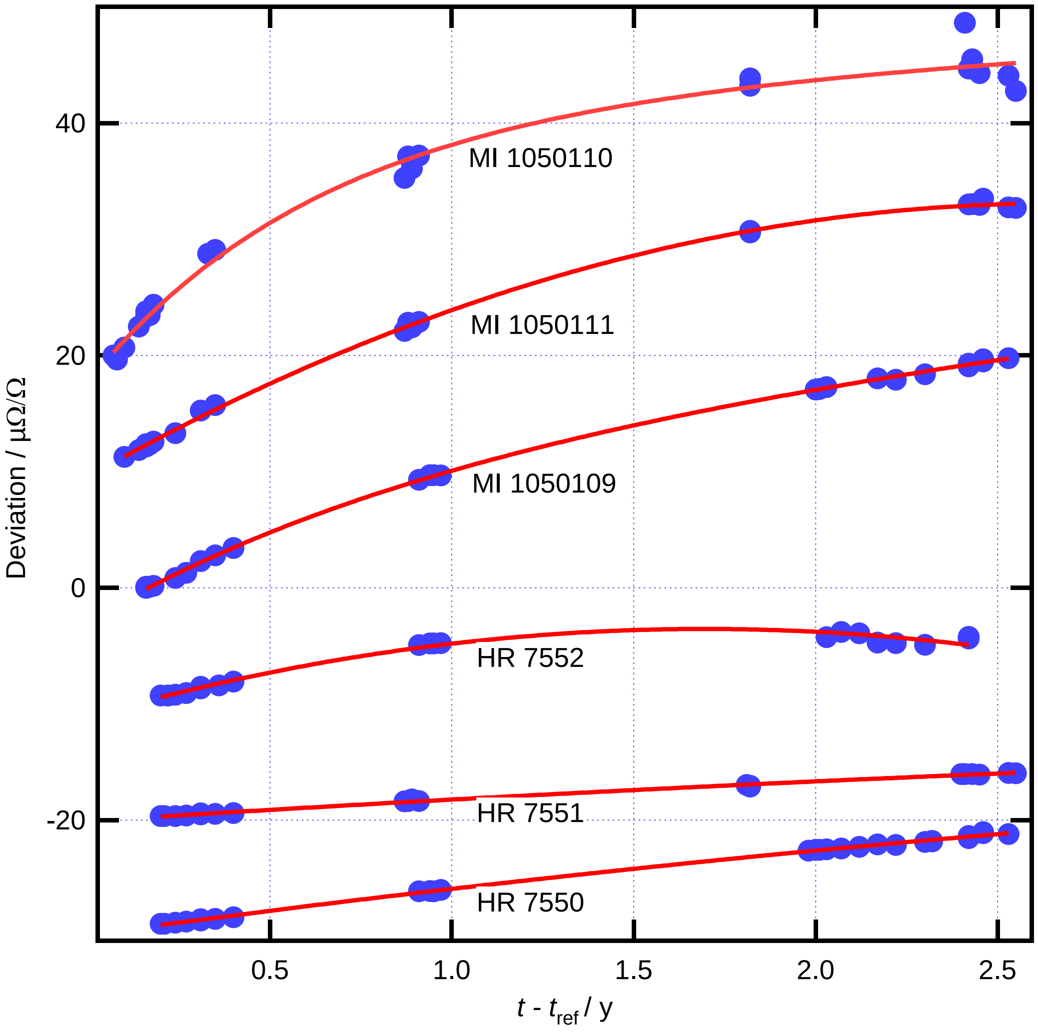


Figure 3: Drift behaviour of the 10 MΩ standards. The solid lines represent the fit functions. The offset was chosen arbitrarily for each standard.

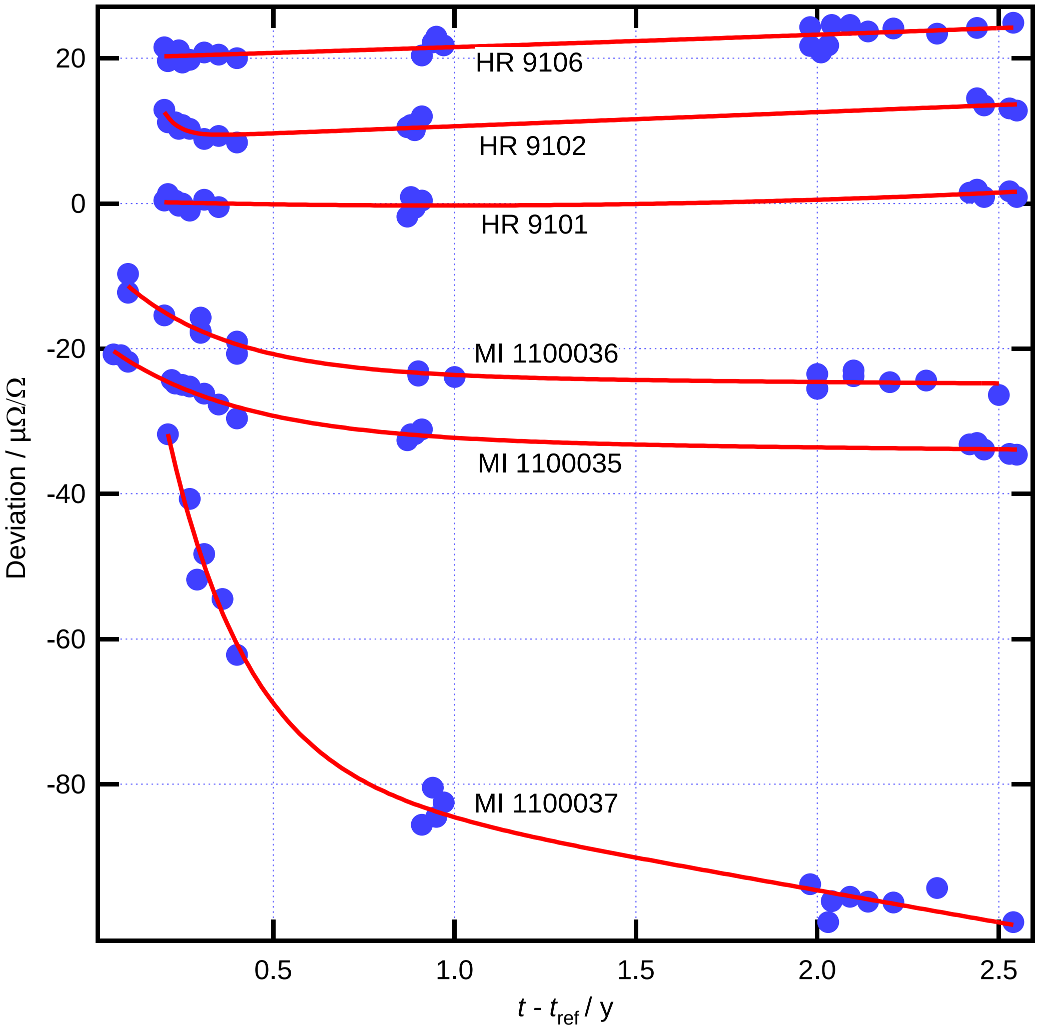


Figure 4: Drift behaviour of the 1 GΩ standards. The solid lines represent the fit functions. The offset was chosen arbitrarily for each standard.

6. Analysis of comparison data set

6.1 Basic strategy

The analysis of the data set consists of two main steps

1. Normalization of results. The data set is corrected for nominal voltage, nominal temperature and time drift of the artefacts. This is described in section 6.3.
2. Determination of comparison reference values and degrees of equivalence from the corrected data set using a method of constrained least square optimization. This part follows with some exceptions the method described in [3]. It is described in section 6.4.

6.2 Results of the participating institutes

The participants were asked to do as many measurements as deemed reasonable distributed in time over the whole period allocated to the laboratory. This should allow to detect a departure of the drift behaviour from the overall drift model fitted by the pilot laboratory. For each measurement point the following information was reported:

- Date of the measurement
- Resistance value
- Repeatability of the result (type A standard deviation of the measurement)
- Temperature including its uncertainty
- Test voltage

Each result reported by the participants can be expressed as:

$$R_{p,a,m} = R_{nom}\left(1+O_{p,a,m}\right) = R_{nom}\left(1+O\left(t_{p,a,m}, T_{p,a,m,} V_{p,a,m}\right)\right), \text{ with} \tag{6.1}$$

- *p*: Index for the participant
- *a*: Index for the artefact
- *m*: Index for the measurement of artefact *a* at participant *p*
- $O_{p,a,m}$: Deviation from the nominal value, reported for time $t_{p,a,m}$, temperature $T_{p,a,m}$ and test voltage $V_{p,a,m}$

Furthermore the following nomenclature is used, unless otherwise noted: $N_{p,a}$ is the number of measurements done by participant *p* with artefact *a*, N_p is the number of all measurements done by participant *p*.

The values $O_{p,a,m}$ and the associated standard deviations, $u_{r\text{-}p,a,m}$, are given in Annex A.

In addition to the individual results, mean values for every resistor and combined standard uncertainties were reported. The mean values were not used in the analysis (see Sect. 6.3). The reported combined uncertainties, $u_{c\text{-}p,a}$, for participant *p* and artefact *a* can be expressed as:

$$u_{c-p,a}{}^{2} = u_{s-p}{}^{2} + u_{T-p,a}{}^{2} + u_{r-p,a}{}^{2}, \text{ where:} \tag{6.2}$$

- $u_{s\text{-}p}$: Combined standard uncertainty of the measurement set-up (step-up procedure, bridge…)
- $u_{T\text{-}p,a}$: Component related to the temperature measurement and the temperature dependence of the standard *a* to be measured.
- $u_{r\text{-}p,a}$: Component related to the repeatability of the measurement; typically the standard deviation of the mean of the series of measurements performed.

The reported uncertainty values are listed in Table 6.

6.3 Normalization of the results

In a ***first step***, temperature and voltage corrections were applied to the reported results. The corrected results (expressed as deviation from the nominal resistance value) are given by:

$$O_{c-p,a,m} = O_{p,a,m} - \alpha_a\left(T_{p,a,m} - T_{nom}\right) - \beta\left(T_{p,a,m} - T_{nom}\right)^2 - \gamma\left(V_{p,a,m} - V_{nom}\right) \tag{6.3}$$

The uncertainty of the mean correction term for every participant and standard may be expressed as:

$$\begin{aligned} u_{TV-p,a}{}^{2} = {} & \left(\alpha \cdot u\left(T_{p,a}\right)\right)^2 + \left(u(\alpha)\cdot\left(\bar{T}_{p,a} - T_{nom}\right)\right)^2 + \left(u(\alpha)\cdot u\left(T_m\right)\right)^2 + \left(2\beta \cdot u\left(T_{p,a}\right)\cdot\left(\bar{T}_{p,a} - T_{nom}\right)\right)^2 \\ & + \left(u(\beta)\cdot\left(\bar{T}_{p,a} - T_{nom}\right)^2\right)^2 + \left(u(\gamma)\cdot\left(\bar{V}_{p,a} - V_{nom}\right)\right)^2 \end{aligned} \tag{6.4}$$

Most of the measurements were carried out close to the nominal temperature. For this reason, also the second order term was taken into account in the linear part of the temperature correction. The resulting uncertainty components are listed in Tables 7 and 8.

In a ***second step***, the time dependence of the standards and an offset term, taken from the results of the pilot laboratory, are removed from the results:

$$M_{p,a,m} = O_{c-p,a,m} - f_{i=1,2}\left(t_{p,a,m}\right) \tag{6.5}$$

$f_1(t)$ and $f_2(t)$ respectively, are the model functions fitted to the results of the pilot laboratory (see Sect. 5.2.

The normalized results $M_{p,a,m}$ are given in Annex A.

In a ***third step***, the uncertainties $u_{r\text{-}p,a,m}$, which are related to the repeatability and which were indicated by the participants for each measured value were checked against the variation of the normalized results. If necessary, a corrected value was determined based on the observed scatter of the data. This was done the following way.

For every participant and artefact, the internal standard deviation of the weighted mean was calculated as

$$s^2_{\text{int}-p,a} = \frac{1}{\sum_m \frac{1}{u^2_{r-p,a,m}}} \tag{6.6}$$

This value can be compared to the external standard deviation calculated from the scatter of the individual results as

$$s^2_{ext-p,a} = \frac{1}{\left(N_{p,a}-1\right)\sum_m \frac{1}{u^2_{r-p,a,m}}} \sum_m \frac{\left(M_{p,a,m} - \overline{M}_{p,a}\right)^2}{u^2_{r-p,a,m}} . \tag{6.7}$$

with $\overline{M}_{p,a} = \frac{1}{N_{p,a}} \sum_m M_{p,a,m}$

The ratio $R^2 = s_{ext-p,a}{}^2 \big/ s_{\text{int}-p,a}{}^2$ can be used to check if the reproducibility values given by the participants are reliable or not. Adjusted values $u^*_{r\text{-}p,a,m}$ for the reproducibility were fixed according to the following rules:

- $R^2 > 1$: $u^*_{r-p,a,m} = R \cdot u_{r-p,a,m}$ (6.8)
- $R^2 \le 1$ $u^*_{r-p,a,m} = u_{r-p,a,m}$.

These adjusted values are listed in the Tables given in Annex A. The standard deviation $u^*_{r\text{-}p,a}$ for the mean value was chosen as:

$$u^*_{r-p,a} = \max\left(s_{\text{int}-p,a}, s_{ext-p,a}\right). \tag{6.9}$$

The resulting values are listed in Tables 7 and 8. In cases where only one result per standard was reported by a participant, the standard deviation given in the report was left unchanged ($u^*_{r-p,a} = u^*_{r-p,a,m} = u_{r-p,a}$).

p	**Laboratory**	10 MΩ				1 GΩ			
		$u_{c\text{-}p,a}$ (ppm)	$u_{r\text{-}p,a}$ (ppm)	$u_{s\text{-}p}$ (ppm)	$u_{T\text{-}p,a}$ *) (ppm)	$u_{c\text{-}p,a}$ (ppm)	$u_{r\text{-}p,a}$ (ppm)	$u_{s\text{-}p}$ (ppm)	$u_{T\text{-}p,a}$ (ppm)
1	METAS	0.35	0.10	0.34	0.00	3.03	0.70	3.0	0.0
2	PTB	0.42	0.40	0.14	0.00	3.24	2.10	2.5	0.0
3	SIQ	0.55	0.11	0.54	0.00	3.50	0.70	3.4	0.0
4	SMU	4.48	1.50	4.22	0.60	18.99	6.50	17.8	1.0

5	VSL	0.96	0.10	0.94	0.17	1.90	1.00	1.6	0.2
6	VMT/PFI	0.60	0.30	0.52	0.00	3.40	1.00	3.2	0.0
7	MIKES	0.87	0.28	0.82	0.10	5.20	2.80	4.4	0.1
8	OMH	2.00	0.35	1.56	1.20	3.80	0.40	2.9	2.4
9	CMI	3.50	0.10	3.48	0.40	15.00	1.20	14.9	0.8
10	INM	3.00	0.58	2.94	0.20	22.00	0.60	21.9	2.0
12	NML	7.40	0.80	7.36	0.10	32.0	8.0	30.84	3.0
13	JV	1.36	0.26	0.76	1.10	6.8	0.4	6.42	2.3
14	INETI	7.60	0.75	7.56	0.00	110.0	36.0	103.94	0.0
15	LNMC	2.70	0.40	2.67	0.00	*not measured*			
16	NPL	0.11	0.06	0.09	0.00	1.5	1.4	0.45	0.0
17	SMD	1.35	0.36	1.16	0.58	9.0	1.9	8.78	0.6
18	UME	2.50	0.70	2.40	0.00	6.0	3.6	4.80	0.0
19	LNE	*not measured*				4.8	1.5	4.6	0.0
20	EIM	5.70	3.30	4.65	0.00	10.0	6.7	7.42	0.0
21	BEV	2.00	1.34	1.47	0.19	9.5	3.9	8.38	2.0
22	CEM	0.34	0.05	0.34	0.00	2.1	0.4	2.05	0.0
23	VNIIM	0.87	0.16	0.80	0.30	2.3	1.0	1.98	0.6

Table 6: Combined uncertainties reported by the laboratories
*) A value of 0 for $u_{\mathrm{T\text{-}p,a}}$ indicates that this component was not explicitly given in the participant's uncertainty budget.

p	**Lab**	***T*** **(°C)**	**V (V)**	***u*(*T*) (ppm)**	$u_{TV\text{-}p,1}$ **(ppm)**	$u^*_{\mathrm{r\text{-}p,1}}$ **(ppm)**	$u_{TV\text{-}p,2}$ **(ppm)**	$u^*_{\mathrm{r\text{-}p,2}}$ **(ppm)**	$u_{TV\text{-}p,3}$ **(ppm)**	$u^*_{\mathrm{r\text{-}p,3}}$ **(ppm)**
1	METAS	23.00	5.0	0.030	0.036	0.042	0.050	0.071	0.029	0.051
2	PTB	23.00	10.0	0.031	0.035	0.157	0.048	0.236	0.027	0.299
3	SIQ	22.91	10.0	0.050	0.058	0.047	0.082	0.059	0.043	0.235
4	SMU	22.98	10.0	0.100	0.112	0.372	0.161	0.614	0.086	0.515
5	VSL	23.05	9.1	0.005	0.008	0.073	0.014	0.078	0.007	0.087
6	VMT/PFI	23.01	10.0	0.080	0.089	0.080	0.129	0.038	0.068	0.037
7	MIKES	23.18	86.6	0.224	0.357	0.210	0.444	0.156	0.302	0.042
8	OMH	23.00	9.1	0.060	0.067	0.350	0.097	0.350	0.051	0.350
9	CMI	23.00	9.0	0.500	0.559	0.058	0.806	0.058	0.428	0.073
10	INM	23.16	10.0	0.040	0.055	0.567	0.072	0.623	0.035	0.574
					$u_{TV\text{-}p,4}$	$u^*_{\mathrm{r\text{-}p,4}}$	$u_{TV\text{-}p,5}$	$u^*_{\mathrm{r\text{-}p,5}}$	$u_{TV\text{-}p,6}$	$u^*_{\mathrm{r\text{-}p,6}}$
12	NML	23.16	5.0	0.100	0.130	1.458	0.048	0.168	0.303	0.291
13	JV	23.00	9.1	0.100	0.126	0.167	0.042	0.103	0.301	0.064
14	INETI	23.08	10.0	0.107	0.139	3.223	0.047	1.415	0.302	0.665
15	LNMC	23.10	9.8	0.100	0.128	2.500	0.043	2.500	0.301	2.500
16	NPL	23.11	10.0	0.100	0.128	0.476	0.043	0.035	0.302	0.137
17	SMD	22.99	10.0	0.041	0.061	0.363	0.021	0.125	0.048	0.070
18	UME	23.10	10.0	0.400	0.505	1.600	0.169	0.700	1.203	0.600
20	EIM	22.92	10.0	0.154	0.196	3.008	0.065	1.448	0.461	2.738
21	BEV	22.99	100.0	0.111	0.388	1.463	0.247	0.423	0.388	0.085
22	CEM	23.04	9.1	0.013	0.019	0.218	0.007	0.187	0.040	0.051
23	VNIIM	19.99	50.0	0.030	0.929	0.140	0.455	0.140	0.616	0.160

Table 7: Averaged measurement conditions for the 10 MΩ standards. Uncertainty contributions due to the temperature/voltage correction and the reproducibility of the measurements.

p	Lab	T (°C)	V (V)	$u(T)$ (ppm)	$u_{TV\text{-}p,7}$ (ppm)	$u^*_{\text{r-p},7}$ (ppm)	$u_{TV\text{-}p,8}$ (ppm)	$u^*_{\text{r-p},8}$ (ppm)	$u_{TV\text{-}p,9}$ (ppm)	$u^*_{\text{r-p},9}$ (ppm)
1	METAS	23.00	100.0	0.050	1.181	0.367	0.054	0.267	1.258	1.196
2	PTB	23.01	100.0	0.030	0.709	2.234	0.033	0.756	0.768	1.591
3	SIQ	23.00	90.0	0.050	1.185	1.006	0.188	0.746	1.264	0.924
4	SMU	22.99	87.5	0.100	2.410	5.350	0.906	2.716	2.558	2.285
5	VSL	23.09	100.0	0.005	0.112	0.206	0.024	0.357	1.080	0.466
6	VMT/PFI	23.01	100.0	0.080	1.889	0.210	0.086	0.108	2.016	0.255
7	MIKES	23.06	100.0	0.223	4.917	1.335	0.254	4.470	5.666	5.618
8	OMH	23.00	9.1	0.120	4.803	0.350	1.651	0.360	5.085	0.360
9	CMI	23.00	90.0	0.500	11.809	1.446	0.569	1.261	12.582	0.738
10	INM	23.13	100.0	0.040	0.951	0.906	0.057	0.346	1.554	0.599
p	Lab	T (°C)	V (V)	$u(T)$ (ppm)	$u_{TV\text{-}p,10}$	$u^*_{\text{r-p},10}$	$u_{TV\text{-}p,11}$	$u^*_{\text{r-p},11}$	$u_{TV\text{-}p,12}$	$u^*_{\text{r-p},12}$
12	NML	23.04	100.0	0.100	2.573	0.850	2.965	1.351	0.125	1.209
13	JV	23.00	9.1	0.100	2.714	0.743	3.032	0.933	1.279	0.705
14	INETI	22.99	100.0	0.068	2.059	36.369	2.372	7.337	0.037	36.000
16	NPL	23.07	100.0	0.100	2.574	3.330	2.965	1.386	0.127	2.317
17	SMD	23.03	90.9	0.007	0.224	1.720	0.090	1.930	0.130	2.270
18	UME	23.19	100.0	0.400	10.294	3.580	11.859	5.080	0.505	1.640
19	LNE	23.00	100.0	0.200	5.146	1.500	5.929	1.500	0.247	1.500
20	EIM	22.92	100.0	0.137	3.483	5.377	4.013	6.445	0.177	6.995
21	BEV	22.40	100.0	0.263	5.892	1.816	7.162	1.743	0.480	0.774
22	CEM	23.05	91.0	0.013	0.351	0.531	0.391	0.454	0.130	0.500
23	VNIIM	19.99	50.0	0.030	4.366	1.000	2.894	0.900	2.377	0.800

Table 8: Averaged measurement conditions for the 1 GΩ standards. Uncertainty contributions due to the temperature/voltage correction and the reproducibility of the measurements.

6.4 Calculation of the reference value and its uncertainty

This comparison involves multiple unstable artefacts which were circulated within two different comparison loops. The method of constrained least squares as proposed in [3] is suitable for handling such a situation of increased complexity.

The analysis is based on a statistical model of the comparison results, which implicitly includes the laboratory biases. The model equation for a single measurement is given as

$$M_{p,a,m} = p_{a,0} + d_p + \delta(R)_{p,a} + \delta(TV)_{p,a} + \delta(M)_{p,a,m} \tag{6.10}$$

- $M_{p,a,m}$ are the participant’s results (deviation from nominal) corrected for time drift, temperature and voltage dependence of the standards according to section 6.3.
- $p_{a,0}$ is the deviation from the nominal value for standard a at the reference time t_0
- d_p is the bias of the laboratory. This model specifically assumes that the laboratory bias is the same for every artefact of the same nominal value (10 MΩ or 1 GΩ).

A random variability (normally distributed about zero) is assigned to each measurement, consisting of three parts:

- $\delta(R)_{p,a}$: Variation of the artefact (e.g. due to transport) with variance ${q_{p,a}}^2$.
- $\delta(TV)_{p,a}$: Variation due to the error in the temperature and voltage correction. The variance corresponds to the uncertainty of this correction: ${u_{TV-p,a}}^2$
- $\delta(M)_{p,a,m}$: Variation of each participant's measurement with a variance that corresponds to ${u^*_{r-p,a,m}}^2$ (a measure of the repeatability).

Constrained least square optimization. Based on the model for a single measurement (6.10) one can write down an over-determined system of linear equations in matrix form

$$\mathbf{M} = \mathbf{CX} + \boldsymbol{\delta} \qquad (6.11)$$

M is a column vector containing the drift, voltage and temperature corrected results $M_{p,a,m}$ of all participants. **X** is a column vector containing the parameters which need to be determined.

$$\mathbf{X} = \left(p_{1,0}, p_{2,0}, \ldots, d_1, d_2, d_3, \ldots\right)^T \qquad (6.12)$$

The superscript T denotes the transpose. **C** is the design matrix (in this case a column vector consisting of ones) and **δ** stands for the three different components of statistical variability in (6.10). A solution for the parameter vector **X** can be found in the least square sense by minimizing the constrained and weighted chi-square function

$$\chi^2 = (\mathbf{CX} - \mathbf{M})^T \mathbf{U}^{-1} (\mathbf{CX} - \mathbf{M}) + \lambda \sum_p w_p d_p \qquad (6.13)$$

The matrix **U,** the inverse of which is used as a weight in equation 6.13, is constructed from the three parts of variability defined in the model 6.10.

$$\mathbf{U} = \mathbf{U_M} + \mathbf{U_R} + \mathbf{U_{TV}} \qquad (6.14)$$

$\mathbf{U_M}$ simply contains the $u^{*\,2}_{r-p,a,m}$ (determined according to the third step in section 6.3 and listed in Annex A) in the diagonal with all off-diagonal elements set to 0. Repeatability is thus considered as an independent statistical variation of each single measurement.

$\mathbf{U_R}$ has a block diagonal structure with $N_{p,a} \times N_{p,a}$ submatrices $\mathbf{u_{R-p,a}}$ in the diagonal and all other elements set to 0

$$\mathbf{U_R} = \begin{pmatrix} \mathbf{u_{R-1,1}} & \mathbf{0} & \mathbf{0} & \cdots & \mathbf{0} & \cdots \\ \mathbf{0} & \mathbf{u_{R-1,2}} & \mathbf{0} & \cdots & \mathbf{0} & \cdots \\ \mathbf{0} & \mathbf{0} & \mathbf{u_{R-1,3}} & & \mathbf{0} & \cdots \\ \vdots & \vdots & & \ddots & & \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & & \mathbf{u_{R-p,a}} & \\ \vdots & \vdots & \vdots & & & \ddots \end{pmatrix} \qquad \mathbf{u_{R-p,a}} = \begin{pmatrix} {q_{p,a}}^2 & \cdots & {q_{p,a}}^2 \\ \vdots & \ddots & \vdots \\ {q_{p,a}}^2 & \cdots & {q_{p,a}}^2 \end{pmatrix}$$

The submatrices are filled with with values $q^2_{p,a}$, i.e. 100% correlation is assumed within a block. The submatrices correspond to the series of measurements of the same artefact in the same laboratory, i.e. the border of each block corresponds to a transport of an artefact from one laboratory to the next. This assumes that transport is inducing a deviation from the nominal value of the artefact which remains constant during the time of measurement in the laboratory. The values $q^2_{p,a}$ are not a priori known, but as pointed out in [3] they can be estimated from the residuals of the fitting procedure itself. This results in an overall transport variability per artefact, which is the same for each laboratory. It however turns out that this does not lead to satisfactory results. Some of the laboratories show larger inconsistencies between measurements of the same type of artefact (10 MΩ or 1 GΩ) than others. It has therefore been decided to introduce an individual (per laboratory) variability due to transport, which can be written as

$$q_{p,a}{}^2 = c_p{}^2 \cdot q_{0,a}{}^2 .$$

$q_{0,a}^2$ represents the base variability per artefact. It is estimated from the typical uncertainties of the fits to the pilot data to determine the time drift of the artefact. The values, which were used for $q_{0,a}^2$ are listed in Table 10a.

c_p is an individual expansion factor per laboratory, which depends on the consistency of measurements of the same type of artefact (10 MΩ or 1 GΩ) in each laboratory. To determine the consistency the normalized data was separated into sets per laboratory and for each set a reduced Chi Square was calculated according to

$$\chi_{p,red}{}^2 = \frac{1}{N_p - 1}\left(\mathbf{C}_p \hat{M}_p - \mathbf{M}_p\right)^T \mathbf{U}_p{}^{-1}\left(\mathbf{C}_p \hat{M}_p - \mathbf{M}_p\right)$$

The quantities are the same as in equation (6.13) and (6.14) but separated per laboratory, which is indicated by the subscript p. $\hat{M}_p$ is a generalized weighted mean given as

$$\hat{M}_p = \left(\mathbf{C}_p{}^T \mathbf{U}_p{}^{-1} \mathbf{C}_p\right)^{-1} \mathbf{C}_p{}^T \mathbf{U}_p{}^{-1} \mathbf{M}_p$$

and N_p is the number of measurements done for each data set.

$\mathbf{U}_p$ is a function of c_p, which initially is set to 1, but subsequently increased for the laboratories with $\chi_{p,red}{}^2 > 1$ until $\chi_{p,red}{}^2 \approx 1$. The c_p values determined this way are listed in Table 10b.

Note: The differences in the observed inconsistencies are not necessarily caused by transport effects, they might as well be caused by inconsistent treatment of the artefacts in the laboratories. It is however not possible to distinguish between changes of the artefacts due to transport and inconsistencies in the measurement procedure. One of the basic assumptions of this analysis is a common bias for the measurements of all artefacts of the same type (10 MΩ or 1 GΩ), thus it makes sense to assign individual transport uncertainties to take the observed inconsistencies into account.

$\mathbf{U_{TV}}$ has the same block diagonal structure as $\mathbf{U_R}$ with the values $u_{TV-p,a}^2$ (determined according to equation 6.4) filled in, assuming that the temperature and voltage corrections of the same standard in the same laboratory are 100% correlated. This is an approximation, because it must be expected, that all corrections on the standards done in the same laboratory are to a certain extent correlated. To determine the magnitude of this correlation one would need to analyze the different uncertainty contributions in the correction procedure (First step, section 6.2) in more detail. Considering the relatively small contribution of this correction to the uncertainty it was decided to repeat the analysis with a $\mathbf{U_{TV}}$ in which all corrections of the same laboratory are 100% correlated, which can be regarded as the upper limit of possible correlation. As expected, the changes in results are insignificant and, thus, support the approximation made.

In (6.13) λ denotes the Lagrange multiplier and the imposed constraint is given as

$$\sum_{p} w_p d_p = 0 \tag{6.15}$$

with normalized weights w_p. The constraint (6.15) in (6.13) is necessary to obtain a single solution in the optimization. Without constraint, an infinite set of solutions would result. This lies in the nature of the model, leaving both, artefact values and laboratory biases, as free parameters.

Furthermore the constraint defines the comparison reference value (CRV) in the sense that (6.15) requires the average weighted bias to be zero. This corresponds to the calculation of the CRV as the weighted mean, as it might be done in a simple one-loop comparison with a single stable artefact. Thus it makes sense to choose the weights w_p in (6.15) as the normalized inverse squares of uncertainties u_{c-p} which reflect the measurement capability of a laboratory. $u_{c\text{-p}}$ is constructed as follows:

$$u_{c-p}{}^2 = u_{s-p}{}^2 + u_{TV-p}{}^2 + u_{r-p}{}^2 + u_{R-p}{}^2$$

with the following individual contributions: (6.16)

- u_{s-p} is the combined standard uncertainty of the measurement set-up, reported by the participant (see Table 6)
- u_{TV-p} is the uncertainty component of the temperature and voltage correction.
  It is calculated as an average of the uncertainty of each artefact:
  $$u_{TV-p}{}^2 = \frac{1}{n_a} \sum_{a} u_{TV-p,a}{}^2 .$$
- The components $u_{TV\text{-}p,a}$ are given in Tables 7 and 8. n_a is the number of artefacts considered in the analysis. Some participants have included a component due to the temperature coefficient of the travelling standard in their uncertainty budget. This component is replaced by the values in Tables 7 and 8.
- u_{r-p} represents the reproducibility of the participant’s measurements. It is calculated as
  $$u_{r-p}{}^2 = \frac{1}{n_a} \sum_{a} u^*_{r-p,a}{}^2 .$$
- u_{R-p} is the contribution due to transport uncertainty. It is simply the average of the individual transport uncertainties
  $$u_{R-p}{}^2 = \frac{1}{n_a} \sum_{a} q_{p,a}{}^2$$

The values are listed in Table 9.

p	Lab	**10 MΩ**					**1 GΩ**				
		u_{s-p} (ppm)	u_{TV-p} (ppm)	u_{r-p} (ppm)	u_{R-p} (ppm)	u_{c-p} (ppm)	u_{s-p} (ppm)	u_{TV-p} (ppm)	u_{r-p} (ppm)	u_{R-p} (ppm)	u_{c-p} (ppm)
1	METAS	0.34	0.04	0.10	0.14	0.39	2.95	1.00	0.74	0.38	3.22
2	PTB	0.14	0.04	0.40	0.29	0.52	2.47	0.60	2.10	2.87	4.37
3	SIQ	0.54	0.06	0.14	0.53	0.77	3.43	1.01	0.90	4.05	5.48
4	SMU	4.18	0.12	1.50	0.96	4.54	17.81	2.10	6.50	5.14	19.76
5	VSL	0.94	0.01	0.10	0.58	1.11	1.61	0.63	1.00	0.87	2.17
6	VMT/PFI	0.52	0.10	0.30	0.29	0.68	3.25	1.60	1.00	0.87	3.86
7	MIKES	0.82	0.37	0.28	0.30	0.99	4.38	4.33	2.80	0.88	6.83
8	OMH	1.56	0.07	0.35	0.53	1.69	2.92	4.15	0.40	0.87	5.16
9	CMI	3.48	0.62	0.10	0.29	3.54	14.93	9.97	1.20	0.88	18.01
10	INM	2.94	0.06	0.59	1.57	3.39	21.90	1.05	0.66	2.33	22.06
12	NML	7.36	0.22	0.80	0.35	7.41	30.84	2.27	8.00	3.01	32.08
13	JV	0.76	0.21	0.26	0.40	0.92	6.42	2.46	0.80	0.87	6.97
14	INETI	7.56	0.22	1.11	7.82	10.94	103.94	1.81	36.00	1.12	110.02
15	LNMC	2.67	0.22	2.50	0.35	3.68	not measured				
16	NPL	0.09	0.22	0.10	1.74	1.76	0.45	2.27	2.47	0.87	3.50
17	SMD	1.16	0.04	0.36	0.35	1.27	8.78	0.16	1.99	0.87	9.04
18	UME	2.40	0.86	0.70	2.59	3.70	4.80	9.07	3.71	0.87	10.94
19	LNE	not measured					4.56	4.53	1.50	0.87	6.66
20	EIM	4.65	0.33	3.30	4.70	7.40	7.42	3.07	6.70	0.87	10.50
21	BEV	1.47	0.32	1.34	0.35	2.05	8.38	5.36	3.90	0.87	10.73
22	CEM	0.34	0.03	0.14	0.35	0.50	2.05	0.31	0.50	1.21	2.46
23	VNIIM	0.80	0.54	0.16	1.34	1.66	1.98	3.32	1.00	0.87	4.08

Table 9: Uncertainty components used to calculate the laboratory weights in the least squares adjustment

Standard	a	$q_{0,a}$ (ppm)	Standard	a	$q_{0,a}$ (ppm)
10 MΩ	1	0.50	1 GΩ	7	1.50
	2	0.50		8	1.50
	3	0.50		9	1.50
	4	Excluded		10	1.50
	5	0.50		11	1.50
	6	0.50		12	1.50

Table 10a: Base transport variability attributed to the artefacts.

p	Lab	**10 MΩ**	**1 GΩ**
		c_p	c_p
1	METAS	1.00	1.00
2	PTB	1.00	3.32
3	SIQ	1.83	4.56
4	SMU	3.31	5.94
5	VSL	2.02	1.00
6	VMT/PFI	1.00	1.00
7	MIKES	1.00	1.00
8	OMH	1.83	1.00
9	CMI	1.00	1.00
10	INM	5.45	2.69
12	NML	1.00	3.28
13	JV	1.00	1.00
14	INETI	21.68	1.00
15	LNMC	1.00	-
16	NPL	4.92	1.00
17	SMD	1.00	1.00
18	UME	7.32	1.00
19	LNE	-	1.00
20	EIM	13.30	1.00
21	BEV	1.00	1.00
22	CEM	1.00	1.27
23	VNIIM	3.79	1.00

Table 10b: Expansion factor for individual transport uncertainties

Solution of the constrained optimization

The optimization problem (6.13) is linear and can thus be solved analytically [4]. For this the constraint (6.15) is best written in matrix form:

$$\mathbf{W}^T\mathbf{X} = 0 \tag{6.17}$$

with the weight vector $\mathbf{W} = (0,...,0, w_1, w_2, w_3,...)^T$ and the parameter vector **X** (6.12).

The estimate of the parameters **X** can then be written as

$$\hat{\mathbf{X}} = \mathbf{A_0}^{-1}\left(\mathbf{C}^T\mathbf{U}^{-1}\mathbf{M} - \hat{\lambda}\mathbf{W}\right) \tag{6.18}$$

with

$$\begin{aligned} \mathbf{A_0} &= \mathbf{C}^T\mathbf{U}^{-1}\mathbf{C} + \mathbf{W}\mathbf{W}^T \\ \hat{\lambda} &= \left(\mathbf{W}^T\mathbf{A_0}^{-1}\mathbf{W}\right)^{-1}\mathbf{W}^T\mathbf{A_0}^{-1}\mathbf{C}^T\mathbf{U}^{-1}\mathbf{M} \end{aligned} \tag{6.19}$$

Using linear uncertainty propagation one can write down the uncertainty matrix of the estimated parameters

$$\mathbf{U}_{\hat{\mathbf{X}}} = \mathbf{A_0}^{-1} - \mathbf{A_0}^{-1}\mathbf{W}\left(\mathbf{W}^T\mathbf{A_0}^{-1}\mathbf{W}\right)^{-1}\mathbf{W}^T\mathbf{A_0}^{-1} \tag{6.20}$$

The diagonal of $\mathbf{U}_{\hat{\mathbf{X}}}$ contains the squared standard uncertainties of the parameters which are further down needed for the calculation of the uncertainties of the degrees of equivalence.

$$diag\left(\mathbf{U}_{\hat{\mathbf{X}}}\right) = \left[u_{fit}^2(p_{1,1}), u_{fit}^2(p_{2,1}),..., u_{fit}^2(d_1), u_{fit}^2(d_2), u_{fit}^2(d_3),...\right] \tag{6.21}$$

Comparison reference value and degrees of equivalence

The constraint (6.15) defines the comparison reference value (CRV) as a consensus value, assuming that the average bias is zero. Artefact values and laboratory biases obtained through the above described constrained optimization can be directly interpreted as the CRV for each artefact and the unilateral degrees of equivalence (DoE) for each participant, respectively.

To calculate the uncertainty of d_p and thus the uncertainty of the DoE, we have to include the uncertainty associated with the constraint. We write:

$$d_{p,meas} = d_p - \sum_j w_j d_j = \sum_j w_j \left(d_p - d_j\right) \tag{6.22}$$

Application of the uncertainty propagation law to (6.22) yields the expected variance in the value of the measured value of d_p arising from the actual d_j values of all participants [3]:

$$\left(1-w_p\right)^2 u_{s-p}{}^2 + \sum_{p'\neq p} w_j{}^2 \cdot u_{s-p}{}^2 , \tag{6.23}$$

where $u_{s\text{-}p}$ (extracted from the participants uncertainty budget according to section 6.2 and listed in Table 6) are the standard uncertainties which characterize the dispersion of values that could reasonably be attributed to the laboratory bias. Adding the uncertainty component due to the least-squares fit $u_{fit}(d_p)$ (6.21), the (expanded) uncertainty for the DoE becomes:

$$\begin{aligned} u_{doe}{}^2\left(d_p\right) &= u_{fit}{}^2\left(d_p\right) + \left(1-w_p\right)^2 u_{s-p}{}^2 + \sum_{p'\neq p} w_p{}^2 \cdot u_{s-p}{}^2 \;. \\ U_{doe}\left(d_p\right) &= 2\cdot u_{doe}\left(d_p\right) \end{aligned} \tag{6.24}$$

To exclude a laboratory from the determination of the CRV one can simply set the corresponding weight in equation 6.13 to zero. Reasons for exclusion of a laboratory are:

- Laboratories who apply a 1:1 substitution method against a standard calibrated at another NMI participating in the comparison. This is known beforehand and the corresponding laboratories are excluded from the start.
- An outlying result in the sense that the unilateral DoE is incompatible with zero on the 95% level, i.e. with $\left|d_p\right| > U_{doe}\left(d_p\right)$. This is established in an iterative manner. For details see the description of the fitting procedure below.

The above equations for the uncertainty of the DoE are valid for both, laboratories contributing to the determination of the CRV and excluded laboratories, respectively. The effect of correlation is controlled by the terms in equation (6.24) which contain the weight of the corresponding laboratory.

The bilateral degree of equivalence (bilateral DoE) is simply the pairwise differences between laboratory biases (i.e the pairwise differences between the unilateral DoEs) obtained from the fitting procedure. It can be written for laboratories $p=i$ and $p=j$ as

$$d_{ij}^{(bi)} = d_i - d_j$$

The uncertainty of the bilateral DoE consists of the uncertainties related to possible bias and of the fit uncertainties. For the latter one needs to take the correlation into account, given as $\mathrm{cov}_{fit}\left(d_i, d_j\right)$ which is a result of the fitting procedure and can be found in the off-diagonal elements of $\mathbf{U}_{\hat{\mathbf{x}}}$

$$\begin{aligned} u^2\left(d_{ij}^{(bi)}\right) &= u_{s-i}{}^2 + u_{s-j}{}^2 + u_{fit}{}^2\left(d_i\right) + u_{fit}{}^2\left(d_j\right) - 2\,\mathrm{cov}_{fit}\left(d_i, d_j\right) \\ U\left(d_{ij}^{(bi)}\right) &= 2\cdot u\left(d_{ij}^{(bi)}\right) \end{aligned}$$

Unilateral DoEs and their expanded uncertainties are shown in Tables 13 and 14.

Fitting procedure

The least squares problem (6.13) was solved iteratively following the procedure below:

1. The χ^2 was calculated according to (6.13), using the normalized results given in Annex A, and an estimate of the parameters was obtained with (6.18). A value of 0.10 ppm was chosen as a starting value for the transport uncertainties q_a.
2. After the first step, it became apparent that the 10 MΩ standard no 4 (MI 105110) in loop B suffered from drastic step-like resistance changes during transport. For 9 of the 12 participants in loop B, the laboratory biases calculated for this standard differs substantially from the values calculated for the other two 10 MΩ standards. ***It was, thus, decided to remove standard no 4 from the analysis***.
3. For 10 MΩ, a new solution, without standard no 4, was calculated.
4. A vector of fit residuals can be obtained through
$$\boldsymbol{\chi} = \left(\chi_{p,a,m}\right) = \mathbf{R}\left(\mathbf{CX} - \mathbf{M}\right) \tag{6.26}$$
with $\mathbf{R}$ being the Cholesky factor of $\mathbf{U}^{-1}$, i.e. $\mathbf{R}^T\mathbf{R} = \mathbf{U}^{-1}$. For every measurement, the value of $\chi_{p,a,m}$ was checked. Measurement points with $\chi_{p,a,m} >> 1$ were removed from the analysis. These points are:
    - Participant no 11 (GUM), 1 GΩ, standard no 9 (MI 1100037). One result out of one removed for this standard ($\chi_{11,9,1} = -45$).
    - Participant no 14 (INETI), 1 GΩ, standard no 12 (MI 1100035). One result out of one removed for this standard ($\chi_{14,12,1} = -26$).
5. Participants with a unilateral DoE which is incompatible with zero on the 95% level, i.e. with $\left|d_p\right| > U_{doe}\left(d_p\right)$, were excluded from the constraint by setting the corresponding weight in (6.12) to zero, and the constrained optimization was then redone with these participants not contributing to the definition of the CRV. The optimization was then iteratively repeated until the largest consistent subset of the data determined the CRV.

The results of the least squares adjustment are given in Tables 11 and 12.

Impact of drift parameters and validation

The above described analysis consisted basically of two steps:

1. Determination of time drift of artefacts by fitting models (5.1) and (5.2) to the data of the pilot laboratory
2. Determination of artefact offset and laboratory bias by employing a constrained linear least square fit on the drift corrected data set

The fitting procedure of step 1 provided uncertainties for the drift parameters of the models (5.1) and (5.2). These uncertainties were determined by the uncertainties of the pilot data, but also by the agreement between data and model. In the analysis presented so far these uncertainties have not been included in step 2. It is principally possible to do this in an analytical way, but for a proper treatment correlation needs to be taken into account, which complicates matters. It has therefore been decided to do a numerical (Monte Carlo) simulation.

Starting point is the voltage and temperature corrected comparison data set. Two sets of random numbers are drawn, one multivariate with a covariance matrix **U** (6.14) reflecting uncertainties due to repeatability, temperature and voltage correction and transport effects, and one univariate with variances u_{s-p} (6.24) reflecting uncertainties due to bias. These random numbers are added to the comparison data set and step 1 and step 2 of the analysis are executed. The whole procedure is repeated $5 \cdot 10^4$ times resulting in a distribution of the DoEs which can be statistically analyzed to arrive at a mean value and an uncertainty of the DoEs. The mean values determined in this way agree within statistical accuracy with the values of the DoEs determined in the analytical procedure, whereas the uncertainties of the DoEs are slightly larger as one would expect. The increase however is insignificant and does not change the principal outcome of the analysis.

The agreement between numerical and analytical results can not be considered as a full validation of the procedure but it provides a certain degree of confidence that the results are correct.

The analysis of the fit residuals gives a good indication on the quality of the fit. As an example, the normalized residuals are shown for the 10 MΩ level, loop A, in Fig. 5. The residuals for the three standards are more or less randomly distributed. No systematic features as a function of time can be seen. This means that the time dependence determined by the pilot laboratory for the standards describe the real behaviour during transit reasonably well. A random distribution of the residuals, for all three standards and the same laboratory, indicates, that the lab bias does not depend on the artefact (which is an important assumption of the analysis).

The residuals for the other 10 MΩ loop and the two 1 GΩ loops look similar to Fig. 5.

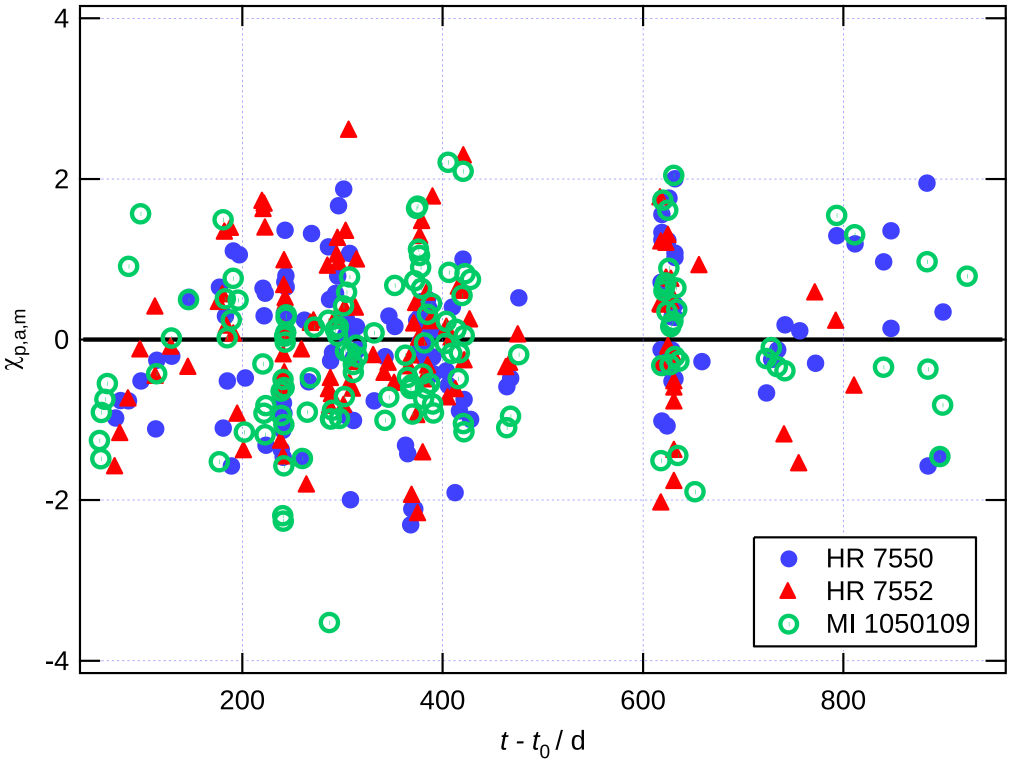


Figure 5: Normalized residuals for the constrained least-squares adjustment; 10 MΩ, loop A.

6.5 Unilateral and bilateral degrees of equivalence of the participating institutes

10 MΩ

p	Lab	w_p	$u_{fit}(d_p)$ (ppm)	d_p = DoE (ppm)	$U_{doe}(d_p)$ (ppm)	$\frac{\lvert d_p \rvert}{U\left(d_p\right)}$
1	METAS	0.3580	0.14	0.49	0.57	0.85
2	PTB	0.1982	0.28	-0.62	0.69	0.90
3	SIQ	0.0896	0.50	1.31	1.45	0.91
4	SMU	0.0026	1.01	6.89	8.59	0.80
5	VSL	0.0434	0.57	-0.50	2.16	0.23
6	VMT/PFI	0.1167	0.29	-0.81	1.13	0.71
7	MIKES	0.0545	0.37	-1.05	1.75	0.60
8	OMH	0.0187	0.57	0.13	3.29	0.04
9	CMI	0.0 *)	0.46	-0.44	7.03	0.06
10	INM	0.0 *)	1.62	8.57	6.72	1.27
12	NML	0.0010	0.46	-0.27	14.74	0.02
13	JV	0.0629	0.42	0.78	1.68	0.46
14	INETI	0.0004	7.71	-19.72	21.59	0.91
15	LNMC	0.0 *)	1.82	-3.68	6.47	0.57
16	NPL	0.0172	1.73	-1.36	3.48	0.39
17	SMD	0.0 **)	0.42	3.65	2.49	1.47
18	UME	0.0039	2.69	0.90	7.21	0.13
20	EIM	0.0010	4.95	-7.18	13.58	0.53
21	BEV	0.0126	0.51	-0.62	3.10	0.20
22	CEM	0.0 **)	0.42	2.33	1.14	2.05
23	VNIIM	0.0193	1.39	-1.07	3.20	0.33

Table 11: Results of the least squares adjustment for the **10 MΩ comparison.** The degree of equivalence DoE is the difference between a laboratory result and the comparison reference value. The uncertainty U_{doe} is the combined expanded uncertainty with a coverage factor of $k = 2$.

*) The weight is set to zero for these laboratories because they apply a 1:1 substitution method against a standard calibrated at another NMI participating in the comparison.

**) The weight is set to zero for these laboratories because the DoE is incompatible with zero.

1 GΩ

p	Lab	w_p	$u_{fit}(d_p)$ (ppm)	d_p = DoE (ppm)	$U_{doe}(d_p)$ (ppm)	$\frac{\lvert d_p \rvert}{U(d_p)}$
1	METAS	0.1055	0.60	-1.41	5.59	0.25
2	PTB	0.0573	2.93	-2.79	7.63	0.37
3	SIQ	0.0365	3.93	-9.30	10.38	0.90
4	SMU	0.0028	5.68	-26.97	37.32	0.72
5	VSL	0.2325	0.93	2.53	3.37	0.75
6	VMT/PFI	0.0735	1.23	-0.38	6.66	0.06
7	MIKES	0.0235	2.24	-0.41	9.77	0.04
8	OMH	0.0411	1.96	3.48	7.00	0.50
9	CMI	0.0 *)	2.20	8.08	30.22	0.27
10	INM	0.0 *)	2.52	-43.48	44.11	0.99
12	NML	0.0011	3.24	-1.53	61.97	0.02
13	JV	0.0225	1.66	1.51	13.07	0.12
14	INETI	0.0001	7.74	-31.98	208.44	0.15
16	NPL	0.0895	1.90	-0.05	4.17	0.01
17	SMD	0.0134	1.56	-1.26	17.67	0.07
18	UME	0.0091	2.31	0.02	10.68	0.00
19	LNE	0.0247	1.98	1.80	9.85	0.18
20	EIM	0.0099	4.12	1.02	16.91	0.06
21	BEV	0.0095	1.80	2.09	17.05	0.12
22	CEM	0.1816	1.13	0.01	4.26	0.00
23	VNIIM	0.0657	1.98	-0.85	5.62	0.15

Table 12: Results of the least squares adjustment for the **1 GΩ comparison.** The degree of equivalence DoE is the difference between a laboratory result and the comparison reference value. The uncertainty U_{doe} is the combined expanded uncertainty with a coverage factor of $k = 2$.

*) The weight is set to zero for these laboratories because they apply a 1:1 substitution method against a standard calibrated at another NMI participating in the comparison.

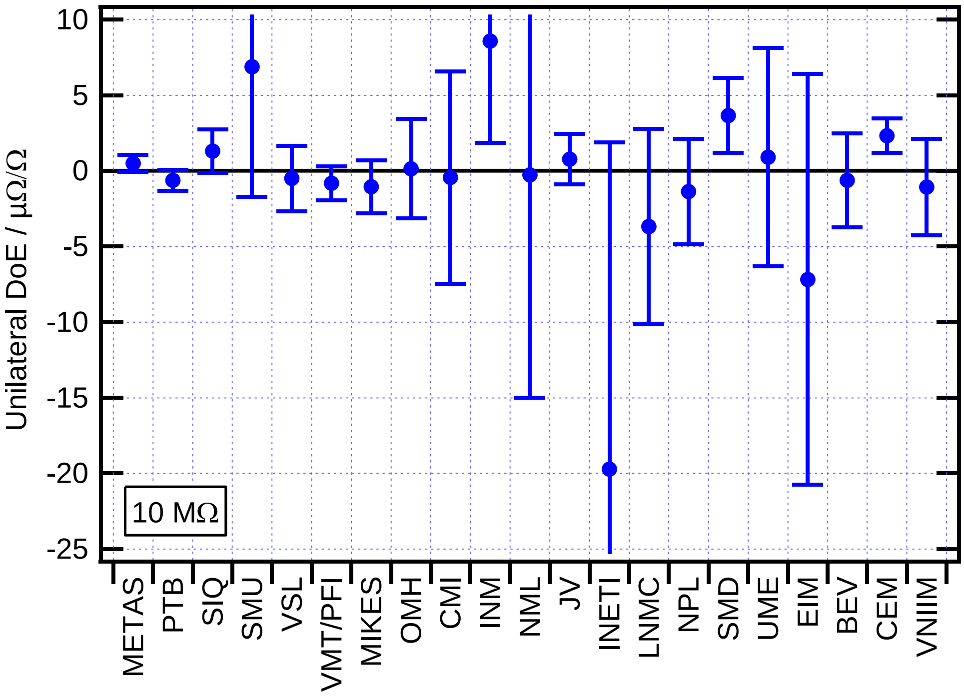


Figure 6: Unilateral degrees of equivalence with respect to the CRV at 10 MΩ.

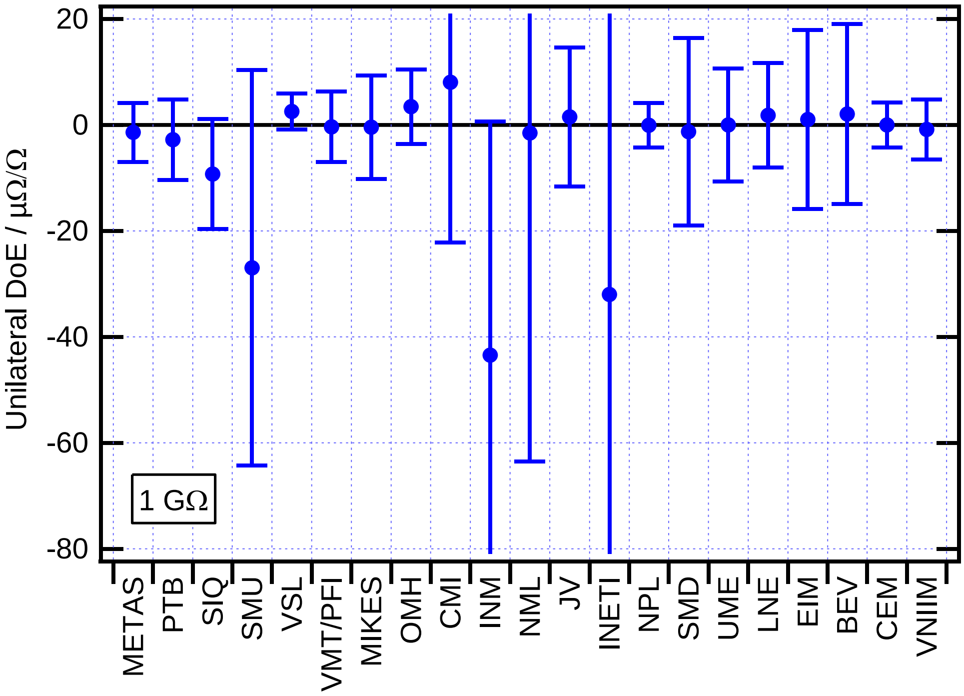


Figure 7: Unilateral degrees of equivalence with respect to the CRV at 1 GΩ.

Lab name	Lab num	1	2	3	4	5	6	7	8	9	10	12	13	14	15	16	17	18	20	21	22	23
METAS	1	-	1.11 (1.03)	-0.83 (1.70)	-6.40 (8.63)	0.99 (2.34)	1.30 (1.42)	1.53 (1.95)	0.35 (3.41)	0.93 (7.06)	-8.08 (6.75)	0.75 (14.76)	-0.29 (1.87)	20.21 (21.60)	4.17 (6.50)	1.84 (3.58)	-3.16 (2.55)	-0.41 (7.26)	7.67 (13.60)	1.11 (3.18)	-1.84 (1.26)	1.55 (3.31)
PTB	2	-1.11 (1.03)	-	-1.94 (1.67)	-7.51 (8.63)	-0.12 (2.32)	0.19 (1.39)	0.42 (1.93)	-0.76 (3.39)	-0.18 (7.05)	-9.19 (6.74)	-0.36 (14.77)	-1.40 (1.91)	19.09 (21.61)	3.06 (6.51)	0.73 (3.60)	-4.27 (2.58)	-1.53 (7.27)	6.56 (13.61)	-0.00 (3.20)	-2.95 (1.32)	0.44 (3.33)
SIQ	3	0.83 (1.70)	1.94 (1.67)	-	-5.57 (8.73)	1.82 (2.69)	2.12 (1.94)	2.36 (2.36)	1.18 (3.65)	1.76 (7.18)	-7.25 (6.88)	1.58 (14.83)	0.53 (2.34)	21.03 (21.65)	5.00 (6.65)	2.67 (3.85)	-2.33 (2.91)	0.41 (7.39)	8.49 (13.67)	1.94 (3.48)	-1.01 (1.89)	2.38 (3.60)
SMU	4	6.40 (8.63)	7.51 (8.63)	5.57 (8.73)	-	7.39 (8.88)	7.70 (8.68)	7.93 (8.78)	6.75 (9.22)	7.33 (11.10)	-1.68 (10.90)	7.15 (17.07)	6.11 (8.78)	26.61 (23.24)	10.57 (10.76)	8.24 (9.30)	3.24 (8.95)	5.99 (11.24)	14.07 (16.08)	7.51 (9.15)	4.56 (8.67)	7.95 (9.19)
VSL	5	-0.99 (2.34)	0.12 (2.32)	-1.82 (2.69)	-7.39 (8.88)	-	0.31 (2.52)	0.54 (2.85)	-0.63 (3.99)	-0.06 (7.36)	-9.07 (7.06)	-0.24 (14.92)	-1.28 (2.84)	19.22 (21.71)	3.18 (6.84)	0.85 (4.17)	-4.15 (3.32)	-1.40 (7.57)	6.68 (13.77)	0.12 (3.83)	-2.83 (2.48)	0.56 (3.94)
VMT/PFI	6	-1.30 (1.42)	-0.19 (1.39)	-2.12 (1.94)	-7.70 (8.68)	-0.31 (2.52)	-	0.24 (2.16)	-0.94 (3.53)	-0.37 (7.12)	-9.38 (6.81)	-0.54 (14.80)	-1.59 (2.14)	18.91 (21.63)	2.87 (6.58)	0.55 (3.73)	-4.46 (2.75)	-1.71 (7.33)	6.37 (13.64)	-0.19 (3.35)	-3.14 (1.64)	0.26 (3.47)
MIKES	7	-1.53 (1.95)	-0.42 (1.93)	-2.36 (2.36)	-7.93 (8.78)	-0.54 (2.85)	-0.24 (2.16)	-	-1.18 (3.78)	-0.60 (7.24)	-9.61 (6.94)	-0.78 (14.86)	-1.83 (2.53)	18.67 (21.67)	2.64 (6.71)	0.31 (3.97)	-4.69 (3.06)	-1.95 (7.45)	6.13 (13.71)	-0.42 (3.61)	-3.37 (2.12)	0.02 (3.72)
OMH	8	-0.35 (3.41)	0.76 (3.39)	-1.18 (3.65)	-6.75 (9.22)	0.63 (3.99)	0.94 (3.53)	1.18 (3.78)	-	0.57 (7.76)	-8.43 (7.48)	0.40 (15.12)	-0.65 (3.77)	19.85 (21.85)	3.82 (7.27)	1.49 (4.85)	-3.52 (4.14)	-0.77 (7.96)	7.31 (13.99)	0.76 (4.56)	-2.20 (3.50)	1.20 (4.65)
CMI	9	-0.93 (7.06)	0.18 (7.05)	-1.76 (7.18)	-7.33 (11.10)	0.06 (7.36)	0.37 (7.12)	0.60 (7.24)	-0.57 (7.76)	-	-9.01 (9.70)	-0.18 (16.33)	-1.22 (7.24)	19.28 (22.71)	3.24 (9.54)	0.91 (7.86)	-4.09 (7.44)	-1.34 (10.08)	6.74 (15.29)	0.18 (7.68)	-2.77 (7.10)	0.62 (7.74)
INM	10	8.08 (6.75)	9.19 (6.74)	7.25 (6.88)	1.68 (10.90)	9.07 (7.06)	9.38 (6.81)	9.61 (6.94)	8.43 (7.48)	9.01 (9.70)	-	8.83 (16.20)	7.79 (6.94)	28.29 (22.61)	12.25 (9.32)	9.92 (7.58)	4.92 (7.15)	7.66 (9.86)	15.74 (15.15)	9.19 (7.40)	6.24 (6.80)	9.63 (7.45)
NML	12	-0.75 (14.76)	0.36 (14.77)	-1.58 (14.83)	-7.15 (17.07)	0.24 (14.92)	0.54 (14.80)	0.78 (14.86)	-0.40 (15.12)	0.18 (16.33)	-8.83 (16.20)	-	-1.05 (14.84)	19.45 (26.14)	3.42 (16.09)	1.09 (15.15)	-3.91 (14.94)	-1.17 (16.41)	6.91 (20.04)	0.36 (15.06)	-2.59 (14.78)	0.80 (15.09)
JV	13	0.29 (1.87)	1.40 (1.91)	-0.53 (2.34)	-6.11 (8.78)	1.28 (2.84)	1.59 (2.14)	1.83 (2.53)	0.65 (3.77)	1.22 (7.24)	-7.79 (6.94)	1.05 (14.84)	-	20.50 (21.66)	4.46 (6.67)	2.14 (3.89)	-2.87 (2.97)	-0.12 (7.42)	7.96 (13.69)	1.40 (3.53)	-1.55 (1.98)	1.85 (3.64)
INETI	14	-20.21 (21.60)	-19.09 (21.61)	-21.03 (21.65)	-26.61 (23.24)	-19.22 (21.71)	-18.91 (21.63)	-18.67 (21.67)	-19.85 (21.85)	-19.28 (22.71)	-28.29 (22.61)	-19.45 (26.14)	-20.50 (21.66)	-	-16.04 (22.53)	-18.36 (21.87)	-23.37 (21.73)	-20.62 (22.76)	-12.54 (25.51)	-19.10 (21.81)	-22.05 (21.61)	-18.65 (21.83)
LNMC	15	-4.17 (6.50)	-3.06 (6.51)	-5.00 (6.65)	-10.57 (10.76)	-3.18 (6.84)	-2.87 (6.58)	-2.64 (6.71)	-3.82 (7.27)	-3.24 (9.54)	-12.25 (9.32)	-3.42 (16.09)	-4.46 (6.67)	16.04 (22.53)	-	-2.33 (7.34)	-7.33 (6.89)	-4.59 (9.68)	3.49 (15.03)	-3.06 (7.15)	-6.01 (6.53)	-2.62 (7.21)
NPL	16	-1.84 (3.58)	-0.73 (3.60)	-2.67 (3.85)	-8.24 (9.30)	-0.85 (4.17)	-0.55 (3.73)	-0.31 (3.97)	-1.49 (4.85)	-0.91 (7.86)	-9.92 (7.58)	-1.09 (15.15)	-2.14 (3.89)	18.36 (21.87)	2.33 (7.34)	-	-5.00 (4.26)	-2.26 (8.02)	5.82 (14.02)	-0.73 (4.67)	-3.68 (3.64)	-0.29 (4.76)
SMD	17	3.16 (2.55)	4.27 (2.58)	2.33 (2.91)	-3.24 (8.95)	4.15 (3.32)	4.46 (2.75)	4.69 (3.06)	3.52 (4.14)	4.09 (7.44)	-4.92 (7.15)	3.91 (14.94)	2.87 (2.97)	23.37 (21.73)	7.33 (6.89)	5.00 (4.26)	-	2.75 (7.62)	10.83 (13.80)	4.27 (3.93)	1.32 (2.63)	4.72 (4.03)
UME	18	0.41 (7.26)	1.53 (7.27)	-0.41 (7.39)	-5.99 (11.24)	1.40 (7.57)	1.71 (7.33)	1.95 (7.45)	0.77 (7.96)	1.34 (10.08)	-7.66 (9.86)	1.17 (16.41)	0.12 (7.42)	20.62 (22.76)	4.59 (9.68)	2.26 (8.02)	-2.75 (7.62)	-	8.08 (15.38)	1.53 (7.85)	-1.43 (7.29)	1.97 (7.90)
EIM	20	-7.67 (13.60)	-6.56 (13.61)	-8.49 (13.67)	-14.07 (16.08)	-6.68 (13.77)	-6.37 (13.64)	-6.13 (13.71)	-7.31 (13.99)	-6.74 (15.29)	-15.74 (15.15)	-6.91 (20.04)	-7.96 (13.69)	12.54 (25.51)	-3.49 (15.03)	-5.82 (14.02)	-10.83 (13.80)	-8.08 (15.38)	-	-6.56 (13.93)	-9.51 (13.62)	-6.11 (13.96)
BEV	21	-1.11 (3.18)	0.00 (3.20)	-1.94 (3.48)	-7.51 (9.15)	-0.12 (3.83)	0.19 (3.35)	0.42 (3.61)	-0.76 (4.56)	-0.18 (7.68)	-9.19 (7.40)	-0.36 (15.06)	-1.40 (3.53)	19.10 (21.81)	3.06 (7.15)	0.73 (4.67)	-4.27 (3.93)	-1.53 (7.85)	6.56 (13.93)	-	-2.95 (3.25)	0.44 (4.46)
CEM	22	1.84 (1.26)	2.95 (1.32)	1.01 (1.89)	-4.56 (8.67)	2.83 (2.48)	3.14 (1.64)	3.37 (2.12)	2.20 (3.50)	2.77 (7.10)	-6.24 (6.80)	2.59 (14.78)	1.55 (1.98)	22.05 (21.61)	6.01 (6.53)	3.68 (3.64)	-1.32 (2.63)	1.43 (7.29)	9.51 (13.62)	2.95 (3.25)	-	3.39 (3.37)
VNIIM	23	-1.55 (3.31)	-0.44 (3.33)	-2.38 (3.60)	-7.95 (9.19)	-0.56 (3.94)	-0.26 (3.47)	-0.02 (3.72)	-1.20 (4.65)	-0.62 (7.74)	-9.63 (7.45)	-0.80 (15.09)	-1.85 (3.64)	18.65 (21.83)	2.62 (7.21)	0.29 (4.76)	-4.72 (4.03)	-1.97 (7.90)	6.11 (13.96)	-0.44 (4.46)	-3.39 (3.37)	-

Table 13: Bilateral degrees of equivalence $d_{ij}^{(bi)}$ for the **10 MΩ comparison.** Expanded uncertainties (k=2) $U\left(d_{ij}^{(bi)}\right)$ are quoted in parenthesis.

Lab name	Lab num	1	2	3	4	5	6	7	8	9	10	12	13	14	16	17	18	19	20	21	22	23
METAS	1	-	1.38 (9.88)	7.88 (12.18)	25.56 (37.86)	-3.95 (7.09)	-1.03 (9.15)	-1.01 (11.51)	-4.89 (9.24)	-9.49 (30.75)	42.06 (44.48)	0.11 (62.30)	-2.92 (14.53)	30.56 (208.54)	-1.36 (7.25)	-0.16 (18.79)	-1.43 (12.18)	-3.21 (11.59)	-2.44 (18.00)	-3.51 (18.13)	-1.43 (7.65)	-0.56 (8.25)
PTB	2	-1.38 (9.88)	-	6.50 (13.16)	24.18 (38.19)	-5.33 (8.67)	-2.41 (10.43)	-2.39 (12.56)	-6.27 (10.52)	-10.87 (31.16)	40.68 (44.76)	-1.26 (62.52)	-4.30 (15.46)	29.18 (208.60)	-2.74 (8.98)	-1.53 (19.52)	-2.81 (13.29)	-4.59 (12.74)	-3.82 (18.76)	-4.89 (18.89)	-2.81 (9.30)	-1.94 (9.80)
SIQ	3	-7.88 (12.18)	-6.50 (13.16)	-	17.67 (38.84)	-11.83 (11.22)	-8.92 (12.63)	-8.89 (14.43)	-12.77 (12.70)	-17.38 (31.96)	34.18 (45.32)	-7.77 (62.93)	-10.81 (17.02)	22.68 (208.72)	-9.25 (11.46)	-8.04 (20.78)	-9.32 (15.07)	-11.10 (14.59)	-10.32 (20.07)	-11.39 (20.18)	-9.31 (11.71)	-8.45 (12.12)
SMU	4	-25.56 (37.86)	-24.18 (38.19)	-17.67 (38.84)	-	-29.51 (37.56)	-26.59 (38.01)	-26.57 (38.64)	-30.45 (38.03)	-35.05 (48.03)	16.50 (57.78)	-25.44 (72.42)	-28.48 (39.68)	5.00 (211.78)	-26.92 (37.63)	-25.71 (41.43)	-26.99 (38.89)	-28.77 (38.70)	-28.00 (41.08)	-29.07 (41.14)	-26.98 (37.71)	-26.12 (37.84)
VSL	5	3.95 (7.09)	5.33 (8.67)	11.83 (11.22)	29.51 (37.56)	-	2.91 (7.84)	2.94 (10.50)	-0.94 (7.95)	-5.55 (30.39)	46.01 (44.23)	4.06 (62.14)	1.02 (13.84)	34.51 (208.50)	2.58 (5.77)	3.79 (18.26)	2.52 (11.36)	0.74 (10.72)	1.51 (17.46)	0.44 (17.59)	2.52 (6.25)	3.39 (6.98)
VMT/PFI	6	1.03 (9.15)	2.41 (10.43)	8.92 (12.63)	26.59 (38.01)	-2.91 (7.84)	-	0.03 (11.98)	-3.86 (9.82)	-8.46 (30.93)	43.10 (44.61)	1.15 (62.41)	-1.89 (15.01)	31.60 (208.58)	-0.33 (8.17)	0.88 (19.16)	-0.40 (12.75)	-2.18 (12.18)	-1.40 (18.39)	-2.47 (18.51)	-0.39 (8.52)	0.47 (9.07)
MIKES	7	1.01 (11.51)	2.39 (12.56)	8.89 (14.43)	26.57 (38.64)	-2.94 (10.50)	-0.03 (11.98)	-	-3.88 (12.04)	-8.49 (31.70)	43.07 (45.15)	1.12 (62.80)	-1.92 (16.55)	31.57 (208.68)	-0.36 (10.75)	0.85 (20.39)	-0.43 (14.54)	-2.20 (14.04)	-1.43 (19.67)	-2.50 (19.78)	-0.42 (11.01)	0.45 (11.44)
OMH	8	4.89 (9.24)	6.27 (10.52)	12.77 (12.70)	30.45 (38.03)	0.94 (7.95)	3.86 (9.82)	3.88 (12.04)	-	-4.60 (30.95)	46.95 (44.63)	5.01 (62.43)	1.97 (15.06)	35.45 (208.58)	3.53 (8.27)	4.74 (19.20)	3.46 (12.81)	1.68 (12.25)	2.45 (18.43)	1.38 (18.56)	3.46 (8.62)	4.33 (9.16)
CMI	9	9.49 (30.75)	10.87 (31.16)	17.38 (31.96)	35.05 (48.03)	5.55 (30.39)	8.46 (30.93)	8.49 (31.70)	4.60 (30.95)	-	51.56 (53.40)	9.61 (68.97)	6.57 (32.97)	40.06 (210.62)	8.13 (30.47)	9.34 (35.06)	8.06 (32.01)	6.28 (31.78)	7.06 (34.64)	5.99 (34.71)	8.07 (30.57)	8.93 (30.73)
INM	10	-42.06 (44.48)	-40.68 (44.76)	-34.18 (45.32)	-16.50 (57.78)	-46.01 (44.23)	-43.10 (44.61)	-43.07 (45.15)	-46.95 (44.63)	-51.56 (53.40)	-	-41.95 (76.09)	-44.99 (46.04)	-11.50 (213.06)	-43.43 (44.29)	-42.22 (47.56)	-43.49 (45.36)	-45.27 (45.20)	-44.50 (47.25)	-45.57 (47.30)	-43.49 (44.36)	-42.62 (44.46)
NML	12	-0.11 (62.30)	1.26 (62.52)	7.77 (62.93)	25.44 (72.42)	-4.06 (62.14)	-1.15 (62.41)	-1.12 (62.80)	-5.01 (62.43)	-9.61 (68.97)	41.95 (76.09)	-	-3.04 (63.40)	30.45 (217.48)	-1.48 (62.14)	-0.27 (64.51)	-1.55 (62.91)	-3.33 (62.79)	-2.55 (64.28)	-3.62 (64.32)	-1.54 (62.18)	-0.68 (62.26)
JV	13	2.92 (14.53)	4.30 (15.46)	10.81 (17.02)	28.48 (39.68)	-1.02 (13.84)	1.89 (15.01)	1.92 (16.55)	-1.97 (15.06)	-6.57 (32.97)	44.99 (46.04)	3.04 (63.40)	-	33.49 (208.88)	1.56 (13.82)	2.77 (22.17)	1.49 (16.93)	-0.29 (16.51)	0.49 (21.51)	-0.58 (21.61)	1.50 (14.03)	2.36 (14.37)
INETI	14	-30.56 (208.54)	-29.18 (208.60)	-22.68 (208.72)	-5.00 (211.78)	-34.51 (208.50)	-31.60 (208.58)	-31.57 (208.68)	-35.45 (208.58)	-40.06 (210.62)	11.50 (213.06)	-30.45 (217.48)	-33.49 (208.88)	-	-31.93 (208.48)	-30.72 (209.20)	-32.00 (208.72)	-33.77 (208.68)	-33.00 (209.14)	-34.07 (209.16)	-31.99 (208.50)	-31.12 (208.52)
NPL	16	1.36 (7.25)	2.74 (8.98)	9.25 (11.46)	26.92 (37.63)	-2.58 (5.77)	0.33 (8.17)	0.36 (10.75)	-3.53 (8.27)	-8.13 (30.47)	43.43 (44.29)	1.48 (62.14)	-1.56 (13.82)	31.93 (208.48)	-	1.21 (18.25)	-0.07 (11.33)	-1.85 (10.69)	-1.07 (17.44)	-2.14 (17.57)	-0.06 (6.20)	0.80 (6.93)
SMD	17	0.16 (18.79)	1.53 (19.52)	8.04 (20.78)	25.71 (41.43)	-3.79 (18.26)	-0.88 (19.16)	-0.85 (20.39)	-4.74 (19.20)	-9.34 (35.06)	42.22 (47.56)	0.27 (64.51)	-2.77 (22.17)	30.72 (209.20)	-1.21 (18.25)	-	-1.28 (20.72)	-3.06 (20.37)	-2.28 (24.58)	-3.35 (24.69)	-1.27 (18.40)	-0.41 (18.67)
UME	18	1.43 (12.18)	2.81 (13.29)	9.32 (15.07)	26.99 (38.89)	-2.52 (11.36)	0.40 (12.75)	0.43 (14.54)	-3.46 (12.81)	-8.06 (32.01)	43.49 (45.36)	1.55 (62.91)	-1.49 (16.93)	32.00 (208.72)	0.07 (11.33)	1.28 (20.72)	-	-1.78 (14.46)	-1.00 (20.01)	-2.08 (20.08)	0.01 (11.61)	0.87 (12.00)
LNE	19	3.21 (11.59)	4.59 (12.74)	11.10 (14.59)	28.77 (38.70)	-0.74 (10.72)	2.18 (12.18)	2.20 (14.04)	-1.68 (12.25)	-6.28 (31.78)	45.27 (45.20)	3.33 (62.79)	0.29 (16.51)	33.77 (208.68)	1.85 (10.69)	3.06 (20.37)	1.78 (14.46)	-	0.78 (19.65)	-0.30 (19.73)	1.79 (10.97)	2.65 (11.39)
EIM	20	2.44 (18.00)	3.82 (18.76)	10.32 (20.07)	28.00 (41.08)	-1.51 (17.46)	1.40 (18.39)	1.43 (19.67)	-2.45 (18.43)	-7.06 (34.64)	44.50 (47.25)	2.55 (64.28)	-0.49 (21.51)	33.00 (209.14)	1.07 (17.44)	2.28 (24.58)	1.00 (20.01)	-0.78 (19.65)	-	-1.07 (24.09)	1.01 (17.60)	1.88 (17.88)
BEV	21	3.51 (18.13)	4.89 (18.89)	11.39 (20.18)	29.07 (41.14)	-0.44 (17.59)	2.47 (18.51)	2.50 (19.78)	-1.38 (18.56)	-5.99 (34.71)	45.57 (47.30)	3.62 (64.32)	0.58 (21.61)	34.07 (209.16)	2.14 (17.57)	3.35 (24.69)	2.08 (20.08)	0.30 (19.73)	1.07 (24.09)	-	2.08 (17.74)	2.95 (18.00)
CEM	22	1.43 (7.65)	2.81 (9.30)	9.31 (11.71)	26.98 (37.71)	-2.52 (6.25)	0.39 (8.52)	0.42 (11.01)	-3.46 (8.62)	-8.07 (30.57)	43.49 (44.36)	1.54 (62.18)	-1.50 (14.03)	31.99 (208.50)	0.06 (6.20)	1.27 (18.40)	-0.01 (11.61)	-1.79 (10.97)	-1.01 (17.60)	-2.08 (17.74)	-	0.86 (7.34)
VNIIM	23	0.56 (8.25)	1.94 (9.80)	8.45 (12.12)	26.12 (37.84)	-3.39 (6.98)	-0.47 (9.07)	-0.45 (11.44)	-4.33 (9.16)	-8.93 (30.73)	42.62 (44.46)	0.68 (62.26)	-2.36 (14.37)	31.12 (208.52)	-0.80 (6.93)	0.41 (18.67)	-0.87 (12.00)	-2.65 (11.39)	-1.88 (17.88)	-2.95 (18.00)	-0.86 (7.34)	-

Table 14: Bilateral degrees of equivalence $d_{ij}^{(bi)}$ for the **1 GΩ comparison.** Expanded uncertainties (k=2) $U\left(d_{ij}^{(bi)}\right)$ are quoted in parenthesis.

6.6 Linking the results of EURAMET.EM-K2 with CCEM-K2 and degrees of equivalence

The purpose of the linking is to determine corrected unilateral and bilateral degrees of equivalence (DoE) for the laboratories that participated exclusively in the RMO comparison. The corrected values should represent best estimates of what would have been the results of the laboratories had they actually participated in the CCEM comparison.

It is assumed that a linking laboratory performed similarly in the CCEM and in the RMO comparison. The difference between its unilateral DoE d_i in the CCEM and RMO comparison can thus be taken as the correction Δ_i which needs to be applied to the RMO values.

$$\Delta_i = d_i^{CCEM} - d_i^{RMO}$$

with i indicating the linking laboratory. For more than one linking laboratory it is reasonable to determine a weighted average of all linking labs as the overall correction Δ

$$\Delta = \sum_{i\in L} w_i \Delta_i \; ; \quad w_i = \left(\frac{1}{\sum_{i\in L} u^2\left(\Delta_i\right)} \right)^{-1} \frac{1}{u^2\left(\Delta_i\right)}$$

with

$$u^2\left(\Delta_i\right) = u^2\left(d_i^{CCEM}\right) + u^2\left(d_i^{RMO}\right)$$

and

$$u^2\left(\Delta\right) = \left(\sum_{i\in L} \frac{1}{u^2\left(\Delta_i\right)} \right)^{-1}$$

$i \in L$ denotes that the sum is over the linking laboratory only.

The correction to the DoEs of those who participated exclusively in the RMO comparison can then be written as

$$d_i^{CCEM} = d_i^{RMO} + \Delta$$

with uncertainties

$$u^2\left(d_i^{CCEM}\right) = u^2\left(d_i^{RMO}\right) + u^2\left(\Delta\right)$$

i indicates the laboratories that participated in the RMO comparison only, whereas the linking laboratories will simply keep the DoEs determined in the CCEM comparison.

For the bilateral DoEs d_{ij} one can use

$$d_{ij}^{CCEM} = d_i^{CCEM} - d_j^{CCEM}$$

with uncertainties

$$u^2\left(d_{ij}^{CCEM}\right) = u^2\left(d_i^{CCEM}\right) + u^2\left(d_j^{CCEM}\right)$$

The bilateral DoEs d_{ij}^{CCEM} are only calculated between laboratories that participated in the RMO comparison and those which participated not in the RMO comparison, i.e. the bilateral DoEs determined within the RMO comparison are used unaltered as the CCEM values.

The above procedure leaves all existing unilateral and bilateral DoEs in the CCEM tables untouched and just adds entries for the laboratories which participated exclusively in the RMO comparison.

The uncertainties in the above procedure are calculated without taking correlations into account. It should however be noted that taking correlation into account would require to dive into the details of both analysis, CCEM and RMO. An effort which can hardly be justified considering that a substantial amount of time has passed between the CCEM and the RMO comparison. Many laboratories have improved and changed their measurement setup in between. As a consequence the uncertainties in the RMO comparison are significantly smaller than those in the CCEM comparison. The linking procedure itself is therefore questionable. This has been recognized and another CCEM comparison is planned, which will be used to link the results of the RMO comparison to. The linking results here should therefore be considered as provisional.

p	Lab	**10 MΩ**				**1 GΩ**			
		CCEM		EURAMET		CCEM		EURAMET	
		d_i	U_i	d_i	U_i	d_i	U_i	d_i	U_i
1	METAS	0.7	2.1	0.49	0.57	2.9	22.8	-1.41	5.59
2	PTB	0.0	5.0	-0.62	0.69	3.3	13.0	-2.79	7.63
5	VSL	0.6	6.4	-0.50	2.16	-32.3	36.3	2.53	3.37
16	NPL	-0.3	2.3	-1.36	3.48	-7.2	11.0	-0.05	4.17
19	LNE					-1.3	18.0	1.80	9.85
23	VNIIM	-0.1	2.8	-1.07	3.20	0.0	7.3	-0.85	5.62

Table 15: Unilateral degrees of equivalence of the linking labs with respect to the CRV and the KCRV

Results

Performing the analysis above, the following correction factors Δ are determined:

10 MΩ: Δ = (0.54 ± 0.81) μΩ/Ω
1 GΩ: Δ = (-1.43 ± 2.97) μΩ/Ω

Table 16a: 10 MΩ : Degree of equivalence with respect to the KCRV and pairwise degree of equivalence

Lab j →

Lab i ⇩			NIST		NRC		LNE		NPL		PTB		NMIA		MSL		NMISA		SP		METAS		INRIM	
	d_i	U_i	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}
NIST	-0.3	2.9			0.8	6.5	-0.3	3.8	-0.1	3.9	-0.4	5.9	-0.1	6.3	0.1	3.8	15.0	79.0	-0.9	5.1	-1.0	3.8	-1.3	6.3
NRC	-1.2	5.7	-0.8	6.5			-1.2	6.0	-0.9	6.1	-1.2	7.5	-0.9	7.8	-0.8	6.0	15.0	79.0	-1.8	6.9	-1.9	6.0	-2.1	7.8
LNE	0.0	2.1	0.3	3.8	1.2	6.0			0.3	3.1	0.0	5.4	0.3	5.8	0.4	2.9	16.0	79.0	-0.6	4.5	-0.7	2.9	-1.0	5.8
NPL	-0.3	2.3	0.1	3.9	0.9	6.1	-0.3	3.1			-0.3	5.5	0.0	5.9	0.1	3.1	15.0	79.0	-0.9	4.6	-1.0	3.1	-1.2	5.9
PTB	0.0	5.0	0.4	5.9	1.2	7.5	0.0	5.4	0.3	5.5			0.3	7.3	0.4	5.4	16.0	79.0	-0.6	6.4	-0.6	5.4	-0.9	7.4
NML	-0.3	5.4	0.1	6.3	0.9	7.8	-0.3	5.8	0.0	5.9	-0.3	7.3			0.1	5.8	15.0	79.0	-0.9	6.7	-0.9	5.8	-1.2	7.7
MSL	-0.4	2.1	-0.1	3.8	0.8	6.0	-0.4	2.9	-0.1	3.1	-0.4	5.4	-0.1	5.8			15.0	79.0	-1.0	4.5	-1.1	3.1	-1.4	5.9
CSIR-NML	-16.0	79.0	-15.0	79.0	-15.0	79.0	-16.0	79.0	-15.0	79.0	-16.0	79.0	-15.0	79.0	-15.0	79.0			-16.0	79.0	-16.0	79.0	-17.0	79.0
SP	0.6	4.0	0.9	5.1	1.8	6.9	0.6	4.5	0.9	4.6	0.6	6.4	0.9	6.7	1.0	4.5	16.0	79.0			-0.1	4.6	-0.4	6.8
METAS	0.7	2.1	1.0	3.8	1.9	6.0	0.7	2.9	1.0	3.1	0.6	5.4	0.9	5.8	1.1	3.1	16.0	79.0	0.1	4.6			-0.3	5.9
INRIM	0.9	5.5	1.3	6.3	2.1	7.8	1.0	5.8	1.2	5.9	0.9	7.4	1.2	7.7	1.4	5.9	17.0	79.0	0.4	6.8	0.3	5.9		
VSL	0.6	6.4	0.9	7.2	1.8	8.5	0.6	6.7	0.9	6.8	0.5	8.1	0.8	8.4	1.0	6.8	16.0	79.0	0.0	7.6	-0.1	6.8	-0.4	8.5
KRISS	-2.3	6.3	-2.0	7.0	-1.2	8.3	-2.3	6.5	-2.1	6.6	-2.4	7.9	-2.1	8.3	-1.9	6.6	13.0	79.0	-2.9	7.4	-3.0	6.6	-3.3	8.3
NIM	0.6	2.5	0.9	4.0	1.8	5.9	0.6	2.8	0.9	3.1	0.6	5.4	0.9	5.8	1.0	3.1	16.0	79.0	0.0	4.6	-0.1	3.2	-0.3	6.0
VNIIM	-0.1	2.8	0.3	4.2	1.1	6.0	0.0	3.1	0.2	3.3	-0.1	5.5	0.2	6.0	0.4	3.3	16.0	79.0	-0.6	4.8	-0.7	3.4	-1.0	6.1
SIQ	1.8	2.2	2.1	3.6	3.0	6.1	1.8	3.0	2.1	2.9	1.8	5.0	2.1	5.8	2.2	3.0	17.8	79.0	1.2	4.5	1.1	2.1	0.9	5.9
SMU	7.4	8.7	7.7	9.2	8.6	10.4	7.4	9.0	7.7	8.9	7.4	9.8	7.7	10.3	7.8	9.0	23.4	79.5	6.8	9.6	6.7	8.7	6.5	10.3
VMT/PFI	-0.3	2.0	0.0	3.5	0.9	6.0	-0.3	2.9	0.0	2.8	-0.3	4.9	0.0	5.7	0.1	2.9	15.7	79.0	-0.9	4.5	-1.0	1.9	-1.2	5.8
MIKES	-0.5	2.4	-0.2	3.8	0.7	6.2	-0.5	3.2	-0.2	3.1	-0.5	5.1	-0.2	5.9	-0.1	3.2	15.5	79.0	-1.1	4.7	-1.2	2.3	-1.4	6.0
OMH	0.7	3.7	1.0	4.7	1.9	6.8	0.7	4.2	1.0	4.1	0.7	5.8	1.0	6.5	1.1	4.2	16.7	79.1	0.1	5.4	0.0	3.6	-0.2	6.6
CMI	0.1	7.2	0.4	7.8	1.3	9.2	0.1	7.5	0.4	7.5	0.1	8.5	0.4	9.0	0.5	7.5	16.1	79.3	-0.5	8.2	-0.6	7.2	-0.8	9.1
INM	9.1	6.9	9.4	7.5	10.3	9.0	9.1	7.2	9.4	7.2	9.1	8.2	9.4	8.8	9.5	7.2	25.1	79.3	8.5	8.0	8.4	6.9	8.2	8.8
NML	0.3	14.8	0.6	15.1	1.5	15.9	0.3	15.0	0.6	15.0	0.3	15.5	0.6	15.8	0.7	15.0	16.3	80.4	-0.3	15.4	-0.4	14.8	-0.6	15.8
JV	1.3	2.3	1.6	3.7	2.5	6.2	1.3	3.1	1.6	3.0	1.3	5.0	1.6	5.9	1.7	3.1	17.3	79.0	0.7	4.6	0.6	2.2	0.4	6.0
INETI	-19.2	21.6	-18.9	21.8	-18.0	22.4	-19.2	21.7	-18.9	21.7	-19.2	22.1	-18.9	22.3	-18.8	21.7	-3.2	81.9	-19.8	22.0	-19.9	21.6	-20.1	22.3
LNMC	-3.1	6.7	-2.8	7.3	-1.9	8.8	-3.1	7.0	-2.8	6.9	-3.1	8.0	-2.8	8.6	-2.7	7.0	12.9	79.3	-3.7	7.8	-3.8	6.6	-4.0	8.7
SMD	4.2	3.0	4.5	4.2	5.4	6.4	4.2	3.6	4.5	3.5	4.2	5.4	4.5	6.2	4.6	3.6	20.2	79.1	3.6	5.0	3.5	2.9	3.3	6.3
UME	1.4	7.4	1.7	7.9	2.6	9.3	1.4	7.7	1.7	7.6	1.4	8.6	1.7	9.1	1.8	7.7	17.4	79.3	0.8	8.4	0.7	7.3	0.5	9.2
EIM	-6.6	13.7	-6.3	14.0	-5.4	14.8	-6.6	13.8	-6.3	13.8	-6.6	14.4	-6.3	14.7	-6.2	13.8	9.4	80.2	-7.2	14.2	-7.3	13.7	-7.5	14.7
BEV	-0.1	3.5	0.2	4.5	1.1	6.7	-0.1	4.1	0.2	4.0	-0.1	5.7	0.2	6.4	0.3	4.1	15.9	79.1	-0.7	5.3	-0.8	3.4	-1.0	6.5
CEM	2.9	2.0	3.2	3.5	4.1	6.0	2.9	2.9	3.2	2.8	2.9	4.9	3.2	5.7	3.3	2.9	18.9	79.0	2.3	4.5	2.2	1.9	2.0	5.8

Table 16b: 10 MΩ : Degree of equivalence with respect to the KCRV and pairwise degree of equivalence

Lab j →

Lab i ⇩			VSL		KRISS		NIM		VNIIM		SIQ		SMU		VMT/PFI		MIKES		OMH		CMI		INM	
	d_i	U_i	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}
NIST	-0.3	2.9	-0.9	7.2	2.0	7.0	-0.9	4.0	-0.3	4.2	-2.1	3.6	-7.7	9.2	0.0	3.5	0.2	3.8	-1.0	4.7	-0.4	7.8	-9.4	7.5
NRC	-1.2	5.7	-1.8	8.5	1.2	8.3	-1.8	5.9	-1.1	6.0	-3.0	6.1	-8.6	10.4	-0.9	6.0	-0.7	6.2	-1.9	6.8	-1.3	9.2	-10.3	9.0
LNE	0.0	2.1	-0.6	6.7	2.3	6.5	-0.6	2.8	0.0	3.1	-1.8	3.0	-7.4	9.0	0.3	2.9	0.5	3.2	-0.7	4.2	-0.1	7.5	-9.1	7.2
NPL	-0.3	2.3	-0.9	6.8	2.1	6.6	-0.9	3.1	-0.2	3.3	-2.1	2.9	-7.7	8.9	0.0	2.8	0.2	3.1	-1.0	4.1	-0.4	7.5	-9.4	7.2
PTB	0.0	5.0	-0.5	8.1	2.4	7.9	-0.6	5.4	0.1	5.5	-1.8	5.0	-7.4	9.8	0.3	4.9	0.5	5.1	-0.7	5.8	-0.1	8.5	-9.1	8.2
NMIA	-0.3	5.4	-0.8	8.4	2.1	8.3	-0.9	5.8	-0.2	6.0	-2.1	5.8	-7.7	10.3	0.0	5.7	0.2	5.9	-1.0	6.5	-0.4	9.0	-9.4	8.8
MSL	-0.4	2.1	-1.0	6.8	1.9	6.6	-1.0	3.1	-0.4	3.3	-2.2	3.0	-7.8	9.0	-0.1	2.9	0.1	3.2	-1.1	4.2	-0.5	7.5	-9.5	7.2
NMISA	-16.0	79.0	-16.0	79.0	-13.0	79.0	-16.0	79.0	-16.0	79.0	-17.8	79.0	-23.4	79.5	-15.7	79.0	-15.5	79.0	-16.7	79.1	-16.1	79.3	-25.1	79.3
SP	0.6	4.0	0.0	7.6	2.9	7.4	0.0	4.6	0.6	4.8	-1.2	4.5	-6.8	9.6	0.9	4.5	1.1	4.7	-0.1	5.4	0.5	8.2	-8.5	8.0
METAS	0.7	2.1	0.1	6.8	3.0	6.6	0.1	3.2	0.7	3.4	-1.1	2.1	-6.7	8.7	1.0	1.9	1.2	2.3	0.0	3.6	0.6	7.2	-8.4	6.9
INRIM	0.9	5.5	0.4	8.5	3.3	8.3	0.3	6.0	1.0	6.1	-0.9	5.9	-6.5	10.3	1.2	5.8	1.4	6.0	0.2	6.6	0.8	9.1	-8.2	8.8
VSL	0.6	6.4			2.9	9.0	0.0	6.9	0.6	7.0	-1.2	6.4	-6.8	10.6	0.9	6.3	1.1	6.5	-0.1	7.0	0.5	9.4	-8.5	9.2
KRISS	-2.3	6.3	-2.9	9.0			-2.9	6.7	-2.3	6.8	-4.1	6.7	-9.7	10.8	-2.0	6.6	-1.8	6.7	-3.0	7.3	-2.4	9.6	-11.4	9.4
NIM	0.6	2.5	0.0	6.9	2.9	6.7			0.7	3.7	-1.2	3.3	-6.8	9.1	0.9	3.2	1.1	3.5	-0.1	4.4	0.5	7.6	-8.5	7.3
VNIIM	-0.1	2.8	-0.6	7.0	2.3	6.8	-0.7	3.7			-1.9	3.2	-7.5	9.0	0.2	3.1	0.4	3.4	-0.8	4.4	-0.2	7.6	-9.2	7.3
SIQ	1.8	2.2	1.2	6.4	4.1	6.7	1.2	3.3	1.9	3.2			-5.6	8.7	2.1	1.9	2.4	2.4	1.2	3.7	1.8	7.2	-7.3	6.9
SMU	7.4	8.7	6.8	10.6	9.7	10.8	6.8	9.1	7.5	9.0	5.6	8.7			7.7	8.7	7.9	8.8	6.8	9.2	7.3	11.1	-1.7	10.9
VMT/PFI	-0.3	2.0	-0.9	6.3	2.0	6.6	-0.9	3.2	-0.2	3.1	-2.1	1.9	-7.7	8.7			0.2	2.2	-0.9	3.5	-0.4	7.1	-9.4	6.8
MIKES	-0.5	2.4	-1.1	6.5	1.8	6.7	-1.1	3.5	-0.4	3.4	-2.4	2.4	-7.9	8.8	-0.2	2.2			-1.2	3.8	-0.6	7.2	-9.6	6.9
OMH	0.7	3.7	0.1	7.0	3.0	7.3	0.1	4.4	0.8	4.4	-1.2	3.7	-6.8	9.2	0.9	3.5	1.2	3.8			0.6	7.8	-8.4	7.5
CMI	0.1	7.2	-0.5	9.4	2.4	9.6	-0.5	7.6	0.2	7.6	-1.8	7.2	-7.3	11.1	0.4	7.1	0.6	7.2	-0.6	7.8			-9.0	9.7
INM	9.1	6.9	8.5	9.2	11.4	9.4	8.5	7.3	9.2	7.3	7.3	6.9	1.7	10.9	9.4	6.8	9.6	6.9	8.4	7.5	9.0	9.7		
NML	0.3	14.8	-0.3	16.0	2.6	16.1	-0.3	15.0	0.4	15.0	-1.6	14.8	-7.2	17.1	0.5	14.8	0.8	14.9	-0.4	15.1	0.2	16.3	-8.8	16.2
JV	1.3	2.3	0.7	6.5	3.6	6.7	0.7	3.4	1.4	3.3	-0.5	2.3	-6.1	8.8	1.6	2.1	1.8	2.5	0.6	3.8	1.2	7.2	-7.8	6.9
INETI	-19.2	21.6	-19.8	22.5	-16.9	22.5	-19.8	21.8	-19.1	21.8	-21.0	21.6	-26.6	23.2	-18.9	21.6	-18.7	21.7	-19.9	21.9	-19.3	22.7	-28.3	22.6
LNMC	-3.1	6.7	-3.7	9.0	-0.8	9.2	-3.7	7.1	-3.0	7.1	-5.0	6.6	-10.6	10.8	-2.9	6.6	-2.6	6.7	-3.8	7.3	-3.2	9.5	-12.3	9.3
SMD	4.2	3.0	3.6	6.7	6.5	7.0	3.6	3.9	4.3	3.8	2.3	2.9	-3.2	8.9	4.5	2.8	4.7	3.1	3.5	4.1	4.1	7.4	-4.9	7.1
UME	1.4	7.4	0.8	9.5	3.7	9.7	0.8	7.8	1.5	7.7	-0.4	7.4	-6.0	11.2	1.7	7.3	1.9	7.5	0.8	8.0	1.3	10.1	-7.7	9.9
EIM	-6.6	13.7	-7.2	14.9	-4.3	15.1	-7.2	13.9	-6.5	13.9	-8.5	13.7	-14.1	16.1	-6.4	13.6	-6.1	13.7	-7.3	14.0	-6.7	15.3	-15.7	15.2
BEV	-0.1	3.5	-0.7	7.0	2.2	7.2	-0.7	4.3	0.0	4.2	-1.9	3.5	-7.5	9.1	0.2	3.3	0.4	3.6	-0.8	4.6	-0.2	7.7	-9.2	7.4
CEM	2.9	2.0	2.3	6.3	5.2	6.6	2.3	3.2	3.0	3.1	1.0	1.9	-4.6	8.7	3.1	1.6	3.4	2.1	2.2	3.5	2.8	7.1	-6.2	6.8

Table 16c: 10 MΩ : Degree of equivalence with respect to the KCRV and pairwise degree of equivalence

Lab j →

Lab i ⇩			NML		JV		INETI		LNMC		SMD		UME		EIM		BEV		CEM	
	d_i	U_i	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	Ui_j	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}
NIST	-0.3	2.9	-0.6	15.1	-1.6	3.7	18.9	21.8	2.8	7.3	-4.5	4.2	-1.7	7.9	6.3	14.0	-0.2	4.5	-3.2	3.5
NRC	-1.2	5.7	-1.5	15.9	-2.5	6.2	18.0	22.4	1.9	8.8	-5.4	6.4	-2.6	9.3	5.4	14.8	-1.1	6.7	-4.1	6.0
LNE	0.0	2.1	-0.3	15.0	-1.3	3.1	19.2	21.7	3.1	7.0	-4.2	3.6	-1.4	7.7	6.6	13.8	0.1	4.1	-2.9	2.9
NPL	-0.3	2.3	-0.6	15.0	-1.6	3.0	18.9	21.7	2.8	6.9	-4.5	3.5	-1.7	7.6	6.3	13.8	-0.2	4.0	-3.2	2.8
PTB	0.0	5.0	-0.3	15.5	-1.3	5.0	19.2	22.1	3.1	8.0	-4.2	5.4	-1.4	8.6	6.6	14.4	0.1	5.7	-2.9	4.9
NMIA	-0.3	5.4	-0.6	15.8	-1.6	5.9	18.9	22.3	2.8	8.6	-4.5	6.2	-1.7	9.1	6.3	14.7	-0.2	6.4	-3.2	5.7
MSL	-0.4	2.1	-0.7	15.0	-1.7	3.1	18.8	21.7	2.7	7.0	-4.6	3.6	-1.8	7.7	6.2	13.8	-0.3	4.1	-3.3	2.9
NMISA	-16.0	79.0	-16.3	80.4	-17.3	79.0	3.2	81.9	-12.9	79.3	-20.2	79.1	-17.4	79.3	-9.4	80.2	-15.9	79.1	-18.9	79.0
SP	0.6	4.0	0.3	15.4	-0.7	4.6	19.8	22.0	3.7	7.8	-3.6	5.0	-0.8	8.4	7.2	14.2	0.7	5.3	-2.3	4.5
METAS	0.7	2.1	0.4	14.8	-0.6	2.2	19.9	21.6	3.8	6.6	-3.5	2.9	-0.7	7.3	7.3	13.7	0.8	3.4	-2.2	1.9
INRIM	0.9	5.5	0.6	15.8	-0.4	6.0	20.1	22.3	4.0	8.7	-3.3	6.3	-0.5	9.2	7.5	14.7	1.0	6.5	-2.0	5.8
VSL	0.6	6.4	0.3	16.0	-0.7	6.5	19.8	22.5	3.7	9.0	-3.6	6.7	-0.8	9.5	7.2	14.9	0.7	7.0	-2.3	6.3
KRISS	-2.3	6.3	-2.6	16.1	-3.6	6.7	16.9	22.5	0.8	9.2	-6.5	7.0	-3.7	9.7	4.3	15.1	-2.2	7.2	-5.2	6.6
NIM	0.6	2.5	0.3	15.0	-0.7	3.4	19.8	21.8	3.7	7.1	-3.6	3.9	-0.8	7.8	7.2	13.9	0.7	4.3	-2.3	3.2
VNIIM	-0.1	2.8	-0.4	15.0	-1.4	3.3	19.1	21.8	3.0	7.1	-4.3	3.8	-1.5	7.7	6.5	13.9	0.0	4.2	-3.0	3.1
SIQ	1.8	2.2	1.6	14.8	0.5	2.3	21.0	21.6	5.0	6.6	-2.3	2.9	0.4	7.4	8.5	13.7	1.9	3.5	-1.0	1.9
SMU	7.4	8.7	7.2	17.1	6.1	8.8	26.6	23.2	10.6	10.8	3.2	8.9	6.0	11.2	14.1	16.1	7.5	9.1	4.6	8.7
VMT/PFI	-0.3	2.0	-0.5	14.8	-1.6	2.1	18.9	21.6	2.9	6.6	-4.5	2.8	-1.7	7.3	6.4	13.6	-0.2	3.3	-3.1	1.6
MIKES	-0.5	2.4	-0.8	14.9	-1.8	2.5	18.7	21.7	2.6	6.7	-4.7	3.1	-1.9	7.5	6.1	13.7	-0.4	3.6	-3.4	2.1
OMH	0.7	3.7	0.4	15.1	-0.6	3.8	19.9	21.9	3.8	7.3	-3.5	4.1	-0.8	8.0	7.3	14.0	0.8	4.6	-2.2	3.5
CMI	0.1	7.2	-0.2	16.3	-1.2	7.2	19.3	22.7	3.2	9.5	-4.1	7.4	-1.3	10.1	6.7	15.3	0.2	7.7	-2.8	7.1
INM	9.1	6.9	8.8	16.2	7.8	6.9	28.3	22.6	12.3	9.3	4.9	7.1	7.7	9.9	15.7	15.2	9.2	7.4	6.2	6.8
NML	0.3	14.8			-1.0	14.8	19.5	26.1	3.4	16.1	-3.9	14.9	-1.2	16.4	6.9	20.0	0.4	15.1	-2.6	14.8
JV	1.3	2.3	1.0	14.8			20.5	21.7	4.5	6.7	-2.9	3.0	-0.1	7.4	8.0	13.7	1.4	3.5	-1.5	2.0
INETI	-19.2	21.6	-19.5	26.1	-20.5	21.7			-16.0	22.5	-23.4	21.7	-20.6	22.8	-12.5	25.5	-19.1	21.8	-22.0	21.6
LNMC	-3.1	6.7	-3.4	16.1	-4.5	6.7	16.0	22.5			-7.3	6.9	-4.6	9.7	3.5	15.0	-3.1	7.2	-6.0	6.5
SMD	4.2	3.0	3.9	14.9	2.9	3.0	23.4	21.7	7.3	6.9			2.7	7.6	10.8	13.8	4.3	3.9	1.3	2.6
UME	1.4	7.4	1.2	16.4	0.1	7.4	20.6	22.8	4.6	9.7	-2.7	7.6			8.1	15.4	1.5	7.8	-1.4	7.3
EIM	-6.6	13.7	-6.9	20.0	-8.0	13.7	12.5	25.5	-3.5	15.0	-10.8	13.8	-8.1	15.4			-6.6	13.9	-9.5	13.6
BEV	-0.1	3.5	-0.4	15.1	-1.4	3.5	19.1	21.8	3.1	7.2	-4.3	3.9	-1.5	7.8	6.6	13.9			-3.0	3.2
CEM	2.9	2.0	2.6	14.8	1.5	2.0	22.0	21.6	6.0	6.5	-1.3	2.6	1.4	7.3	9.5	13.6	3.0	3.2		

Table 17a: **1 GΩ** : Degree of equivalence with respect to the KCRV and pairwise degree of equivalence

Lab j →

Lab i ⇩			NIST		NRC		LNE		NPL		PTB		NMIA		MSL		NMISA		SP		METAS		INRIM		VSL	
	d_i	U_i	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}
NIST	-0.1	8.6			0.1	22.1	1.2	20.5	7.1	14.7	-3.4	16.3	-2.2	67.5	-4.7	11.8	53.0	581.0	1.5	14.0	-3.0	24.8	-2.6	21.6	32.2	37.6
NRC	-0.2	19.8	-0.1	22.1			1.0	26.7	6.9	22.7	-3.5	23.7	-2.3	69.7	-4.8	20.9	53.0	581.0	1.3	22.1	-3.1	30.1	-2.7	27.5	32.1	41.2
LNE	-1.3	18.0	-1.2	20.5	-1.0	26.7			5.9	21.2	-4.5	22.3	-3.4	69.3	-5.9	19.3	52.0	581.0	0.3	20.7	-4.2	29.0	-3.7	26.3	31.1	40.5
NPL	-7.2	11.0	-7.1	14.7	-6.9	22.7	-5.9	21.2			-10.4	17.2	-9.2	67.8	-11.8	13.1	46.0	581.0	-5.6	15.1	-10.0	25.4	-9.6	22.2	25.2	37.9
PTB	3.3	13.0	3.4	16.3	3.5	23.7	4.5	22.3	10.4	17.2			1.2	68.1	-1.3	14.9	56.0	581.0	4.8	16.6	0.4	26.3	0.8	23.3	35.6	38.6
NMIA	2.1	66.8	2.2	67.5	2.3	69.7	3.4	69.3	9.2	67.8	-1.2	68.1			-2.5	67.2	55.0	585.0	3.7	67.7	-0.8	70.7	-0.4	69.6	34.4	76.1
MSL	4.6	6.6	4.7	11.8	4.8	20.9	5.9	19.3	11.8	13.1	1.3	14.9	2.5	67.2			57.0	581.0	6.2	12.5	1.7	23.9	2.2	20.6	36.9	37.0
NMISA	-53.0	581.0	-53.0	581.0	-53.0	581.0	-52.0	581.0	-46.0	581.0	-56.0	581.0	-55.0	585.0	-57.0	581.0			-51.0	581.0	-56.0	581.0	-55.0	581.0	-20.0	582.0
SP	-1.6	10.0	-1.5	14.0	-1.3	22.1	-0.3	20.7	5.6	15.1	-4.8	16.6	-3.7	67.7	-6.2	12.5	51.0	581.0			-4.5	25.1	-4.0	22.0	30.8	37.8
METAS	2.9	22.8	3.0	24.8	3.1	30.1	4.2	29.0	10.0	25.4	-0.4	26.3	0.8	70.7	-1.7	23.9	56.0	581.0	4.5	25.1			0.4	30.0	35.2	42.9
INRIM	2.5	19.3	2.6	21.6	2.7	27.5	3.7	26.3	9.6	22.2	-0.8	23.3	0.4	69.6	-2.2	20.6	55.0	581.0	4.0	22.0	-0.4	30.0			34.8	41.2
VSL	-32.3	36.3	-32.2	37.6	-32.1	41.2	-31.1	40.5	-25.2	37.9	-35.6	38.6	-34.4	76.1	-36.9	37.0	20.0	582.0	-30.8	37.8	-35.2	42.9	-34.8	41.2		
KRISS	-1.5	12.4	-1.4	15.8	-1.2	23.0	-0.2	21.6	5.7	16.4	-4.7	17.9	-3.5	68.0	-6.1	14.2	51.0	581.0	0.1	16.2	-4.3	26.1	-3.9	23.1	30.9	38.4
NIM	-0.6	8.3	-0.5	12.9	-0.4	20.8	0.6	19.3	6.5	13.3	-3.9	15.1	-2.7	67.3	-5.2	10.5	52.0	581.0	1.0	13.1	-3.5	24.3	-3.1	21.0	31.7	37.2
VNIIM	0.0	7.3	0.1	12.2	0.2	20.3	1.2	18.8	7.1	12.5	-3.3	14.4	-2.1	67.2	-4.7	9.5	53.0	581.0	1.5	12.3	-2.9	23.9	-2.5	20.6	32.3	37.0
INTI	-7.5	12.6	-8.2	10.0	-1.4	16.0	-6.2	21.9	-0.3	16.7	-10.8	18.1	-9.6	68.0	-12.1	14.2	45.0	581.0	-5.9	16.1	-10.4	26.0	-10.0	23.0	24.8	38.4
INMETRO	-4.2	11.8	-4.9	9.0	2.0	15.4	-2.9	21.5	3.0	16.1	-7.5	17.5	-6.3	67.8	-8.8	13.5	49.0	581.0	-2.6	15.4	-7.1	25.7	-6.7	22.6	28.1	38.2
UTE	-4.3	35.5	-5.0	34.7	1.9	36.9	-3.0	39.8	2.9	37.2	-7.6	37.8	-6.4	75.6	-8.9	36.1	49.0	582.0	-2.7	36.9	-7.2	42.2	-6.8	40.4	28.0	50.8
CENAM	3.7	16.0	3.0	14.0	9.9	18.7	5.0	24.1	10.9	19.4	0.4	20.6	1.6	68.7	-0.9	17.3	57.0	581.0	5.3	18.8	0.8	27.8	1.2	25.0	36.0	39.7
SIQ	-10.7	12.0	-10.6	14.7	-10.5	23.1	-9.4	20.3	-3.5	14.2	-14.0	16.1	-12.8	67.9	-15.3	13.7	42.3	581.1	-9.1	15.6	-13.6	24.4	-13.2	22.7	21.6	37.3
SMU	-28.4	37.8	-28.3	38.8	-28.2	42.7	-27.1	41.2	-21.2	38.6	-31.7	39.3	-30.5	76.8	-33.0	38.4	24.6	582.2	-26.8	39.1	-31.3	43.4	-30.9	42.4	3.9	51.7
VMT/PFI	-1.8	8.9	-1.7	12.4	-1.6	21.7	-0.5	18.7	5.4	11.8	-5.1	14.0	-3.9	67.4	-6.4	11.1	51.2	581.1	-0.2	13.4	-4.7	23.1	-4.3	21.3	30.5	36.4
MIKES	-1.8	11.4	-1.7	14.3	-1.6	22.9	-0.5	20.0	5.4	13.8	-5.1	15.7	-3.9	67.8	-6.4	13.2	51.2	581.1	-0.2	15.2	-4.7	24.2	-4.3	22.4	30.5	37.1
OMH	2.0	9.2	2.1	12.6	2.2	21.8	3.3	18.8	9.2	12.0	-1.3	14.2	-0.1	67.4	-2.6	11.3	55.0	581.1	3.6	13.6	-0.9	23.2	-0.5	21.4	34.3	36.5
CMI	6.7	30.8	6.8	32.0	6.8	36.6	8.0	34.9	13.9	31.7	3.4	32.6	4.5	73.6	2.0	31.5	59.6	581.8	8.3	32.4	3.8	37.4	4.2	36.3	39.0	46.9
INM	-44.9	44.5	-44.8	45.3	-44.7	48.7	-43.6	47.4	-37.7	45.2	-48.2	45.8	-47.0	80.3	-49.5	45.0	8.1	582.7	-43.3	45.6	-47.8	49.3	-47.4	48.5	-12.6	56.8
NML	-3.0	62.3	-2.9	62.8	-2.8	65.3	-1.7	64.4	4.2	62.7	-6.3	63.2	-5.1	91.3	-7.6	62.6	50.0	584.3	-1.4	63.1	-5.9	65.8	-5.5	65.2	29.3	71.6
JV	0.1	14.4	0.2	16.7	0.3	24.5	1.4	21.8	7.3	16.3	-3.2	18.0	-2.0	68.3	-4.5	15.8	53.1	581.2	1.7	17.5	-2.8	25.7	-2.4	24.1	32.4	38.1
INETI	-33.4	208.5	-33.3	208.7	-33.2	209.5	-32.1	209.2	-26.2	208.7	-36.7	208.8	-35.5	219.0	-38.0	208.6	19.6	617.3	-31.8	208.8	-36.3	209.6	-35.9	209.4	-1.1	211.5
SMD	-2.7	18.6	-2.6	20.5	-2.5	27.2	-1.4	24.8	4.5	20.2	-6.0	21.5	-4.8	69.4	-7.3	19.8	50.3	581.3	-1.1	21.2	-5.6	28.3	-5.2	26.8	29.6	39.9
UME	-1.4	12.2	-1.3	14.9	-1.2	23.3	-0.1	20.5	5.8	14.4	-4.7	16.3	-3.5	67.9	-6.0	13.9	51.6	581.1	0.2	15.8	-4.3	24.6	-3.9	22.8	30.9	37.4
EIM	-0.4	17.9	-0.3	19.9	-0.2	26.7	0.9	24.3	6.8	19.5	-3.7	20.9	-2.5	69.2	-5.0	19.1	52.6	581.3	1.2	20.5	-3.3	27.8	-2.9	26.3	31.9	39.6
BEV	0.7	18.1	0.8	20.0	0.9	26.8	2.0	24.4	7.9	19.6	-2.6	21.0	-1.4	69.2	-3.9	19.2	53.7	581.3	2.3	20.6	-2.2	27.9	-1.8	26.4	33.0	39.7
CEM	-1.4	7.3	-1.3	11.3	-1.2	21.1	-0.1	18.0	5.8	10.6	-4.7	13.0	-3.5	67.2	-6.0	9.8	51.6	581.0	0.2	12.4	-4.3	22.5	-3.9	20.6	30.9	36.1

Table 17b: 1 GΩ : Degree of equivalence with respect to the KCRV and pairwise degree of equivalence

Lab *j* →

Lab *i* ⇩			KRISS		NIM		VNIIM		INTI		INMETRO		UTE		CENAM		SIQ		SMU		VMT/PFI		MIKES		OMH	
	d_i	U_i	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}
NIST	-0.1	8.6	1.4	15.8	0.5	12.9	-0.1	12.2	8.2	10.0	4.9	9.0	5.0	34.7	-3.0	14.0	10.6	14.7	28.3	38.8	1.7	12.4	1.7	14.3	-2.1	12.6
NRC	-0.2	19.8	1.2	23.0	0.4	20.8	-0.2	20.3	1.4	16.0	-2.0	15.4	-1.9	36.9	-9.9	18.7	10.5	23.1	28.2	42.7	1.6	21.7	1.6	22.9	-2.2	21.8
LNE	-1.3	18.0	0.2	21.6	-0.6	19.3	-1.2	18.8	6.2	21.9	2.9	21.5	3.0	39.8	-5.0	24.1	9.4	20.3	27.1	41.2	0.5	18.7	0.5	20.0	-3.3	18.8
NPL	-7.2	11.0	-5.7	16.4	-6.5	13.3	-7.1	12.5	0.3	16.7	-3.0	16.1	-2.9	37.2	-10.9	19.4	3.5	14.2	21.2	38.6	-5.4	11.8	-5.4	13.8	-9.2	12.0
PTB	3.3	13.0	4.7	17.9	3.9	15.1	3.3	14.4	10.8	18.1	7.5	17.5	7.6	37.8	-0.4	20.6	14.0	16.1	31.7	39.3	5.1	14.0	5.1	15.7	1.3	14.2
NMIA	2.1	66.8	3.5	68.0	2.7	67.3	2.1	67.2	9.6	68.0	6.3	67.8	6.4	75.6	-1.6	68.7	12.8	67.9	30.5	76.8	3.9	67.4	3.9	67.8	0.1	67.4
MSL	4.6	6.6	6.1	14.2	5.2	10.5	4.7	9.5	12.1	14.2	8.8	13.5	8.9	36.1	0.9	17.3	15.3	13.7	33.0	38.4	6.4	11.1	6.4	13.2	2.6	11.3
NMISA	-53.0	581.0	-51.0	581.0	-52.0	581.0	-53.0	581.0	-45.0	581.0	-49.0	581.0	-49.0	582.0	-57.0	581.0	-42.3	581.1	-24.6	582.2	-51.2	581.1	-51.2	581.1	-55.0	581.1
SP	-1.6	10.0	-0.1	16.2	-1.0	13.1	-1.5	12.3	5.9	16.1	2.6	15.4	2.7	36.9	-5.3	18.8	9.1	15.6	26.8	39.1	0.2	13.4	0.2	15.2	-3.6	13.6
METAS	2.9	22.8	4.3	26.1	3.5	24.3	2.9	23.9	10.4	26.0	7.1	25.7	7.2	42.2	-0.8	27.8	13.6	24.4	31.3	43.4	4.7	23.1	4.7	24.2	0.9	23.2
INRIM	2.5	19.3	3.9	23.1	3.1	21.0	2.5	20.6	10.0	23.0	6.7	22.6	6.8	40.4	-1.2	25.0	13.2	22.7	30.9	42.4	4.3	21.3	4.3	22.4	0.5	21.4
VSL	-32.3	36.3	-30.9	38.4	-31.7	37.2	-32.3	37.0	-24.8	38.4	-28.1	38.2	-28.0	50.8	-36.0	39.7	-21.6	37.3	-3.9	51.7	-30.5	36.4	-30.5	37.1	-34.3	36.5
KRISS	-1.5	12.4			-0.8	15.0	-1.4	14.4	6.0	17.7	2.7	17.1	2.8	37.6	-5.2	20.2	9.2	17.2	26.9	39.8	0.3	15.3	0.3	16.9	-3.5	15.4
NIM	-0.6	8.3	0.8	15.0			-0.6	11.0	6.9	15.1	3.6	14.4	3.7	36.5	-4.3	18.0	10.1	14.6	27.8	38.7	1.2	12.2	1.2	14.1	-2.6	12.4
VNIIM	0.0	7.3	1.4	14.4	0.6	11.0			7.5	14.5	4.2	13.8	4.3	36.2	-3.7	17.5	10.7	12.3	28.4	37.9	1.8	9.4	1.8	11.8	-2.0	9.7
INTI	-7.5	12.6	-6.0	17.7	-6.9	15.1	-7.5	14.5			-3.4	13.1	-3.2	35.9	-11.2	17.0	3.2	17.4	20.9	39.8	-5.7	15.4	-5.7	17.0	-9.5	15.6
INMETRO	-4.2	11.8	-2.7	17.1	-3.6	14.4	-4.2	13.8	3.4	13.1			0.1	35.7	-7.8	16.4	6.5	16.8	24.2	39.6	-2.4	14.8	-2.4	16.4	-6.2	14.9
UTE	-4.3	35.5	-2.8	37.6	-3.7	36.5	-4.3	36.2	3.2	35.9	-0.1	35.7			-8.0	37.4	6.4	37.5	24.1	51.9	-2.5	36.6	-2.5	37.3	-6.3	36.7
CENAM	3.7	16.0	5.2	20.2	4.3	18.0	3.7	17.5	11.2	17.0	7.8	16.4	8.0	37.4			14.4	20.0	32.1	41.0	5.5	18.3	5.5	19.7	1.7	18.4
SIQ	-10.7	12.0	-9.2	17.2	-10.1	14.6	-10.7	12.3	-3.2	17.4	-6.5	16.8	-6.4	37.5	-14.4	20.0			17.7	38.8	-8.9	12.6	-8.9	14.4	-12.8	12.7
SMU	-28.4	37.8	-26.9	39.8	-27.8	38.7	-28.4	37.9	-20.9	39.8	-24.2	39.6	-24.1	51.9	-32.1	41.0	-17.7	38.8			-26.6	38.0	-26.6	38.6	-30.4	38.0
VMT/PFI	-1.8	8.9	-0.3	15.3	-1.2	12.2	-1.8	9.4	5.7	15.4	2.4	14.8	2.5	36.6	-5.5	18.3	8.9	12.6	26.6	38.0			0.0	12.0	-3.9	9.8
MIKES	-1.8	11.4	-0.3	16.9	-1.2	14.1	-1.8	11.8	5.7	17.0	2.4	16.4	2.5	37.3	-5.5	19.7	8.9	14.4	26.6	38.6	0.0	12.0			-3.9	12.0
OMH	2.0	9.2	3.5	15.4	2.6	12.4	2.0	9.7	9.5	15.6	6.2	14.9	6.3	36.7	-1.7	18.4	12.8	12.7	30.4	38.0	3.9	9.8	3.9	12.0		
CMI	6.7	30.8	8.2	33.2	7.3	31.9	6.7	30.9	14.2	33.3	10.9	33.0	10.9	47.0	3.0	34.7	17.4	32.0	35.1	48.0	8.5	30.9	8.5	31.7	4.6	30.9
INM	-44.9	44.5	-43.4	46.2	-44.3	45.3	-44.9	44.6	-37.4	46.3	-40.7	46.0	-40.6	56.9	-48.6	47.3	-34.2	45.3	-16.5	57.8	-43.1	44.6	-43.1	45.1	-47.0	44.6
NML	-3.0	62.3	-1.5	63.5	-2.4	62.8	-3.0	62.3	4.5	63.5	1.2	63.4	1.3	71.7	-6.7	64.3	7.8	62.9	25.4	72.4	-1.1	62.4	-1.1	62.8	-5.0	62.4
JV	0.1	14.4	1.6	19.0	0.7	16.6	0.1	14.7	7.6	19.1	4.3	18.6	4.4	38.3	-3.6	21.5	10.8	17.0	28.5	39.7	1.9	15.0	1.9	16.5	-2.0	15.1
INETI	-33.4	208.5	-31.9	208.9	-32.8	208.7	-33.4	208.5	-25.9	208.9	-29.2	208.9	-29.1	211.5	-37.1	209.1	-22.7	208.7	-5.0	211.8	-31.6	208.6	-31.6	208.7	-35.5	208.6
SMD	-2.7	18.6	-1.2	22.4	-2.1	20.4	-2.7	18.9	4.8	22.5	1.5	22.1	1.6	40.1	-6.4	24.6	8.0	20.8	25.7	41.4	-0.9	19.2	-0.9	20.4	-4.7	19.2
UME	-1.4	12.2	0.1	17.4	-0.8	14.8	-1.4	12.6	6.1	17.6	2.8	17.0	2.9	37.5	-5.1	20.1	9.3	15.1	27.0	38.9	0.4	12.8	0.4	14.5	-3.5	12.8
EIM	-0.4	17.9	1.1	21.8	0.2	19.8	-0.4	18.2	7.1	21.9	3.8	21.5	3.9	39.8	-4.1	24.0	10.3	20.1	28.0	41.1	1.4	18.4	1.4	19.7	-2.5	18.4
BEV	0.7	18.1	2.2	21.9	1.3	19.9	0.7	18.3	8.2	22.0	4.9	21.6	5.0	39.8	-3.0	24.1	11.4	20.2	29.1	41.1	2.5	18.5	2.5	19.8	-1.4	18.6
CEM	-1.4	7.3	0.1	14.4	-0.8	11.1	-1.4	7.9	6.1	14.6	2.8	13.9	2.9	36.2	-5.1	17.6	9.3	11.7	27.0	37.7	0.4	8.5	0.4	11.0	-3.5	8.6

Table 17c: **1 GΩ** : Degree of equivalence with respect to the KCRV and pairwise degree of equivalence

Lab *j* →

Lab *i* ⇩			CMI		INM		NML		JV		INETI		SMD		UME		EIM		BEV		CEM	
	d_i	U_i	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}	d_{ij}	U_{ij}
NIST	-0.1	8.6	-6.8	32.0	44.8	45.3	2.9	62.8	-0.2	16.7	33.3	208.7	2.6	20.5	1.3	14.9	0.3	19.9	-0.8	20.0	1.3	11.3
NRC	-0.2	19.8	-6.8	36.6	44.7	48.7	2.8	65.3	-0.3	24.5	33.2	209.5	2.5	27.2	1.2	23.3	0.2	26.7	-0.9	26.8	1.2	21.1
LNE	-1.3	18.0	-8.0	34.9	43.6	47.4	1.7	64.4	-1.4	21.8	32.1	209.2	1.4	24.8	0.1	20.5	-0.9	24.3	-2.0	24.4	0.1	18.0
NPL	-7.2	11.0	-13.9	31.7	37.7	45.2	-4.2	62.7	-7.3	16.3	26.2	208.7	-4.5	20.2	-5.8	14.4	-6.8	19.5	-7.9	19.6	-5.8	10.6
PTB	3.3	13.0	-3.4	32.6	48.2	45.8	6.3	63.2	3.2	18.0	36.7	208.8	6.0	21.5	4.7	16.3	3.7	20.9	2.6	21.0	4.7	13.0
NMIA	2.1	66.8	-4.5	73.6	47.0	80.3	5.1	91.3	2.0	68.3	35.5	219.0	4.8	69.4	3.5	67.9	2.5	69.2	1.4	69.2	3.5	67.2
MSL	4.6	6.6	-2.0	31.5	49.5	45.0	7.6	62.6	4.5	15.8	38.0	208.6	7.3	19.8	6.0	13.9	5.0	19.1	3.9	19.2	6.0	9.8
NMISA	-53.0	581.0	-59.6	581.8	-8.1	582.7	-50.0	584.3	-53.1	581.2	-19.6	617.3	-50.3	581.3	-51.6	581.1	-52.6	581.3	-53.7	581.3	-51.6	581.0
SP	-1.6	10.0	-8.3	32.4	43.3	45.6	1.4	63.1	-1.7	17.5	31.8	208.8	1.1	21.2	-0.2	15.8	-1.2	20.5	-2.3	20.6	-0.2	12.4
METAS	2.9	22.8	-3.8	37.4	47.8	49.3	5.9	65.8	2.8	25.7	36.3	209.6	5.6	28.3	4.3	24.6	3.3	27.8	2.2	27.9	4.3	22.5
INRIM	2.5	19.3	-4.2	36.3	47.4	48.5	5.5	65.2	2.4	24.1	35.9	209.4	5.2	26.8	3.9	22.8	2.9	26.3	1.8	26.4	3.9	20.6
VSL	-32.3	36.3	-39.0	46.9	12.6	56.8	-29.3	71.6	-32.4	38.1	1.1	211.5	-29.6	39.9	-30.9	37.4	-31.9	39.6	-33.0	39.7	-30.9	36.1
KRISS	-1.5	12.4	-8.2	33.2	43.4	46.2	1.5	63.5	-1.6	19.0	31.9	208.9	1.2	22.4	-0.1	17.4	-1.1	21.8	-2.2	21.9	-0.1	14.4
NIM	-0.6	8.3	-7.3	31.9	44.3	45.3	2.4	62.8	-0.7	16.6	32.8	208.7	2.1	20.4	0.8	14.8	-0.2	19.8	-1.3	19.9	0.8	11.1
VNIIM	0.0	7.3	-6.7	30.9	44.9	44.6	3.0	62.3	-0.1	14.7	33.4	208.5	2.7	18.9	1.4	12.6	0.4	18.2	-0.7	18.3	1.4	7.9
INTI	-7.5	12.6	-14.2	33.3	37.4	46.3	-4.5	63.5	-7.6	19.1	25.9	208.9	-4.8	22.5	-6.1	17.6	-7.1	21.9	-8.2	22.0	-6.1	14.6
INMETRO	-4.2	11.8	-10.9	33.0	40.7	46.0	-1.2	63.4	-4.3	18.6	29.2	208.9	-1.5	22.1	-2.8	17.0	-3.8	21.5	-4.9	21.6	-2.8	13.9
UTE	-4.3	35.5	-10.9	47.0	40.6	56.9	-1.3	71.7	-4.4	38.3	29.1	211.5	-1.6	40.1	-2.9	37.5	-3.9	39.8	-5.0	39.8	-2.9	36.2
CENAM	3.7	16.0	-3.0	34.7	48.6	47.3	6.7	64.3	3.6	21.5	37.1	209.1	6.4	24.6	5.1	20.1	4.1	24.0	3.0	24.1	5.1	17.6
SIQ	-10.7	12.0	-17.4	32.0	34.2	45.3	-7.8	62.9	-10.8	17.0	22.7	208.7	-8.0	20.8	-9.3	15.1	-10.3	20.1	-11.4	20.2	-9.3	11.7
SMU	-28.4	37.8	-35.1	48.0	16.5	57.8	-25.4	72.4	-28.5	39.7	5.0	211.8	-25.7	41.4	-27.0	38.9	-28.0	41.1	-29.1	41.1	-27.0	37.7
VMT/PFI	-1.8	8.9	-8.5	30.9	43.1	44.6	1.1	62.4	-1.9	15.0	31.6	208.6	0.9	19.2	-0.4	12.8	-1.4	18.4	-2.5	18.5	-0.4	8.5
MIKES	-1.8	11.4	-8.5	31.7	43.1	45.1	1.1	62.8	-1.9	16.5	31.6	208.7	0.9	20.4	-0.4	14.5	-1.4	19.7	-2.5	19.8	-0.4	11.0
OMH	2.0	9.2	-4.6	30.9	47.0	44.6	5.0	62.4	2.0	15.1	35.5	208.6	4.7	19.2	3.5	12.8	2.5	18.4	1.4	18.6	3.5	8.6
CMI	6.7	30.8			51.6	53.4	9.6	69.0	6.6	33.0	40.1	210.6	9.3	35.1	8.1	32.0	7.1	34.6	6.0	34.7	8.1	30.6
INM	-44.9	44.5	-51.6	53.4			-41.9	76.1	-45.0	46.0	-11.5	213.1	-42.2	47.6	-43.5	45.4	-44.5	47.3	-45.6	47.3	-43.5	44.4
NML	-3.0	62.3	-9.6	69.0	41.9	76.1			-3.0	63.4	30.4	217.5	-0.3	64.5	-1.5	62.9	-2.6	64.3	-3.6	64.3	-1.5	62.2
JV	0.1	14.4	-6.6	33.0	45.0	46.0	3.0	63.4			33.5	208.9	2.8	22.2	1.5	16.9	0.5	21.5	-0.6	21.6	1.5	14.0
INETI	-33.4	208.5	-40.1	210.6	11.5	213.1	-30.4	217.5	-33.5	208.9			-30.7	209.2	-32.0	208.7	-33.0	209.1	-34.1	209.2	-32.0	208.5
SMD	-2.7	18.6	-9.3	35.1	42.2	47.6	0.3	64.5	-2.8	22.2	30.7	209.2			-1.3	20.7	-2.3	24.6	-3.4	24.7	-1.3	18.4
UME	-1.4	12.2	-8.1	32.0	43.5	45.4	1.5	62.9	-1.5	16.9	32.0	208.7	1.3	20.7			-1.0	20.0	-2.1	20.1	0.0	11.6
EIM	-0.4	17.9	-7.1	34.6	44.5	47.3	2.6	64.3	-0.5	21.5	33.0	209.1	2.3	24.6	1.0	20.0			-1.1	24.1	1.0	17.6
BEV	0.7	18.1	-6.0	34.7	45.6	47.3	3.6	64.3	0.6	21.6	34.1	209.2	3.4	24.7	2.1	20.1	1.1	24.1			2.1	17.7
CEM	-1.4	7.3	-8.1	30.6	43.5	44.4	1.5	62.2	-1.5	14.0	32.0	208.5	1.3	18.4	0.0	11.6	-1.0	17.6	-2.1	17.7		

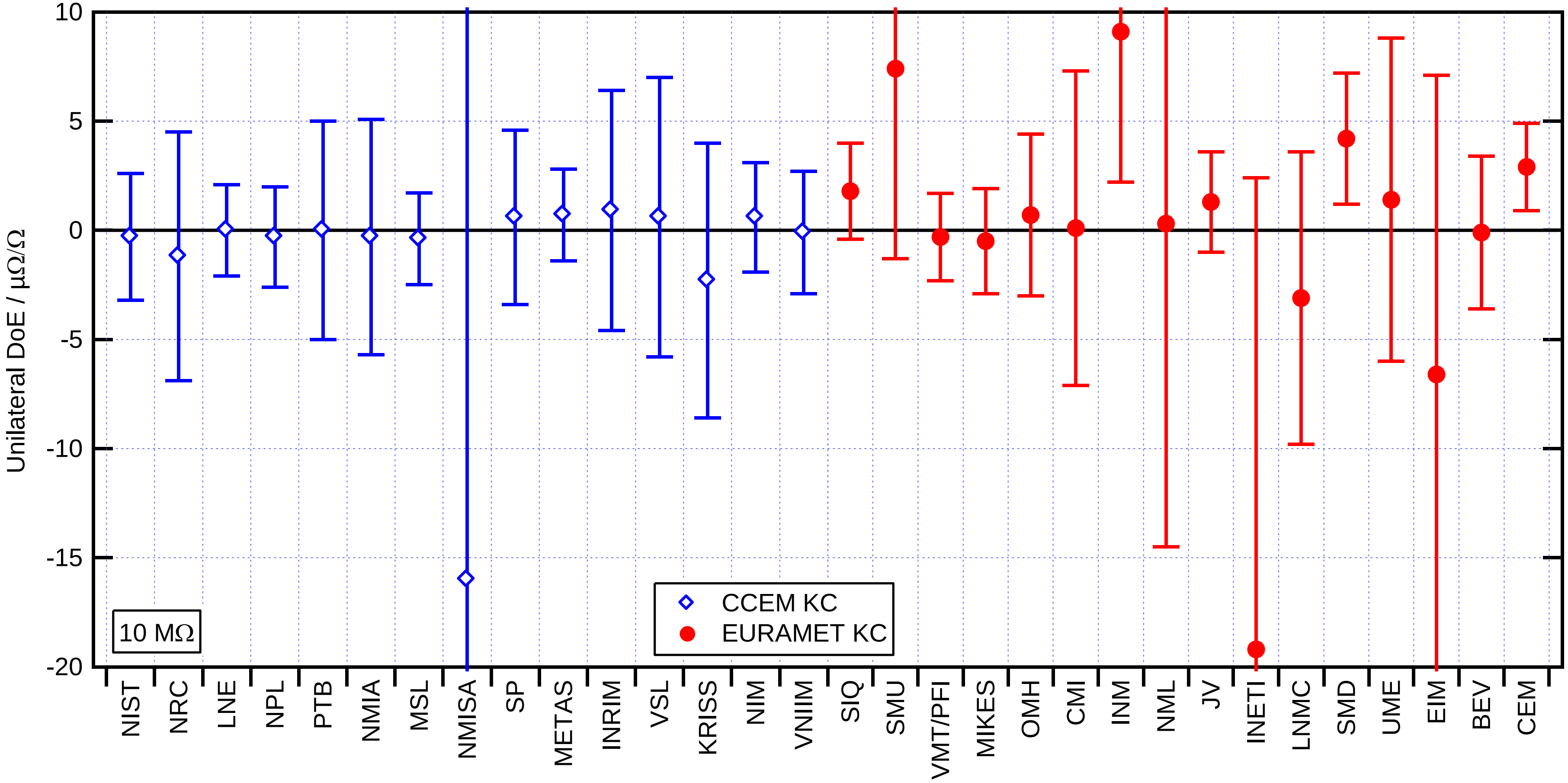


Figure 8: Unilateral degrees of equivalence with respect to the KCRV of CCEM-K2 at 10 MΩ.

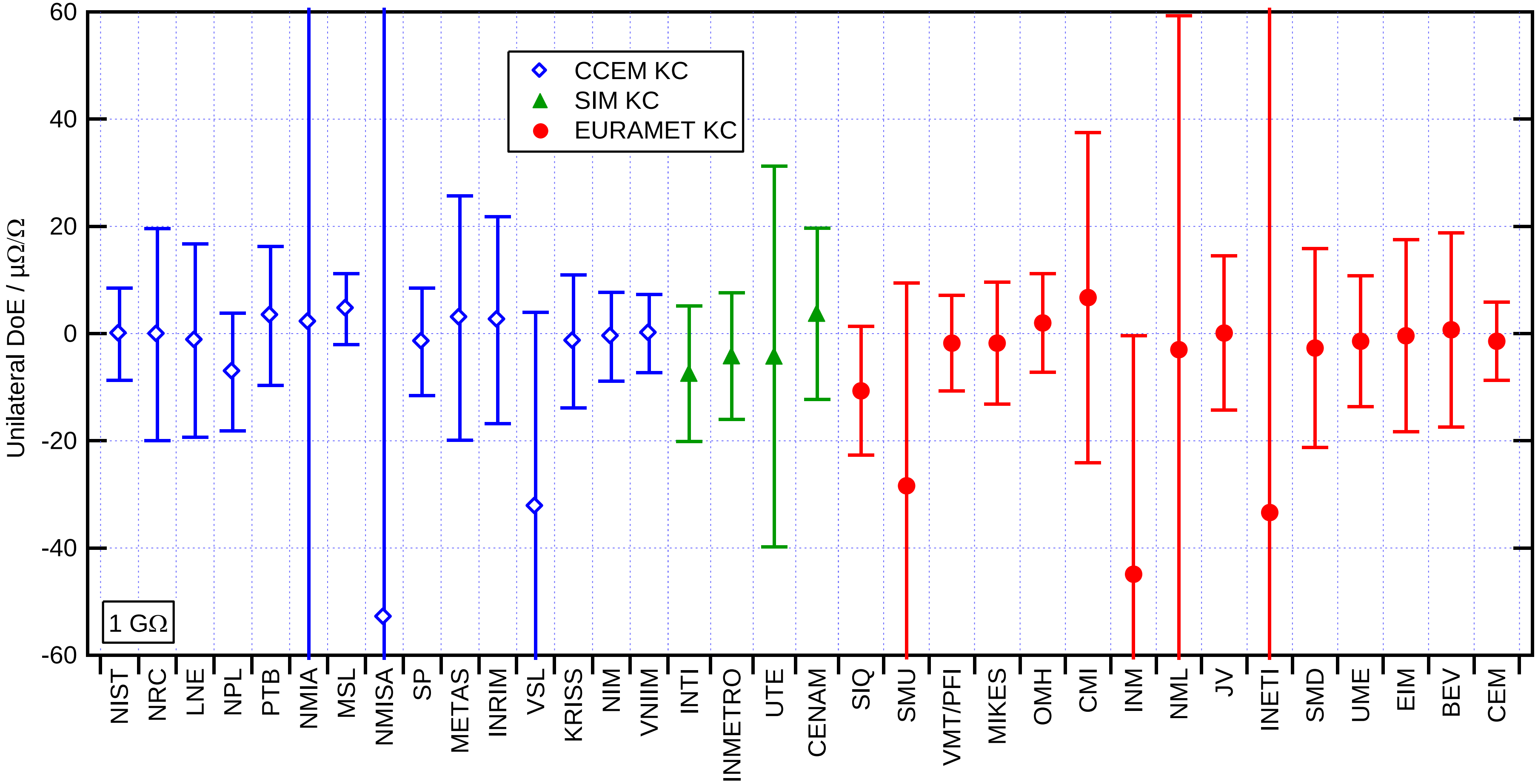


Figure 9: Unilateral degrees of equivalence with respect to the KCRV of CCEM-K2 at 1 GΩ.

7. Changes with respect to draft A version 1 and 2

7.1 Changes requested by the participants

- Laboratory 11, GUM Poland, withdrew its result from the comparison
- Laboratory 4, SMU Slovakia, increased one of the components in the uncertainty budget for both, the 10 MΩ and the 1 GΩ standard.

7.2 Changes and corrections by the pilot laboratory

- A refined treatment of transport uncertainty (for details see description of analysis)
- Laboratory 8, OMH: A sign error in the 1 GΩ data was corrected.
- Laboratory 7, MIKES: 1 GΩ measurements not taken at the nominal voltage (100 V) have been removed from the comparison data set.
- A small error which affected the uncertainty of the temperature and voltage correction, equation (6.4), has been corrected. The resulting changes are insignificant.

8. Summary and conclusions

Twenty-four National Metrology Institutes, among them twenty-two EURAMET members, participated in the comparison EUROMET.EM-K2 aimed at evaluating the degrees of equivalence of the measurements of 10 MΩ and 1 GΩ resistance standards. With three exceptions at 10 MΩ, all results supplied by the participants agreed with the comparison reference value within the expanded uncertainty. The analysis of the comparison results with respect to the CMC claims of the participating institutes and the measures to be taken in the case of inconsistencies are described in a separate executive report.

The method of constrained least squares was applied to calculate the comparison reference value. Generally one can say that this method has proven to be useful in this analysis, because it provides a single, consistent and transparent approach for the determination of the key values of this measurement comparison involving multiple artefacts and overlapping loops.

The characteristics of the standards used as transport artefacts ultimately limit the accuracy of comparisons in the resistance field. Besides an uniform drift behaviour in time, step-like resistance changes may occur during transport due to temperature shocks or mechanical shocks. Such behaviour is difficult to model and introduces an undesired bias in the laboratory results. At the 10 MΩ level, the transport uncertainties are the level of the uncertainties claimed by some of the participants and, thus, limit the meaningfulness of the comparison results.

The link to the CCEM comparison CCEM-K2 and the degrees of equivalence with respect to the key comparison reference value were evaluated. However, it should be noted that a substantial amount of time has passed between the CCEM and the RMO comparison. Many laboratories have improved and changed their measurement setup in between. As a consequence the uncertainties in the RMO comparison are significantly smaller than those in the CCEM comparison. The linking procedure itself is therefore questionable. This has been recognized and another CCEM comparison is planned, which will be used to link the results of the RMO comparison to. The linking results here should therefore be considered as provisional.

9. References

[1] R.F. Dziuba and D. G. Jarett, Final report on key comparison CCEM-K2 of resistance standards at 10 MΩ and 1 GΩ, Metrologia, 39, Tech. Suppl., 01001, 2002.

[2] N. F. Zhang, N. Sedransk and D. G. Jarrett, Statistical uncertainty analysis of key comparison CCEM-K2, IEEE Trans. Instrum, Meas., 52, pp. 491-4, 2003.

[3] D. R. White, “On the analysis of measurement comparisons”, Metrologia 41, pp. 122-131, 2004.

[4] W. Bich, “Bias and Optimal Linear Estimation in Comparison Calibrations”, Metrologia 29, pp. 15-22, 1992

Annexes

A Measurement results reported by the participants
B Methods of measurement
C Uncertainty budgets
D Comparison protocol

Annex A: Raw Results

A1 10 MΩ

A1.1 Loop A, 10 MΩ standard HR 7550, *a* = 1

p	*Meas. #* m	Date $t_{p,1,m}$	$T_{p,1,m}$ (°C)	$u(T)$ (°C)	$V_{p,1,m}$ (V)	$O_{p,1,m}$ (ppm)	$u_{r\text{-}p,1,m}$ (ppm)	$u^*_{r-p,1,m}$ (ppm)	T,V-corr. (ppm)	$f(t_{p,1,m})$ (ppm)	$M_{p,1,m}$ (ppm)
1	METAS, CH										
	1	15.04.05	22.91	0.03	5.0	45.98	0.12	0.12	0.10	45.98	0.09
	2	20.04.05	22.90	0.03	5.0	45.98	0.12	0.12	0.11	46.04	0.05
	3	28.04.05	22.91	0.03	5.0	46.08	0.12	0.12	0.10	46.13	0.04
	4	10.05.05	22.91	0.03	5.0	46.18	0.12	0.12	0.10	46.28	-0.01
	5	25.05.05	22.93	0.03	5.0	46.41	0.12	0.12	0.08	46.45	0.04
	6	26.05.05	22.91	0.03	5.0	46.27	0.12	0.12	0.10	46.46	-0.09
	7	10.06.05	22.92	0.03	5.0	46.44	0.12	0.12	0.09	46.63	-0.11
	8	27.06.05	22.92	0.03	5.0	46.58	0.12	0.12	0.09	46.82	-0.16
2	PTB, Germany										
	1	28.07.05	23.04	0.03	10.0	45.70	0.40	0.66	-0.04	47.16	-1.51
	2	01.08.05	22.95	0.03	10.0	46.80	0.40	0.66	0.06	47.21	-0.35
	3	03.08.05	23.01	0.03	10.0	46.00	0.30	0.50	-0.01	47.23	-1.24
	4	05.08.05	23.04	0.03	10.0	46.80	0.70	1.16	-0.04	47.25	-0.49
	5	09.08.05	23.05	0.04	10.0	46.70	0.20	0.33	-0.05	47.29	-0.65
	6	11.08.05	22.94	0.03	10.0	45.70	0.20	0.33	0.07	47.32	-1.55
	7	17.08.05	22.96	0.03	10.0	46.00	0.20	0.33	0.04	47.38	-1.34
	8	23.08.05	23.01	0.03	10.0	46.80	0.30	0.50	-0.01	47.45	-0.66
3	SIQ, Slovenia										
	1	09.09.05	22.98	0.05	10.0	48.00	0.10	0.10	0.02	47.64	0.38
	2	10.09.05	23.20	0.05	10.0	48.30	0.10	0.10	-0.22	47.65	0.43
	3	11.09.05	23.20	0.05	10.0	48.30	0.10	0.10	-0.22	47.66	0.42
	4	12.09.05	23.05	0.05	10.0	48.30	0.10	0.10	-0.06	47.67	0.57
	5	27.09.05	22.94	0.05	10.0	48.50	0.30	0.30	0.07	47.83	0.73
	6	28.09.05	22.95	0.05	10.0	48.50	0.50	0.50	0.06	47.84	0.72
	7	29.09.05	23.06	0.05	10.0	48.70	0.50	0.50	-0.07	47.85	0.78
	8	29.09.05	22.87	0.05	10.0	48.60	0.50	0.50	0.14	47.85	0.89
	9	29.09.05	22.97	0.05	10.0	48.40	0.60	0.60	0.03	47.86	0.58
	10	30.09.05	22.86	0.05	10.0	48.30	0.50	0.50	0.15	47.86	0.59
	11	30.09.05	23.08	0.05	10.0	48.50	0.60	0.60	-0.09	47.87	0.55
	12	30.09.05	22.83	0.05	10.0	47.50	0.50	0.50	0.19	47.87	-0.18
	13	01.10.05	22.60	0.05	10.0	47.10	0.50	0.50	0.44	47.87	-0.33
	14	01.10.05	22.75	0.05	10.0	47.20	0.40	0.40	0.28	47.88	-0.40
	15	01.10.05	22.75	0.05	10.0	47.70	0.60	0.60	0.28	47.88	0.10
	16	02.10.05	22.78	0.05	10.0	47.70	0.40	0.40	0.24	47.88	0.06
	17	02.10.05	22.81	0.05	10.0	47.90	0.60	0.60	0.21	47.89	0.22
	18	02.10.05	22.78	0.05	10.0	48.30	0.70	0.70	0.24	47.89	0.65
4	SMU, Slovakia										
	1	18.10.05	23.00	0.10	10.0	54.30	0.92	1.11	0.00	48.05	6.25
	2	21.10.05	23.00	0.10	10.0	52.52	0.45	0.54	0.00	48.08	4.44
	3	25.10.05	22.90	0.10	10.0	53.20	1.00	1.20	0.11	48.12	5.19
	4	28.10.05	23.00	0.10	10.0	52.31	0.55	0.66	0.00	48.16	4.15

p	Meas. # m	Date $t_{p,1,m}$	$T_{p,1,m}$ (°C)	$u(T)$ (°C)	$V_{p,1,m}$ (V)	$O_{p,1,m}$ (ppm)	$u_{\text{r-}p,1,m}$ (ppm)	$u^*_{r-p,1,m}$ (ppm)	T,V-corr. (ppm)	$f(t_{p,1,m})$ (ppm)	$M_{p,1,m}$ (ppm)
5	VSL, Netherlands										
	1	14.11.05	22.99	0.00	9.1	47.12	0.45	0.55	0.02	48.33	-1.19
	2	15.11.05	23.01	0.02	9.1	47.71	0.15	0.18	-0.01	48.34	-0.64
	3	16.11.05	23.02	0.00	9.1	47.93	0.30	0.37	-0.02	48.35	-0.44
	4	18.11.05	22.99	0.00	9.1	47.86	0.20	0.24	0.01	48.37	-0.51
	5	21.11.05	22.98	0.00	9.1	47.36	0.68	0.83	0.03	48.41	-1.02
	6	23.11.05	23.00	0.00	9.1	47.52	0.38	0.46	0.00	48.43	-0.90
	7	24.11.05	22.97	0.00	9.1	47.52	0.19	0.23	0.03	48.44	-0.89
	8	29.11.05	22.99	0.01	9.1	47.43	0.27	0.33	0.01	48.49	-1.05
	9	30.11.05	22.99	0.01	9.1	48.40	0.29	0.35	0.01	48.50	-0.09
	10	01.12.05	23.00	0.00	9.1	48.01	0.90	1.10	0.00	48.51	-0.50
	11	02.12.05	23.02	0.00	9.1	47.90	0.68	0.83	-0.02	48.52	-0.64
	12	05.12.05	23.02	0.00	9.1	47.52	0.48	0.58	-0.02	48.55	-1.05
	13	06.12.05	23.04	0.00	9.1	48.38	0.12	0.15	-0.04	48.56	-0.22
	14	09.12.05	23.04	0.00	9.1	48.49	0.44	0.54	-0.05	48.59	-0.15
	15	09.12.05	23.05	0.00	9.1	47.95	0.17	0.21	-0.06	48.59	-0.70
	16	12.12.05	23.05	0.00	9.1	47.78	0.64	0.78	-0.05	48.62	-0.90
	17	13.12.05	23.05	0.00	9.1	47.95	0.33	0.40	-0.06	48.63	-0.74
1	METAS, CH										
	9	29.12.05	23.04	0.03	5.0	48.98	0.12	0.12	-0.05	48.80	0.13
	10	09.01.06	22.98	0.03	5.0	48.94	0.12	0.12	0.02	48.91	0.04
	11	13.01.06	22.99	0.03	5.0	48.92	0.12	0.12	0.01	48.95	-0.01
	12	19.01.06	22.99	0.03	5.0	49.03	0.12	0.12	0.01	49.01	0.03
6	SPI, Lithuania										
	1	30.01.06	23.07	0.08	10.0	48.83	0.17	0.37	-0.08	49.12	-0.37
	2	01.02.06	23.04	0.08	10.0	48.83	0.17	0.37	-0.04	49.14	-0.35
	3	04.02.06	22.96	0.08	10.0	49.01	0.16	0.35	0.04	49.17	-0.11
	4	05.02.06	23.00	0.08	10.0	48.95	0.16	0.35	0.00	49.18	-0.23
	5	08.02.06	23.03	0.08	10.0	49.06	0.18	0.39	-0.03	49.21	-0.18
	6	10.02.06	23.04	0.08	10.0	48.16	0.16	0.35	-0.04	49.23	-1.11
	7	11.02.06	22.97	0.08	10.0	48.24	0.16	0.35	0.03	49.24	-0.96
	8	12.02.06	22.98	0.08	10.0	48.10	0.17	0.37	0.02	49.25	-1.12
	9	13.02.06	23.00	0.08	10.0	48.25	0.16	0.35	0.00	49.26	-1.01
	10	14.02.06	23.00	0.08	10.0	48.18	0.17	0.37	0.00	49.27	-1.09
	11	15.02.06	23.00	0.08	10.0	48.10	0.16	0.35	0.00	49.28	-1.17
	12	16.02.06	23.01	0.08	10.0	48.18	0.16	0.35	-0.01	49.29	-1.12
	13	18.02.06	22.96	0.08	10.0	48.30	0.16	0.35	0.04	49.31	-0.96
	14	19.02.06	22.95	0.08	10.0	48.37	0.17	0.37	0.06	49.32	-0.89
	15	21.02.06	23.04	0.08	10.0	48.22	0.16	0.35	-0.04	49.34	-1.16
	16	22.02.06	23.09	0.08	10.0	48.35	0.16	0.35	-0.10	49.35	-1.10
	17	23.02.06	23.01	0.08	10.0	48.57	0.17	0.37	-0.01	49.36	-0.80
	18	25.02.06	23.05	0.08	10.0	48.42	0.16	0.35	-0.06	49.38	-1.01
	19	26.02.06	22.99	0.08	10.0	48.47	0.16	0.35	0.01	49.39	-0.91
	20	27.02.06	23.00	0.08	10.0	48.48	0.17	0.37	0.00	49.40	-0.91
7	MIKES, Finland										
	1	11.03.06	23.16	0.30	100.0	48.84	0.09	0.33	-0.17	49.52	-0.85
	2	13.03.06	23.32	0.30	100.0	49.17	0.16	0.58	-0.34	49.54	-0.71
	3	17.03.06	23.12	0.20	10.0	47.90	0.50	1.82	-0.13	49.58	-1.81
	4	20.03.06	22.98	0.20	100.0	49.41	0.15	0.55	0.03	49.61	-0.17
	5	24.03.06	23.01	0.20	40.0	49.87	0.50	1.82	-0.01	49.65	0.22

p	*Meas. #* m	Date $t_{p,1,m}$	$T_{p,1,m}$ (°C)	$u(T)$ (°C)	$V_{p,1,m}$ (V)	$O_{p,1,m}$ (ppm)	$u_{\text{r-}p,1,m}$ (ppm)	$u^*_{r-p,1,m}$ (ppm)	T,V-corr. (ppm)	$f(t_{p,1,m})$ (ppm)	$M_{p,1,m}$ (ppm)
	6	28.03.06	23.13	0.20	100.0	48.04	0.13	0.47	-0.13	49.68	-1.77
	7	29.03.06	23.24	0.20	100.0	49.22	0.19	0.69	-0.26	49.69	-0.73
8	OMH, Hungary										
	1	05.04.06	23.00	0.06	9.1	50.49	0.35	0.35	0.00	49.75	0.74
9	CMI, Czech Republic										
	1	11.05.06	23.00	0.50	9.0	49.00	0.10	0.10	0.00	50.10	-1.10
	2	15.05.06	23.00	0.50	9.0	49.00	0.10	0.10	0.00	50.13	-1.13
	3	23.05.06	23.00	0.50	9.0	49.00	0.10	0.10	0.00	50.21	-1.21
10	INM, Romania										
	1	12.10.06	23.09	0.04	10.0	57.00	2.50	2.54	-0.10	51.47	5.43
	2	12.10.06	23.17	0.04	10.0	55.00	2.50	2.54	-0.19	51.47	3.34
	3	13.10.06	23.16	0.04	10.0	53.00	2.50	2.54	-0.18	51.48	1.34
	4	13.10.06	23.16	0.04	10.0	54.00	2.50	2.54	-0.18	51.48	2.34
	5	13.10.06	23.19	0.04	10.0	54.00	2.50	2.54	-0.21	51.48	2.31
	6	13.10.06	23.21	0.04	10.0	60.00	2.50	2.54	-0.23	51.48	8.29
	7	18.10.06	23.19	0.04	10.0	60.00	2.50	2.54	-0.21	51.52	8.27
	8	18.10.06	23.17	0.04	10.0	58.00	2.50	2.54	-0.19	51.52	6.29
	9	19.10.06	23.09	0.04	10.0	54.00	2.50	2.54	-0.10	51.53	2.37
	10	20.10.06	23.10	0.04	10.0	53.00	2.50	2.54	-0.11	51.54	1.35
	11	20.10.06	22.92	0.04	10.0	58.00	2.50	2.54	0.09	51.54	6.55
	12	23.10.06	23.14	0.04	10.0	58.00	2.50	2.54	-0.15	51.56	6.28
	13	23.10.06	23.16	0.04	10.0	57.00	2.50	2.54	-0.18	51.56	5.26
	14	23.10.06	23.17	0.04	10.0	59.00	2.50	2.54	-0.19	51.56	7.25
	15	26.10.06	23.25	0.04	10.0	53.00	2.50	2.54	-0.28	51.59	1.14
	16	26.10.06	23.24	0.04	10.0	56.00	2.50	2.54	-0.26	51.59	4.15
	17	26.10.06	23.22	0.04	10.0	58.00	2.50	2.54	-0.24	51.59	6.17
	18	26.10.06	23.22	0.04	10.0	57.00	2.50	2.54	-0.24	51.59	5.17
	19	26.10.06	23.21	0.04	10.0	61.00	2.50	2.54	-0.23	51.59	9.18
	20	26.10.06	23.22	0.04	10.0	59.00	2.50	2.54	-0.24	51.59	7.17
1	METAS, CH										
	13	25.01.07	22.93	0.03	5.0	52.29	0.12	0.12	0.07	52.33	0.03
	14	30.01.07	23.06	0.03	5.0	52.51	0.12	0.12	-0.07	52.37	0.07
	15	05.02.07	23.05	0.03	5.0	52.49	0.12	0.12	-0.06	52.42	0.02
	16	12.02.07	23.07	0.03	5.0	52.55	0.12	0.12	-0.08	52.48	0.00
	17	27.02.07	22.97	0.03	5.0	52.53	0.12	0.12	0.03	52.59	-0.04
	18	15.03.07	22.97	0.03	5.0	52.65	0.12	0.12	0.04	52.71	-0.02
	19	05.04.07	22.99	0.03	5.0	52.88	0.12	0.12	0.01	52.87	0.02
	20	23.04.07	22.97	0.03	5.0	52.81	0.12	0.12	0.03	53.00	-0.16
	21	22.05.07	23.04	0.03	5.0	53.12	0.12	0.12	-0.04	53.21	-0.13
	22	29.05.07	23.04	0.03	5.0	53.22	0.12	0.12	-0.04	53.26	-0.09
	23	29.05.07	23.04	0.03	5.0	53.20	0.12	0.12	-0.04	53.26	-0.11
	24	04.07.07	23.02	0.03	5.0	53.59	0.12	0.12	-0.02	53.52	0.05
	25	05.07.07	23.02	0.03	5.0	53.41	0.12	0.12	-0.02	53.52	-0.13
	26	17.07.07	23.04	0.03	5.0	53.94	0.12	0.12	-0.04	53.61	0.30
	27	20.07.07	23.04	0.03	5.0	53.86	0.12	0.12	-0.04	53.63	0.19
	28	13.08.07	23.03	0.03	5.0	53.76	0.12	0.12	-0.04	53.79	-0.06

A 1.2 Loop A, 10 MΩ standard HR 7552, *a* = 2

p	*Meas. #* *m*	Date $t_{p,2,m}$	$T_{p,2,m}$ (°C)	$u(T)$ (°C)	$V_{p,2,m}$ (V)	$O_{p,2,m}$ (ppm)	$u_{\text{r-}p,2,m}$ (ppm)	$u^*_{r-p,2,m}$ (ppm)	*T*,V-corr. (ppm)	$f(t_{p,2,m})$ (ppm)	$M_{p,2,m}$ (ppm)
1	METAS, CH										
	1	15.04.05	22.91	0.03	5.0	40.61	0.20	0.20	0.14	40.47	0.27
	2	20.04.05	22.90	0.03	5.0	40.58	0.20	0.20	0.16	40.59	0.15
	3	28.04.05	22.92	0.03	5.0	40.69	0.20	0.20	0.14	40.78	0.04
	4	10.05.05	22.91	0.03	5.0	40.83	0.20	0.20	0.14	41.06	-0.10
	5	25.05.05	22.93	0.03	5.0	41.08	0.20	0.20	0.12	41.40	-0.20
	6	26.05.05	22.91	0.03	5.0	41.23	0.20	0.20	0.14	41.40	-0.03
	7	10.06.05	22.92	0.03	5.0	41.49	0.20	0.20	0.13	41.74	-0.13
	8	27.06.05	22.92	0.03	5.0	41.84	0.20	0.20	0.13	42.10	-0.13
2	PTB, Germany										
	1	28.07.05	22.92	0.03	10.0	41.00	0.20	0.54	0.13	42.70	-1.57
	2	01.08.05	23.06	0.03	10.0	41.30	0.20	0.54	-0.10	42.77	-1.57
	3	03.08.05	22.91	0.03	10.0	40.40	0.30	0.81	0.14	42.81	-2.26
	4	05.08.05	23.03	0.03	10.0	41.60	0.40	1.08	-0.05	42.85	-1.29
	5	09.08.05	23.02	0.03	10.0	41.20	0.20	0.54	-0.03	42.92	-1.75
	6	12.08.05	22.97	0.03	10.0	42.00	0.30	0.81	0.05	42.98	-0.93
	7	16.08.05	23.00	0.03	10.0	43.40	0.50	1.36	0.00	43.05	0.35
	8	22.08.05	23.03	0.03	10.0	42.80	0.20	0.54	-0.05	43.16	-0.40
3	SIQ, Slovenia										
	1	09.09.05	23.14	0.05	10.0	43.20	0.10	0.22	-0.22	43.48	-0.51
	2	10.09.05	23.16	0.05	10.0	43.30	0.10	0.22	-0.26	43.50	-0.46
	3	11.09.05	23.14	0.05	10.0	43.30	0.10	0.22	-0.22	43.52	-0.44
	4	12.09.05	23.07	0.05	10.0	43.30	0.10	0.22	-0.11	43.53	-0.35
	5	27.09.05	22.94	0.05	10.0	43.80	0.10	0.22	0.10	43.78	0.11
	6	28.09.05	22.93	0.05	10.0	43.90	0.10	0.22	0.11	43.79	0.22
	7	29.09.05	23.10	0.05	10.0	44.30	0.30	0.66	-0.16	43.81	0.33
	8	29.09.05	22.91	0.05	10.0	43.70	0.10	0.22	0.14	43.81	0.03
	9	29.09.05	22.98	0.05	10.0	43.90	0.20	0.44	0.03	43.82	0.11
	10	30.09.05	22.86	0.05	10.0	43.80	0.10	0.22	0.22	43.83	0.20
	11	30.09.05	23.03	0.05	10.0	43.70	0.10	0.22	-0.05	43.83	-0.18
	12	30.09.05	22.77	0.05	10.0	43.40	0.20	0.44	0.37	43.83	-0.07
	13	01.10.05	22.65	0.05	10.0	43.00	0.10	0.22	0.56	43.84	-0.28
	14	01.10.05	22.72	0.05	10.0	43.10	0.10	0.22	0.45	43.85	-0.30
	15	01.10.05	22.70	0.05	10.0	43.50	0.20	0.44	0.48	43.85	0.13
	16	02.10.05	22.82	0.05	10.0	43.50	0.10	0.22	0.29	43.86	-0.07
	17	02.10.05	22.78	0.05	10.0	43.40	0.10	0.22	0.35	43.86	-0.11
	18	02.10.05	22.75	0.05	10.0	43.50	0.20	0.44	0.40	43.87	0.03
4	SMU, Slovak Republic										
	1	19.10.05	23.00	0.10	10.0	51.35	0.56	1.44	0.00	44.12	7.23
	2	24.10.05	22.90	0.10	10.0	52.03	0.32	0.83	0.16	44.19	8.00
	3	28.10.05	23.00	0.10	10.0	49.55	0.85	2.19	0.00	44.25	5.30
	4	31.10.05	23.00	0.10	10.0	49.87	0.55	1.42	0.00	44.29	5.58
5	VSL, Netherland										
	1	14.11.05	23.05	0.00	9.1	42.18	0.30	0.36	-0.09	44.49	-2.40
	2	15.11.05	23.03	0.00	9.1	42.63	0.21	0.25	-0.05	44.51	-1.92
	3	16.11.05	23.07	0.01	9.1	42.75	0.21	0.25	-0.11	44.52	-1.89
	4	17.11.05	23.08	0.00	9.1	42.71	0.29	0.34	-0.12	44.54	-1.95
	5	18.11.05	23.07	0.00	9.1	42.66	0.17	0.20	-0.11	44.55	-1.99

p	*Meas. #* *m*	Date $t_{p,2,m}$	$T_{p,2,m}$ (°C)	$u(T)$ (°C)	$V_{p,2,m}$ (V)	$O_{p,2,m}$ (ppm)	$u_{\text{r-}p,2,m}$ (ppm)	$u^{*}_{r-p,2,m}$ (ppm)	*T*,V-corr. (ppm)	$f(t_{p,2,m})$ (ppm)	$M_{p,2,m}$ (ppm)
	6	21.11.05	23.06	0.00	9.1	42.44	0.35	0.42	-0.10	44.59	-2.25
	7	23.11.05	23.03	0.00	9.1	42.18	0.29	0.34	-0.05	44.62	-2.49
	8	24.11.05	23.07	0.01	9.1	42.33	0.22	0.26	-0.10	44.63	-2.41
	9	25.11.05	23.07	0.00	9.1	42.50	0.21	0.25	-0.11	44.64	-2.26
	10	30.11.05	23.02	0.00	9.1	43.08	0.35	0.42	-0.04	44.71	-1.66
	11	01.12.05	23.04	0.00	9.1	42.62	0.35	0.42	-0.06	44.72	-2.17
	12	02.12.05	23.05	0.00	9.1	42.39	0.30	0.36	-0.09	44.74	-2.43
	13	05.12.05	23.06	0.01	9.1	41.99	0.35	0.42	-0.10	44.78	-2.89
	14	06.12.05	23.06	0.00	9.1	43.33	0.27	0.32	-0.10	44.79	-1.57
	15	09.12.05	23.07	0.00	9.1	43.22	0.21	0.25	-0.11	44.83	-1.72
	16	09.12.05	23.08	0.00	9.1	43.25	1.24	1.47	-0.13	44.83	-1.71
	17	12.12.05	23.08	0.00	9.1	42.35	1.16	1.38	-0.13	44.87	-2.65
	18	13.12.05	23.08	0.00	9.1	42.34	0.78	0.92	-0.13	44.88	-2.67
1	METAS, CH										
	9	29.12.05	23.02	0.03	5.0	45.16	0.15	0.15	-0.04	45.08	0.04
	10	09.01.06	22.98	0.03	5.0	45.24	0.15	0.15	0.03	45.21	0.05
	11	13.01.06	22.99	0.03	5.0	45.24	0.15	0.15	0.02	45.25	0.01
	12	19.01.06	22.99	0.03	5.0	45.27	0.15	0.15	0.02	45.32	-0.03
6	SPI, Lithuania										
	1	03.02.06	23.04	0.08	10.0	43.12	0.15	0.16	-0.06	45.47	-2.41
	2	05.02.06	23.00	0.08	10.0	43.05	0.14	0.15	0.00	45.49	-2.44
	3	06.02.06	23.00	0.08	10.0	43.34	0.15	0.16	0.00	45.50	-2.17
	4	08.02.06	23.05	0.08	10.0	43.08	0.16	0.17	-0.08	45.52	-2.52
	5	10.02.06	23.03	0.08	10.0	43.03	0.15	0.16	-0.05	45.54	-2.56
	6	11.02.06	22.95	0.08	10.0	43.12	0.14	0.15	0.08	45.55	-2.35
	7	12.02.06	22.94	0.08	10.0	43.28	0.14	0.15	0.10	45.56	-2.18
	8	13.02.06	23.02	0.08	10.0	43.07	0.16	0.17	-0.03	45.57	-2.53
	9	14.02.06	23.00	0.08	10.0	42.85	0.15	0.16	0.00	45.58	-2.73
	10	16.02.06	23.03	0.08	10.0	42.93	0.14	0.15	-0.05	45.60	-2.72
	11	17.02.06	23.00	0.08	10.0	43.33	0.14	0.15	0.00	45.61	-2.28
	12	18.02.06	22.98	0.08	10.0	43.15	0.15	0.16	0.03	45.62	-2.43
	13	19.02.06	22.95	0.08	10.0	43.09	0.14	0.15	0.08	45.63	-2.46
	14	21.02.06	23.06	0.08	10.0	43.12	0.15	0.16	-0.10	45.65	-2.62
	15	22.02.06	23.09	0.08	10.0	43.33	0.15	0.16	-0.14	45.65	-2.47
	16	25.02.06	23.00	0.08	10.0	43.12	0.14	0.15	0.00	45.68	-2.56
	17	26.02.06	23.03	0.08	10.0	43.19	0.15	0.16	-0.05	45.69	-2.55
	18	27.02.06	23.01	0.08	10.0	43.14	0.15	0.16	-0.02	45.70	-2.57
7	MIKES, Finland										
	1	12.03.06	23.38	0.30	100.0	44.52	0.11	0.42	-0.53	45.82	-1.83
	2	13.03.06	23.38	0.30	100.0	45.03	0.16	0.61	-0.53	45.83	-1.33
	3	17.03.06	23.23	0.20	10.0	44.40	0.50	1.90	-0.37	45.86	-1.83
	4	21.03.06	22.97	0.20	100.0	44.15	0.08	0.32	0.12	45.89	-1.62
	5	24.03.06	23.12	0.20	40.0	43.00	0.50	1.90	-0.17	45.92	-3.08
	6	28.03.06	23.20	0.20	100.0	43.79	0.25	0.95	-0.24	45.95	-2.40
	7	29.03.06	23.28	0.20	100.0	42.84	0.20	0.76	-0.37	45.96	-3.48
	8	30.03.06	23.21	0.20	100.0	44.56	0.06	0.23	-0.26	45.96	-1.66
8	OMH, Hungary										
	1	05.04.06	23.00	0.06	9.1	45.09	0.35	0.35	0.00	46.00	-0.91

p	*Meas. # m*	Date $t_{p,2,m}$	$T_{p,2,m}$ (°C)	$u(T)$ (°C)	$V_{p,2,m}$ (V)	$O_{p,2,m}$ (ppm)	$u_{\text{r-}p,2,m}$ (ppm)	$u^*_{r-p,2,m}$ (ppm)	*T*,V-corr. (ppm)	$f(t_{p,2,m})$ (ppm)	$M_{p,2,m}$ (ppm)
9	CMI, Czech Republic										
	1	11.05.06	23.00	0.50	9.0	45.00	0.10	0.10	0.00	46.24	-1.24
	2	15.05.06	23.00	0.50	9.0	45.00	0.10	0.10	0.00	46.26	-1.26
	3	23.05.06	23.00	0.50	9.0	45.00	0.10	0.10	0.00	46.30	-1.30
10	INM, Romania										
	1	12.10.06	23.10	0.04	10.0	53.00	2.74	2.79	-0.16	46.55	6.29
	2	12.10.06	23.20	0.04	10.0	57.00	2.74	2.79	-0.32	46.55	10.13
	3	13.10.06	23.16	0.04	10.0	59.00	2.74	2.79	-0.26	46.54	12.20
	4	13.10.06	23.16	0.04	10.0	57.00	2.74	2.79	-0.26	46.54	10.20
	5	13.10.06	23.20	0.04	10.0	55.00	2.74	2.79	-0.32	46.54	8.14
	6	13.10.06	23.21	0.04	10.0	64.00	2.74	2.79	-0.34	46.54	17.12
	7	18.10.06	23.16	0.04	10.0	56.00	2.74	2.79	-0.26	46.54	9.21
	8	18.10.06	23.17	0.04	10.0	55.00	2.74	2.79	-0.27	46.54	8.19
	9	19.10.06	23.10	0.04	10.0	57.00	2.74	2.79	-0.16	46.53	10.31
	10	20.10.06	23.10	0.04	10.0	55.00	2.74	2.79	-0.16	46.53	8.31
	11	20.10.06	23.10	0.04	10.0	59.00	2.74	2.79	-0.16	46.53	12.31
	12	23.10.06	22.95	0.04	10.0	57.00	2.74	2.79	0.08	46.53	10.55
	13	23.10.06	23.14	0.04	10.0	57.00	2.74	2.79	-0.22	46.53	10.25
	14	23.10.06	23.15	0.04	10.0	58.00	2.74	2.79	-0.24	46.53	11.23
	15	26.10.06	23.17	0.04	10.0	64.00	2.74	2.79	-0.27	46.52	17.21
	16	26.10.06	23.16	0.04	10.0	60.00	2.74	2.79	-0.26	46.52	13.22
	17	26.10.06	23.22	0.04	10.0	60.00	2.74	2.79	-0.35	46.52	13.13
	18	26.10.06	23.22	0.04	10.0	60.00	2.74	2.79	-0.35	46.52	13.13
	19	26.10.06	23.23	0.04	10.0	58.00	2.74	2.79	-0.37	46.52	11.11
	20	26.10.06	23.21	0.04	10.0	60.00	2.74	2.79	-0.34	46.52	13.14
1	METAS, CH										
	13	12.02.07	23.07	0.03	5.0	45.85	0.15	0.27	-0.11	45.99	-0.25
	14	27.02.07	22.97	0.03	5.0	46.16	0.15	0.27	0.04	45.88	0.32
	15	15.03.07	22.97	0.03	5.0	46.02	0.15	0.27	0.05	45.74	0.33
	16	05.04.07	22.98	0.03	5.0	45.24	0.15	0.27	0.03	45.55	-0.29
	17	23.04.07	22.98	0.03	5.0	45.18	0.15	0.27	0.04	45.36	-0.14
	18	22.05.07	23.04	0.03	5.0	45.11	0.15	0.27	-0.06	45.03	0.01

A 1.3 Loop A, 10 MΩ standard MI 105109, *a* = 3

p	*Meas. # m*	Date $t_{p,3,m}$	$T_{p,3,m}$ (°C)	$u(T)$ (°C)	$V_{p,3,m}$ (V)	$O_{p,3,m}$ (ppm)	$u_{\text{r-}p,3,m}$ (ppm)	$u^*_{r-p,3,m}$ (ppm)	*T*,V-corr. (ppm)	$f(t_{p,3,m})$ (ppm)	$M_{p,3,m}$ (ppm)
1	METAS, CH										
	1	30.03.05	20.03	0.03	5.0	-3.71	0.16	0.16	2.63	-1.27	0.19
	2	31.03.05	21.18	0.03	5.0	-2.60	0.16	0.16	1.59	-1.21	0.20
	3	01.04.05	21.18	0.03	5.0	-2.69	0.16	0.16	1.59	-1.18	0.08
	4	04.04.05	22.03	0.03	5.0	-1.83	0.16	0.16	0.83	-1.03	0.03
	5	07.04.05	22.91	0.03	5.0	-1.00	0.16	0.16	0.08	-0.90	-0.01
	6	28.04.05	22.91	0.03	5.0	-0.30	0.16	0.16	0.07	0.02	-0.25
	7	10.05.05	22.91	0.03	5.0	0.14	0.16	0.16	0.08	0.53	-0.30
	8	26.05.05	22.91	0.03	5.0	1.15	0.16	0.16	0.08	1.19	0.05
	9	10.06.05	22.92	0.03	5.0	1.67	0.16	0.16	0.07	1.78	-0.04
	10	27.06.05	22.91	0.03	5.0	2.30	0.16	0.16	0.07	2.43	-0.06

p	Meas. # m	Date $t_{p,3,m}$	$T_{p,3,m}$ (°C)	$u(T)$ (°C)	$V_{p,3,m}$ (V)	$O_{p,3,m}$ (ppm)	$u_{\text{r-}p,3,m}$ (ppm)	$u^*_{r-p,3,m}$ (ppm)	T,V-corr. (ppm)	$f(t_{p,3,m})$ (ppm)	$M_{p,3,m}$ (ppm)
2	PTB, Germany										
	1	28.07.05	23.04	0.03	10.0	3.80	0.20	0.79	-0.03	3.55	0.22
	2	01.08.05	22.95	0.03	10.0	1.50	0.20	0.79	0.04	3.69	-2.15
	3	03.08.05	23.01	0.03	10.0	2.50	0.20	0.79	-0.01	3.76	-1.27
	4	05.08.05	23.04	0.03	10.0	3.00	0.30	1.18	-0.03	3.83	-0.86
	5	09.08.05	23.05	0.04	10.0	3.00	0.20	0.79	-0.04	3.97	-1.01
	6	11.08.05	23.00	0.03	10.0	2.70	0.20	0.79	0.00	4.04	-1.34
	7	16.08.05	23.00	0.03	10.0	3.00	0.30	1.18	0.00	4.21	-1.21
	8	22.08.05	23.03	0.03	10.0	4.60	0.20	0.79	-0.03	4.41	0.16
3	SIQ, Slovenia										
	1	09.09.05	23.17	0.05	10.0	7.60	0.10	0.83	-0.15	5.03	2.43
	2	10.09.05	23.17	0.05	10.0	8.10	0.10	0.83	-0.15	5.06	2.89
	3	11.09.05	22.96	0.05	10.0	8.10	0.10	0.83	0.03	5.09	3.04
	4	12.09.05	23.02	0.05	10.0	7.80	0.10	0.83	-0.02	5.12	2.66
	5	27.09.05	22.95	0.05	10.0	8.00	0.10	0.83	0.04	5.60	2.44
	6	28.09.05	22.97	0.05	10.0	8.20	0.10	0.83	0.03	5.61	2.61
	7	29.09.05	22.97	0.05	10.0	9.10	0.10	0.83	0.03	5.65	3.47
	8	29.09.05	22.95	0.05	10.0	9.20	0.50	4.16	0.04	5.66	3.58
	9	29.09.05	23.01	0.05	10.0	8.90	0.10	0.83	-0.01	5.67	3.22
	10	30.09.05	23.02	0.05	10.0	8.60	0.20	1.66	-0.02	5.68	2.90
	11	30.09.05	22.94	0.05	10.0	7.90	0.10	0.83	0.05	5.69	2.26
	12	30.09.05	22.69	0.05	10.0	7.20	0.20	1.66	0.26	5.70	1.77
	13	01.10.05	22.74	0.05	10.0	6.20	0.10	0.83	0.22	5.72	0.71
	14	01.10.05	22.66	0.05	10.0	6.10	0.20	1.66	0.29	5.72	0.67
	15	01.10.05	22.72	0.05	10.0	6.30	0.20	1.66	0.24	5.73	0.81
	16	02.10.05	22.81	0.05	10.0	6.20	0.20	1.66	0.16	5.75	0.62
	17	02.10.05	22.78	0.05	10.0	5.90	0.20	1.66	0.19	5.75	0.33
	18	02.10.05	22.75	0.05	10.0	6.20	0.10	0.83	0.21	5.76	0.65
4	SMU, Slovak Republic										
	1	19.10.05	23.00	0.10	10.0	15.60	1.20	1.39	0.00	6.25	9.35
	2	24.10.05	22.90	0.10	10.0	13.95	0.65	0.75	0.09	6.40	7.64
	3	27.10.05	23.00	0.10	10.0	13.60	1.00	1.16	0.00	6.49	7.11
	4	31.10.05	23.00	0.10	10.0	12.90	1.00	1.16	0.00	6.61	6.29
5	VSL, Netherland										
	1	14.11.05	23.05	0.01	9.1	6.57	0.38	0.68	-0.04	7.01	-0.48
	2	15.11.05	23.02	0.01	9.1	7.22	0.09	0.16	-0.02	7.04	0.16
	3	16.11.05	23.05	0.01	9.1	7.24	0.37	0.66	-0.04	7.07	0.13
	4	17.11.05	23.06	0.01	9.1	7.14	0.30	0.53	-0.05	7.10	-0.01
	5	18.11.05	23.11	0.00	9.1	7.18	0.33	0.59	-0.10	7.12	-0.04
	6	21.11.05	23.19	0.00	9.1	6.70	0.49	0.87	-0.16	7.21	-0.67
	7	23.11.05	23.03	0.00	9.1	6.69	0.37	0.66	-0.02	7.26	-0.60
	8	24.11.05	23.06	0.00	9.1	6.72	0.23	0.41	-0.05	7.29	-0.63
	9	25.11.05	23.12	0.00	9.1	7.21	0.21	0.37	-0.10	7.32	-0.21
	10	29.11.05	23.06	0.01	9.1	6.79	0.14	0.25	-0.05	7.43	-0.69
	11	30.11.05	23.07	0.01	9.1	7.36	0.33	0.59	-0.06	7.46	-0.16
	12	01.12.05	23.09	0.01	9.1	7.06	0.37	0.66	-0.07	7.49	-0.50
	13	02.12.05	23.09	0.00	9.1	6.86	0.15	0.27	-0.08	7.51	-0.73
	14	05.12.05	23.10	0.01	9.1	6.58	0.42	0.75	-0.09	7.60	-1.11
	15	06.12.05	23.11	0.00	9.1	7.42	0.72	1.28	-0.09	7.62	-0.29
	16	09.12.05	23.11	0.00	9.1	7.62	0.61	1.09	-0.09	7.71	-0.18

p	*Meas. #* m	Date $t_{p,3,m}$	$T_{p,3,m}$ (°C)	$u(T)$ (°C)	$V_{p,3,m}$ (V)	$O_{p,3,m}$ (ppm)	$u_{\text{r-}p,3,m}$ (ppm)	$u^*_{r-p,3,m}$ (ppm)	T,V-corr. (ppm)	$f(t_{p,3,m})$ (ppm)	$M_{p,3,m}$ (ppm)
	17	09.12.05	23.12	0.00	9.1	7.42	0.22	0.39	-0.10	7.71	-0.38
	18	12.12.05	23.11	0.01	9.1	7.33	0.13	0.23	-0.10	7.79	-0.56
	19	13.12.05	23.12	0.00	9.1	7.38	0.31	0.55	-0.10	7.81	-0.54
1	METAS, CH										
	11	29.12.05	23.05	0.03	5.0	8.30	0.15	0.15	-0.05	8.26	0.00
	12	09.01.06	22.98	0.03	5.0	8.66	0.15	0.15	0.02	8.54	0.14
	13	13.01.06	22.99	0.03	5.0	8.65	0.15	0.15	0.01	8.64	0.03
	14	19.01.06	22.99	0.03	5.0	8.63	0.15	0.15	0.01	8.79	-0.15
6	SPI, Lithuania										
	1	30.01.06	23.07	0.08	10.0	8.54	0.17	0.17	-0.06	9.06	-0.58
	2	01.02.06	23.03	0.08	10.0	8.60	0.17	0.17	-0.03	9.10	-0.53
	3	04.02.06	22.99	0.08	10.0	8.65	0.16	0.16	0.01	9.18	-0.52
	4	05.02.06	23.00	0.08	10.0	8.67	0.16	0.16	0.00	9.20	-0.53
	5	06.02.06	23.00	0.08	10.0	8.75	0.17	0.17	0.00	9.23	-0.47
	6	08.02.06	23.05	0.08	10.0	8.57	0.16	0.16	-0.04	9.28	-0.75
	7	10.02.06	23.01	0.08	10.0	8.44	0.17	0.17	-0.01	9.32	-0.90
	8	11.02.06	22.98	0.08	10.0	8.45	0.17	0.17	0.02	9.35	-0.88
	9	12.02.06	23.01	0.08	10.0	8.61	0.17	0.17	-0.01	9.37	-0.77
	10	13.02.06	23.02	0.08	10.0	8.61	0.23	0.23	-0.02	9.40	-0.81
	11	14.02.06	23.00	0.08	10.0	8.72	0.16	0.16	0.00	9.42	-0.70
	12	15.02.06	23.00	0.08	10.0	8.80	0.16	0.16	0.00	9.45	-0.64
	13	16.02.06	23.00	0.08	10.0	9.00	0.17	0.17	0.00	9.47	-0.47
	14	17.02.06	23.00	0.08	10.0	9.07	0.17	0.17	0.00	9.49	-0.43
	15	18.02.06	22.98	0.08	10.0	8.95	0.17	0.17	0.02	9.52	-0.55
	16	19.02.06	22.95	0.08	10.0	9.03	0.16	0.16	0.04	9.54	-0.47
	17	21.02.06	23.01	0.08	10.0	8.97	0.16	0.16	-0.01	9.59	-0.62
	18	23.02.06	23.01	0.08	10.0	9.16	0.17	0.17	-0.01	9.64	-0.49
	19	25.02.06	23.06	0.08	10.0	9.08	0.17	0.17	-0.05	9.68	-0.66
	20	26.02.06	22.98	0.08	10.0	9.23	0.17	0.17	0.02	9.71	-0.47
	21	27.02.06	23.01	0.08	10.0	9.14	0.17	0.17	-0.01	9.73	-0.60
7	MIKES, Finland										
	1	10.03.06	23.37	0.30	100.0	8.58	0.18	0.76	-0.35	10.00	-1.77
	2	11.03.06	23.33	0.20	100.0	8.39	0.15	0.64	-0.31	10.03	-1.95
	3	13.03.06	23.38	0.20	100.0	6.28	0.25	1.06	-0.36	10.07	-4.15
	4	14.03.06	23.34	0.20	100.0	8.18	0.12	0.51	-0.32	10.09	-2.23
	5	17.03.06	23.21	0.20	100.0	9.00	0.60	2.55	-0.21	10.15	-1.36
	6	21.03.06	23.21	0.20	100.0	8.56	0.19	0.81	-0.22	10.25	-1.90
	7	23.03.06	22.88	0.20	100.0	10.50	1.00	4.25	0.07	10.30	0.27
	8	24.03.06	22.85	0.20	100.0	8.85	0.60	2.55	0.09	10.32	-1.38
	9	27.03.06	23.05	0.20	100.0	7.50	0.50	2.12	-0.08	10.39	-2.96
	10	28.03.06	23.28	0.20	100.0	7.01	0.21	0.89	-0.27	10.41	-3.67
	11	28.03.06	23.28	0.20	100.0	10.76	0.42	1.78	-0.27	10.42	0.07
	12	29.03.06	23.19	0.20	100.0	9.26	0.09	0.38	-0.20	10.43	-1.36
	13	29.03.06	23.10	0.20	100.0	8.65	0.51	2.17	-0.12	10.44	-1.91
	14	30.03.06	23.15	0.20	100.0	8.80	0.01	0.04	-0.16	10.45	-1.81
8	OMH, Hungary										
	1	05.04.06	23.00	0.06	9.1	9.69	0.35	0.35	0.00	10.58	-0.89
9	CMI, Czech Republic										
	1	11.05.06	23.00	0.50	9.0	11.00	0.10	0.13	0.00	11.35	-0.35

p	*Meas. #* *m*	Date $t_{p,3,m}$	$T_{p,3,m}$ (°C)	$u(T)$ (°C)	$V_{p,3,m}$ (V)	$O_{p,3,m}$ (ppm)	$u_{\text{r-}p,3,m}$ (ppm)	$u^*_{r-p,3,m}$ (ppm)	T,V-corr. (ppm)	$f(t_{p,3,m})$ (ppm)	$M_{p,3,m}$ (ppm)
	2	15.05.06	23.00	0.50	9.0	11.00	0.10	0.13	0.00	11.43	-0.43
	3	23.05.06	23.00	0.50	9.0	11.00	0.10	0.13	0.00	11.60	-0.60
10	INM, Romania										
	1	12.10.06	23.09	0.04	10.0	26.00	2.50	2.50	-0.08	14.22	11.70
	2	13.10.06	23.16	0.04	10.0	23.00	2.50	2.50	-0.14	14.24	8.62
	3	14.10.06	23.20	0.04	10.0	18.00	2.50	2.50	-0.17	14.26	3.57
	4	15.10.06	23.18	0.04	10.0	21.00	2.50	2.50	-0.15	14.27	6.57
	5	16.10.06	23.20	0.04	10.0	21.00	2.50	2.50	-0.17	14.29	6.54
	6	17.10.06	23.18	0.04	10.0	21.00	2.50	2.50	-0.15	14.31	6.54
	7	18.10.06	23.18	0.04	10.0	22.00	2.50	2.50	-0.15	14.32	7.52
	8	19.10.06	23.11	0.04	10.0	19.00	2.50	2.50	-0.09	14.34	4.57
	9	20.10.06	23.01	0.04	10.0	21.00	2.50	2.50	-0.01	14.36	6.64
	10	21.10.06	22.92	0.04	10.0	24.00	2.50	2.50	0.07	14.37	9.70
	11	22.10.06	23.14	0.04	10.0	23.00	2.50	2.50	-0.12	14.39	8.49
	12	23.10.06	23.17	0.04	10.0	23.00	2.50	2.50	-0.15	14.41	8.45
	13	24.10.06	23.15	0.04	10.0	23.00	2.50	2.50	-0.13	14.42	8.45
	14	25.10.06	23.27	0.04	10.0	19.00	2.50	2.50	-0.23	14.44	4.33
	15	26.10.06	23.24	0.04	10.0	25.00	2.50	2.50	-0.20	14.45	10.34
	16	27.10.06	23.24	0.04	10.0	23.00	2.50	2.50	-0.20	14.47	8.32
	17	28.10.06	23.22	0.04	10.0	24.00	2.50	2.50	-0.19	14.49	9.32
	18	29.10.06	23.21	0.04	10.0	28.00	2.50	2.50	-0.18	14.50	13.32
	19	30.10.06	23.23	0.04	10.0	24.00	2.50	2.50	-0.20	14.52	9.28
1	METAS, CH										
	15	25.01.07	22.93	0.03	5.0	16.18	0.15	0.19	0.06	15.87	0.36
	16	30.01.07	23.06	0.03	5.0	16.02	0.15	0.19	-0.05	15.95	0.03
	17	05.02.07	23.05	0.03	5.0	16.07	0.15	0.19	-0.04	16.03	0.00
	18	12.02.07	23.07	0.03	5.0	16.23	0.15	0.19	-0.06	16.14	0.04
	19	05.04.07	22.99	0.03	5.0	16.90	0.15	0.19	0.01	16.87	0.04
	20	23.04.07	22.98	0.03	5.0	16.77	0.15	0.19	0.02	17.11	-0.32
	21	22.05.07	23.04	0.03	5.0	17.29	0.15	0.19	-0.03	17.50	-0.23
	22	04.07.07	23.01	0.03	5.0	18.16	0.15	0.19	-0.01	18.05	0.10
	23	05.07.07	23.01	0.03	5.0	17.93	0.15	0.19	-0.01	18.07	-0.14
	24	17.07.07	23.04	0.03	5.0	18.37	0.15	0.19	-0.03	18.22	0.13
	25	20.07.07	23.04	0.03	5.0	18.56	0.15	0.19	-0.03	18.25	0.28
	26	14.08.07	23.01	0.03	5.0	18.61	0.15	0.19	-0.01	18.55	0.05
	27	03.12.07	22.98	0.03	5.0	19.63	0.15	0.19	0.01	19.86	-0.22

A 1.4 Loop B, 10 MΩ standard MI 105110, *a* = 4

p	Meas. # m	Date $t_{p,4,m}$	$T_{p,4,m}$ (°C)	$u(T)$ (°C)	$V_{p,4,m}$ (V)	$O_{p,4,m}$ (ppm)	$u_{r\text{-}p,4,m}$ (ppm)	$u^*_{r-p,4,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,4,m})$ (ppm)	$M_{p,4,m}$ (ppm)
1	METAS, CH										
	1	03.03.05	22.98	0.05	5.0	12.83	0.50	0.55	-0.04	13.78	-0.98
	2	10.03.05	22.98	0.05	5.0	13.89	0.50	0.55	-0.04	14.49	-0.64
	3	22.03.05	23.11	0.05	5.0	15.52	0.50	0.55	0.14	15.62	0.04
	4	30.03.05	20.03	0.05	5.0	13.36	0.50	0.55	3.18	16.31	0.23
	5	31.03.05	21.18	0.05	5.0	16.66	0.50	0.55	0.31	16.43	0.54
	6	01.04.05	21.18	0.05	5.0	16.42	0.50	0.55	0.31	16.49	0.25
	7	04.04.05	22.04	0.05	5.0	17.13	0.50	0.55	-0.49	16.78	-0.13
	8	07.04.05	22.91	0.05	5.0	17.65	0.50	0.55	-0.12	17.01	0.52
	9	01.06.05	22.92	0.05	5.0	22.06	0.50	0.55	-0.11	21.21	0.74
	10	10.06.05	22.92	0.05	5.0	22.39	0.50	0.55	-0.11	21.80	0.48
12	NML, Ireland										
	1	02.08.05	23.16	0.10	5.0	-25.70	0.30	3.36	0.19	24.86	-50.37
	2	03.08.05	23.12	0.10	5.0	-24.90	0.30	3.36	0.14	24.91	-49.67
	3	04.08.05	23.22	0.10	5.0	-22.60	0.50	5.59	0.26	24.96	-47.30
	4	05.08.05	23.28	0.10	5.0	-26.60	0.90	10.07	0.34	25.01	-51.28
	5	08.08.05	23.32	0.10	5.0	-17.80	0.50	5.59	0.39	25.16	-42.58
	6	09.08.05	22.64	0.10	5.0	-28.90	0.60	6.71	-0.46	25.21	-54.57
	7	10.08.05	23.33	0.10	5.0	-37.80	0.60	6.71	0.40	25.27	-62.67
	8	11.08.05	23.32	0.10	5.0	-36.20	0.30	3.36	0.39	25.32	-61.13
	9	12.08.05	23.02	0.10	5.0	-31.20	4.50	50.34	0.01	25.36	-56.55
	10	15.08.05	22.50	0.10	5.0	-25.40	2.00	22.37	-0.63	25.51	-51.55
	11	16.08.05	23.13	0.10	5.0	-27.50	1.50	16.78	0.15	25.56	-52.91
	12	17.08.05	23.13	0.10	5.0	-33.10	1.00	11.19	0.15	25.61	-58.56
	13	18.08.05	23.14	0.10	5.0	-32.50	0.80	8.95	0.16	25.66	-58.00
	14	19.08.05	23.21	0.10	5.0	-32.80	1.20	13.42	0.25	25.71	-58.26
	15	24.08.05	23.21	0.10	5.0	-29.50	1.40	15.66	0.25	25.95	-55.20
	16	24.08.05	23.26	0.10	5.0	-29.20	0.40	4.47	0.31	25.95	-54.84
13	JV, Norway										
	1	26.09.05	23.00	0.10	9.1	30.24	0.24	0.24	0.00	27.40	2.84
	2	26.09.05	23.00	0.10	9.1	30.38	0.65	0.65	0.00	27.40	2.98
	3	27.09.05	23.00	0.10	9.1	30.15	0.25	0.25	0.00	27.44	2.71
14	INETI, Portugal										
	1	12.10.05	23.12	0.11	10.0	-69.27	0.70	25.06	0.15	28.04	-97.16
	2	28.10.05	22.94	0.11	10.0	-73.99	0.50	17.90	-0.07	28.64	-102.70
	3	31.10.05	23.13	0.11	10.0	-62.50	0.24	8.59	0.16	28.74	-91.08
	4	02.11.05	22.97	0.11	10.0	-51.40	0.10	3.58	-0.04	28.81	-80.25
15	LNMC, Lettland										
	1	25.11.05	23.10	0.10	9.8	-10.40	2.50	2.50	0.12	29.59	-39.87
1	METAS, CH										
	11	14.12.05	23.15	0.05	5.0	28.32	0.50	0.79	0.18	30.20	-1.69
	12	20.12.05	22.91	0.05	5.0	30.48	0.50	0.79	-0.11	30.37	-0.01
	13	23.12.05	22.89	0.05	5.0	29.48	0.50	0.79	-0.15	30.47	-1.13
	14	29.12.05	22.99	0.05	5.0	30.46	0.50	0.79	-0.03	30.63	-0.20

p	*Meas. #* *m*	Date $t_{p,4,m}$	$T_{p,4,m}$ (°C)	$u(T)$ (°C)	$V_{p,4,m}$ (V)	$O_{p,4,m}$ (ppm)	$u_{\text{r-}p,4,m}$ (ppm)	$u^*_{r-p,4,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,4,m})$ (ppm)	$M_{p,4,m}$ (ppm)
16	NPL, United Kingdom										
	1	27.01.06	23.09	0.10	10.0	10.07	0.02	0.64	0.11	31.41	-21.24
	2	30.01.06	23.08	0.10	10.0	11.53	0.05	1.96	0.10	31.48	-19.86
	3	01.02.06	23.11	0.10	10.0	10.98	0.70	27.91	0.14	31.53	-20.41
	4	01.02.06	23.11	0.10	10.0	11.85	0.02	0.76	0.14	31.53	-19.55
17	SMD, Belgium										
	1	01.03.06	22.97	0.05	10.0	39.40	0.36	0.36	-0.03	32.18	7.19
18	UME, Turkey										
	1	27.05.06	23.10	0.40	10.0	56.80	1.60	1.60	0.12	33.85	23.07
20	EIM, Greece										
	1	12.09.06	22.94	0.17	10.0	59.70	0.30	6.68	-0.07	35.37	24.26
	2	13.09.06	23.00	0.18	10.0	32.20	0.60	13.35	0.00	35.38	-3.18
	3	14.09.06	22.88	0.21	10.0	42.70	0.30	6.68	-0.15	35.39	7.16
	4	15.09.06	22.98	0.12	10.0	51.20	0.60	13.35	-0.02	35.40	15.77
	5	22.09.06	22.96	0.13	10.0	70.50	0.60	13.35	-0.05	35.49	34.96
	6	25.09.06	22.93	0.13	10.0	52.30	0.50	11.13	-0.09	35.52	16.69
	7	29.09.06	22.82	0.13	10.0	52.30	0.90	20.03	-0.22	35.57	16.51
	8	04.10.06	22.90	0.12	10.0	57.90	0.40	8.90	-0.12	35.62	22.15
	9	05.10.06	22.91	0.17	10.0	60.00	0.30	6.68	-0.11	35.63	24.25
	10	09.10.06	22.91	0.16	10.0	45.60	0.80	17.80	-0.11	35.68	9.81
21	BEV, Austria										
	1	25.10.06	23.01	0.05	100.0	42.78	0.69	10.29	0.24	35.86	7.16
	2	25.10.06	23.00	0.05	100.0	41.95	0.92	13.67	0.23	35.86	6.32
	3	26.10.06	23.01	0.05	100.0	40.81	0.89	13.21	0.23	35.86	5.18
	4	26.10.06	23.01	0.05	100.0	41.22	0.94	13.88	0.23	35.87	5.59
	5	26.10.06	23.01	0.05	100.0	42.57	0.84	12.53	0.23	35.87	6.93
	6	26.10.06	23.01	0.05	100.0	42.86	1.51	22.49	0.23	35.87	7.22
	7	26.10.06	23.01	0.05	100.0	44.71	0.66	9.77	0.23	35.87	9.07
	8	27.10.06	23.01	0.05	100.0	45.06	0.34	5.11	0.23	35.88	9.42
	9	27.10.06	23.01	0.05	100.0	44.40	0.42	6.20	0.23	35.88	8.76
	10	27.10.06	23.01	0.05	100.0	44.82	0.37	5.47	0.24	35.88	9.18
	11	28.10.06	23.00	0.05	100.0	50.69	7.19	106.68	0.23	35.89	15.03
	12	29.10.06	23.00	0.05	100.0	42.57	3.92	58.17	0.23	35.90	6.90
	13	30.10.06	23.01	0.05	100.0	37.20	7.01	103.99	0.24	35.91	1.53
	14	30.10.06	22.98	0.05	100.0	29.07	1.69	25.02	0.20	35.91	-6.65
	15	31.10.06	23.00	0.05	100.0	27.53	3.38	50.20	0.23	35.92	-8.16
	16	02.11.06	23.01	0.05	100.0	26.66	1.65	24.53	0.23	35.95	-9.05
	17	10.11.06	22.99	0.05	100.0	25.66	0.80	11.94	0.22	36.03	-10.15
	18	10.11.06	22.99	0.05	100.0	26.05	0.33	4.91	0.22	36.03	-9.76
	19	10.11.06	23.00	0.05	100.0	25.84	0.43	6.33	0.22	36.03	-9.97
	20	11.11.06	23.00	0.05	100.0	25.13	0.47	7.01	0.22	36.03	-10.68
	21	11.11.06	23.00	0.05	100.0	25.33	0.47	7.01	0.22	36.03	-10.48
	22	11.11.06	23.00	0.05	100.0	25.79	0.53	7.91	0.22	36.04	-10.03
	23	11.11.06	23.00	0.05	100.0	25.15	0.52	7.72	0.22	36.04	-10.67
	24	11.11.06	23.00	0.05	100.0	25.15	1.13	16.84	0.22	36.04	-10.67
	25	12.11.06	23.00	0.05	100.0	25.88	0.29	4.30	0.22	36.04	-9.94
	26	12.11.06	22.99	0.05	100.0	25.68	1.09	16.22	0.22	36.04	-10.14
	27	13.11.06	23.00	0.05	100.0	25.53	0.27	4.02	0.22	36.06	-10.31
	28	13.11.06	23.01	0.05	100.0	25.93	1.00	14.82	0.23	36.06	-9.90
	29	14.11.06	23.00	0.05	100.0	25.80	1.85	27.51	0.23	36.06	-10.03

p	*Meas. #* m	Date $t_{p,4,m}$	$T_{p,4,m}$ (°C)	$u(T)$ (°C)	$V_{p,4,m}$ (V)	$O_{p,4,m}$ (ppm)	$u_{\text{r-}p,4,m}$ (ppm)	$u^{*}_{r-p,4,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,4,m})$ (ppm)	$M_{p,4,m}$ (ppm)
	30	14.11.06	23.01	0.05	100.0	26.06	0.42	6.18	0.23	36.06	-9.77
	31	14.11.06	23.01	0.05	100.0	28.26	1.94	28.86	0.24	36.07	-7.57
	32	14.11.06	23.01	0.05	100.0	29.21	0.88	13.02	0.24	36.07	-6.62
	33	15.11.06	23.01	0.05	100.0	33.09	0.66	9.74	0.24	36.07	-2.74
	34	16.11.06	22.28	0.50	100.0	31.43	2.87	42.63	-0.67	36.08	-5.32
	35	18.11.06	22.33	0.51	100.0	33.13	2.65	39.39	-0.60	36.11	-3.58
1	METAS, CH										
	15	25.11.06	23.01	0.05	5.0	37.05	0.50	0.50	0.01	36.18	0.88
	16	26.11.06	23.02	0.05	5.0	36.40	0.50	0.50	0.01	36.19	0.22
22	CEM, SP										
	1	06.02.07	23.09	0.01	9.1	43.52	0.62	0.66	0.11	36.84	6.79
	2	07.02.07	23.05	0.01	9.1	43.01	0.62	0.66	0.06	36.84	6.23
	3	07.02.07	23.01	0.01	9.1	43.06	0.62	0.66	0.01	36.84	6.23
	4	07.02.07	23.05	0.01	9.1	43.27	0.62	0.66	0.05	36.84	6.48
	5	08.02.07	23.05	0.01	9.1	44.17	0.62	0.66	0.05	36.85	7.37
	6	08.02.07	23.05	0.01	9.1	43.75	0.62	0.66	0.05	36.85	6.95
	7	08.02.07	23.03	0.01	9.1	44.49	0.62	0.66	0.03	36.85	7.67
	8	09.02.07	23.03	0.01	9.1	44.81	0.62	0.66	0.03	36.86	7.98
	9	09.02.07	23.03	0.01	9.1	44.45	0.62	0.66	0.03	36.86	7.62
23	VNIIM, Russia										
	1	24.04.07	19.97	0.03	50.0	21.60	0.14	0.14	-3.67	37.44	-19.51
1	METAS, CH										
	17	03.07.07	23.04	0.05	5.0	37.79	0.50	1.15	0.03	37.94	-0.12
	18	06.07.07	23.04	0.05	5.0	38.57	0.50	1.15	0.04	37.96	0.65
	19	13.07.07	23.03	0.05	5.0	37.39	0.50	1.15	0.03	38.01	-0.59
	20	13.08.07	23.25	0.05	5.0	36.85	0.50	1.15	0.34	38.21	-1.01
	21	20.08.07	22.99	0.05	5.0	35.89	0.50	1.15	-0.03	38.25	-2.39
	22	03.12.07	22.98	0.05	5.0	39.59	0.50	1.15	-0.04	38.89	0.67

A 1.5 Loop B, 10 MΩ standard MI 105111, $a = 5$

p	*Meas. #* m	Date $t_{p,5,m}$	$T_{p,5,m}$ (°C)	$u(T)$ (°C)	$V_{p,5,m}$ (V)	$O_{p,5,m}$ (ppm)	$u_{\text{r-}p,5,m}$ (ppm)	$u^{*}_{r-p,5,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,5,m})$ (ppm)	$M_{p,5,m}$ (ppm)
1	METAS, CH										
	1	10.03.05	22.98	0.05	5.0	1.25	0.26	0.26	0.00	1.33	-0.09
	2	22.03.05	23.11	0.05	5.0	1.90	0.26	0.26	-0.06	1.89	-0.04
	3	30.03.05	20.03	0.05	5.0	-0.15	0.26	0.26	2.31	2.24	-0.08
	4	31.03.05	21.18	0.05	5.0	1.14	0.26	0.26	1.15	2.30	-0.01
	5	01.04.05	21.18	0.05	5.0	1.22	0.26	0.26	1.15	2.33	0.04
	6	04.04.05	22.04	0.05	5.0	1.84	0.26	0.26	0.50	2.49	-0.14
	7	07.04.05	22.91	0.05	5.0	2.54	0.26	0.26	0.03	2.61	-0.04
	8	28.04.05	22.91	0.05	5.0	3.27	0.26	0.26	0.03	3.55	-0.26
	9	26.05.05	22.91	0.05	5.0	5.25	0.26	0.26	0.03	4.78	0.50
	10	10.06.05	22.92	0.05	5.0	5.71	0.26	0.26	0.02	5.41	0.33

p	Meas. # m	Date $t_{p,5,m}$	$T_{p,5,m}$ (°C)	$u(T)$ (°C)	$V_{p,5,m}$ (V)	$O_{p,5,m}$ (ppm)	$u_{r\text{-}p,5,m}$ (ppm)	$u^*_{r-p,5,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,5,m})$ (ppm)	$M_{p,5,m}$ (ppm)
12	NML, Ireland										
	1	02.08.05	23.16	0.10	5.0	5.30	0.40	0.91	-0.08	7.56	-2.33
	2	03.08.05	23.12	0.10	5.0	5.80	0.30	0.68	-0.06	7.60	-1.86
	3	04.08.05	23.22	0.10	5.0	6.10	0.50	1.13	-0.10	7.64	-1.64
	4	05.08.05	23.28	0.10	5.0	6.90	0.70	1.59	-0.13	7.68	-0.90
	5	08.08.05	23.32	0.10	5.0	6.50	0.50	1.13	-0.14	7.79	-1.43
	6	09.08.05	22.64	0.10	5.0	7.20	0.30	0.68	0.14	7.83	-0.50
	7	10.08.05	23.33	0.10	5.0	6.70	0.70	1.59	-0.15	7.87	-1.32
	8	11.08.05	23.32	0.10	5.0	6.00	1.00	2.27	-0.14	7.91	-2.05
	9	12.08.05	23.32	0.10	5.0	7.20	0.60	1.36	-0.14	7.95	-0.89
	10	15.08.05	23.28	0.10	5.0	7.40	1.50	3.40	-0.13	8.07	-0.79
	11	16.08.05	23.13	0.10	5.0	7.00	0.40	0.91	-0.06	8.11	-1.17
	12	17.08.05	23.13	0.10	5.0	7.50	0.10	0.23	-0.06	8.14	-0.71
	13	18.08.05	23.14	0.10	5.0	8.60	0.40	0.91	-0.07	8.18	0.35
	14	19.08.05	23.21	0.10	5.0	6.40	0.20	0.45	-0.10	8.22	-1.92
13	JV, Norway										
	1	14.09.05	23.00	0.10	9.1	9.62	0.10	0.12	0.00	9.21	0.41
	2	26.09.05	23.00	0.10	9.1	10.43	0.21	0.25	0.00	9.66	0.77
	3	27.09.05	23.00	0.10	9.1	10.38	0.37	0.44	0.00	9.69	0.69
14	INETI, Portugal										
	1	12.10.05	23.10	0.11	10.0	-5.81	0.55	3.02	-0.04	10.24	-16.09
	2	13.10.05	23.10	0.11	10.0	-2.33	0.62	3.41	-0.04	10.27	-12.64
	3	02.11.05	22.94	0.11	10.0	-0.15	0.33	1.81	0.03	10.98	-11.10
15	LNMC, Lettland										
	1	25.11.05	23.10	0.10	9.8	5.90	2.50	2.50	-0.04	11.77	-5.91
1	METAS, CH										
	11	14.12.05	23.03	0.05	5.0	12.19	0.26	0.26	-0.02	12.42	-0.25
	12	20.12.05	22.90	0.05	5.0	12.83	0.26	0.26	0.03	12.61	0.25
	13	23.12.05	22.88	0.05	5.0	12.43	0.26	0.26	0.04	12.72	-0.25
	14	29.12.05	22.99	0.05	5.0	12.95	0.26	0.26	0.00	12.90	0.04
16	NPL, United Kingdom										
	1	30.01.06	23.09	0.10	10.0	10.56	0.07	0.15	-0.04	13.90	-3.38
	2	30.01.06	23.10	0.10	10.0	10.39	0.02	0.04	-0.04	13.90	-3.55
	3	01.02.06	23.11	0.10	10.0	10.63	0.06	0.13	-0.05	13.96	-3.38
	4	01.02.06	23.11	0.10	10.0	10.64	0.12	0.28	-0.05	13.96	-3.37
17	SMD, Belgium										
	1	03.03.06	22.99	0.05	10.0	18.10	0.13	0.13	0.00	14.83	3.27
18	UME, Turkey										
	1	26.05.06	23.13	0.40	10.0	20.00	0.70	0.70	-0.05	17.07	2.88
20	EIM, Greece										
	1	13.09.06	23.00	0.18	10.0	16.50	0.40	3.64	0.00	19.45	-2.95
	2	14.09.06	22.88	0.21	10.0	15.50	0.30	2.73	0.05	19.47	-3.92
	3	15.09.06	22.98	0.12	10.0	18.30	0.50	4.55	0.01	19.49	-1.18
	4	22.09.06	22.96	0.13	10.0	26.00	0.50	4.55	0.02	19.62	6.39

p	Meas. # m	Date $t_{p,5,m}$	$T_{p,5,m}$ (°C)	$u(T)$ (°C)	$V_{p,5,m}$ (V)	$O_{p,5,m}$ (ppm)	$u_{r\text{-}p,5,m}$ (ppm)	$u^*_{r-p,5,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,5,m})$ (ppm)	$M_{p,5,m}$ (ppm)
	5	25.09.06	22.93	0.13	10.0	19.30	0.50	4.55	0.03	19.68	-0.35
	6	29.09.06	22.82	0.13	10.0	9.70	0.60	5.46	0.07	19.75	-9.98
	7	04.10.06	22.90	0.12	10.0	12.70	0.60	5.46	0.04	19.84	-7.10
	8	05.10.06	22.91	0.17	10.0	14.10	0.50	4.55	0.04	19.86	-5.72
	9	09.10.06	22.91	0.16	10.0	7.90	1.30	11.84	0.04	19.93	-11.99
21	BEV, Austria										
	1	25.10.06	23.01	0.05	100.0	20.99	0.68	3.24	0.19	20.22	0.96
	2	25.10.06	23.00	0.05	100.0	20.64	1.00	4.75	0.19	20.22	0.61
	3	26.10.06	23.01	0.05	100.0	20.44	1.29	6.13	0.19	20.22	0.40
	4	26.10.06	23.01	0.05	100.0	20.85	0.80	3.78	0.19	20.23	0.81
	5	26.10.06	23.01	0.05	100.0	20.66	1.08	5.13	0.19	20.23	0.62
	6	26.10.06	23.00	0.05	100.0	22.06	1.67	7.92	0.19	20.23	2.01
	7	27.10.06	23.01	0.05	100.0	21.51	0.29	1.38	0.19	20.24	1.46
	8	27.10.06	23.01	0.05	100.0	22.88	0.31	1.47	0.19	20.24	2.82
	9	27.10.06	23.01	0.05	100.0	22.50	1.01	4.80	0.19	20.25	2.44
	10	27.10.06	23.00	0.05	100.0	22.15	0.35	1.65	0.19	20.25	2.09
	11	28.10.06	23.01	0.05	100.0	18.63	10.77	51.11	0.19	20.26	-1.44
	12	29.10.06	23.01	0.05	100.0	17.96	8.56	40.62	0.19	20.28	-2.13
	13	30.10.06	23.00	0.05	100.0	15.05	5.95	28.25	0.19	20.29	-5.05
	14	30.10.06	22.98	0.05	100.0	20.62	2.22	10.53	0.20	20.30	0.52
	15	31.10.06	23.00	0.05	100.0	17.04	2.76	13.09	0.19	20.31	-3.09
	16	02.11.06	23.01	0.05	100.0	15.85	3.04	14.44	0.19	20.35	-4.32
	17	10.11.06	23.00	0.05	100.0	17.37	0.31	1.45	0.19	20.48	-2.92
	18	10.11.06	22.99	0.05	100.0	16.94	0.56	2.66	0.19	20.48	-3.35
	19	10.11.06	23.00	0.05	100.0	17.19	0.27	1.28	0.19	20.48	-3.10
	20	11.11.06	23.00	0.05	100.0	17.04	0.72	3.44	0.19	20.49	-3.25
	21	11.11.06	23.00	0.05	100.0	16.59	0.28	1.32	0.19	20.49	-3.71
	22	11.11.06	22.99	0.05	100.0	17.04	0.37	1.76	0.19	20.49	-3.26
	23	11.11.06	23.00	0.05	100.0	17.27	0.45	2.12	0.19	20.49	-3.03
	24	11.11.06	23.00	0.05	100.0	17.41	0.91	4.32	0.19	20.50	-2.90
	25	12.11.06	22.99	0.05	100.0	17.51	0.94	4.46	0.19	20.50	-2.80
	26	12.11.06	23.00	0.05	100.0	17.42	0.75	3.57	0.19	20.50	-2.89
	27	13.11.06	23.00	0.05	100.0	17.01	0.72	3.42	0.19	20.53	-3.33
	28	14.11.06	23.01	0.05	100.0	17.52	0.75	3.54	0.19	20.53	-2.82
	29	14.11.06	23.01	0.05	100.0	16.50	0.25	1.18	0.19	20.53	-3.85
	30	14.11.06	23.01	0.05	100.0	17.16	0.61	2.90	0.19	20.54	-3.19
	31	14.11.06	23.01	0.05	100.0	18.08	1.66	7.89	0.19	20.54	-2.27
	32	14.11.06	23.01	0.05	100.0	18.71	0.59	2.78	0.19	20.54	-1.65
	33	15.11.06	23.01	0.05	100.0	18.89	1.01	4.79	0.18	20.55	-1.47
	34	16.11.06	22.33	0.51	100.0	19.35	0.82	3.91	0.46	20.56	-0.75
1	METAS, CH										
	15	25.11.06	23.01	0.05	5.0	20.77	0.26	0.26	-0.02	20.71	0.04
	16	26.11.06	23.02	0.05	5.0	20.61	0.26	0.26	-0.02	20.73	-0.13
22	CEM, SP										
	1	06.02.07	23.08	0.01	9.1	22.60	0.56	0.56	-0.03	21.68	0.89
	2	07.02.07	23.04	0.01	9.1	22.78	0.56	0.56	-0.02	21.69	1.07
	3	07.02.07	23.01	0.01	9.1	22.45	0.56	0.56	-0.01	21.69	0.75
	4	07.02.07	23.00	0.01	9.1	22.46	0.56	0.56	0.00	21.69	0.77
	5	08.02.07	23.04	0.01	9.1	22.86	0.56	0.56	-0.02	21.70	1.14
	6	08.02.07	23.04	0.01	9.1	22.73	0.56	0.56	-0.02	21.70	1.01

p	*Meas. #* m	Date $t_{p,5,m}$	$T_{p,5,m}$ (°C)	$u(T)$ (°C)	$V_{p,5,m}$ (V)	$O_{p,5,m}$ (ppm)	$u_{\text{r-}p,5,m}$ (ppm)	$u^*_{r-p,5,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,5,m})$ (ppm)	$M_{p,5,m}$ (ppm)
	7	08.02.07	23.03	0.01	9.1	22.73	0.56	0.56	-0.01	21.70	1.02
	8	09.02.07	23.03	0.01	9.1	23.12	0.56	0.56	-0.01	21.71	1.40
	9	09.02.07	23.03	0.01	9.1	22.85	0.56	0.56	-0.01	21.71	1.13
23	VNIIM, Russia										
	1	24.04.07	20.00	0.03	50.0	17.10	0.14	0.14	1.31	22.41	-4.00
1	METAS, CH										
	17	03.07.07	23.04	0.05	5.0	22.97	0.26	0.33	-0.03	22.83	0.12
	18	06.07.07	23.04	0.05	5.0	22.98	0.26	0.33	-0.03	22.84	0.12
	19	13.07.07	23.03	0.05	5.0	22.92	0.26	0.33	-0.02	22.86	0.03
	20	20.07.07	23.04	0.05	5.0	23.46	0.26	0.33	-0.03	22.89	0.55
	21	13.08.07	23.17	0.05	5.0	22.74	0.26	0.33	-0.07	22.95	-0.28
	22	20.08.07	22.99	0.05	5.0	22.61	0.26	0.33	0.00	22.96	-0.36

A 1.6 Loop B, 10 MΩ standard HR 7551, *a* = 6

p	*Meas. #* m	Date $t_{p,6,m}$	$T_{p,6,m}$ (°C)	$u(T)$ (°C)	$V_{p,6,m}$ (V)	$O_{p,6,m}$ (ppm)	$u_{\text{r-}p,6,m}$ (ppm)	$u^*_{r-p,6,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,6,m})$ (ppm)	$M_{p,6,m}$ (ppm)
1	METAS, CH										
	1	15.04.05	22.91	0.03	5.0	14.06	0.10	0.10	0.27	14.30	0.04
	2	20.04.05	22.90	0.03	5.0	14.03	0.10	0.10	0.30	14.32	0.01
	3	28.04.05	22.92	0.03	5.0	14.09	0.10	0.10	0.25	14.37	-0.03
	4	10.05.05	22.91	0.03	5.0	14.12	0.10	0.10	0.26	14.43	-0.05
	5	25.05.05	22.93	0.03	5.0	14.35	0.10	0.10	0.21	14.51	0.05
	6	26.05.05	22.91	0.03	5.0	14.21	0.10	0.10	0.27	14.51	-0.04
	7	10.06.05	22.92	0.03	5.0	14.31	0.10	0.10	0.23	14.59	-0.06
	8	27.06.05	22.92	0.03	5.0	14.35	0.10	0.10	0.24	14.68	-0.09
12	NML, Ireland										
	1	02.08.05	23.16	0.10	5.0	13.70	0.20	0.49	-0.49	14.86	-1.65
	2	03.08.05	23.12	0.10	5.0	15.80	0.80	1.95	-0.37	14.87	0.57
	3	04.08.05	23.22	0.10	5.0	15.80	0.50	1.22	-0.66	14.87	0.26
	4	05.08.05	23.28	0.10	5.0	16.60	0.90	2.19	-0.85	14.88	0.88
	5	08.08.05	23.32	0.10	5.0	14.80	0.40	0.97	-0.97	14.89	-1.06
	6	09.08.05	22.64	0.10	5.0	14.90	0.80	1.95	1.08	14.90	1.08
	7	10.08.05	23.33	0.10	5.0	16.80	0.30	0.73	-0.99	14.90	0.90
	8	11.08.05	23.32	0.10	5.0	15.70	0.50	1.22	-0.97	14.91	-0.17
	9	12.08.05	23.32	0.10	5.0	16.40	0.40	0.97	-0.97	14.91	0.52
	10	15.08.05	23.07	0.10	5.0	14.00	1.50	3.65	-0.22	14.93	-1.14
	11	16.08.05	23.13	0.10	5.0	15.20	1.00	2.44	-0.39	14.93	-0.13
	12	17.08.05	23.13	0.10	5.0	15.10	0.50	1.22	-0.39	14.94	-0.23
	13	18.08.05	23.14	0.10	5.0	15.80	0.60	1.46	-0.43	14.94	0.43
	14	19.08.05	23.21	0.10	5.0	15.80	1.20	2.92	-0.64	14.95	0.22
13	JV, Norway										
	1	01.09.05	23.00	0.10	9.1	14.84	0.31	0.31	0.00	15.01	-0.17
	2	02.09.05	23.00	0.10	9.1	14.83	0.47	0.47	0.00	15.02	-0.19
	3	06.09.05	23.00	0.10	9.1	14.71	0.51	0.51	0.00	15.04	-0.33
	4	07.09.05	23.00	0.10	9.1	14.84	0.31	0.31	0.00	15.04	-0.20

p	*Meas. #* m	Date $t_{p,6,m}$	$T_{p,6,m}$ (°C)	$u(T)$ (°C)	$V_{p,6,m}$ (V)	$O_{p,6,m}$ (ppm)	$u_{\mathrm{r}\text{-}p,6,m}$ (ppm)	$u^*_{r-p,6,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,6,m})$ (ppm)	$M_{p,6,m}$ (ppm)
	5	12.09.05	23.00	0.10	9.1	15.12	0.25	0.25	0.00	15.07	0.05
	6	12.09.05	23.00	0.10	9.1	15.09	0.08	0.08	0.00	15.07	0.02
	7	15.09.05	23.00	0.10	9.1	14.97	0.16	0.16	0.00	15.08	-0.11
	8	26.09.05	23.00	0.10	9.1	15.44	0.81	0.81	0.00	15.14	0.30
	9	26.09.05	23.00	0.10	9.1	14.74	0.59	0.59	0.00	15.14	-0.40
14	INETI, Portugal										
	1	28.10.05	23.12	0.10	10.0	-11.81	0.30	0.78	-0.37	15.29	-27.48
	2	31.10.05	23.16	0.10	10.0	-13.20	0.50	1.29	-0.47	15.31	-28.98
15	LNMC, Lettland										
	1	25.11.05	23.10	0.10	9.8	13.30	2.50	2.50	-0.30	15.43	-2.43
1	METAS, CH										
	9	14.12.05	23.01	0.03	5.0	15.61	0.10	0.10	-0.02	15.53	0.06
	10	20.12.05	22.92	0.03	5.0	15.40	0.10	0.10	0.23	15.55	0.08
	11	23.12.05	22.94	0.03	5.0	15.57	0.10	0.10	0.19	15.57	0.19
	12	29.12.05	22.99	0.03	5.0	15.58	0.10	0.10	0.04	15.60	0.03
16	NPL, United Kingdom										
	1	27.01.06	23.09	0.10	10.0	15.94	0.06	0.31	-0.28	15.73	-0.07
	2	30.01.06	23.08	0.10	10.0	16.05	0.04	0.21	-0.23	15.75	0.08
	3	01.02.06	23.17	0.10	10.0	15.78	0.05	0.26	-0.51	15.76	-0.48
	4	01.02.06	23.15	0.10	10.0	15.92	0.07	0.41	-0.45	15.76	-0.29
17	SMD, Belgium										
	1	16.03.06	23.00	0.02	10.0	19.00	0.07	0.07	-0.01	15.95	3.04
18	UME, Turkey										
	1	26.05.06	23.08	0.40	10.0	14.20	0.60	0.60	-0.24	16.27	-2.31
20	EIM, Greece										
	1	13.09.06	23.00	0.18	10.0	9.40	0.30	9.67	0.00	16.75	-7.35
	2	14.09.06	22.88	0.20	10.0	9.80	0.20	6.45	0.36	16.75	-6.59
	3	15.09.06	22.98	0.12	10.0	12.00	0.20	6.45	0.06	16.76	-4.70
	4	22.09.06	22.96	0.13	10.0	23.70	0.90	29.01	0.12	16.79	7.03
	5	25.09.06	22.93	0.13	10.0	10.70	0.30	9.67	0.21	16.80	-5.89
	6	29.09.06	22.82	0.13	10.0	-3.30	0.50	16.12	0.54	16.82	-19.58
	7	05.10.06	22.91	0.17	10.0	-4.40	0.20	6.45	0.27	16.84	-20.97
	8	06.10.06	22.90	0.14	10.0	-4.40	0.30	9.67	0.30	16.85	-20.95
	9	10.10.06	22.92	0.16	10.0	-4.60	0.20	6.45	0.24	16.86	-21.22
21	BEV, Austria										
	1	25.10.06	23.01	0.05	100.0	16.40	1.23	1.23	0.05	16.93	-0.48
	2	25.10.06	23.00	0.05	100.0	15.93	0.35	0.35	0.08	16.93	-0.92
	3	26.10.06	23.01	0.05	100.0	16.47	0.33	0.33	0.07	16.93	-0.39
	4	26.10.06	23.01	0.05	100.0	15.91	1.06	1.06	0.07	16.93	-0.95
	5	26.10.06	23.00	0.05	100.0	16.00	0.23	0.23	0.08	16.93	-0.85
	6	26.10.06	23.01	0.05	100.0	15.48	0.51	0.51	0.07	16.93	-1.38
	7	26.10.06	23.01	0.05	100.0	16.27	0.74	0.74	0.07	16.93	-0.59
	8	27.10.06	23.01	0.05	100.0	15.30	0.30	0.30	0.07	16.93	-1.56
	9	27.10.06	23.01	0.05	100.0	16.09	0.59	0.59	0.07	16.93	-0.77

p	*Meas. #* m	Date $t_{p,6,m}$	$T_{p,6,m}$ (°C)	$u(T)$ (°C)	$V_{p,6,m}$ (V)	$O_{p,6,m}$ (ppm)	$u_{\mathrm{r}\text{-}p,6,m}$ (ppm)	$u^*_{r-p,6,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,6,m})$ (ppm)	$M_{p,6,m}$ (ppm)
	10	27.10.06	23.01	0.05	100.0	15.96	0.49	0.49	0.07	16.93	-0.91
	11	28.10.06	23.01	0.05	100.0	15.55	7.60	7.60	0.07	16.94	-1.32
	12	29.10.06	23.01	0.05	100.0	15.16	3.32	3.32	0.07	16.94	-1.71
	13	29.10.06	23.01	0.05	100.0	14.75	4.94	4.94	0.07	16.94	-2.13
	14	30.10.06	22.98	0.05	100.0	16.62	1.91	1.91	0.16	16.95	-0.16
	15	31.10.06	23.00	0.05	100.0	17.18	0.95	0.95	0.10	16.95	0.33
	16	02.11.06	23.03	0.05	100.0	15.39	2.85	2.85	0.01	16.96	-1.56
	17	10.11.06	22.99	0.05	100.0	16.59	0.39	0.39	0.11	16.99	-0.30
	18	10.11.06	22.99	0.05	100.0	16.60	1.21	1.21	0.11	16.99	-0.28
	19	10.11.06	23.00	0.05	100.0	17.01	0.74	0.74	0.10	16.99	0.11
	20	11.11.06	23.00	0.05	100.0	16.48	0.34	0.34	0.10	16.99	-0.41
	21	11.11.06	23.00	0.05	100.0	16.32	0.82	0.82	0.10	16.99	-0.57
	22	11.11.06	23.00	0.05	100.0	14.94	0.82	0.82	0.10	17.00	-1.95
	23	11.11.06	23.00	0.05	100.0	16.51	0.64	0.64	0.10	17.00	-0.39
	24	11.11.06	23.00	0.05	100.0	16.45	0.20	0.20	0.10	17.00	-0.45
	25	12.11.06	22.99	0.05	100.0	16.67	0.86	0.86	0.11	17.00	-0.22
	26	12.11.06	22.99	0.05	100.0	16.60	0.32	0.32	0.11	17.00	-0.29
	27	13.11.06	22.99	0.05	100.0	17.45	0.98	0.98	0.12	17.00	0.57
	28	13.11.06	23.01	0.05	100.0	16.33	1.03	1.03	0.07	17.01	-0.61
	29	14.11.06	23.01	0.05	100.0	16.95	0.64	0.64	0.07	17.01	0.02
	30	14.11.06	23.01	0.05	100.0	16.49	0.61	0.61	0.07	17.01	-0.44
	31	14.11.06	23.01	0.05	100.0	16.69	0.67	0.67	0.06	17.01	-0.26
	32	14.11.06	23.01	0.05	100.0	16.48	0.37	0.37	0.06	17.01	-0.47
	33	15.11.06	23.01	0.05	100.0	16.52	2.03	2.03	0.06	17.01	-0.43
	34	17.11.06	23.33	0.51	100.0	15.27	0.91	0.91	-0.90	17.02	-2.65
1	METAS, CH										
	13	24.11.06	23.00	0.03	5.0	17.02	0.10	0.10	-0.01	17.05	-0.04
	14	25.11.06	23.01	0.03	5.0	16.99	0.10	0.10	-0.05	17.05	-0.11
	15	26.11.06	23.02	0.03	5.0	16.92	0.10	0.10	-0.05	17.06	-0.19
22	CEM, SP										
	1	06.02.07	23.03	0.01	9.1	20.02	0.16	0.16	-0.09	17.34	2.59
	2	06.02.07	23.04	0.01	9.1	20.00	0.16	0.16	-0.11	17.34	2.55
	3	07.02.07	23.04	0.01	9.1	19.95	0.16	0.16	-0.13	17.34	2.48
	4	07.02.07	23.04	0.01	9.1	20.21	0.16	0.16	-0.13	17.34	2.74
	5	07.02.07	23.06	0.01	9.1	19.93	0.16	0.16	-0.17	17.34	2.41
	6	08.02.07	23.03	0.01	9.1	19.91	0.16	0.16	-0.09	17.35	2.47
	7	08.02.07	23.03	0.01	9.1	20.27	0.16	0.16	-0.09	17.35	2.83
	8	08.02.07	23.03	0.01	9.1	20.05	0.16	0.16	-0.09	17.35	2.61
	9	09.02.07	23.05	0.01	9.1	20.20	0.16	0.16	-0.14	17.35	2.71
	10	09.02.07	23.05	0.01	9.1	19.80	0.16	0.16	-0.14	17.35	2.31
23	VNIIM, Russia										
	1	24.04.07	20.00	0.03	50.0	8.40	0.16	0.16	9.04	17.63	-0.19
1	METAS, CH										
	16	28.06.07	23.14	0.03	5.0	18.38	0.10	0.10	-0.43	17.87	0.07
	17	02.07.07	23.03	0.03	5.0	18.05	0.10	0.10	-0.10	17.89	0.07
	18	06.07.07	23.04	0.03	5.0	18.07	0.10	0.10	-0.13	17.90	0.04
	19	13.07.07	23.03	0.03	5.0	18.01	0.10	0.10	-0.11	17.93	-0.02
	20	13.08.07	23.29	0.03	5.0	18.93	0.10	0.10	-0.88	18.03	0.02
	21	20.08.07	22.99	0.03	5.0	18.00	0.10	0.10	0.03	18.06	-0.03

A2 1 GΩ

A2.1 Loop A, 1 GΩ standard HR 9106, *a* = 7

p	*Meas. #* *m*	Date $t_{p,7,m}$	$T_{p,7,m}$ (°C)	$u(T)$ (°C)	$V_{p,7,m}$ (V)	$O_{p,7,m}$ (ppm)	$u_{\text{r-}p,7,m}$ (ppm)	$u^*_{r-p,7,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,7,m})$ (ppm)	$M_{p,7,m}$ (ppm)
1	METAS, CH										
	1	15.04.05	23.04	0.05	100.0	778.01	1.10	1.10	0.92	777.67	1.27
	2	19.04.05	23.10	0.05	100.0	774.58	1.10	1.10	2.42	777.69	-0.68
	3	26.04.05	20.04	0.05	100.0	854.83	1.10	1.10	-77.29	777.72	-0.17
	4	28.04.05	20.97	0.05	100.0	829.99	1.10	1.10	-51.51	777.73	0.75
	5	02.05.05	22.00	0.05	100.0	801.21	1.10	1.10	-24.40	777.75	-0.94
	6	10.05.05	23.20	0.05	100.0	772.44	1.10	1.10	4.78	777.79	-0.57
	7	26.05.05	23.00	0.05	100.0	778.27	1.10	1.10	-0.05	777.87	0.36
	8	10.06.05	23.04	0.05	100.0	777.05	1.10	1.10	0.82	777.94	-0.06
	9	28.06.05	23.03	0.05	100.0	776.74	1.10	1.10	0.68	778.03	-0.60
2	PTB, Germany										
	1	11.08.05	23.01	0.03	100.0	778.00	2.00	5.91	0.24	778.24	-0.01
	2	12.08.05	23.05	0.03	100.0	789.90	2.00	5.91	1.18	778.25	12.83
	3	15.08.05	22.98	0.03	100.0	789.10	2.00	5.91	-0.47	778.26	10.37
	4	17.08.05	22.93	0.03	100.0	780.50	2.00	5.91	-1.65	778.27	0.58
	5	19.08.05	23.05	0.03	100.0	785.00	2.00	5.91	1.18	778.28	7.90
	6	22.08.05	22.96	0.03	100.0	777.60	2.00	5.91	-0.94	778.30	-1.64
	7	23.08.05	23.03	0.03	100.0	777.50	2.00	5.91	0.71	778.30	-0.09
3	SIQ, Slovenia										
	1	20.09.05	22.98	0.05	90.0	755.10	1.20	12.13	-0.50	778.44	-23.84
	2	20.09.05	22.97	0.05	90.0	756.10	0.40	4.04	-0.74	778.44	-23.08
	3	21.09.05	22.98	0.05	90.0	755.60	0.30	3.03	-0.50	778.45	-23.35
	4	21.09.05	22.99	0.05	90.0	757.00	0.60	6.06	-0.26	778.45	-21.71
	5	22.09.05	23.04	0.05	90.0	760.20	0.50	5.05	0.92	778.45	-17.34
	6	23.09.05	23.02	0.05	90.0	759.90	0.40	4.04	0.44	778.45	-18.11
	7	23.09.05	23.02	0.05	90.0	759.80	0.30	3.03	0.44	778.45	-18.21
	8	23.09.05	23.03	0.05	90.0	768.70	0.40	4.04	0.68	778.46	-9.08
	9	24.09.05	23.04	0.05	90.0	766.30	0.80	8.09	0.92	778.46	-11.24
	10	24.09.05	23.04	0.05	90.0	765.10	0.50	5.05	0.92	778.46	-12.44
	11	24.09.05	23.11	0.05	90.0	765.90	0.50	5.05	2.57	778.46	-10.00
	12	24.09.05	23.10	0.05	90.0	764.40	0.60	6.06	2.33	778.46	-11.73
	13	25.09.05	23.06	0.05	90.0	764.20	0.50	5.05	1.39	778.46	-12.88
	14	25.09.05	22.96	0.05	90.0	767.30	1.00	10.11	-0.97	778.47	-12.14
	15	26.09.05	22.96	0.05	90.0	766.50	0.30	3.03	-0.97	778.47	-12.94
	16	26.09.05	22.95	0.05	90.0	767.10	0.90	9.10	-1.21	778.47	-12.58
	17	26.09.05	22.95	0.05	90.0	766.50	0.50	5.05	-1.21	778.47	-13.18
	18	26.09.05	23.01	0.05	90.0	765.10	1.10	11.12	0.21	778.47	-13.16
	19	26.09.05	23.09	0.05	90.0	762.20	0.30	3.03	2.10	778.47	-14.18
	20	27.09.05	23.12	0.05	90.0	761.50	0.50	5.05	2.80	778.47	-14.17
	21	27.09.05	23.04	0.05	90.0	766.60	0.60	6.06	0.92	778.48	-10.96
4	SMU, Slovak Republic										
	1	12.10.05	23.10	0.10	50.0	757.20	4.50	20.04	2.22	778.55	-19.13
	2	20.10.05	23.00	0.10	100.0	750.50	2.50	11.13	0.00	778.59	-28.09
	3	25.10.05	23.00	0.10	100.0	768.50	1.90	8.46	0.00	778.61	-10.11
	4	29.10.05	23.00	0.10	100.0	775.20	2.20	9.80	0.00	778.63	-3.43

p	*Meas. #* *m*	Date $t_{p,7,m}$	$T_{p,7,m}$ (°C)	$u(T)$ (°C)	$V_{p,7,m}$ (V)	$O_{p,7,m}$ (ppm)	$u_{\text{r-}p,7,m}$ (ppm)	$u^{*}_{r-p,7,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,7,m})$ (ppm)	$M_{p,7,m}$ (ppm)
5	VSL, Netherland										
	1	21.11.05	23.02	0.01	100.0	780.01	0.44	1.06	0.35	778.75	1.62
	2	23.11.05	23.04	0.01	100.0	780.81	0.47	1.13	0.85	778.76	2.90
	3	23.11.05	23.04	0.00	100.0	780.91	0.78	1.88	0.83	778.76	2.98
	4	30.11.05	23.06	0.00	100.0	781.75	0.34	0.82	1.39	778.79	4.35
	5	01.12.05	23.06	0.00	100.0	780.55	0.47	1.13	1.44	778.79	3.20
	6	01.12.05	23.06	0.00	100.0	780.75	0.54	1.30	1.39	778.79	3.35
	7	01.12.05	23.06	0.00	100.0	781.45	0.44	1.06	1.46	778.80	4.12
	8	01.12.05	23.05	0.00	100.0	781.05	0.31	0.75	1.23	778.80	3.48
	9	02.12.05	23.08	0.00	100.0	781.98	0.34	0.82	1.77	778.80	4.95
	10	03.12.05	23.08	0.00	100.0	781.78	0.66	1.59	1.77	778.80	4.75
	11	03.12.05	23.08	0.00	100.0	782.18	0.43	1.04	1.79	778.81	5.17
	12	04.12.05	23.08	0.00	100.0	782.48	0.52	1.25	1.89	778.81	5.56
	13	04.12.05	23.08	0.00	100.0	781.78	0.62	1.49	1.94	778.81	4.90
	14	09.12.05	23.10	0.00	100.0	781.87	0.38	0.92	2.41	778.84	5.45
	15	13.12.05	23.08	0.01	100.0	782.47	0.59	1.42	1.91	778.85	5.53
	16	13.12.05	23.10	0.00	100.0	780.68	0.28	0.67	2.43	778.86	4.25
	17	14.12.05	23.10	0.00	100.0	780.18	0.37	0.89	2.41	778.86	3.73
	18	14.12.05	23.10	0.00	100.0	779.78	0.28	0.67	2.34	778.86	3.26
	19	14.12.05	23.08	0.00	100.0	780.78	0.19	0.46	1.77	778.86	3.69
1	METAS, CH										
	10	29.12.05	23.07	0.05	100.0	776.20	1.10	1.10	1.69	778.93	-1.04
	11	10.01.06	23.05	0.05	100.0	778.61	1.10	1.10	1.06	778.99	0.68
	12	13.01.06	23.02	0.05	100.0	780.13	1.10	1.10	0.35	779.01	1.47
	13	19.01.06	23.06	0.05	100.0	777.96	1.10	1.10	1.34	779.04	0.26
6	SPI, Lithuania										
	1	03.02.06	22.97	0.08	100.0	783.43	0.53	0.70	-0.71	779.11	3.61
	2	07.02.06	23.00	0.08	100.0	783.06	0.60	0.79	0.00	779.13	3.93
	3	08.02.06	23.00	0.08	100.0	782.97	0.96	1.27	0.00	779.13	3.84
	4	11.02.06	23.00	0.08	100.0	782.34	0.48	0.63	0.00	779.15	3.19
	5	13.02.06	23.02	0.08	100.0	783.03	0.60	0.79	0.47	779.16	4.34
	6	15.02.06	23.03	0.08	100.0	783.51	0.62	0.82	0.71	779.17	5.05
	7	17.02.06	22.94	0.08	100.0	783.17	0.52	0.69	-1.42	779.18	2.58
	8	18.02.06	23.00	0.08	100.0	783.53	0.53	0.70	0.00	779.18	4.35
	9	20.02.06	23.06	0.08	100.0	782.94	0.63	0.83	1.42	779.19	5.16
	10	21.02.06	23.00	0.08	100.0	782.54	0.46	0.61	0.00	779.20	3.34
	11	22.02.06	23.01	0.08	100.0	783.01	0.52	0.69	0.24	779.20	4.04
	12	23.02.06	23.03	0.08	100.0	782.34	0.51	0.67	0.71	779.21	3.84
	13	26.02.06	23.00	0.08	100.0	783.37	0.72	0.95	0.00	779.22	4.15
7	MIKES, Finland										
	1	10.03.06	23.25	0.30	100.0	770.50	2.20	22.96	5.83	779.28	-2.95
	2	17.03.06	22.70	0.20	100.0	784.00	0.40	4.18	-7.01	779.32	-2.33
	3	20.03.06	23.06	0.20	100.0	804.00	2.70	28.18	1.42	779.33	26.08
	4	20.03.06	22.63	0.20	100.0	795.80	0.40	4.18	-8.80	779.33	7.67
	5	20.03.06	22.64	0.20	100.0	803.30	0.40	4.18	-8.50	779.33	15.47
	6	22.03.06	22.91	0.20	100.0	765.00	3.40	35.49	-2.19	779.34	-16.54
	7$^{*)}$	22.03.06	23.16	0.20	300.0	764.00	3.60	37.58	4.34	779.34	-11.01
	8$^{*)}$	23.03.06	23.07	0.20	500.0	772.00	1.70	17.75	2.68	779.35	-4.67
	9$^{*)}$	24.03.06	23.09	0.20	1000.0	769.90	2.50	26.10	4.71	779.35	-4.74

p	*Meas. #* m	Date $t_{p,7,m}$	$T_{p,7,m}$ (°C)	$u(T)$ (°C)	$V_{p,7,m}$ (V)	$O_{p,7,m}$ (ppm)	$u_{\text{r-}p,7,m}$ (ppm)	$u^*_{r-p,7,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,7,m})$ (ppm)	$M_{p,7,m}$ (ppm)
	10	25.03.06	22.95	0.20	100.0	797.30	3.50	36.53	-1.25	779.36	16.69
	11	27.03.06	23.20	0.20	100.0	776.00	0.50	5.22	4.72	779.37	1.35
	12	28.03.06	23.20	0.20	100.0	771.80	0.70	7.31	4.72	779.37	-2.85
	13	28.03.06	23.06	0.20	100.0	781.30	0.40	4.18	1.42	779.37	3.34
	14	28.03.06	23.31	0.20	100.0	772.40	0.40	4.18	7.32	779.37	0.34
	15	28.03.06	23.21	0.20	100.0	775.80	0.40	4.18	4.96	779.37	1.38
	16	29.03.06	23.08	0.20	100.0	783.60	0.40	4.18	1.89	779.38	6.11
	17	30.03.06	23.15	0.20	100.0	776.10	0.40	4.18	3.54	779.38	0.26
	18	30.03.06	23.30	0.20	100.0	769.30	0.50	5.22	7.08	779.38	-3.00
	*) point not used in analysis: test voltage outside range										
8	OMH, Hungary										
	1	14.04.06	23.00	0.20	9.1	780.96	0.35	0.35	-0.25	779.45	1.25
9	CMI, Czech Republic										
	1	10.05.06	23.00	0.50	90.0	803.00	1.20	2.51	-0.03	779.58	23.39
	2	16.05.06	23.00	0.50	90.0	800.00	1.20	2.51	-0.03	779.61	20.36
	3	22.05.06	23.00	0.50	90.0	805.00	1.20	2.51	-0.03	779.64	25.33
10	INM, Romania										
	1	18.10.06	23.15	0.04	100.0	731.00	0.60	3.95	3.54	780.37	-45.83
	2	18.10.06	23.20	0.04	100.0	734.00	0.60	3.95	4.72	780.37	-41.65
	3	19.10.06	23.21	0.04	100.0	735.00	0.60	3.95	4.96	780.38	-40.42
	4	19.10.06	23.20	0.04	100.0	733.00	0.60	3.95	4.72	780.38	-42.66
	5	19.10.06	23.20	0.04	100.0	735.00	0.60	3.95	4.72	780.38	-40.66
	6	20.10.06	23.03	0.04	100.0	727.00	0.60	3.95	0.71	780.38	-52.67
	7	20.10.06	23.04	0.04	100.0	728.00	0.60	3.95	0.94	780.38	-51.44
	8	20.10.06	23.06	0.04	100.0	729.00	0.60	3.95	1.42	780.38	-49.97
	9	20.10.06	23.06	0.04	100.0	734.00	0.60	3.95	1.42	780.38	-44.97
	10	23.10.06	23.08	0.04	100.0	727.00	0.60	3.95	1.89	780.40	-51.51
	11	23.10.06	23.10	0.04	100.0	732.00	0.60	3.95	2.36	780.40	-46.04
	12	23.10.06	23.07	0.04	100.0	729.00	0.60	3.95	1.65	780.40	-49.74
	13	23.10.06	23.09	0.04	100.0	730.00	0.60	3.95	2.12	780.40	-48.27
	14	25.10.06	22.91	0.04	100.0	732.00	0.60	3.95	-2.12	780.41	-50.53
	15	25.10.06	22.94	0.04	100.0	730.00	0.60	3.95	-1.42	780.41	-51.82
	16	25.10.06	22.96	0.04	100.0	733.00	0.60	3.95	-0.94	780.41	-48.35
	17	26.10.06	23.27	0.04	100.0	728.00	0.60	3.95	6.37	780.41	-46.04
	18	26.10.06	23.27	0.04	100.0	730.00	0.60	3.95	6.37	780.41	-44.04
	19	26.10.06	23.25	0.04	100.0	730.00	0.60	3.95	5.90	780.41	-44.51
1	METAS, CH										
	14	25.01.07	23.06	0.05	100.0	780.43	1.10	1.27	1.51	780.86	1.08
	15	26.01.07	22.98	0.05	100.0	779.94	1.10	1.27	-0.59	780.87	-1.52
	16	05.02.07	22.94	0.05	100.0	779.74	1.10	1.27	-1.37	780.91	-2.55
	17	13.02.07	22.98	0.05	100.0	780.03	1.10	1.27	-0.57	780.96	-1.49
	18	15.02.07	22.95	0.05	100.0	783.29	1.10	1.27	-1.11	780.96	1.22
	19	06.03.07	22.96	0.05	100.0	783.24	1.10	1.27	-0.97	781.06	1.21
	20	22.03.07	22.93	0.05	100.0	783.02	1.10	1.27	-1.73	781.14	0.16
	21	19.04.07	22.90	0.05	100.0	784.09	1.10	1.27	-2.32	781.28	0.50
	22	01.06.07	23.00	0.05	100.0	781.09	1.10	1.27	-0.07	781.49	-0.47
	23	12.07.07	22.89	0.05	100.0	784.40	1.10	1.27	-2.51	781.69	0.20
	24	15.08.07	22.86	0.05	100.0	785.88	1.10	1.27	-3.32	781.85	0.70

A2.2 Loop A, 1 GΩ standard MI 1100036, *a* = 8

p	*Meas. #* *m*	Date $t_{p,8,m}$	$T_{p,8,m}$ (°C)	$u(T)$ (°C)	$V_{p,8,m}$ (V)	$O_{p,8,m}$ (ppm)	$u_{\text{r-}p,8,m}$ (ppm)	$u^*_{r-p,8,m}$ (ppm)	*T*,V-corr (ppm)	$f(t_{p,8,m})$ (ppm)	$M_{p,8,m}$ (ppm)
1	METAS, CH										
	1	22.02.05	22.96	0.05	100.0	1.10	0.80	0.80	0.04	0.50	0.64
	2	03.03.05	22.99	0.05	100.0	-1.45	0.80	0.80	0.01	-0.47	-0.97
	3	11.03.05	22.87	0.05	100.0	-1.46	0.80	0.80	0.14	-1.26	-0.06
	4	20.04.05	23.00	0.05	100.0	-4.50	0.80	0.80	0.00	-4.74	0.24
	5	11.05.05	23.23	0.05	100.0	-4.60	0.80	0.80	-0.24	-6.15	1.31
	6	17.05.05	23.23	0.05	100.0	-6.44	0.80	0.80	-0.24	-6.52	-0.15
	7	26.05.05	23.08	0.05	100.0	-6.87	0.80	0.80	-0.08	-7.03	0.08
	8	10.06.05	23.06	0.05	100.0	-7.99	0.80	0.80	-0.07	-7.82	-0.24
	9	27.06.05	23.07	0.05	100.0	-9.71	0.80	0.80	-0.07	-8.59	-1.19
2	PTB, Germany										
	1	11.08.05	23.00	0.03	100.0	-9.40	2.00	2.00	0.00	-10.19	0.79
	2	12.08.05	23.05	0.03	100.0	-10.60	2.00	2.00	-0.05	-10.22	-0.43
	3	15.08.05	22.97	0.03	100.0	-7.40	2.00	2.00	0.03	-10.31	2.94
	4	17.08.05	22.92	0.03	100.0	-9.90	2.00	2.00	0.08	-10.36	0.55
	5	19.08.05	23.04	0.03	100.0	-6.50	2.00	2.00	-0.04	-10.42	3.88
	6	22.08.05	23.04	0.03	100.0	-8.10	2.00	2.00	-0.04	-10.50	2.36
	7	23.08.05	23.08	0.03	100.0	-9.10	2.00	2.00	-0.08	-10.53	1.35
3	SIQ, Slovenia										
	1	22.09.05	22.80	0.05	90.0	-15.50	0.60	6.05	0.23	-11.26	-4.02
	2	22.09.05	22.83	0.05	90.0	-16.40	0.70	7.06	0.20	-11.26	-4.95
	3	22.09.05	23.02	0.05	90.0	-17.60	0.40	4.03	0.00	-11.26	-6.34
	4	22.09.05	22.97	0.05	90.0	-17.10	0.30	3.02	0.05	-11.26	-5.79
	5	22.09.05	22.96	0.05	90.0	-17.40	0.20	2.02	0.06	-11.26	-6.08
	6	22.09.05	22.94	0.05	90.0	-17.70	0.30	3.02	0.08	-11.26	-6.35
	7	24.09.05	23.05	0.05	90.0	-14.40	0.40	4.03	-0.03	-11.30	-3.14
	8	24.09.05	23.07	0.05	90.0	-14.90	0.30	3.02	-0.05	-11.30	-3.66
	9	24.09.05	23.02	0.05	90.0	-15.00	0.20	2.02	0.00	-11.30	-3.70
	10	25.09.05	23.02	0.05	90.0	-12.40	0.70	7.06	0.00	-11.32	-1.08
	11	25.09.05	22.96	0.05	90.0	-12.60	0.40	4.03	0.06	-11.32	-1.22
	12	25.09.05	22.98	0.05	90.0	-13.10	0.80	8.07	0.04	-11.32	-1.74
	13	26.09.05	23.08	0.05	90.0	-9.40	0.30	3.02	-0.06	-11.34	1.88
	14	26.09.05	23.10	0.05	90.0	-10.60	0.20	2.02	-0.08	-11.35	0.66
	15	27.09.05	23.03	0.05	90.0	-11.50	0.20	2.02	-0.01	-11.35	-0.16
	16	27.09.05	23.02	0.05	90.0	-10.30	0.30	3.02	0.00	-11.36	1.06
4	SMU, Slovak Republic										
	1	14.10.05	23.00	0.10	50.0	-48.50	3.00	7.32	0.10	-11.67	-36.73
	2	21.10.05	23.00	0.10	100.0	-47.10	2.50	6.10	0.00	-11.79	-35.31
	3	25.10.05	22.90	0.10	100.0	-42.50	1.80	4.39	0.10	-11.85	-30.54
	4	27.10.05	23.00	0.10	100.0	-35.80	2.10	5.12	0.00	-11.88	-23.92
5	VSL, Netherland										
	1	17.11.05	23.05	0.01	100.0	-11.10	0.19	1.60	-0.05	-12.19	1.05
	2	21.11.05	23.03	0.00	100.0	-8.16	0.21	1.77	-0.04	-12.24	4.05
	3	23.11.05	23.07	0.00	100.0	-9.25	0.23	1.93	-0.07	-12.27	2.95
	4	24.11.05	23.06	0.00	100.0	-9.16	0.19	1.60	-0.06	-12.27	3.05
	5	24.11.05	23.06	0.00	100.0	-9.45	0.20	1.68	-0.06	-12.27	2.76
	6	24.11.05	23.07	0.00	100.0	-9.65	0.32	2.69	-0.07	-12.28	2.55
	7	01.12.05	23.09	0.01	100.0	-9.41	0.12	1.01	-0.09	-12.36	2.86

p	*Meas. #* m	Date $t_{p,8,m}$	$T_{p,8,m}$ (°C)	$u(T)$ (°C)	$V_{p,8,m}$ (V)	$O_{p,8,m}$ (ppm)	$u_{\mathrm{r}\text{-}p,8,m}$ (ppm)	$u^*_{r-p,8,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,8,m})$ (ppm)	$M_{p,8,m}$ (ppm)
	8	02.12.05	23.09	0.01	100.0	-7.76	0.63	5.30	-0.10	-12.37	4.52
	9	05.12.05	23.11	0.00	100.0	-6.70	0.55	4.63	-0.11	-12.41	5.60
	10	08.12.05	23.12	0.00	100.0	-5.66	0.26	2.19	-0.12	-12.44	6.66
	11	09.12.05	23.12	0.00	100.0	-5.82	0.22	1.85	-0.13	-12.45	6.50
	12	12.12.05	23.11	0.00	100.0	-4.69	0.63	5.30	-0.12	-12.48	7.67
	13	12.12.05	23.12	0.00	100.0	-6.19	0.18	1.51	-0.12	-12.48	6.17
	14	13.12.05	23.11	0.00	100.0	-6.29	0.15	1.26	-0.12	-12.49	6.08
	15	13.12.05	23.11	0.00	100.0	-6.19	0.18	1.51	-0.12	-12.49	6.18
	16	13.12.05	23.12	0.00	100.0	-6.29	0.18	1.51	-0.12	-12.49	6.07
	17	14.12.05	23.12	0.00	100.0	-7.29	0.24	2.02	-0.12	-12.50	5.08
	18	14.12.05	23.10	0.00	100.0	-6.69	0.22	1.85	-0.10	-12.50	5.71
	19	14.12.05	23.10	0.00	100.0	-6.99	0.11	0.93	-0.10	-12.50	5.41
	20	14.12.05	23.10	0.00	100.0	-6.69	0.18	1.51	-0.10	-12.51	5.71
	21	15.12.05	23.10	0.00	100.0	-7.19	0.22	1.85	-0.11	-12.51	5.21
1	METAS, CH										
	10	29.12.05	22.99	0.05	100.0	-12.55	0.80	0.80	0.01	-12.64	0.11
	11	10.01.06	23.05	0.05	100.0	-12.04	0.80	0.80	-0.05	-12.74	0.66
	12	13.01.06	23.05	0.05	100.0	-12.72	0.80	0.80	-0.05	-12.77	0.00
	13	19.01.06	23.15	0.05	100.0	-12.79	0.80	0.80	-0.15	-12.81	-0.13
6	SPI, Lithuania										
	1	06.02.06	22.95	0.08	100.0	-13.99	0.41	0.41	0.05	-12.93	-1.01
	2	07.02.06	23.05	0.08	100.0	-13.08	0.44	0.44	-0.05	-12.93	-0.20
	3	08.02.06	23.00	0.08	100.0	-14.64	0.46	0.46	0.00	-12.94	-1.70
	4	10.02.06	22.97	0.08	100.0	-13.70	0.42	0.42	0.03	-12.95	-0.71
	5	11.02.06	23.03	0.08	100.0	-13.55	0.42	0.42	-0.03	-12.96	-0.63
	6	12.02.06	23.00	0.08	100.0	-13.16	0.42	0.42	0.00	-12.96	-0.19
	7	13.02.06	23.03	0.08	100.0	-13.69	0.42	0.42	-0.03	-12.97	-0.76
	8	17.02.06	22.96	0.08	100.0	-13.61	0.42	0.42	0.04	-12.99	-0.57
	9	18.02.06	23.00	0.08	100.0	-13.96	0.41	0.41	0.00	-13.00	-0.96
	10	19.02.06	23.05	0.08	100.0	-13.23	0.42	0.42	-0.05	-13.00	-0.28
	11	20.02.06	23.06	0.08	100.0	-13.52	0.41	0.41	-0.06	-13.01	-0.58
	12	22.02.06	22.98	0.08	100.0	-13.66	0.41	0.41	0.02	-13.02	-0.62
	13	23.02.06	23.04	0.08	100.0	-13.31	0.42	0.42	-0.04	-13.02	-0.33
	14	24.02.06	22.96	0.08	100.0	-13.67	0.41	0.41	0.04	-13.03	-0.60
	15	25.02.06	22.96	0.08	100.0	-13.97	0.42	0.42	0.04	-13.03	-0.89
7	MIKES, Finland										
	1	08.03.06	23.27	0.30	100.0	-2.40	1.00	43.42	-0.28	-13.09	10.41
	2	09.03.06	23.31	0.30	100.0	-25.70	1.10	47.76	-0.32	-13.09	-12.93
	3	14.03.06	23.40	0.30	100.0	-33.60	0.80	34.73	-0.42	-13.11	-20.91
	4	16.03.06	23.01	0.30	100.0	-19.20	3.00	130.26	-0.01	-13.12	-6.09
	5	17.03.06	22.67	0.20	100.0	-15.00	0.60	26.05	0.35	-13.12	-1.53
	6	17.03.06	22.91	0.20	100.0	-14.30	0.60	26.05	0.09	-13.12	-1.08
	7	18.03.06	23.07	0.20	100.0	-35.30	1.00	43.42	-0.07	-13.13	-22.24
	8	20.03.06	22.64	0.20	100.0	-2.70	0.60	26.05	0.38	-13.14	10.81
	9$^{*)}$	23.03.06	23.12	0.20	500.0	-50.30	0.28	12.16	-0.93	-13.15	-38.08
	10$^{*)}$	24.03.06	23.06	0.20	1000.0	-44.80	0.40	17.37	-1.86	-13.15	-33.51
	11	26.03.06	22.98	0.20	100.0	-29.50	0.47	20.41	0.02	-13.16	-16.32
	12	29.03.06	23.10	0.20	100.0	-9.60	0.20	8.68	-0.10	-13.17	3.46
	13	29.03.06	23.13	0.20	100.0	-14.70	0.50	21.71	-0.14	-13.17	-1.67
	14	30.03.06	23.10	0.20	100.0	-6.70	0.20	8.68	-0.10	-13.17	6.37
	15	30.03.06	23.17	0.20	100.0	-14.30	0.50	21.71	-0.18	-13.17	-1.31

p	Meas. # m	Date $t_{p,8,m}$	$T_{p,8,m}$ (°C)	$u(T)$ (°C)	$V_{p,8,m}$ (V)	$O_{p,8,m}$ (ppm)	$u_{\mathrm{r}\text{-}p,8,m}$ (ppm)	$u^*_{r-p,8,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,8,m})$ (ppm)	$M_{p,8,m}$ (ppm)
	*) point not used in analysis: test voltage outside range										
8	OMH, Hungary										
	1	14.04.06	23.00	0.20	9.1	-7.00	0.36	0.36	0.18	-13.22	6.40
9	CMI, Czech Republic										
	1	10.05.06	23.00	0.50	90.0	-3.00	0.80	1.97	0.02	-13.28	10.30
	2	16.05.06	23.00	0.50	90.0	0.00	1.20	2.96	0.02	-13.29	13.31
	3	22.05.06	23.00	0.50	90.0	-5.00	0.80	1.97	0.02	-13.30	8.32
10	INM, Romania										
	1	18.10.06	23.16	0.04	100.0	-51.00	0.37	1.47	-0.17	-13.33	-37.84
	2	19.10.06	23.21	0.04	100.0	-52.00	0.37	1.47	-0.22	-13.33	-38.89
	3	19.10.06	23.20	0.04	100.0	-51.00	0.37	1.47	-0.21	-13.33	-37.88
	4	19.10.06	23.20	0.04	100.0	-51.00	0.37	1.47	-0.21	-13.33	-37.88
	5	19.10.06	23.20	0.04	100.0	-53.00	0.37	1.47	-0.21	-13.33	-39.88
	6	20.10.06	23.03	0.04	100.0	-55.00	0.37	1.47	-0.03	-13.33	-41.70
	7	20.10.06	23.04	0.04	100.0	-53.00	0.37	1.47	-0.04	-13.33	-39.71
	8	20.10.06	23.06	0.04	100.0	-54.00	0.37	1.47	-0.06	-13.33	-40.73
	9	20.10.06	23.06	0.04	100.0	-52.00	0.37	1.47	-0.06	-13.33	-38.73
	10	23.10.06	23.10	0.04	100.0	-54.00	0.37	1.47	-0.10	-13.33	-40.78
	11	23.10.06	23.10	0.04	100.0	-51.00	0.37	1.47	-0.10	-13.33	-37.78
	12	23.10.06	23.07	0.04	100.0	-55.00	0.37	1.47	-0.07	-13.33	-41.75
	13	23.10.06	23.09	0.04	100.0	-52.00	0.37	1.47	-0.09	-13.33	-38.77
	14	25.10.06	23.06	0.04	100.0	-53.00	0.37	1.47	-0.06	-13.33	-39.74
	15	25.10.06	23.27	0.04	100.0	-54.00	0.37	1.47	-0.28	-13.33	-40.96
	16	25.10.06	23.27	0.04	100.0	-50.00	0.37	1.47	-0.28	-13.33	-36.96
	17	26.10.06	23.25	0.04	100.0	-52.00	0.37	1.47	-0.26	-13.32	-38.94
	18	26.10.06	23.25	0.04	100.0	-54.00	0.37	1.47	-0.26	-13.32	-40.94
1	METAS, CH										
	14	26.01.07	23.12	0.05	100.0	-14.26	0.80	0.89	-0.13	-13.22	-1.17
	15	13.02.07	22.96	0.05	100.0	-14.47	0.80	0.89	0.04	-13.19	-1.23
	16	15.02.07	22.67	0.05	100.0	-12.76	0.80	0.89	0.35	-13.19	0.78
	17	06.03.07	23.02	0.05	100.0	-11.86	0.80	0.89	-0.02	-13.16	1.28
	18	22.03.07	23.07	0.05	100.0	-12.67	0.80	0.89	-0.07	-13.13	0.39
	19	19.04.07	22.92	0.05	100.0	-13.58	0.80	0.89	0.08	-13.09	-0.41
	20	04.06.07	23.02	0.05	100.0	-13.24	0.80	0.89	-0.02	-13.01	-0.25
	21	11.12.07	23.04	0.05	100.0	-12.36	0.80	0.89	-0.04	-12.67	0.27

A2.3 Loop A, 1 GΩ standard MI 1100037, *a* = 9

p	Meas. # m	Date $t_{p,9,m}$	$T_{p,9,m}$ (°C)	$u(T)$ (°C)	$V_{p,9,m}$ (V)	$O_{p,9,m}$ (ppm)	$u_{\mathrm{r}\text{-}p,9,m}$ (ppm)	$u^*_{r-p,9,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,9,m})$ (ppm)	$M_{p,9,m}$ (ppm)
1	METAS, CH										
	1	20.04.05	22.90	0.05	100.0	46.10	2.50	2.93	-2.39	43.59	0.13
	2	11.05.05	23.21	0.05	100.0	29.61	2.50	2.93	5.23	31.97	2.87
	3	17.05.05	22.90	0.05	100.0	26.04	2.50	2.93	-2.34	28.95	-5.26
	4	26.05.05	23.03	0.05	100.0	26.48	2.50	2.93	0.69	25.20	1.97
	5	10.06.05	23.07	0.05	100.0	19.36	2.50	2.93	1.70	19.74	1.31
	6	27.06.05	23.07	0.05	100.0	11.70	2.50	2.93	1.65	14.54	-1.20

p	*Meas. #* m	Date $t_{p,9,m}$	$T_{p,9,m}$ (°C)	$u(T)$ (°C)	$V_{p,9,m}$ (V)	$O_{p,9,m}$ (ppm)	$u_{\mathrm{r}\text{-}p,9,m}$ (ppm)	$u^{*}_{r-p,9,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,9,m})$ (ppm)	$M_{p,9,m}$ (ppm)
2	PTB, Germany										
	1	11.08.05	23.07	0.03	100.0	-6.00	2.00	4.21	1.65	5.07	-9.42
	2	12.08.05	23.09	0.03	100.0	-7.70	2.00	4.21	2.12	4.90	-10.49
	3	15.08.05	22.96	0.03	100.0	-5.60	2.00	4.21	-0.94	4.42	-10.96
	4	18.08.05	22.87	0.03	100.0	-11.00	2.00	4.21	-3.05	3.95	-18.01
	5	19.08.05	23.03	0.03	100.0	-6.30	2.00	4.21	0.71	3.80	-9.40
	6	22.08.05	23.05	0.03	100.0	-2.30	2.00	4.21	1.18	3.35	-4.48
	7	23.08.05	23.04	0.03	100.0	-4.60	2.00	4.21	0.94	3.21	-6.87
3	SIQ, Slovenia										
	1	21.09.05	22.87	0.05	90.0	-1.10	0.30	2.01	-3.07	-0.51	-3.67
	2	21.09.05	22.83	0.05	90.0	-3.80	0.30	2.01	-4.01	-0.52	-7.30
	3	22.09.05	22.83	0.05	90.0	-6.30	0.30	2.01	-4.01	-0.53	-9.79
	4	24.09.05	23.12	0.05	90.0	-1.40	0.90	6.04	2.80	-0.80	2.20
	5	24.09.05	23.07	0.05	90.0	-4.30	0.90	6.04	1.63	-0.81	-1.87
	6	24.09.05	23.08	0.05	90.0	-5.60	0.40	2.69	1.86	-0.81	-2.92
	7	25.09.05	23.01	0.05	90.0	-5.20	0.90	6.04	0.22	-0.91	-4.07
	8	25.09.05	23.00	0.05	90.0	-6.60	0.80	5.37	-0.02	-0.92	-5.70
	9	26.09.05	23.09	0.05	90.0	-2.30	0.80	5.37	2.10	-1.01	0.81
	10	26.09.05	23.10	0.05	90.0	-4.20	1.10	7.38	2.33	-1.03	-0.84
	11	27.09.05	22.91	0.05	90.0	-5.20	0.60	4.03	-2.13	-1.05	-6.28
	12	27.09.05	22.97	0.05	90.0	-4.80	0.60	4.03	-0.72	-1.09	-4.43
4	SMU, Slovak Republic										
	1	17.10.05	23.00	0.10	50.0	-35.80	2.00	6.15	-0.09	-2.88	-33.01
	2	20.10.05	22.90	0.10	100.0	-36.00	1.30	4.00	-2.35	-3.12	-35.23
	3	26.10.05	23.00	0.10	100.0	-27.90	1.90	5.85	0.00	-3.60	-24.30
	4	31.10.05	23.00	0.10	100.0	-32.40	1.20	3.69	0.00	-3.98	-28.42
5	VSL, Netherland										
	1	21.11.05	23.04	0.01	100.0	-9.75	0.63	6.57	0.94	-5.42	-3.39
	2	24.11.05	23.08	0.01	100.0	-8.86	0.28	2.92	1.76	-5.61	-1.48
	3	24.11.05	23.07	0.00	100.0	-9.48	0.25	2.61	1.69	-5.62	-2.16
	4	01.12.05	23.11	0.01	100.0	-10.21	0.27	2.82	2.51	-6.03	-1.66
	5	02.12.05	23.13	0.01	100.0	-8.81	0.15	1.57	2.98	-6.09	0.26
	6	05.12.05	23.12	0.01	100.0	-5.41	0.60	6.26	2.82	-6.25	3.66
	7	07.12.05	23.15	0.00	100.0	-5.16	0.23	2.40	3.45	-6.38	4.68
	8	08.12.05	23.15	0.00	100.0	-5.06	0.27	2.82	3.41	-6.39	4.74
	9	08.12.05	23.14	0.00	100.0	-5.06	0.25	2.61	3.36	-6.40	4.70
	10	08.12.05	23.14	0.01	100.0	-3.66	0.68	7.10	3.17	-6.41	5.93
	11	09.12.05	23.14	0.00	100.0	-5.73	0.22	2.30	3.29	-6.47	4.04
	12	09.12.05	23.13	0.00	100.0	-5.90	0.40	4.17	3.05	-6.49	3.64
	13	10.12.05	23.13	0.00	100.0	-6.60	0.21	2.19	3.15	-6.50	3.05
	14	10.12.05	23.13	0.00	100.0	-5.68	0.41	4.28	3.01	-6.51	3.84
	15	10.12.05	23.13	0.00	100.0	-6.23	0.42	4.38	3.15	-6.53	3.44
	16	10.12.05	23.13	0.00	100.0	-7.05	0.31	3.23	3.05	-6.54	2.54
	17	12.12.05	23.13	0.01	100.0	-5.20	0.08	0.83	3.03	-6.64	4.47
	18	13.12.05	23.12	0.01	100.0	-6.69	0.09	0.94	2.70	-6.69	2.70
	19	14.12.05	23.10	0.02	100.0	-6.69	0.37	3.86	2.30	-6.74	2.35
1	METAS, CH										
	7	29.12.05	23.02	0.05	100.0	-10.50	2.50	2.50	0.50	-7.48	-2.52

p	*Meas. #* m	Date $t_{p,9,m}$	$T_{p,9,m}$ (°C)	$u(T)$ (°C)	$V_{p,9,m}$ (V)	$O_{p,9,m}$ (ppm)	$u_{\text{r-}p,9,m}$ (ppm)	$u^*_{r-p,9,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,9,m})$ (ppm)	$M_{p,9,m}$ (ppm)
	8	10.01.06	23.11	0.05	100.0	-7.54	2.50	2.50	2.68	-8.03	3.17
	9	13.01.06	23.02	0.05	100.0	-9.42	2.50	2.50	0.52	-8.15	-0.75
	10	19.01.06	23.12	0.05	100.0	-9.69	2.50	2.50	2.80	-8.42	1.53
6	SPI, Lithuania										
	1	30.01.06	23.00	0.08	100.0	-5.85	0.62	0.85	0.00	-8.84	2.99
	2	31.01.06	23.05	0.08	100.0	-6.12	0.61	0.84	1.18	-8.88	3.93
	3	01.02.06	23.00	0.08	100.0	-6.25	0.63	0.86	0.00	-8.91	2.67
	4	02.02.06	23.01	0.08	100.0	-6.06	0.63	0.86	0.24	-8.95	3.13
	5	07.02.06	23.00	0.08	100.0	-6.76	0.62	0.85	0.00	-9.15	2.39
	6	07.02.06	23.00	0.08	100.0	-6.96	0.61	0.84	0.00	-9.15	2.18
	7	08.02.06	23.00	0.08	100.0	-7.74	0.61	0.84	0.00	-9.18	1.45
	8	18.02.06	23.00	0.08	100.0	-7.07	0.61	0.84	0.00	-9.55	2.48
	9	19.02.06	23.05	0.08	100.0	-6.25	0.62	0.85	1.18	-9.59	4.51
	10	26.02.06	23.00	0.08	100.0	-6.98	0.61	0.84	0.00	-9.84	2.86
	11	27.02.06	23.03	0.08	100.0	-7.17	0.61	0.84	0.71	-9.87	3.41
7	MIKES, Finland										
	1	09.03.06	23.27	0.30	100.0	-29.90	2.20	110.01	6.34	-10.23	-13.32
	2	16.03.06	23.09	0.30	100.0	-23.00	0.60	30.00	2.12	-10.46	-10.42
	3	17.03.06	23.02	0.20	100.0	-1.40	1.40	70.01	0.47	-10.49	9.56
	4	17.03.06	23.17	0.20	100.0	-20.60	0.60	30.00	3.88	-10.50	-6.23
	5	18.03.06	22.93	0.20	100.0	-27.30	0.77	38.50	-1.65	-10.53	-18.41
	6	20.03.06	22.64	0.20	100.0	-7.90	0.60	30.00	-8.46	-10.60	-5.76
	7$^{*)}$	24.03.06	22.99	0.20	500.0	-56.20	0.15	7.50	0.48	-10.72	-45.00
	8$^{*)}$	24.03.06	23.01	0.20	1000.0	-58.70	0.30	15.00	1.83	-10.72	-46.14
	9	29.03.06	23.20	0.20	100.0	-10.70	1.90	95.01	4.70	-10.88	4.88
	10	29.03.06	23.18	0.20	100.0	-14.90	0.40	20.00	4.23	-10.89	0.22
	11	30.03.06	23.04	0.20	100.0	-16.90	0.40	20.00	0.94	-10.91	-5.05
	12	30.03.06	23.20	0.20	100.0	-13.90	2.60	130.01	4.70	-10.91	1.71
	$^{*)}$ point not used in analysis: test voltage outside range										
8	OMH, Hungary										
	1	14.04.06	23.00	0.20	9.1	-10.15	0.36	0.36	-0.16	-11.36	1.05
9	CMI, Czech Republic										
	1	10.05.06	23.00	0.50	90.0	-6.50	0.70	1.21	-0.02	-12.12	5.60
	2	16.05.06	23.00	0.50	90.0	-7.00	1.20	2.08	-0.02	-12.29	5.27
	3	22.05.06	23.00	0.50	90.0	-9.00	0.60	1.04	-0.02	-12.46	3.44
10	INM, Romania										
	1	18.10.06	23.12	0.04	100.0	-58.00	0.41	2.61	2.82	-16.30	-38.88
	2	18.10.06	23.16	0.04	100.0	-60.00	0.41	2.61	3.76	-16.30	-39.94
	3	18.10.06	23.20	0.04	100.0	-60.00	0.41	2.61	4.70	-16.30	-39.00
	4	19.10.06	23.20	0.04	100.0	-60.00	0.41	2.61	4.70	-16.33	-38.97
	5	19.10.06	23.20	0.04	100.0	-60.00	0.41	2.61	4.70	-16.33	-38.97
	6	19.10.06	23.20	0.04	100.0	-60.00	0.41	2.61	4.70	-16.33	-38.97
	7	19.10.06	23.20	0.04	100.0	-58.00	0.41	2.61	4.70	-16.33	-36.97
	8	20.10.06	23.03	0.04	100.0	-57.00	0.41	2.61	0.71	-16.35	-39.94
	9	20.10.06	23.04	0.04	100.0	-60.00	0.41	2.61	0.94	-16.35	-42.71
	10	20.10.06	23.06	0.04	100.0	-62.00	0.41	2.61	1.41	-16.35	-44.24
	11	20.10.06	23.06	0.04	100.0	-62.00	0.41	2.61	1.41	-16.35	-44.24
	12	23.10.06	23.08	0.04	100.0	-57.00	0.41	2.61	1.88	-16.43	-38.69
	13	23.10.06	23.10	0.04	100.0	-62.00	0.41	2.61	2.35	-16.43	-43.22
	14	23.10.06	23.08	0.04	100.0	-60.00	0.41	2.61	1.88	-16.43	-41.69

p	*Meas. #* m	Date $t_{p,9,m}$	$T_{p,9,m}$ (°C)	$u(T)$ (°C)	$V_{p,9,m}$ (V)	$O_{p,9,m}$ (ppm)	$u_{\text{r-}p,9,m}$ (ppm)	$u^*_{r-p,9,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,9,m})$ (ppm)	$M_{p,9,m}$ (ppm)
	15	23.10.06	23.08	0.04	100.0	-59.00	0.41	2.61	1.88	-16.43	-40.69
	16	25.10.06	22.91	0.04	100.0	-57.00	0.41	2.61	-2.12	-16.48	-42.64
	17	26.10.06	23.26	0.04	100.0	-61.00	0.41	2.61	6.11	-16.50	-38.39
	18	26.10.06	23.27	0.04	100.0	-57.00	0.41	2.61	6.34	-16.50	-34.15
	19	26.10.06	23.25	0.04	100.0	-60.00	0.41	2.61	5.88	-16.50	-37.62
1	METAS, CH										
	11	25.01.07	23.09	0.05	100.0	-20.16	2.50	2.50	2.06	-18.75	0.65
	12	12.02.07	22.96	0.05	100.0	-22.27	2.50	2.50	-1.05	-19.19	-4.13
	13	15.02.07	22.98	0.05	100.0	-19.91	2.50	2.50	-0.51	-19.26	-1.16
	14	06.03.07	22.96	0.05	100.0	-18.76	2.50	2.50	-1.00	-19.72	-0.04
	15	22.03.07	22.94	0.05	100.0	-19.12	2.50	2.50	-1.37	-20.11	-0.38
	16	19.04.07	22.99	0.05	100.0	-20.18	2.50	2.50	-0.35	-20.78	0.25
	17	01.06.07	23.03	0.05	100.0	-19.21	2.50	2.50	0.61	-21.84	3.24
	18	15.08.07	22.88	0.05	100.0	-20.47	2.50	2.50	-2.81	-23.65	0.37

A2.4 Loop B, 1 GΩ standard HR 9101, *a* = 10

p	*Meas. #* m	Date $t_{p,10,m}$	$T_{p,10,m}$ (°C)	$u(T)$ (°C)	$V_{p,10,m}$ (V)	$O_{p,10,m}$ (ppm)	$u_{\text{r-}p,10,m}$ (ppm)	$u^*_{r-p,10,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,10,m})$ (ppm)	$M_{p,10,m}$ (ppm)
1	METAS, CH										
	1	15.04.05	22.92	0.05	100.0	51.57	0.80	0.80	-2.01	49.35	0.21
	2	19.04.05	22.88	0.05	100.0	53.65	0.80	0.80	-3.13	49.34	1.18
	3	26.04.05	19.89	0.05	100.0	141.79	0.80	0.80	-92.18	49.32	0.29
	4	28.04.05	20.98	0.05	100.0	106.15	0.80	0.80	-57.24	49.31	-0.40
	5	02.05.05	21.95	0.05	100.0	77.52	0.80	0.80	-28.38	49.30	-0.16
	6	10.05.05	23.19	0.05	100.0	43.30	0.80	0.80	4.84	49.28	-1.14
	7	25.05.05	23.01	0.05	100.0	49.38	0.80	0.80	0.33	49.24	0.47
	8	08.06.05	23.02	0.05	100.0	48.10	0.80	0.80	0.59	49.21	-0.52
12	NML, Ireland										
	1	03.08.05	23.17	0.10	100.0	41.00	8.00	14.05	4.37	49.11	-3.74
	2	04.08.05	23.37	0.10	100.0	34.00	1.00	1.76	9.51	49.11	-5.59
	3	08.08.05	23.27	0.10	100.0	41.00	3.00	5.27	6.94	49.10	-1.16
	4	09.08.05	22.90	0.10	100.0	44.00	2.00	3.51	-2.57	49.10	-7.67
	5	10.08.05	23.47	0.10	100.0	32.00	4.00	7.03	12.08	49.10	-5.01
	6	12.08.05	23.07	0.10	100.0	51.00	3.00	5.27	1.80	49.09	3.71
	7	15.08.05	22.66	0.10	100.0	64.00	3.00	5.27	-8.74	49.09	6.17
	8	16.08.05	22.91	0.10	100.0	51.00	2.00	3.51	-2.31	49.09	-0.40
	9	17.08.05	22.98	0.10	100.0	45.00	2.00	3.51	-0.51	49.09	-4.60
	10	18.08.05	22.92	0.10	100.0	44.00	3.00	5.27	-2.06	49.08	-7.14
	11	19.08.05	22.99	0.10	100.0	47.00	1.00	1.76	-0.26	49.08	-2.34
	12	24.08.05	22.95	0.10	100.0	45.00	1.00	1.76	-1.29	49.08	-5.36
13	JV, Norway										
	1	16.09.05	23.00	0.10	9.1	44.00	1.90	1.90	-0.45	49.05	-5.49
	2	17.09.05	23.00	0.10	9.1	45.10	3.60	3.60	-0.45	49.05	-4.39
	3	18.09.05	23.00	0.10	9.1	46.90	2.60	2.60	-0.45	49.05	-2.59
	4	20.09.05	23.00	0.10	9.1	45.10	2.90	2.90	-0.45	49.04	-4.39
	5	21.09.05	23.00	0.10	9.1	45.60	3.20	3.20	-0.45	49.04	-3.89

p	*Meas. #* m	Date $t_{p,10,m}$	$T_{p,10,m}$ (°C)	$u(T)$ (°C)	$V_{p,10,m}$ (V)	$O_{p,10,m}$ (ppm)	$u_{\text{r-}p,10,m}$ (ppm)	$u^{*}_{r-p,10,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,10,m})$ (ppm)	$M_{p,10,m}$ (ppm)
	6	22.09.05	23.00	0.10	9.1	45.30	1.70	1.70	-0.45	49.04	-4.19
	7	23.09.05	23.00	0.10	9.1	44.80	2.50	2.50	-0.45	49.04	-4.69
	8	24.09.05	23.00	0.10	9.1	45.30	1.90	1.90	-0.45	49.04	-4.18
	9	25.09.05	23.00	0.10	9.1	45.40	1.80	1.80	-0.45	49.04	-4.08
14	INETI, Portugal										
	1	24.10.05	22.99	0.08	100.0	-40.37	36.00	51.43	-0.26	49.01	-89.64
	2	04.11.05	22.92	0.08	100.0	34.16	36.00	51.43	-2.06	49.01	-16.90
1	METAS, CH										
	9	14.12.05	22.92	0.05	100.0	49.48	0.80	1.17	-1.99	48.99	-1.50
	10	19.12.05	22.93	0.05	100.0	52.05	0.80	1.17	-1.91	48.99	1.15
	11	23.12.05	22.97	0.05	100.0	49.58	0.80	1.17	-0.88	48.99	-0.29
	12	29.12.05	22.96	0.05	100.0	50.71	0.80	1.17	-1.06	48.99	0.66
16	NPL, United Kingdom										
	1	20.01.06	23.00	0.10	100.0	42.91	0.19	6.76	-0.05	49.00	-6.13
	2	23.01.06	23.01	0.10	100.0	46.05	0.27	9.30	0.34	49.00	-2.61
	3	23.01.06	23.01	0.10	100.0	45.74	0.30	10.59	0.17	49.00	-3.09
	4	31.01.06	23.14	0.10	100.0	53.86	0.15	5.08	3.48	49.00	8.33
	5	31.01.06	23.15	0.10	100.0	54.82	0.30	10.48	3.89	49.00	9.71
17	SMD, Belgium										
	1	20.03.06	23.02	0.01	90.9	51.00	1.72	1.72	0.50	49.04	2.46
18	UME, Turkey										
	1	18.05.06	23.20	0.40	100.0	52.00	3.58	3.58	5.14	49.11	8.03
19	LNE, France										
	1	03.07.06	23.00	0.20	100.0	49.60	1.50	1.50	0.00	49.20	0.40
20	EIM, Greece										
	1	21.09.06	22.91	0.13	100.0	74.00	0.50	19.60	-2.31	49.41	22.28
	2	22.09.06	22.96	0.13	100.0	71.90	0.60	23.52	-1.03	49.41	21.46
	3	26.09.06	23.00	0.14	100.0	66.90	0.40	15.68	0.00	49.43	17.47
	4	02.10.06	22.89	0.15	100.0	42.40	0.50	19.60	-2.83	49.45	-9.87
	5	03.10.06	22.84	0.12	100.0	42.80	0.30	11.76	-4.11	49.45	-10.76
	6	06.10.06	22.90	0.14	100.0	46.10	0.20	7.84	-2.57	49.46	-5.93
21	BEV, Austria										
	1	29.10.06	22.38	0.23	100.0	75.44	4.66	4.66	-15.94	49.54	9.96
	2	03.11.06	22.37	0.22	100.0	73.17	4.22	4.22	-16.20	49.55	7.42
	3	08.11.06	22.30	0.24	100.0	73.56	2.99	2.99	-18.00	49.57	5.99
	4	13.11.06	22.36	0.22	100.0	73.90	3.35	3.35	-16.45	49.59	7.86
22	CEM, SP										
	1	25.01.07	23.09	0.01	91.0	53.32	1.20	2.71	2.17	49.89	5.60
	2	25.01.07	23.09	0.01	91.0	54.30	1.20	2.71	2.17	49.89	6.58
	3	26.01.07	23.10	0.01	91.0	54.73	1.20	2.71	2.45	49.89	7.29
	4	26.01.07	23.10	0.01	91.0	53.96	1.20	2.71	2.45	49.89	6.52
	5	27.01.07	23.09	0.01	91.0	55.13	1.20	2.71	2.32	49.90	7.56
	6	27.01.07	23.09	0.01	91.0	53.59	1.20	2.71	2.32	49.90	6.02

p	*Meas. #* m	Date $t_{p,10,m}$	$T_{p,10,m}$ (°C)	$u(T)$ (°C)	$V_{p,10,m}$ (V)	$O_{p,10,m}$ (ppm)	$u_{\mathrm{r}-p,10,m}$ (ppm)	$u^*_{r-p,10,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,10,m})$ (ppm)	$M_{p,10,m}$ (ppm)
	7	28.01.07	23.09	0.01	91.0	53.56	1.20	2.71	2.17	49.90	5.83
	8	28.01.07	23.09	0.01	91.0	55.06	1.20	2.71	2.17	49.90	7.33
	9	29.01.07	23.04	0.01	91.0	56.78	1.20	2.71	1.06	49.91	7.94
	10	29.01.07	23.05	0.01	91.0	54.80	1.20	2.71	1.24	49.91	6.14
	11	29.01.07	23.06	0.01	91.0	50.50	1.20	2.71	1.40	49.91	1.99
	12	30.01.07	23.06	0.01	91.0	50.71	1.20	2.71	1.47	49.91	2.27
	13	30.01.07	23.05	0.01	91.0	49.83	1.20	2.71	1.32	49.91	1.24
	14	30.01.07	23.05	0.01	91.0	51.28	1.20	2.71	1.32	49.91	2.69
	15	01.02.07	23.05	0.01	91.0	49.07	1.20	2.71	1.32	49.92	0.47
	16	01.02.07	23.05	0.01	91.0	49.12	1.20	2.71	1.32	49.92	0.52
	17	01.02.07	23.05	0.01	91.0	48.60	1.20	2.71	1.32	49.92	0.00
	18	01.02.07	23.05	0.01	91.0	52.68	1.20	2.71	1.32	49.92	4.08
	19	02.02.07	23.05	0.01	91.0	49.04	1.20	2.71	1.32	49.92	0.44
	20	02.02.07	23.05	0.01	91.0	50.44	1.20	2.71	1.32	49.92	1.84
	21	02.02.07	23.05	0.01	91.0	52.95	1.20	2.71	1.32	49.92	4.35
	22	03.02.07	23.05	0.01	91.0	50.05	1.20	2.71	1.32	49.93	1.44
	23	03.02.07	23.05	0.01	91.0	49.58	1.20	2.71	1.32	49.93	0.97
	24	03.02.07	23.05	0.01	91.0	49.83	1.20	2.71	1.32	49.93	1.22
	25	04.02.07	23.05	0.01	91.0	49.48	1.20	2.71	1.32	49.93	0.87
	26	04.02.07	23.05	0.01	91.0	51.34	1.20	2.71	1.32	49.93	2.73
23	VNIIM, Russia										
	1	19.04.07	20.00	0.03	50.0	141.70	1.00	1.00	-77.38	50.30	14.02
1	METAS, CH										
	13	03.07.07	23.11	0.05	100.0	48.06	0.80	0.80	2.89	50.75	0.20
	14	11.07.07	23.01	0.05	100.0	51.25	0.80	0.80	0.13	50.80	0.58
	15	12.07.07	22.88	0.05	100.0	54.26	0.80	0.80	-3.05	50.80	0.40
	16	20.07.07	22.93	0.05	100.0	52.25	0.80	0.80	-1.88	50.85	-0.49
	17	14.08.07	22.94	0.05	100.0	52.73	0.80	0.80	-1.62	51.02	0.08
	18	20.08.07	22.87	0.05	100.0	53.76	0.80	0.80	-3.42	51.06	-0.72

A2.5 Loop B, 1 GΩ standard HR 9102, *a* = 11

p	*Meas. #* m	Date $t_{p,11,m}$	$T_{p,11,m}$ (°C)	$u(T)$ (°C)	$V_{p,11,m}$ (V)	$O_{p,11,m}$ (ppm)	$u_{\mathrm{r}-p,11,m}$ (ppm)	$u^*_{r-p,11,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,11,m})$ (ppm)	$M_{p,11,m}$ (ppm)
1	METAS, CH										
	1	15.04.05	22.95	0.05	100.0	-57.43	0.70	0.70	-1.57	-59.26	0.26
	2	19.04.05	22.95	0.05	100.0	-59.31	0.70	0.70	-1.42	-60.12	-0.62
	3	26.04.05	19.96	0.05	100.0	33.69	0.70	0.70	-94.45	-61.07	0.30
	4	28.04.05	20.97	0.05	100.0	0.39	0.70	0.70	-61.97	-61.29	-0.29
	5	02.05.05	21.94	0.05	100.0	-29.14	0.70	0.70	-31.96	-61.64	0.54
	6	10.05.05	23.18	0.05	100.0	-66.95	0.70	0.70	5.29	-62.06	0.40
	7	25.05.05	23.02	0.05	100.0	-63.48	0.70	0.70	0.50	-62.42	-0.56
	8	08.06.05	23.02	0.05	100.0	-63.15	0.70	0.70	0.53	-62.49	-0.13
	9	28.06.05	23.02	0.05	100.0	-64.05	0.70	0.70	0.53	-62.45	-1.07
12	NML, Ireland										
	1	03.08.05	23.12	0.10	100.0	-73.00	19.00	62.97	3.56	-62.27	-7.17
	2	04.08.05	23.30	0.10	100.0	-70.00	1.00	3.31	8.89	-62.27	1.16
	3	08.08.05	23.34	0.10	100.0	-63.00	2.00	6.63	10.08	-62.25	9.32
	4	09.08.05	22.94	0.10	100.0	-63.00	1.00	3.31	-1.78	-62.24	-2.54

p	Meas. # m	Date $t_{p,11,m}$	$T_{p,11,m}$	$u(T)$	$V_{p,11,m}$	$O_{p,11,m}$	$u_{\text{r-}p,11,m}$	$u^{*}_{r-p,11,m}$	T,V-corr	$f(t_{p,11,m})$	$M_{p,11,m}$
			(°C)	(°C)	(V)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
	5	10.08.05	23.57	0.10	100.0	-77.00	5.00	16.57	16.89	-62.23	2.13
	6	12.08.05	23.32	0.10	100.0	-74.00	2.00	6.63	9.48	-62.22	-2.29
	7	15.08.05	22.71	0.10	100.0	-55.00	2.00	6.63	-8.60	-62.21	-1.39
	8	16.08.05	22.92	0.10	100.0	-65.00	1.00	3.31	-2.37	-62.20	-5.17
	9	17.08.05	22.96	0.10	100.0	-71.00	3.00	9.94	-1.19	-62.19	-9.99
	10	18.08.05	22.92	0.10	100.0	-70.00	1.00	3.31	-2.37	-62.19	-10.18
	11	19.08.05	23.01	0.10	100.0	-67.00	1.00	3.31	0.30	-62.18	-4.52
	12	24.08.05	22.97	0.10	100.0	-68.00	3.00	9.94	-0.89	-62.15	-6.73
13	JV, Norway										
	1	17.09.05	23.00	0.10	9.1	-66.40	3.10	3.10	0.36	-62.02	-4.02
	2	17.09.05	23.00	0.10	9.1	-66.10	1.70	1.70	0.36	-62.02	-3.72
	3	18.09.05	23.00	0.10	9.1	-68.80	4.10	4.10	0.36	-62.01	-6.43
	4	20.09.05	23.00	0.10	9.1	-66.90	7.80	7.80	0.36	-62.00	-4.54
	5	21.09.05	23.00	0.10	9.1	-68.60	2.90	2.90	0.36	-61.99	-6.24
	6	22.09.05	23.00	0.10	9.1	-67.30	3.10	3.10	0.36	-61.99	-4.95
	7	23.09.05	23.00	0.10	9.1	-68.90	2.50	2.50	0.36	-61.98	-6.55
	8	24.09.05	23.00	0.10	9.1	-67.20	2.30	2.30	0.36	-61.98	-4.86
	9	25.09.05	23.00	0.10	9.1	-68.20	4.40	4.40	0.36	-61.97	-5.87
14	INETI, Portugal										
	1	18.10.05	23.05	0.08	100.0	-95.69	14.00	14.67	1.48	-61.84	-32.37
	2	19.10.05	23.07	0.08	100.0	-104.86	14.00	14.67	2.07	-61.83	-40.95
	3	26.10.05	22.92	0.08	100.0	-98.78	14.00	14.67	-2.37	-61.79	-39.36
	4	04.11.05	23.04	0.08	100.0	-72.10	14.00	14.67	1.19	-61.74	-9.17
1	METAS, CH										
	10	14.12.05	22.93	0.05	100.0	-59.33	0.70	0.77	-2.05	-61.51	0.13
	11	19.12.05	22.94	0.05	100.0	-59.35	0.70	0.77	-1.72	-61.48	0.41
	12	23.12.05	22.97	0.05	100.0	-60.88	0.70	0.77	-0.83	-61.45	-0.26
	13	29.12.05	22.99	0.05	100.0	-59.55	0.70	0.77	-0.33	-61.42	1.54
16	NPL, United Kingdom										
	1	20.01.06	23.03	0.10	100.0	-65.31	0.49	4.79	0.81	-61.29	-3.21
	2	31.01.06	23.15	0.10	100.0	-65.92	0.44	4.28	4.32	-61.23	-0.37
	3	31.01.06	23.13	0.10	100.0	-63.95	0.61	5.97	3.95	-61.23	1.23
	4	01.02.06	23.12	0.10	100.0	-59.25	0.22	2.20	3.52	-61.23	5.49
	5	01.02.06	23.10	0.10	100.0	-59.52	0.23	2.30	2.99	-61.23	4.70
17	SMD, Belgium										
	1	21.03.06	23.04	0.00	90.9	-64.00	1.93	1.93	1.10	-60.95	-1.94
18	UME, Turkey										
	1	22.05.06	23.18	0.40	100.0	-58.00	5.08	5.08	5.34	-60.59	7.93
19	LNE, France										
	1	03.07.06	23.00	0.20	100.0	-60.00	1.50	1.50	0.00	-60.35	0.35
20	EIM, Greece										
	1	21.09.06	22.91	0.13	100.0	-33.50	0.80	32.28	-2.67	-59.89	23.72
	2	22.09.06	22.96	0.13	100.0	-33.70	0.60	24.21	-1.19	-59.89	25.00
	3	26.09.06	23.00	0.14	100.0	-39.50	0.40	16.14	0.00	-59.86	20.36

p	*Meas. #* *m*	Date $t_{p,11,m}$	$T_{p,11,m}$ (°C)	$u(T)$ (°C)	$V_{p,11,m}$ (V)	$O_{p,11,m}$ (ppm)	$u_{\text{r-}p,11,m}$ (ppm)	$u^*_{r-p,11,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,11,m})$ (ppm)	$M_{p,11,m}$ (ppm)
	4	02.10.06	22.89	0.15	100.0	-67.20	0.20	8.07	-3.26	-59.83	-10.63
	5	03.10.06	22.84	0.12	100.0	-61.10	0.70	28.24	-4.74	-59.82	-6.02
	6	06.10.06	22.90	0.14	100.0	-65.50	0.80	32.28	-2.96	-59.81	-8.66
21	BEV, Austria										
	1	29.10.06	22.44	0.28	100.0	-32.15	2.83	2.83	-16.60	-59.67	10.92
	2	04.11.06	22.34	0.24	100.0	-30.27	4.55	4.55	-19.56	-59.64	9.80
	3	08.11.06	22.32	0.22	100.0	-29.18	3.40	3.40	-20.16	-59.62	10.28
	4	12.11.06	22.43	0.22	100.0	-32.01	3.79	3.79	-16.89	-59.59	10.69
22	CEM, SP										
	1	27.01.07	23.03	0.01	91.0	-61.99	1.20	1.20	0.90	-59.15	-1.94
	2	28.01.07	23.03	0.01	91.0	-61.21	1.20	1.20	0.90	-59.15	-1.17
	3	29.01.07	23.03	0.01	91.0	-58.91	1.20	1.20	0.90	-59.14	1.13
	4	30.01.07	23.03	0.01	91.0	-59.29	1.20	1.20	0.90	-59.14	0.74
	5	31.01.07	23.03	0.01	91.0	-61.63	1.20	1.20	0.90	-59.13	-1.60
	6	01.02.07	23.00	0.01	91.0	-59.37	1.20	1.20	0.12	-59.13	-0.12
	7	02.02.07	23.00	0.01	91.0	-59.13	1.20	1.20	0.12	-59.12	0.11
23	VNIIM, Russia										
	1	19.04.07	19.99	0.03	50.0	34.10	0.90	0.90	-89.02	-58.68	3.77
1	METAS, CH										
	14	11.07.07	22.88	0.05	100.0	-53.75	0.70	0.81	-3.44	-58.20	1.00
	15	20.07.07	22.90	0.05	100.0	-55.26	0.70	0.81	-2.94	-58.15	-0.04
	16	14.08.07	22.89	0.05	100.0	-55.33	0.70	0.81	-3.21	-58.00	-0.53
	17	20.08.07	22.83	0.05	100.0	-53.85	0.70	0.81	-4.96	-57.97	-0.84

A2.6 Loop B, 1 GΩ standard MI 1100035, *a* = 12

p	*Meas. #* *m*	Date $t_{p,12,m}$	$T_{p,12,m}$ (°C)	$u(T)$ (°C)	$V_{p,12,m}$ (V)	$O_{p,12,m}$ (ppm)	$u_{\text{r-}p,12,m}$ (ppm)	$u^*_{r-p,12,m}$ (ppm)	T,V-corr. (ppm)	$f(t_{p,12,m})$ (ppm)	$M_{p,12,m}$ (ppm)
1	METAS, CH										
	1	22.02.05	23.01	0.05	100.0	-4.20	0.70	0.70	0.01	-3.60	-0.59
	2	03.03.05	23.01	0.05	100.0	-4.25	0.70	0.70	0.01	-4.44	0.20
	3	10.03.05	23.10	0.05	100.0	-5.22	0.70	0.70	0.12	-5.04	-0.05
	4	20.04.05	23.03	0.05	100.0	-7.60	0.70	0.70	0.03	-8.01	0.43
	5	25.04.05	20.04	0.05	100.0	-15.77	0.70	0.70	7.67	-8.29	0.19
	6	02.05.05	21.96	0.05	100.0	-8.54	0.70	0.70	0.19	-8.70	0.36
	7	11.05.05	23.19	0.05	100.0	-8.75	0.70	0.70	0.25	-9.19	0.69
	8	26.05.05	23.04	0.05	100.0	-9.57	0.70	0.70	0.05	-9.96	0.44
	9	10.06.05	23.02	0.05	100.0	-10.99	0.70	0.70	0.02	-10.63	-0.34
	10	27.06.05	23.04	0.05	100.0	-12.95	0.70	0.70	0.05	-11.32	-1.58
12	NML, Ireland										
	1	17.08.05	23.00	0.10	100.0	-15.00	6.00	9.05	0.00	-12.93	-2.07
	2	18.08.05	22.91	0.10	100.0	-9.00	6.00	9.05	-0.10	-12.96	3.85
	3	19.08.05	22.98	0.10	100.0	-11.00	2.00	3.02	-0.02	-12.98	1.96
	4	23.08.05	22.89	0.10	100.0	-10.00	2.00	3.02	-0.12	-13.08	2.96
	5	24.08.05	23.03	0.10	100.0	-6.00	1.00	1.51	0.03	-13.11	7.14

p	Meas. # m	Date $t_{p,12,m}$	$T_{p,12,m}$ (°C)	$u(T)$ (°C)	$V_{p,12,m}$ (V)	$O_{p,12,m}$ (ppm)	$u_{\mathrm{r}\text{-}p,12,m}$ (ppm)	$u^{*}_{r-p,12,m}$ (ppm)	T,V-corr. (ppm)	$f(t_{p,12,m})$ (ppm)	$M_{p,12,m}$ (ppm)
13	JV, Norway										
	1	17.09.05	23.00	0.10	9.1	-6.00	1.80	1.80	0.91	-13.66	8.57
	2	18.09.05	23.00	0.10	9.1	-3.70	5.80	5.80	0.91	-13.68	10.89
	3	19.09.05	23.00	0.10	9.1	-5.30	2.50	2.50	0.91	-13.70	9.31
	4	21.09.05	23.00	0.10	9.1	-5.60	2.90	2.90	0.91	-13.75	9.05
	5	21.09.05	23.00	0.10	9.1	-4.10	1.40	1.40	0.91	-13.75	10.55
	6	22.09.05	23.00	0.10	9.1	-6.10	1.60	1.60	0.91	-13.77	8.57
	7	23.09.05	23.00	0.10	9.1	-5.20	2.80	2.80	0.91	-13.79	9.50
	8	24.09.05	23.00	0.10	9.1	-5.30	3.40	3.40	0.91	-13.81	9.42
	9	25.09.05	23.00	0.10	9.1	-8.20	1.90	1.90	0.91	-13.83	6.54
14	INETI, Portugal										
	1	24.10.05	23.00	0.03	100.0	-994.44	36.00	36.00	0.00	-14.35	-980.09
1	METAS, CH										
	11	14.12.05	22.94	0.05	100.0	-15.78	0.70	0.70	-0.07	-15.05	-0.79
	12	19.12.05	22.96	0.05	100.0	-15.00	0.70	0.70	-0.05	-15.11	0.06
	13	23.12.05	23.08	0.05	100.0	-15.18	0.70	0.70	0.09	-15.16	0.07
	14	29.12.05	23.07	0.05	100.0	-14.45	0.70	0.70	0.08	-15.22	0.85
16	NPL, United Kingdom										
	1	20.01.06	23.00	0.10	100.0	-57.62	0.38	23.80	0.00	-15.43	-42.20
	2	23.01.06	23.01	0.10	100.0	-30.74	0.35	21.57	0.02	-15.45	-15.27
	3	23.01.06	23.01	0.10	100.0	-30.66	0.40	24.79	0.01	-15.45	-15.20
	4	31.01.06	23.13	0.10	100.0	-15.43	0.08	4.65	0.14	-15.52	0.24
	5	31.01.06	23.13	0.10	100.0	-15.36	0.04	2.73	0.14	-15.52	0.30
17	SMD, Belgium										
	1	22.03.06	23.04	0.01	90.9	-17.00	2.27	2.27	0.14	-15.87	-1.00
18	UME, Turkey										
	1	18.05.06	23.20	0.40	100.0	-15.00	1.64	1.64	0.22	-16.15	1.37
19	LNE, France										
	1	03.07.06	23.00	0.20	100.0	-12.00	1.50	1.50	0.00	-16.32	4.32
20	EIM, Greece										
	1	20.09.06	22.94	0.13	100.0	6.80	0.50	35.19	-0.07	-16.52	23.25
	2	21.09.06	22.91	0.13	100.0	8.40	0.20	14.07	-0.10	-16.52	24.82
	3	26.09.06	23.00	0.14	100.0	7.00	0.20	14.07	0.00	-16.53	23.53
	4	02.10.06	22.89	0.15	100.0	-21.10	0.30	21.11	-0.12	-16.55	-4.68
	5	03.10.06	22.84	0.12	100.0	-20.00	0.30	21.11	-0.18	-16.55	-3.63
	6	09.10.06	22.91	0.16	100.0	-26.00	0.20	14.07	-0.10	-16.56	-9.54
21	BEV, Austria										
	1	31.10.06	22.36	0.22	100.0	-12.23	2.00	2.00	-0.72	-16.60	3.65
	2	04.11.06	22.59	0.42	100.0	-12.83	1.61	1.61	-0.46	-16.61	3.32
	3	08.11.06	22.35	0.24	100.0	-13.08	1.16	1.16	-0.73	-16.61	2.81
	4	12.11.06	22.51	0.33	100.0	-12.23	1.85	1.85	-0.55	-16.62	3.84

p	*Meas. #* *m*	Date $t_{p,12,m}$	$T_{p,12,m}$ (°C)	$u(T)$ (°C)	$V_{p,12,m}$ (V)	$O_{p,12,m}$ (ppm)	$u_{\text{r-}p,12,m}$ (ppm)	$u^{*}_{r-p,12,m}$ (ppm)	T,V-corr. (ppm)	$f(t_{p,12,m})$ (ppm)	$M_{p,12,m}$ (ppm)
22	CEM, SP										
	1	25.01.07	23.08	0.01	91.0	-12.55	1.20	2.50	0.18	-16.73	4.36
	2	25.01.07	23.08	0.01	91.0	-15.07	1.20	2.50	0.18	-16.73	1.84
	3	26.01.07	23.08	0.01	91.0	-14.31	1.20	2.50	0.18	-16.73	2.60
	4	26.01.07	23.08	0.01	91.0	-14.23	1.20	2.50	0.18	-16.73	2.68
	5	27.01.07	23.07	0.01	91.0	-14.13	1.20	2.50	0.17	-16.73	2.77
	6	27.01.07	23.07	0.01	91.0	-13.31	1.20	2.50	0.17	-16.73	3.59
	7	28.01.07	23.07	0.01	91.0	-14.92	1.20	2.50	0.17	-16.73	1.98
	8	28.01.07	23.07	0.01	91.0	-13.33	1.20	2.50	0.17	-16.73	3.57
	9	29.01.07	23.07	0.01	91.0	-14.67	1.20	2.50	0.17	-16.73	2.23
	10	29.01.07	23.07	0.01	91.0	-14.53	1.20	2.50	0.17	-16.73	2.37
	11	29.01.07	23.07	0.01	91.0	-15.05	1.20	2.50	0.17	-16.73	1.85
	12	30.01.07	23.07	0.01	91.0	-14.34	1.20	2.50	0.17	-16.73	2.56
	13	30.01.07	23.07	0.01	91.0	-14.56	1.20	2.50	0.17	-16.73	2.34
	14	30.01.07	23.07	0.01	91.0	-14.06	1.20	2.50	0.17	-16.73	2.84
	15	01.02.07	23.08	0.01	91.0	-14.86	1.20	2.50	0.18	-16.74	2.06
	16	01.02.07	23.00	0.01	91.0	-18.49	1.20	2.50	0.09	-16.74	-1.66
	17	01.02.07	23.02	0.01	91.0	-17.89	1.20	2.50	0.12	-16.74	-1.04
	18	01.02.07	23.02	0.01	91.0	-18.96	1.20	2.50	0.12	-16.74	-2.11
	19	02.02.07	23.02	0.01	91.0	-18.14	1.20	2.50	0.12	-16.74	-1.28
	20	02.02.07	23.02	0.01	91.0	-21.49	1.20	2.50	0.12	-16.74	-4.63
	21	02.02.07	23.02	0.01	91.0	-19.45	1.20	2.50	0.12	-16.74	-2.59
	22	03.02.07	23.02	0.01	91.0	-17.71	1.20	2.50	0.12	-16.74	-0.85
	23	03.02.07	23.02	0.01	91.0	-17.56	1.20	2.50	0.12	-16.74	-0.70
	24	03.02.07	23.02	0.01	91.0	-19.53	1.20	2.50	0.12	-16.74	-2.67
	25	04.02.07	23.02	0.01	91.0	-19.43	1.20	2.50	0.12	-16.74	-2.57
23	VNIIM, Russia										
	1	19.04.07	19.99	0.03	50.0	-25.00	0.80	0.80	-2.87	-16.82	-11.05
1	METAS, CH										
	15	03.07.07	22.87	0.05	100.0	-16.09	0.70	0.72	-0.13	-16.90	0.68
	16	11.07.07	23.06	0.05	100.0	-16.15	0.70	0.72	0.07	-16.90	0.82
	17	20.07.07	22.91	0.05	100.0	-16.90	0.70	0.72	-0.09	-16.91	-0.08
	18	14.08.07	22.94	0.05	100.0	-17.47	0.70	0.72	-0.07	-16.94	-0.60
	19	20.08.07	22.91	0.05	100.0	-17.59	0.70	0.72	-0.09	-16.94	-0.75

Annex B: Methods of Measurement

Lab No	Lab	10 MΩ Method	Traceability	1 GΩ Method	Traceability
1	METAS	Potentiometric bridge (MI 6000B)	QHR, Cryogenic current comparator to 1 MΩ, Hamon Step up to 10 MΩ	Active arm Wheatstone bridge	QHR, Cryogenic current comparator to 1 MΩ, Hamon Step up to 100 MΩ
2	PTB	Potentiometric bridge (MI 6000A)	QHR, Cryogenic current comparator to 10 kΩ, Step up to 10 MΩ based on binary voltage divider of the MI bridge	Active arm Wheatstone bridge	QHR, Cryogenic current comparator to 10 kΩ; Step up to 100 MΩ based on binary voltage divider of a MI 6000 bridge
3	SIQ	Potentiometric bridge (MI 6000B)	10 kΩ calibrated at PTB; step up based on binary voltage divider of the MI bridge	Potentiometric bridge (MI 6000B)	10 kΩ calibrated at PTB; step up based on binary voltage divider of the MI bridge
4	SMU	Potentiometric bridge (MI 6000B)	10 kΩ calibrated at BIPM; step up based on binary voltage divider of the MI bridge	Potentiometric bridge (MI 6000B)	10 kΩ calibrated at BIPM; step up based on binary voltage divider of the MI bridge
5	VSL	Potentiometric bridge (MI 6000A)	QHR to 10 kΩ; step up based on binary voltage divider of the MI 6000 bridge; MI 6000 bridge checked with a Hamon step-up procedure	Active arm Wheatstone bridge	QHR to 10 kΩ; step up to 10 MΩ based on binary voltage divider of the MI 6000 bridge
6	VMT/ PFI	Potentiometric bridge (MI 6000B)	10 kΩ calibrated at PTB and CMI; step up based on binary voltage divider of the MI bridge	Potentiometric bridge (MI 6000B)	10 kΩ calibrated at PTB and CMI; step up based on binary voltage divider of the MI bridge
7	MIKES	DC current comparator bridge (DCCT) Guildline 6675; Substitution against Hamon using an electrometer	QHR, Cryogenic current comparator to 10 kΩ, Hamon Step up to 10 MΩ	Active arm Wheatstone bridge; Substitution against Hamon using an electrometer	QHR to 10 kΩ; Hamon step-up procedure

Lab No	Lab	10 MΩ Method	Traceability	1 GΩ Method	Traceability
8	OMH	Potentiometric bridge (MI 6000A)	1 Ω calibrated at BIPM; step up based on DCCT bridge and on binary voltage divider of the MI bridge	Potentiometric bridge (MI 6000A)	1 Ω calibrated at BIPM; step up based on DCCT bridge and on binary voltage divider of the MI bridge
9	CMI	Potentiometric bridge (MI 6000B)	10 MΩ calibrated at PTB	Potentiometric bridge (MI 6000B)	1 GΩ calibrated at PTB
10	INM	Teraohmmeter Guildline 6520	10 MΩ calibrated at PTB	Teraohmmeter Guildline 6520	1 GΩ calibrated by Measurement Int. Standards Calibration Lab., Canada
12	NML	Potentiometric bridge (MI 6000A)	10 kΩ calibrated at BIPM, Hamon Step up to 10 MΩ	Substitution against Hamon using a Fluke 8508 DMM	10 kΩ calibrated at BIPM, Hamon Step up to 1 GΩ
13	JV	Potentiometric bridge (MI 6000A)	QHR to 10 kΩ; Hamon step-up procedure to 1 MΩ and MI 6000 bridge step-up procedure	Potentiometric bridge (MI 6000A)	QHR to 10 kΩ; Hamon step-up procedure to 1 MΩ and MI 6000 bridge step-up procedure
14	INETI /LME	Active arm Wheatstone bridge	1 Ω and 10 kΩ calibrated at BIPM; Step-up using a DCCT bridge	Active arm Wheatstone bridge	1 Ω and 10 kΩ calibrated at BIPM; Step-up using a DCCT bridge
15	LNMC	Substitution against 10 MΩ using a DMM	10 MΩ calibrated at SP	not measured	
16	NPL	Cryogenic current comparator (CCC)	QHR, step-up using CCC	Cryogenic current comparator (CCC)	QHR, step-up using CCC
17	SMD	Potentiometric bridge (MI 6000B)	10 kΩ calibrated at BIPM; step up based on binary voltage divider of the MI bridge	Potentiometric bridge (MI 6000B)	10 kΩ calibrated at BIPM; step up based on binary voltage divider of the MI bridge
18	UME	Active arm Wheatstone bridge	QHR, step-up using CCC and binary voltage divider of a MI 6000 bridge	Active arm Wheatstone bridge	QHR, step-up using CCC and binary voltage divider of a MI 6000 bridge

Lab No	Lab	10 MΩ Method	Traceability	1 GΩ Method	Traceability
19	LNE	not measured		“Controlled” Wheatstone bridge (LNE type)	QHR
20	EIM	Active arm Wheatstone bridge	QHR to 10 kΩ; step-up procedure not declared	Active arm Wheatstone bridge	QHR to 10 kΩ; step-up procedure not declared
21	BEV	DCCT bridge Guildline 6675A	1 Ω and 10 kΩ calibrated at BIPM; Step-up using a DCCT bridge	Active arm Wheatstone bridge	1 Ω and 10 kΩ calibrated at BIPM; Step-up using a DCCT bridge
22	CEM	Potentiometric bridge (MI 6000B)	QHR to 10 kΩ; Hamon step-up procedure to 1 MΩ and MI 6000 bridge step-up procedure; additional 10:1 ratio checks	Potentiometric bridge (MI 6000B)	QHR to 10 kΩ; Hamon step-up procedure to 1 MΩ and MI 6000 bridge step-up procedure; additional 10:1 ratio checks
23	VNIIM	Wheatstone bridge VNIIM	QHR; DCC to 1 kΩ and 10 kΩ; Hamon step up procedure to 10 MΩ using Wheatstone bridge	Wheatstone bridge VNIIM	QHR; DCC to 1 kΩ and 10 kΩ; Hamon step up procedure to 1 GΩ using Wheatstone bridge

Uncertainty Budgets provided by the Participants for ***R*** = 10 MΩ

1 METAS

The measurement consists in a 1:1 comparison ($r_{1:1}$) against a reference standard R_s calibrated in terms of the quantized Hall resistance. The step-up to 10 MΩ is carried out using a cryogenic current comparator up to 100 kΩ and a Hamon device from 100 kΩ to 10 MΩ. The model for the 1:1 comparison at 10 MΩ can be simplified to:

$$R_x = r_{1:1} \cdot R_s \cdot \prod k_i$$

k_i are correction factors. The corresponding uncertainties (grouped together according to the main influence factors) are given below.

Quantity X_i	Standard uncertainty $u(x_i)/x_i$ 10^{-6}	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R)/R$ µΩ/Ω	Degree of freedom ν_i
Step-up QHR to 10 MΩ	0.26	normal A	1	0.26	22
10 MΩ reference standard: stability, temperature and loading effects	0.15	normal A	1	0.15	90
1:1 bridge ratio: accuracy, interchange effects	0.14	normal A	1	0.14	24
Leakage effects	0.10	rectangular B	1	0.10	1000
Temperature dependence DUT	0.0*)	rectangular B	1	0.00	1000
Reproducibility R_x measurement	0.10	normal A	1	0.10	22
	Combined standard uncertainty:			0.36 µΩ/Ω	
	Effective degrees of freedom:			73	
	Expanded uncertainty (95% coverage factor):			0.72 µΩ/Ω	

*) The temperature dependence of the device under test is taken into account in the analysis (see report)

2 PTB

The value for R_X is determined by

$$R_X = V \cdot R_N \cdot k_D \cdot k_T$$

where R_N is the reference resistor, k_D the drift correction and k_T the temperature correction for R_N. V denotes the ratio determined by the bridge. It is calculated from the settings ε_i of the binary divider and the voltage differences U_i between the divider and the respective voltage taps of the resistors. U_0 denotes the voltage across both, R_X and R_N.

$$V = \frac{U_0 \cdot (\varepsilon_1 - \varepsilon_2) - (U_1 - U_2)}{U_0 \cdot (\varepsilon_3 - \varepsilon_4) - (U_3 - U_4)}$$

The uncertainty budget also includes the type A uncertainty for the repeatability of the measurements over several days (repeat).

All quantities are considered to be uncorrelated.

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$	Degree of freedom ν_i
R_N	1,0000044 MΩ	0,05 Ω	normal B	10	0,50 Ω	50
V	10,000384	$0{,}2 \cdot 10^{-6}$	normal A	$1 \cdot 10^6 \Omega$	0,20 Ω	9
k_V	1	$0{,}054 \cdot 10^6$	normal B	$10 \cdot 10^6 \Omega$	0,54 Ω	310
k_T	1	$0{,}029 \cdot 10^6$	rectangular B	$10 \cdot 10^6$ Ω	0,29 Ω	inf
k_D	1	$0{,}12 \cdot 10^6$	rectangular B	$10 \cdot 10^6 \Omega$	1,2 Ω	inf
repeat	1	$0{,}4 \cdot 10^6$	normal A	$10 \cdot 10^6 \Omega$	4 Ω	7
R_x	10,000428 MΩ					
		Combined standard uncertainty:			4,24 Ω	
		Effective degrees of freedom:			8	
		Expanded uncertainty (95% coverage factor):			10 Ω k=2,4)	

3 SIQ

Uncertainty budget (10 MΩ NIST, Ser. No. HR 7550):

Quantity *Xi*	Estimate *xi*	Standard uncertainty *u(xi)*	Probability distribution / method of evaluation (A, B)	Sensitivity coefficient *ci*	Uncertainty contribution *u(Ri)*	Degree of freedom *vi*
Rs	1.0000084 MΩ	0.0000005 MΩ	normal / B	10.0003970	0.000005 MΩ	1E+99
K_drift_Rs	0 MΩ	0.0000001 MΩ	rectangular / B	10.0003970	0.000001 MΩ	1E+99
K_Tc_Rs	0 MΩ	0.00000001 MΩ	rectangular / B	10.0003970	0.0000001 MΩ	1E+99
Ratio	10.0003970	0.0000006	rectangular / B	1.0000084 MΩ	0.000001 MΩ	1E+99
K_rep	0	0.0000011	normal / A	1.0000084 MΩ	0.000001 MΩ	17
Rx	10.000481 MΩ					
		Combined standard uncertainty:			0.000005 MΩ	
		Effective degrees of freedom:			8704	
		Expanded uncertainty (95% coverage factor):			0.000011 MΩ	

4 SMU

Uncertainty budget for 10 MΩ - (result)

Quantity X_i	Estimate x_i	Relative standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Relative uncertainty contribution $u(R_i)$	Degree of freedom ν_i
R_s	999 982,0 Ω	2,0x10^{-6}	B	1,0	2,0x10^{-6}	∞
δR_s	- 1,5 Ω	8,7x10^{-7}	B	1,0	8,7x10^{-7}	50
δR_{sT}	0,0 Ω	6,0x10^{-7}	B	1,0	6,0x10^{-7}	50
δR_{sH}	0,0 Ω	1,5x10^{-6}	B	1,0	2,5x10^{-6}	50
δR_{xT}	0,0 Ω	6,0x10^{-7}	B	1,0	6,0x10^{-7}	50
δR_{xH}	0,0 Ω	1,2x10^{-6}	B	1,0	2,2x10^{-6}	50
$\delta R_{x\ U\ 10\ V}$	10 V	1,0x10^{-6}	B	1,0	1,0x10^{-6}	∞
$\delta R_{x\ MI\ 6000B}$	10,000000	5,0x10^{-7}	B	1,0	5,0x10^{-7}	∞
R_x	R_x	1,2x10^{-6}	A	10,000 000 M	1,5x10^{-6}	120
		Combined relative standard uncertainty:			*4,48 x 10^{-6}*	
		Effective degrees of freedom:			*100*	
		Expanded relative uncertainty (95% coverage factor):			*9,0 x 10^{-6}*	

5 VSL

The following model equation is the basis for the uncertainty budget of the 10 MΩ resistors:

$$R_{10\mathrm{M}} = r_{10\mathrm{M}} * (1+\delta r_{10\mathrm{M}} + \delta r_{\mathrm{power}}) * r_{1\mathrm{M}} * (1+\delta r_{1\mathrm{M}}) * (1+ \delta r_{\mathrm{leak}}) * R_{\mathrm{ref}} / (1+\delta R_{10\mathrm{MT}})$$

with as value of the 10 kΩ reference resistor:

$$R_{\mathrm{ref}} = R_{10\mathrm{K}} * (1+\delta R_{10\mathrm{KT}} + \delta R_{10\mathrm{Kdrift}} + \delta R_{10\mathrm{Kpower}})$$

This equation is based on the two-step step-up procedure: first from 10 kΩ to 1 MΩ (via two 1:10 ratio measurements, checked with a 10 x 100 kΩ Hamon device), followed by a 1 MΩ to 10 MΩ measurement (checked with a 10 x 10 MΩ Hamon device).

Quantity	Definition
$R_{10\mathrm{M}}$	DUT
$r_{10\mathrm{M}}$	Measured ratio in 1 MΩ - 10 MΩ measurement. The uncertainty in the mean of the data is only 0.09 ppm. This reflects the stability of the measurement bridge as well as the small variation in temperature during the measurements combined with a small temperature coefficient of the DUT.
$\delta r_{10\mathrm{M}}$	Uncertainty of 1 MΩ - 10 MΩ ratio. A measurement of the 1:100 ratio of a 10 x 10 MΩ Hamon device using the same bridge leads to a result that is equal to 100 within 2 ppm. Therefore the uncertainty in the step from 1 MΩ to 10 MΩ is estimated to be at most 1 ppm.
δr_{leak}	Effect of leakage in bridge, cables, reference resistor and DUT. Most of the leakage effects are already contained in $\delta \mathrm{r}_{10\mathrm{M}}$ and $\delta \mathrm{r}_{1\mathrm{M}}$. The residual effects of leakage are estimated to be less than 1 ppm.
$\delta r_{\mathrm{power}}$	Power / voltage effect in the 1 MΩ transfer resistor; this resistor is used at two different voltages during the step-up chain. The uncertainty contribution is estimated to be smaller than 0.4 ppm.
$r_{1\mathrm{M}}$	Measured ratio in 10 kΩ - 1 MΩ measurement. The uncertainty in the mean of the data is only 0.05 ppm.
$\delta r_{1\mathrm{M}}$	Uncertainty of 10 kΩ - 1 MΩ ratio. A measurement of the 1:100 ratio of a 10 x 100 kΩ Hamon device using the same bridge leads to a result that is equal to 100 within typically 0.2 ppm – 0.5 ppm. Therefore the uncertainty in the step from 10 kΩ to 1 MΩ is estimated to be at most 0.7 ppm.

$\delta R_{10\mathrm{MT}}$	Temperature effect on unknown 10 MΩ resistor, including non equilibrium temperature of resistor and temperature sensor. Plotting the measurement values as a function of temperature indicates that the temperature coefficient of the 10 MΩ resistor is smaller than 10 ppm/°C. Combining this with the maximum temperature excursion of 0.1 °C during the measurements, residual effects that are not averaged lead to an uncertainty of at most 0.3 ppm.
$R_{10\mathrm{K}}$	Reference resistor with nominal value 10 kΩ. Via 1:1 measurements to a 10 kΩ resistor that is directly measured against the QHE setup of the NMi VSL, the 10 kΩ reference of all MI 6000A measurements is calibrated at a level of 0.04 ppm ($k = 2$).
$\delta R_{10\mathrm{KT}}$	Temperature effect on reference resistor, including non-equilibrium temperature of resistor and temperature sensor. Given the total temperature excursion of around 0.1 °C and a temperature coefficient of -0.06 ppm/°C, the uncertainty of this contribution is less than 0.01 ppm.
$\delta R_{10\mathrm{Kdrift}}$	Drift in reference resistor since last calibration. Based on the well-known history of the standard and the QHE calibration in September 2005, only 2 months before the comparison, the uncertainty in the correction for the drift is 0.01 ppm.
$\delta R_{10\mathrm{Kpower}}$	Power effect in the 10 kΩ reference resistor, which is estimated to be at most 0.01 ppm.

This results in the following uncertainty budget for the NIST HR 7550 resistor:

Quantity	**Value**	**Standard Uncertainty**	**Degrees of Freedom**	**Distribution**	**Sensitivity Coefficient**	**Uncertainty Contribution**
$r_{10\mathrm{M}}$	10.000458900	$900\cdot10^{-9}$	16	normal; A	$1.0\cdot10^{6}$	0.90 Ω
$\delta r_{10\mathrm{M}}$	0.0	$577\cdot10^{-9}$	∞	rect; B	$10\cdot10^{6}$	5.8 Ω
$\delta r_{\mathrm{power}}$	0.0	$231\cdot10^{-9}$	∞	rect; B	$10\cdot10^{6}$	2.3 Ω
δr_{leak}	0.0	$577\cdot10^{-9}$	∞	rect; B	$10\cdot10^{6}$	5.8 Ω
$r_{1\mathrm{M}}$	99.99993400	$5.00\cdot10^{-6}$	19	normal; A	$100\cdot10^{3}$	0.50 Ω
$\delta r_{1\mathrm{M}}$	0.0	$404\cdot10^{-9}$	∞	rect; B	$10\cdot10^{6}$	4.0 Ω
$\delta R_{10\mathrm{MT}}$	0.0	$173\cdot10^{-9}$	∞	rect; B	$-10\cdot10^{6}$	-1.7 Ω
$R_{10\mathrm{K}}$	10000.025820 Ω	$200\cdot10^{-6}$ Ω	50	normal; B	1000	0.20 Ω
$\delta R_{10\mathrm{KT}}$	0.0	$5.77\cdot10^{-9}$	∞	rect; B	$10\cdot10^{6}$	0.058 Ω
$\delta R_{10\mathrm{Kdrift}}$	0.0	$10.0\cdot10^{-9}$	50	normal; B	$10\cdot10^{6}$	0.10 Ω
$\delta R_{10\mathrm{Kpower}}$	0.0	$5.77\cdot10^{-9}$	∞	rect; B	$10\cdot10^{6}$	0.058 Ω
$R_{10\mathrm{M}}$	10.00047812 MΩ	9.62 Ω	∞			

With as final result: $R_{10\mathrm{M\_HR\ 7550}}$ = (10.000 478 ± 0.000 019) MΩ ($k = 2$)

The uncertainty budgets for the other two 10 MΩ resistors are essentially equal.

6 VMT/PFI

Uncertainty budget for Rx s/n HR7552
Date: 2006.02.11

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution/ method of evaluation (A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$	Degree of freedom υ_i
X1	0	0.01	Rectangular / B	1.0E+01	0.058	infinity
X2	0	0.10	Normal / B	1.0E+01	1.000	4
X3	0	2.00E-01	Normal /B	1.0E+01	2.000	11
X4	999981.8772	3.00E-01	Normal / B	1.0E+01	3.000	23
X5	0	2.89E-03	Rectangular / B	1.0E+01	0.029	12
X6	10.00061246	5.90E-07	Normal / A	1.0E+06	0.590	7
X7	0	5.77E-07	Rectangular / B	1.0E+06	0.577	infinity
X8	0	5.77E-08	Rectangular / B	1.0E+06	0.058	infinity
X9	0	3.00E-06	Normal / A	1.0E+06	3.000	46
X10	0	3.46E+00	Rectangular /B	1.0E+00	3.464	infinity
Rx	10000431.23					
		Combined standard uncertainty:			6.0	
		Effective degrees of freedom:			infinity	
		Expanded uncertainty (95% coverage factor):			12.0	

Model function:

Rx = (X1 + X2 + X3 + X4 + X5) * (X6 + X9 + X7 + X8) + X10

where:

X1	Traceability SR104 10 kΩ (Ω)
X2	Stability of SR104 (Ω)
X3	Scaling 10 kΩ to 1 MΩ (Ω)
X4	Resistance of 1 MΩ reference (Ω)
X5	Temperature stability of 1 MW reference (Ω)
X6	10:1 ratio 10MΩ unknown/ 1 MΩ reference (includes detector resolution, voltage source stability)
X7	Bridge 10:1 ratio error
X8	Bridge linearity error
X9	Repeatability of 10:1 ratio measurements
X10	Leakage (Ω)

7 MIKES

Budget of uncertainty for 10 MOhm resistor (NIST_7550) measured by DCC 6675 Guildline bridge with 1:1 ratio from 10 MOhm reference.

Mathematical model:

When DCC bridge is balanced, the value R_{10M} of the unknown resistor is obtained from the relationship:

$$R_x = R_{ref} * (1 + \delta_{Ref} + K_{Drift} + K_{Temper} + K_{load}) * k_{DCC} (1 + k_{br} + k_{leak} + k_{pos})*(1 + k_{Rx})$$

where:

R_{Ref} is the value of reference resistor.
δ_{Ref} is the relative error of the reference resistor.
K_{Drift} is the relative error due to drifts in reference resistor.
K_{Temper} is the relative error due to uncorrected temperature instabilities of reference resistor.
K_{load} is the relative error due to uncorrected loading effects in reference resistor.
k_{DCC} is the nominal ratio of the bridge.
k_{br} is specified 1 σ uncertainty of the bridge ratio for that range.
k_{leak} is the relative error due to leakage currents
k_{pos} is the relative error due to relative position of the unknown and the reference resistors.
k_{Rx} is the relative error due to temperature effects and drifts of the unknown resistor during its stay in laboratory

The relative standard uncertainty is given by :

$$u(R_x) / R_x = \sqrt{\{ [u (R_{Ref}) /R_{Ref}]^2 + [u (k_{DCC})/ k_{DCC}]^2 + [u (k_{read})/ k_{read}]^2\}}$$

Where $u(k_{read}) / k_{read}$ is the relative standard deviation of the measurement results.

Table III. Uncertainty budget for the 10M traveling resistor (NIST7550)

Quantity X_i	Estimate x_I Ohm	Relative standard uncertainty $u(x_i)$, 10^{-6}	Probability distribution / Method of evaluation (A,B)	Sensitivity coefficient c_I	Relative uncertainty contribution $u_i(Rx)$, (10^{-6})	Degree of Freedom v_i
R_{Ref}	1 000 041.21	0	rect/B	1	0	inf
δ_{Ref}	0	0.68	rect/B	1	0.68	inf
k_{Drift}	0	0.1	rect/B	1	0.1	inf
K_{Temper}	0	0.23	rect/B	1	0.23	inf
K_{load}	0	0.07	rect/B	1	0.07	inf
k_{DCC}	1	0	rect/B	1	0	inf
k_{br}	0	0.375	rect/B	1	0.375	inf
k_{pos}	0	0.1	rect/B	1	0.1	inf
k_{leak}	0	0.05	rect/B	1	0.05	inf
k_{Rx}	0	0.1	rect/B	1	0.1	inf
k_{read}	0	0.15	normal/A	1	0.15	60
R_{10M}	10 000488.6	Combined standard uncertainty (1 σ)			0.85	3
		RSS of Type A uncertainties			0.15	
		RSS of Type B uncertainties			0.82	

MIKES Budget of uncertainty for 10 MOhm resistor (NIST_7550) measured by substitution method with the Keithley 6517A electrometer, from Hamon 10 MOhm reference with 1:1 ratio.

Mathematical model:
When DCC bridge is balanced, the value R_{10M} of the unknown resistor is obtained from the relationship:
$R_x = R_{ref} * (1 + \delta_{Ref} + K_{Drift} + K_{Temper} + K_{load}) * k_{DMM} (1 + k_{Det} + k_{leak}) * (1 + k_{Rx})$
where:
R_{Ref} is the value of reference resistor
δ_{Ref} is the relative error of the reference resistor.
K_{Drift} is the relative error due to drifts in reference resistor
K_{Temper} is the relative error due to uncorrected temperature instabilities of reference resistor
K_{load} is the relative error due to uncorrected loading effects in reference resistor
k_{DMM} is the nominal ratio
k_{Det} is the relative error of Keithley readings due to the drifts in DMM during measurements
k_{leak} is the relative error due to leakage currents
k_{Rx} is the relative error due to temperature effects and drifts of unknown resistor during its stay in laboratory

The relative standard uncertainty is given by :
$u(R_x) / R_x = \sqrt{\{ [u (R_{Ref}) / R_{Ref}]^2 + [u (k_{DCC}) / k_{DCC}]^2 + [u (k_{read}) / k_{read}]^2 \}}$

Where $u(k_{read}) / k_{read}$ is the relative standard deviation of the measurement results.

Table 1. Uncertainty budget for 10M

Quantity X_I	Estimate x_I Ohm	Relative standard uncertainty $u(x_i)$, 10^{-6}	Probability distribution / Method of evaluation (A,B)	Sensitivity coefficient c_i	Relative uncertainty contribution $u_i(Rx)$, (10^{-6})	Degree of Freedom v_i
R_{Ref}	1 000 041.21	0	rect/B	1	0	inf
δ_{Ref}	0	0.44	rect/B	1	0.44	inf
k_{DMM}	1	0	rect/B	1	0	inf
k_{Det}	0	0.4	rect/B	1	0.4	inf
k_{leak}	0	0.1	rect/B	1	0.1	inf
k_{Drift}	0	0.1	rect/B	1	0.1	inf
K_{Temper}	0	0.23	rect/B	1	0.23	inf
K_{load}	0	0.1	rect/B	1	0.07	inf
k_{Rx}	0	0.1	rect/B	1	0.1	inf
k_{read}	0	0.58	normal/A	1	0.58	50
R_{10M}	10 000489.9	Combined standard uncertainty (1 σ)			0.94	2
		RSS of Type A uncertainties			0.58	
		RSS of Type B uncertainties			0.73	

MIKES Budget of uncertainty for 10 MOhm resistor (NIST_7550) measured by DCC 6675 Guildline bridge with 1:1 ratio from 10 MOhm Hamon reference.

Mathematical model:
When DCC bridge is balanced, the value R_{10M} of the unknown resistor is obtained from the relationship:
$R_x = R_{ref} * (1 + \delta_{Ref} + K_{Drift} + K_{Temper} + K_{load}) * k_{DCC} (1 + k_{br} + k_{leak} + k_{pos})*(1 + k_{Rx})$
where:
R_{Ref} is the value of reference resistor.
δ_{Ref} is the relative error of the reference resistor.
K_{Drift} is the relative error due to drifts in reference resistor.
K_{Temper} is the relative error due to uncorrected temperature instabilities of reference resistor.
K_{load} is the relative error due to uncorrected loading effects in reference resistor.
k_{DCC} is the nominal ratio of the bridge.
k_{br} is specified 1 σ uncertainty of the bridge ratio for that range.
k_{leak} is the relative error due to leakage currents
k_{pos} is the relative error due to relative position of unknown and reference resistors.
k_{Rx} is the relative error due to temperature effects and drifts of unknown resistor during its stay in laboratory

The relative standard uncertainty is given by :
$u(R_x) / R_x = \sqrt{ [u (R_{Ref}) / R_{Ref}]^2 + [u (k_{DCC}) / k_{DCC}]^2 + [u (k_{read}) / k_{read}]^2 }$

Where $u(k_{read}) / k_{read}$ is the relative standard deviation of the measurement results.

Table 2. Uncertainty budget for the 10M traveling resistor (NIST7550)

Quantity X_i	Estimate x_I Ohm	Relative standard uncertainty $u(x_i)$, 10^{-6}	Probability distribution / Method of evaluation (A,B)	Sensitivity coefficient c_i	Relative uncertainty contribution $u_i(Rx)$, (10^{-6})	Degree of Freedom v_i
R_{Ref}	1 000 041.21	0	rect/B	1	0	inf
δ_{Ref}	0	0.44	rect/B	1	0.68	inf
k_{Drift}	0	0.1	rect/B	1	0.1	inf
K_{Temper}	0	0.2	rect/B	1	0.23	inf
K_{load}	0	0.05	rect/B	1	0.07	inf
k_{DCC}	1	0	rect/B	1	0	inf
k_{br}	0	0.375	rect/B	1	0.375	inf
k_{pos}	0	0.1	rect/B	1	0.1	inf
k_{leak}	0	0.05	rect/B	1	0.05	inf
k_{Rx}	0	0.1	rect/B	1	0.1	inf
k_{read}	0	0.15	normal/A	1	0.15	60
R_{10M}	10 000488.6	Combined standard uncertainty (1 σ)			0.65	1
		RSS of Type A uncertainties			0.15	
		RSS of Type B uncertainties			0.62	

8 OMH

Uncertainty budget for 10 MΩ HR550

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$	Degree of freedom ν_i
1 MΩ working standard	1.0001808 MΩ	1.55 ppm	B normal	1	1.55	inf.
working standard drift	0	0.1ppm/year	B rectangular	2 years	0.2	inf.
MI 6000A bridge	0	0.05 ppm	B rectangular	1	0.05	inf.
temperature dependence	0	0.12°C	B rectangular	10ppm/°C	1.2	inf.
Ratio measurement	9.99869709	0.35 ppm	A normal	1	0.35	11
R_x	10.000504854 MΩ					
		Combined standard uncertainty:			2.0 ppm	
		Effective degrees of freedom:			11772	
		Expanded uncertainty (95% coverage factor):			4.0 ppm	

9 CMI

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution [MΩ] $u(R_i)$	Degree of freedom ν_i
R_S	9.999 92 MΩ	1.5 x 10^{-5} MΩ	normal	1.000	1.5 x 10^{-5}	∞
δ R_{SD}	+1 x 10^{-5} MΩ	5 x 10^{-5} / √ 3 MΩ	rectangular	1.000	2.9 x 10^{-5}	∞
δ_{p}	0.5 x 10^{-6}	0.5 x 10^{-6} / √ 3	rectangular	10.000 MΩ	0.29 x 10^{-5}	∞
δ_{STD}	0.2 x 10^{-6}	0.2 x 10^{-6} / √ 3	rectangular	10.000 MΩ	0.12 x 10^{-5}	∞
$\delta_{R\,T}$	0 MΩ	1 x 10^{-5} / √ 3 MΩ	rectangular	1.000	0.58 x 10^{-5}	∞
$\delta_{R\,RH}$	0 MΩ	1 x 10^{-5} / √ 3 MΩ	rectangular	1.000	0.58 x 10^{-5}	∞
$\delta_{R\,L}$	0 MΩ	1 x 10^{-5} / √ 3 MΩ	rectangular	1.000	0.58 x 10^{-5}	∞
$\delta_{R\,C}$	0 MΩ	1 x 10^{-5} / √ 3 MΩ	rectangular	1.000	0.58 x 10^{-5}	∞
repeatability p	1.000 056 3	0.1 x 10^{-6}	normal	10.000 MΩ	0.1 x 10^{-5}	14
R_x	10.000 49 MΩ					
		Combined relative standard uncertainty:			3.5 x 10^{-6}	
		Effective degrees of freedom:			21 008 750	
		Expanded relative uncertainty (95% coverage factor):			7 x 10^{-6}	

10 INM

Model equation of the measurement:

The principle of measurement applied was the substitution method. The measurand is described by the equation

$$R_X = R_S + (R_{XM} - R_{SM})$$

If this equation is expanded in order to include relevant deviation of the input quantities , it becomes:

$$R_X = R_S + (R_{XM} - R_{SM}) + \delta R_D + \delta R_{ST} + \delta R_m - \delta R_{XT}$$

To obtain the conventional value and the standard uncertainty of the resistor under test – UUT- **MI 9331, SN 1050109**, the two-terminal method - “grounded mode” variant was used (see Fig.1) and the following input quantities were considered:

Reference standard (R_S)
Resistance value of the 10 MΩ standard resistor. The last calibration certificate for the reference standard gives a resistance value of 9.99942 MΩ and a standard uncertainty of 0,02 kΩ at the specified reference temperature of 23 °C.

Difference between the measured values of UUT and the reference standard (R_{XM} - R_{SM}) R_{XM} and R_{SM} are the indications of the teraohmmeter for each of the two resistors (UUT and standard).

Nineteen observations were made. The mean difference was of +0.81 kΩ with an estimated associated standard uncertainty: $s_0 = 0.006$ kΩ (see Table 4).

Drift of the value of the standard (δR_D)
The uncertainty due to the drift of standards value has a rectangular distribution with bounds at ± 0.03 kΩ.

Temperature corrections (δR_{ST}, δR_{XT})
The air bath temperature at the time of calibration was measured with a digital thermometer. The mean value of the temperature was 23,16 °C and the range of variation was 22.92 °C ÷ 23.27 °C. The associated uncertainty was ± 0.08 °C.
The known values of the temperature coefficients of the reference resistor $\alpha_S = -3.8 \times 10^{-6}$/K; $\beta_S = 0.2 \times 10^{-6}/K^2$ (at $T_{ref} = 23$ °C), result the ± 0,003 kΩ bounds for the deviation (rectangular distribution).
For the UUT the temperature coefficients are unknown, but the uncertainty of the correction is approximately 0.002 kΩ (Technical Protocol).

Change of the indicated values caused by disturbances in the power supply line (δR_m) We estimated the changes of the teraohmmeter indication due to the instabilities in the power supply line to be ± 0.03 kΩ (triangular distribution).

Standard Serial No **1050109**

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$	Degree of freedom ν_i
R_S	9.99942 MΩ	0.02 kΩ	Normal/B	1	0.02 kΩ	∞
$\bar{r}$	+0.81 kΩ	0.006 kΩ	Normal/A	1	0.006 kΩ	18
δR_{SD}	0	0.02 kΩ	Rectangular/B	1	0.02 kΩ	2
δR_{ST}	-0.006 kΩ	0.002 kΩ	Rectangular/B	1	0.002 kΩ	2
δR_{XT}	0	0.002 kΩ	Normal/B	-1	0.002 kΩ	∞
δR_m	0	0.012 kΩ	Triangular/B	1	0.012 kΩ	50
R_x	**10.00022 MΩ**					
		Combined standard uncertainty:			*0.03* kΩ	
		Effective degrees of freedom:			*11*	
		Expanded uncertainty (95% coverage factor):			***0.07* kΩ**	

12 NML

The measurement model, containing the significant input quantities, is :

$$R_X = r_1 \cdot r_2 \cdot r_3 \cdot R_S \cdot [1 + \alpha \cdot (23 - T)] + \Delta_L + \Delta_R \qquad \ldots(1)$$

where R_X is the resistance of the unknown 10 MΩ resistor;
r_1 is the ratio of the resistance of the unknown 10 MΩ resistor to the resistance of the 1 MΩ/step transfer standard in the series configuration;
r_2 is the ratio of the resistance of the 1 MΩ/step transfer standard in the series configuration, to its resistance in the parallel configuration;
r_3 is the ratio of the resistance of the 1 MΩ/step transfer standard in the parallel configuration to the resistance of the 10 kΩ reference standard;
R_S is the resistance of the 10 kΩ reference standard;
α is the relative temperature coefficient of R_X ;
T is the mean measuring temperature;
Δ_L is the correction due to leakage effects;
Δ_R is the correction due to all effects which change randomly during the measurement.

If we write the resistance values and ratios in terms of their nominal values ($R_X^{(N)}, r_1^{(N)}, r_2^{(N)}, r_3^{(N)}, R_S^{(N)}$), and fractional deviations from nominal ($\delta_X, \delta_1, \delta_2, \delta_3, \delta_S$) we have :

$$\begin{aligned} R_X &= R_X^{(N)} \cdot (1 + \delta_X) \\ r_i &= r_i^{(N)} \cdot (1 + \delta_i) \qquad i = 1,2,3 \qquad \ldots(2) \\ R_S &= R_S^{(N)} \cdot (1 + \delta_S) \end{aligned}$$

and equation (1) reduces to :

$$\delta_X \approx \delta_1 + \delta_2 + \delta_3 + \delta_S + \alpha \cdot (23 - T) + \frac{\Delta_L}{R_X^{(N)}} + \frac{\Delta_R}{R_X^{(N)}} \qquad \ldots(3)$$

where we have retained only the first order terms of small quantities.

The uncertainty budget for the 10 MΩ measurement is presented in Table 1 below.

In order to simplify the presentation, the standard uncertainties for the input quantities $\delta_X, \delta_1, \delta_2, \delta_3, \delta_S$ include the effects due to calibration, drift, non-linearity, temperature, and other influences. The standard uncertainties of these input quantities are dominated by contributions from systematic effects whose uncertainty contributions are obtained by a type B method. Consequently, the number of degrees of freedom associated with these estimates is taken to be infinite. The relative temperature coefficient used in the table is obtained from the MI 9331 specification sheet.

Quantity	Estimate	Standard Uncertainty	Method of Evaluation	Sensitivity Coefficient	Uncertainty Contribution	Degrees of Freedom
δ_1	4.7 μΩ/Ω	5 μΩ/Ω	B	1	5 μΩ/Ω	∞
δ_2	0.0 μΩ/Ω	4 μΩ/Ω	B	1	4 μΩ/Ω	∞
δ_3	2.6 μΩ/Ω	2 μΩ/Ω	B	1	2 μΩ/Ω	∞
δ_S	1.4 μΩ/Ω	0.5 μΩ/Ω	B	1	0.5 μΩ/Ω	∞
$(T\text{-}23)$	0.00°C	0.10°C	B	0.6 μΩ/Ω°C^{-1}	0.1 μΩ/Ω	∞
Δ_L	0 Ω	30 Ω	B	10^{-7} Ω^{-1}	3 μΩ/Ω	∞
Δ_R	0 Ω	8 Ω	A	10^{-7} Ω^{-1}	0.8 μΩ/Ω	13
δ_X	8.7 μΩ/Ω					
		Combined Standard Uncertainty			7.4 μΩ/Ω	
		Effective Degrees of Freedom			$>10^4$	
		Expanded Uncertainty (95% C.F.)			15 μΩ/Ω	

Table 1 Uncertainty Budget for 10 MΩ Measurement

13 JV

Making a linear approximation in the deviations, the measurement function can be written as:

$$\mathbf{R_X = r \cdot (R_S + \delta R_{DS} + \delta R_{PS} + \delta R_{TS}) + r \cdot R_S \cdot (\delta r_C + \delta r_B + \delta r_{LB} + \delta r_{LG}) - \delta R_{PX} - \delta R_{TX}}$$

where :

$\mathbf{R_X}$ - Value of unknown resistor (object),
$\mathbf{r}$ - Measured ratio r,
$\mathbf{R_S}$ - Resistance of reference standard,
$\mathbf{\delta R_{DS}}$ - Drift/Stability of reference standard,
$\mathbf{\delta R_{PS}}$ - Influence of Pressure on reference standard,
$\mathbf{\delta R_{TS}}$ - Influence of Temperature on reference standard,
$\mathbf{\delta r_C}$ - Correction factor for influence of thermoelectric voltages,
$\mathbf{\delta r_B}$ - Correction factor for Bridge linearity /offset,
$\mathbf{\delta r_{LB}}$ - Correction factor for Leakage currents in Bridge/scanner,
$\mathbf{\delta r_{LG}}$ - Correction factor for Leakage currents in ref. & object (w. active Guard),
$\mathbf{\delta R_{PX}}$ - Influence of Pressure on object,
$\mathbf{\delta R_{TX}}$ - Influence of Temperature on object.

Uncertainty budget 10 MΩ SN. 1050111

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$ (Ω)	Degree of freedom ν_i
r	10,000 0971	2,6e-6	Norm./ A	1,0e+6 Ω	2,6	2
R_S	1 000 000,43 Ω	0,57 Ω	Norm./ B	10	5,7	∞
δR_{DS}	0 Ω	0,19 Ω	Norm./ B	10	1,9	∞
δR_{PS}	0 Ω	0,03 Ω	Norm./ B	10	0,3	∞
δR_{TS}	0 Ω	0,23 Ω	Rect./ B	10	2,3	∞
δr_{LB}	0	60e-9	Rect./ B	1,0e+7 Ω	0,6	∞
δr_{LG}	0	50e-9	Norm./ B	1,0e+7 Ω	0,5	∞
δR_{PX}	0 Ω	0,3 Ω	Norm./ B	1	0,3	∞
δR_{TX}	0 Ω	11,5 Ω	Rect./ B	1	11,5	∞
δr_C	0	10e-9	Rect./ B	1,0e+7 Ω	0,1	∞
δr_B	0	200e-9	Rect./ B	1,0e+7 Ω	2,0	∞
R_x , deviation from nominal value	101,4 Ω					
		Combined standard uncertainty:			*13,6 Ω*	
		Effective degrees of freedom:			*1 522*	
		Expanded uncertainty (95% coverage factor):			*27 Ω*	

14 INETI

Quantity *Xi*	Estimate *xi*	Standard uncertainty *u(xi)*	Probability distribuition / method of evaluation (A, B)	Sensitivity coefficient *ci*	Relative uncertainty contribution *[ui(Rx)]2*	Degree of freedom *ν ι*
Rs + δRD + δRsT	1000069	5,5E-01 Ω	B / rectangular	10	3,00E+01 Ω^2	∞
Ratio	9,9986624	7,54E-05	B / rectangular	1,00E+06 Ω	5,68E+03 Ω^2	∞
Ratio	-	7,49E-06	A / normal	1,00E+06 Ω	5,61E+01 Ω^2	17
RX	**9,999349E+06**	▨	▨	▨	**5,8E+03 Ω**	***∞***

Combined Standard Uncertainty, Uc (Rx) =	7,6E+00	μΩ/Ω
Effective degrees of freedom=	∞	
Expanded uncertainty (95% coverage factor) =	**15**	**μΩ/Ω**

15 LNMC

Uncertainty budget Type: NHR No. 7551

Quantity X_i	Estimate x_i	Relative standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A)	Sens. coeff c_i	Relative uncertainty contribution $u(R_i)$	Degree of freedom ν_i
Resistance of the reference R_S	9,999650 MΩ	2,5 × 10^{-5} MΩ	Normal	1	2,5 × 10^{-5} MΩ	infinity
Drift of the resistance of the reference since its last calibration Drift R_S	1× 10^{-5} MΩ	0,578 × 10^{-5} MΩ	Rectangular	1	0,578 × 10^{-5} MΩ	infinity
Temperature related resistance variation of the reference δR_{TS}	1,3 × 10^{-5} MΩ	0,75 × 10^{-5} MΩ	Rectangular	1	0,75× 10^{-5} MΩ	infinity
Standard deviation of the Multimeter $\delta R_{multimeeter}$	0,7 × 10^{-5} MΩ	0,4 × 10^{-5} MΩ	Rectangular	1	0,4× 10^{-5} MΩ	infinity
R_x	10,000133 MΩ					
		Combined relative standard uncertainty:			2,7 × 10^{-5} MΩ	
		Effective degrees of freedom:			infinity	
		Expanded relative uncertainty (95% coverage factor):			± 5,4 × 10^{-5} MΩ	

16 NPL

The uncertainty contributions of the bridge consist of the ratio error ε_{CCC}, error due to the combining network ε_{cn}, and the error due to non-linearity of the SQUID readout ε_{SQUID} in the case of the measurement without SQUID servo (i.e. only in the 1 GΩ measurement).

10 MΩ Uncertainty Budget

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$	Degree of freedom ν_i
ε_{CCC}	-	0.012 ppm	Rectangular/B	1	0.012 μΩ/Ω	Inf
ε_{cn}	-	< 0.1 ppb	Rectangular/B	1	< 0.0001μΩ/Ω	Inf
ε_{SQUID}	-	N/A			-	
$R_{standard}$	1 MΩ	0.018 μΩ/Ω	Normal/A	1	0.018μΩ/Ω	4
$R_{standard}$	1 MΩ	0.046 μΩ/Ω	Rectangular/B	1	0.046μΩ/Ω	Inf
$T_{standard}$	20°C	0.1 °C	Rectangular/B	0.2 ppm/°C	0.020 μΩ/Ω	Inf
R_{buffer}	10 MΩ	0.020 μΩ/Ω	Normal/A	1	0.020 μΩ/Ω	4
R_{buffer}	10 MΩ	0.012 μΩ/Ω	Rectangular/B	1	0.012 μΩ/Ω	Inf
T_{buffer}	20°C	0.1 °C	Rectangular/B	0.5 ppm/°C	0.050 μΩ/Ω	Inf
$P/coeff_{buffer}$	1 mW	1 mW	Rectangular/B	50 ppm/W	0.050 μΩ/Ω	Inf
R_x	10 MΩ	0.055 μΩ/Ω	Normal/A	1	0.055 μΩ/Ω	3
R_x	10 MΩ					
		Combined standard uncertainty:			**0.107 μΩ/Ω**	
		Effective degrees of freedom:			**42**	
		Expanded uncertainty (95% coverage factor):			**0.220 μΩ/Ω**	

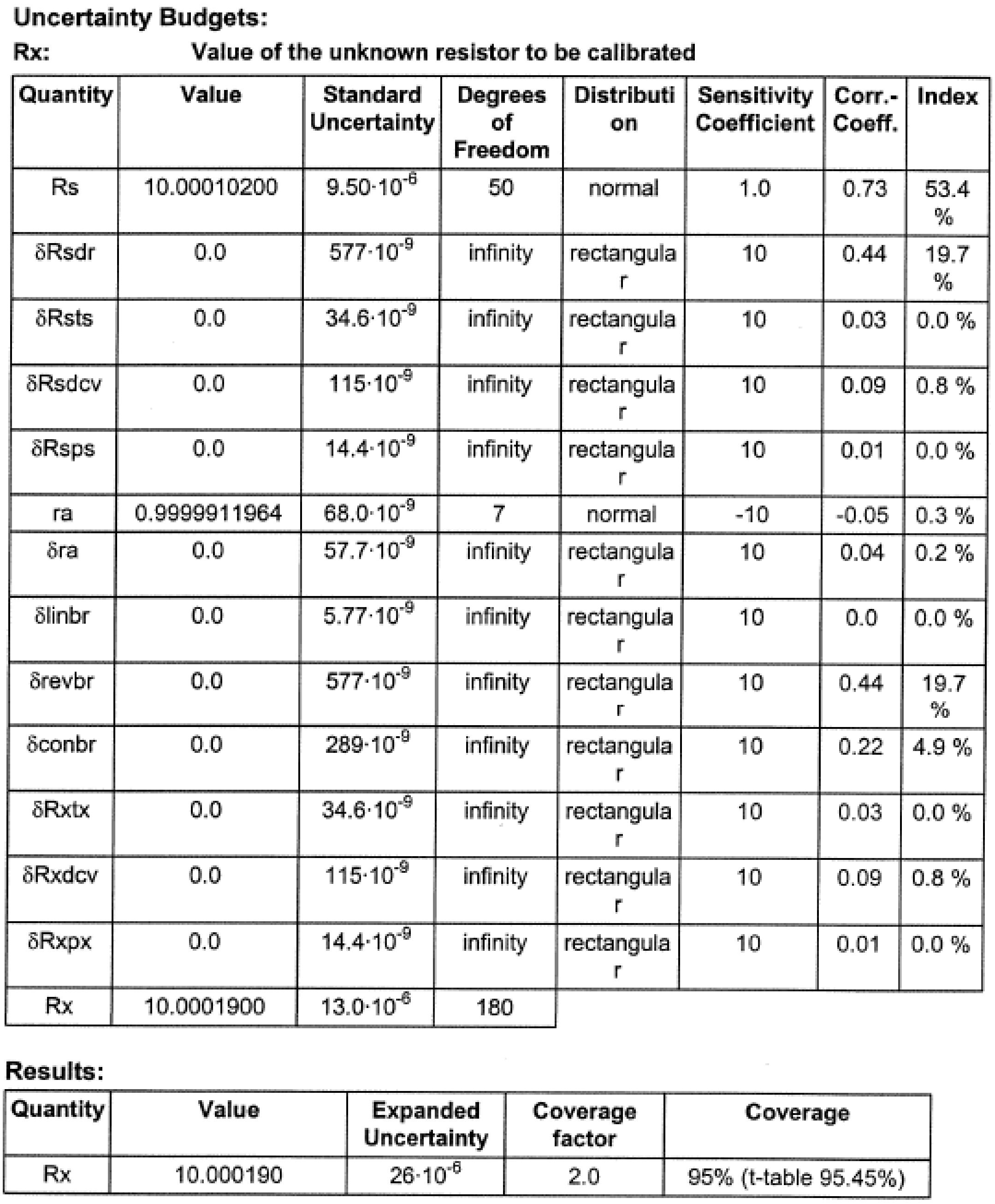
17 SMD

The uncertainty calculations were made using commercially available software developed according the rules of the GUM [2], [3] and [4]. The following mathematical models were used:

$$R_x = R_s \times (1 + \delta Rsdr + \delta Rsts + \delta Rsdcv + \delta Rsps) \times r_a \times (1 + \delta r_a + \delta linbr + \delta conbr)/(1 + \delta Rxtx + \delta Rxdcv + \delta Rxpx)$$

The following components were taken into account:

- ***R_x*** = value of the unknown resistor.
- ***R_s*** = value of the reference resistor calibrated by SMD and corrected for the temperature difference.
- ***δRsdr*** : uncertainty on the value of the correction for the drift of Rs.
- ***δRsts*** = uncertainty of Rs due to the uncertainty on the exact knowledge of the temperature of this resistor. This is due to the short-term stability of the climatic test chamber.
- ***δRsdcv*** = influence of the applied voltage on Rs
- ***δRsps*** = uncertainty due to the possible influence of atmospheric pressure on Rs.
- ***r_a*** : successively means of measurement results recorded the ratios R_s/R_x or R_x/R_s.
- ***δr_a*** = correction for the ratios R_s/R_x or R_x/R_s.
- ***δlinbr*** : uncertainty coming from the non-linearity of the bridge.
- ***δconbr***: uncertainty coming from the influence of the limited insulation of the bridge and of the connecting leads, the guarding, grounding and shielding, the thermal emfs, the electromagnetic interference,…
- ***δRxtx*** : uncertainty on Rx due to the uncertainty on the exact knowledge of the temperature of the unknown resistor. This due to the short-term instability of the climatic test chamber.
- ***δRxdcv*** = influence of the applied voltage on Rx
- ***δRxpx*** : uncertainty due to influence of the atmospheric pressure on Rx.



Uncertainty Budgets:

Rx: Value of the unknown resistor to be calibrated

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Distribution	Sensitivity Coefficient	Corr.-Coeff.	Index
Rs	10.00010200	$9.50\cdot10^{-6}$	50	normal	1.0	0.73	53.4 %
δRsdr	0.0	$577\cdot10^{-9}$	infinity	rectangular	10	0.44	19.7 %
δRsts	0.0	$34.6\cdot10^{-9}$	infinity	rectangular	10	0.03	0.0 %
δRsdcv	0.0	$115\cdot10^{-9}$	infinity	rectangular	10	0.09	0.8 %
δRsps	0.0	$14.4\cdot10^{-9}$	infinity	rectangular	10	0.01	0.0 %
ra	0.9999911964	$68.0\cdot10^{-9}$	7	normal	-10	-0.05	0.3 %
δra	0.0	$57.7\cdot10^{-9}$	infinity	rectangular	10	0.04	0.2 %
δlinbr	0.0	$5.77\cdot10^{-9}$	infinity	rectangular	10	0.0	0.0 %
δrevbr	0.0	$577\cdot10^{-9}$	infinity	rectangular	10	0.44	19.7 %
δconbr	0.0	$289\cdot10^{-9}$	infinity	rectangular	10	0.22	4.9 %
δRxtx	0.0	$34.6\cdot10^{-9}$	infinity	rectangular	10	0.03	0.0 %
δRxdcv	0.0	$115\cdot10^{-9}$	infinity	rectangular	10	0.09	0.8 %
δRxpx	0.0	$14.4\cdot10^{-9}$	infinity	rectangular	10	0.01	0.0 %
Rx	10.0001900	$13.0\cdot10^{-6}$	180				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
Rx	10.000190	$26\cdot10^{-6}$	2.0	95% (t-table 95.45%)

18 UME

The model function of uncertainty can be written as below

$$R_X = \frac{(R_S + \delta R_{Sdrf} + \delta R_{STemp} + \delta R_{Svolt}) \times (E_{Xappl} + \delta E_{Xdrf})}{(E_{Sappl} + \delta E_{Sdrf})} - \delta R_{xTemp}$$

R_S , reference resistance value.

u_{Rcal}, calibration uncertainty of the reference resistance value. It’s always given 2σ and has got normal distribution.

$u_{\delta Rsdrf}$, drift of the reference resistance of the reference since its last calibration. This value is added to the uncertainty calculation as rectangular distribution.

$u_{\delta Rstemp}$, temperature related resistance variation of the reference. This value is added to the uncertainty calculation as rectangular distribution.

$u_{\delta Rsvolt}$, power related resistance variation of the reference. This value is added to the uncertainty calculation as rectangular distribution.

E_{Xappl}, applied voltage value.

u_{Excal}, calibration uncertainty of the voltage value. It’s always given 2σ and has normal distribution.

$u_{\delta Exdrf}$, drift of the voltage of the reference since its last calibration. This value is added to the uncertainty calculation as rectangular distribution.
E_{Sappl}, applied voltage value

u_{Escal}, calibration uncertainty of the voltage value. It’s always given 2σ and has normal distribution.

u_{Esdrf}, drift of the reference voltage since its last calibration. This value is added to the uncertainty calculation as rectangular distribution.

R_X , calibrated resistance value.

$u_{\delta Rxtemp}$, temperature related resistance variation of the unknown. This value is added to the uncertainty calculation as rectangular distribution.

u_{Rstd}, standard deviation of the measurement and it has normal distribution.

Proposed scheme for an uncertainty budget for R_X (S/N: HR7551 , 10MΩ)

Quantity X_i	Estimate x_i	Relative standard uncertainty $u(x_i)$	Probability distribution	Sensitivity coefficient c_i	Relative uncertainty contribution $u_i(R_x)$
Reference resistance value (R_S)	1E+06	$3x10^{-6}$	Normal , k=2	10	$1,5\ x10^{-6}$
Reference Resistance Drift (δR_{Sdrf})		$1x10^{-6}$	Rectangular	10	$0,58x10^{-6}$
Ref.Resistance temperature effect (δR_{Stemp})		$2x10^{-6}$	Rectangular	10	$1,16x10^{-6}$
Ref.Resistance Voltage effect (δR_{Svolt})		$0,3x10^{-6}$	Rectangular	10	$0,17x10^{-6}$
Applied voltage (E_{Xappl})	10	$1x10^{-6}$	Normal, k=2	1E+06	$0,5x10^{-6}$
Drift of the voltage (δE_{Xdrf})		$1x10^{-6}$	Rectangular	1E+06	$0,58x10^{-6}$
Applied voltage (E_{Sappl})	1	$1x10^{-6}$	Normal, k=2	1E+07	$0,5x10^{-6}$
Drift of the voltage (δE_{Sdrf})		$1x10^{-6}$	Rectangular	1E+07	$0,58x10^{-6}$
Calibrated Res.Temperature effect (δR_{Xtemp})		0	Rectangular	-1	0
Repeatability (R_{std})		$0,6x10^{-6}$	Normal	1	$0,6x10^{-6}$
					$4,69x10^{-6}$
R_X	**10000142Ω**	u_c			≈5 μΩ/Ω

20 EIM

10M HR7551

Quantity X_i	Estimate χ_i		Standard uncertainty $u(\chi_i)$		Probability Distribution (Type A/B)	Sensitivity coefficient c_i		Uncertainty contribution $u(R_i)$		Degrees of freedom ν_i
Reference resistor value	10 000 345	Ω	41	Ω	B	1		41	Ω	∞
Electrometer uncertainty	1.E-11	A	6.E-14	A	B	-7.E+12	Ω/A	0.4	Ω	∞
Bridge linearity	1.E-11	A	9.E-13	A	B	-7.E+12	Ω/A	6	Ω	∞
Leakages	1.E-11	A	5.E-13	A	B	-7.E+12	Ω/A	4	Ω	∞
Calibrator	10	V	3.E-05	V	B	-7.E+05	Ω/V	20	Ω	∞
Reproducibility	10 000 054	Ω	33	Ω	A	1		33	Ω	8
Rx	10 000 054	Ω								

Combined standard uncertainty:	57	Ω
Effective degrees of freedom:	67	
Expanded uncertainty (95 % coverage factor):	114	Ω

21 BEV

The following sources of uncertainty as stated in the respective tables are taken into account:

- $R_{\mathrm{ref,cal}}$: This is the calibration uncertainty of the standard resistors of BEV which were used for this comparison. These calibration uncertainties are calculated for each standard resistor of BEV when the internal calibration procedure is done. The largest calibration uncertainty is used for calculating the uncertainty budget of this comparison.
  The value of the estimate is given in the respective table e.g. “10 MΩ” as an example for a measurement against a 10 MΩ standard resistor of BEV. At the 10 MΩ-level the drift of the standards since the last calibration are included in this contribution.
- $\delta R_{\mathrm{ref,drift}}$: This is the uncertainty associated with the standard resistors of BEV due their drift within the time since the last internal calibration. This contribution is considered at the 1 GΩ level.
- δR_{6675}: This is the uncertainty associated with the measuring bridge.
- $\delta R_{\mathrm{6675,res}}$: This is the contribution from the resolution of the bridge.
- δR_{temp}: This is the uncertainty of the temperature measurement. The following contributions are taken into account: calibration uncertainty, type A uncertainty, uncertainty of temperature measuring bridge, uncertainty due to temperature instabilities within the bath.
- δR_{meas}: This is the type A uncertainty of the measurements.
- δR_{wire}: This is the contribution from the measurement wires because of the two-wire-measurement method.
- $\delta R_{\mathrm{offsetNull}}$: This is the contribution from not compensated offset effects of the null detector.
- $\delta R_{\mathrm{thermo}}$: This is the contribution from not compensated thermal emfs.
- $\delta R_{\mathrm{DVMratio}}$: This is the contribution from the ratio voltmeter according to the manufacturer specification.
- δR_{TkRs}: This is the contribution from the temperature coefficient of the standard resistors from manufacturer specification.
- δR_{TkRx}: This is the contribution from a rough estimation of the temperature coefficient of the DUT resistor.
- δR_{VkRs}: This is the contribution from an estimation of the voltage coefficient of the standard resistor.

NIST standard, SN HR 7551

Quantity X_i	**Estimate x_i [Ω]**	**Relative standard uncert. $u(x_i)$**		**Probability distribution /method of evaluation (A,B)**	**Sensitivity coefficient c_i**		**Rel. uncert. contr. $u(y_i)$**	**Deg. of freedom ν_i**
$R_{ref,cal}$	10 000 000.000	1.365	μΩ/Ω	normal/B	1.0		1.365	50
δR_{6675}	0	0.577	μΩ/Ω	rect/B	1.0		0.577	infinite
$\delta R_{6675,res}$	0	0.001	μΩ/Ω	rect/B	1.0		0.001	infinite
δR_{Temp}	0	0.042	K	rect/B	5.0	(μΩ/Ω)/K	0.208	infinite
δR_{meas}	10 000 161.990	1.340	μΩ/Ω	normal/A	1.0		1.340	33
					combined uncertainty [μΩ/Ω], k=1		2.009	
Deviation from nominal value [μΩ/Ω]	16.199				expanded uncertainty [μΩ/Ω], k=2		4.018	
					Effective degree of freedom $\nu_{i,eff}$			97.42

22 CEM

In the analysis of uncertainty for this comparison, the following mathematical model is considered. For the 10 MΩ standards:

$$R_{x10M} = r_{x1}\left(1+\delta_{10}\right) r_{H10k} N_H R_{10k} \tag{1}$$

, where:

- R_{x10M}: Value of the 10 MΩ travelling standard, relative to Quantum Hall Resistance.
- r_{x1}: Measured ratio of travelling standard to the Hamon device in series. Nominally equal to 10.
- δ_{10}: Correction to 10:1 bridge ratio
- $r_{\mathrm{H}10k}$: Ratio Hamon device in parallel to the 10 kΩ standard. Nominally equal to 1.
- N_H: Ratio series-parallel of the Hamon device, nominally equal to 100.
- R_{10k}: Value of the 10 kΩ standard resistor, referred directly to Quantum Hall Resistance.

Resulting the following formula for the relative uncertainty:

$$\frac{u^2\left(R_{x10M}\right)}{\left(R_{x10M}\right)^2} = \frac{u^2\left(r_{x1}\right)}{\left(r_{x1}\right)^2} + \frac{u^2\left(\delta_{10}\right)}{\left(1+\delta_{10}\right)^2} + \frac{u^2\left(R_{10k}\right)}{\left(R_{10k}\right)^2} + \frac{u^2\left(r_{H10k}\right)}{\left(r_{H10k}\right)^2} + \frac{u^2\left(N_H\right)}{\left(N_H\right)^2} \tag{2}$$

The results individualized for every resistor are presented in separated tables.

Uncertainty budget for HR 755110 MΩ standard

Quantity X_i	Estimate x_i	Relative standard uncertainty $u(x_\mathrm{i})$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Relative uncertainty contribution $u(R_\mathrm{i})$	Degree of freedom ν_i
r_{x1}	10,000 054 02	5×10^{-8}	A	1	5×10^{-8}	9
δ_{10}	0	3.2×10^{-7}	B	1	3.2×10^{-7}	∞
$r_{\mathrm{H}10k}$	1.000 013 590	2×10^{-8}	A	1	2×10^{-8}	11
N_H	100	1×10^{-7}	B	1	1×10^{-7}	∞
R_{10k}	10 000.0104 2 Ω	3×10^{-8}	B	1	3×10^{-8}	∞
R_{x10M}	10.000 200 3 MΩ					
		Combined relative standard uncertainty:			$3{,}4\times 10^{-7}$	
		Effective degrees of freedom:			19045	
		Expanded relative uncertainty (95% coverage factor):			$6{,}7\times 10^{-7}$	

23 VNIIM

The model for the measurement of 10 MΩ

$R\ (10M)_x = R_{s1} \cdot N_{H1} \cdot (1 + \delta_{comp} + \delta_{leak1} + \delta_{Wb1} + \delta_{Wbarm} + \delta_{t1})$

The components are:

$R(10M)_x$: the unknown resistor,
R_{s1}: the standard resistor of 100 kΩ
N_{H1} : the ratio of the parallel- series transfer of the Hamon device No. 1 (10 ×1 MΩ)
δ_{comp}: the relative uncertainty due to digital comparator linearity (readings),
δ_{leak1}: the relative uncertainty due to leakage resistance from node points of the Wheatstone bridge (Wb),
δ_{Wb1}: the relative uncertainty due to Wb balancing for 10 MΩ resistors (sensitivity, reproducibility),
δ_{Wbarm}: the relative uncertainty due to the stability of the Wb arms (100 kΩ)
δ_{t1}: the relative uncertainty due to instability temperature of the resistors.

The relative standard uncertainty is then given by:

$$\frac{u(R(10M)_x)}{R(10M)_x} = \sqrt{\left(\frac{u(R_{s1})}{R_{s1}}\right)^2 + \left(\frac{u(N_{H1})}{N_{H1}}\right)^2 + \sum_1^5 \left(\delta_i^2\right)}$$

Uncertainty budget for the 10 MΩ NIST S/N HR7551

Quantity X_i	Estimate x_i	Relative standard uncertainty, 10^{-7} $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Relative uncertainty contribution, 10^{-7} $u(R_i)$	Degree of freedom ν_i
R_{s1}	100.0000 kΩ					
N_{H1}	100	1.8	Rectangular/ B	1.0	1.8	Inf
δ_{comp}	0	1.6	Normal/A	1.0	1.6	19
δ_{leak}	0	1.0	Rectangular/ B	1.0	1.0	Inf
δ_{Wb1}	0	2.5	Normal/A	1.0	2.5	17
δ_{Wbarm}	0	4.5	Normal/B	1.0	4.5	12
δ_t	0	3.2	Normal/B	1.0	3.2	12
R_x	10.000084 MΩ					
		Relative combined standard uncertainty:			$8.7 \cdot 10^{-7}$	
		Effective degrees of freedom:			68	
		Relative expanded uncertainty (95% coverage factor):			$17.7 \cdot 10^{-7}$ (k = 2.03)	

Uncertainty Budgets provided by the Participants for *R* = 1 GΩ

1 METAS

The measurement consists in a 10:1 comparison ($r_{10:1}$) against a reference standard R_s (100 MΩ) calibrated in terms of the quantized Hall resistance. The step-up to 100 MΩ is carried out using a cryogenic current comparator up to 1 MΩ and then a Hamon device from 1 MΩ to 100 MΩ. The model for the 10:1 comparison up to 1 GΩ can be simplified to:

$$R_x = r_{10:1} \cdot R_s \cdot \prod k_i$$

k_i are correction factors. The corresponding uncertainties (grouped together according to the main influence factors) are given below.

Quantity X_i	Standard uncertainty $u(x_i)/x_i$ 10^{-6}	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R)/R$ µΩ/Ω	Degree of freedom ν_i
Step-up QHR to 100 MΩ	1.40	normal A	1	1.40	25
100 MΩ reference standard: stability, temperature and loading effects	0.44	normal A	1	0.44	60
Voltage dependence reference	1.00	normal A	1	1.00	10
Bridge, 10:1 ratio: voltage ratio calibration	0.50	normal A	1	0.50	8
Bridge, 10:1 ratio: voltage ratio stability	2.30	rectangular B	1	2.30	1000
Temperature dependence DUT	0.0*)	rectangular B	1	0.00	1000
Reproducibility R_x measurement	0.70	normal A	1	0.70	18
	Combined standard uncertainty:			3.03 µΩ/Ω	
	Effective degrees of freedom:			278	
	Expanded uncertainty (95% coverage factor):			6.1 µΩ/Ω	

*) The temperature dependence of the device under test is taken into account in the analysis (see report)

2 PTB

The value for R_X is determined by

$$\frac{R_\mathrm{X}}{R_\mathrm{N}} = -\frac{U_\mathrm{X}}{U_\mathrm{N}} \bullet \frac{1}{1-\dfrac{I_\mathrm{B} \bullet R_\mathrm{N}}{U_\mathrm{N}}} \quad \text{with} \quad R_\mathrm{N} = R_\mathrm{N0} \cdot k_\mathrm{D} \cdot k_\mathrm{T}$$

The voltage across R_X is kept fixed and the voltage across the reference standard is varied to balance the bridge. The balancing condition is $I_\mathrm{B} = 0$. The residual value of I_B is taken into account in the calculation. R_N is the reference resistor, and k_D the drift correction and k_T the temperature correction for R_N.

The measurement uncertainty includes a contribution for the short term instability of the standards (repeat), and for the bridge error (bridge).

All quantities are considered to be uncorrelated.

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_\mathrm{i})$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R_\mathrm{i})$	Degree of freedom ν_i
R_N	100,00305 MΩ	200 Ω	normal B	10	2000 Ω	50
k_T	1	$0{,}346 \cdot 10^{6}$	rectangular B	$1 \cdot 10^{9}$Ω	350 Ω	inf
k_D	1	$0{,}12 \cdot 10^{6}$	rectangular B	$1 \cdot 10^{9}$Ω	120 Ω	inf
U_X	100,04111 V	$9 \cdot 10^{-6}$ V	normal A	$1 \cdot 10^{7}$ΩV	90 Ω	9
U_N	-9,996568 V	$9 \cdot 10^{-6}$ V	normal A	$1 \cdot 10^{8}$Ω/V	900 Ω	9
I_B	$0{,}551 \cdot 10^{-12}$ A	$0{,}05 \cdot 10^{-12}$ A	normal A	$-1 \cdot 10^{15}$Ω/A	-500 Ω	59
bridge	1	$0{,}924 \cdot 10^{-6}$	rectangular B	$1 \cdot 10^{9}$Ω	920 Ω	inf
repeat	1	$2{,}1 \cdot 10^{6}$	normal A	$1 \cdot 10^{9}$Ω	2100 Ω	7
R_x	1,0007796 GΩ					
		Combined standard uncertainty:			3240 Ω	
		Effective degrees of freedom:			16	
		Expanded uncertainty (95% coverage factor):			6800 Ω k=2,2)	

3 SIQ

Uncertainty budget (1 GΩ NIST, Ser. No. HR 9106):

Quantity *Xi*	Estimate *xi*	Standard uncertainty *u(xi)*	Probability distribution / method of evaluation (A, B)	Sensitivity coefficient *ci*	Uncertainty contribution *u(Ri)*	Degree of freedom *vi*
Rs	100.0029 MΩ	0.00015 MΩ	normal / B	10.007339	0.0015 MΩ	1E+99
K_drift_Rs	0 MΩ	0.00009 MΩ	rectangular / B	10.007339	0.0009 MΩ	1E+99
K_Tc_Rs	0 MΩ	0.00006 MΩ	rectangular / B	10.007339	0.0006 MΩ	1E+99
Ratio	10.007339	0.00003	rectangular / B	100.0029 MΩ	0.0029 MΩ	1E+99
K_rep	0	0.00001	normal / A	100.0029 MΩ	0.0009 MΩ	20
Rx	1000.763 MΩ					
		Combined standard uncertainty:			0.0035 MΩ	
		Effective degrees of freedom:			4097	
		Expanded uncertainty (95% coverage factor):			0.0071 MΩ	

4 SMU

Uncertainty budget for 1 GΩ - (result)

Quantity X_i	Estimate x_i	Relative standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Relative uncertainty contribution $u(R_i)$	Degree of freedom ν_i
R_s	99 997 700 Ω	$7{,}0\text{x}10^{-6}$	B	1,0	$7{,}0\text{x}10^{-6}$	∞
δR_s	- 180 Ω	$1{,}0\text{x}10^{-6}$	B	1,0	$1{,}0\text{x}10^{-6}$	50
δR_{sT}	0,0 Ω	$1{,}0\text{x}10^{-6}$	B	1,0	$1{,}0\text{x}10^{-6}$	50
δR_{sH}	0,0 Ω	$4{,}5\text{x}10^{-6}$	B	1,0	$12\text{x}10^{-6}$	50
δR_{xT}	0,0 Ω	$1{,}0\text{x}10^{-6}$	B	1,0	$1{,}0\text{x}10^{-6}$	50
δR_{xH}	0,0 Ω	$3{,}5\text{x}10^{-6}$	B	1,0	$8{,}5\text{x}10^{-6}$	50
$\delta R_{x\,U\,100\,V}$	100 V	$5{,}0\text{x}10^{-6}$	B	1,0	$5{,}0\text{x}10^{-6}$	∞
$\delta R_{x\,MI\,6000B}$	10,000000	$5{,}0\text{x}10^{-6}$	B	1,0	$5{,}0\text{x}10^{-6}$	∞
R_x	R_x	$6{,}5\text{x}10^{-6}$	A	1 000 000 000	$6{,}5\text{x}10^{-6}$	120
		Combined relative standard uncertainty:			$18{,}99\,x\,10^{-6}$	
		Effective degrees of freedom:			100	
		Expanded relative uncertainty (95% coverage factor):			$38\,x\,10^{-6}$	

5 VSL

The following model equation is the basis for the uncertainty budget of the 1 GΩ resistors:

$$R_{1G} = r_{1G} * (1+\delta r_{1G}) * R_{10M} * (1+\delta r_{power}) * (1+\delta r_{leak}+\delta r_{bridge}) / (1+\delta R_{1GT});$$

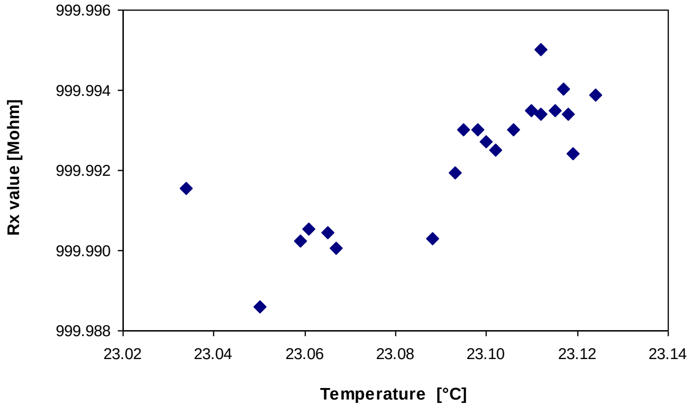
Quantity	**Definition**
R_{1G}	DUT
r_{1G}	Measured ratio in 10 MΩ - 1 GΩ measurement. The standard uncertainty in the mean of the data is only 0.25 ppm for the NIST resistor and 0.4 ppm for the MI resistors. This reflects the stability of the measurement bridge as well as the small variation in temperature during the measurements combined with a not too large temperature coefficient of the DUT.
δr_{1G}	Uncertainty of 10 MΩ - 1 GΩ ratio, including the calibration of the bridge voltages. A measurement of the 1:100 ratio of a 10 x 100 MΩ Hamon device using the same bridge leads to a result that is equal to 100 within 0.7 ppm (see appendix B). Therefore the uncertainty in the step from 10 MΩ to 1 GΩ is estimated to be at most 1.5 ppm.
δr_{leak}	Effect of leakage in bridge, cables, reference resistor and DUT. Most of the leakage effects are already contained in δr_{1G}. The residual effects of leakage are estimated to be less than 2 ppm.
δr_{power}	Power / voltage effect in the 100 MΩ transfer resistor; this resistor is used at two different voltages during the step-up chain. The uncertainty contribution is estimated to be smaller than 1 ppm.
δr_{bridge}	Bridge linearity – better than 0.5 ppm, given the good balancing of the bridge and the good linearity of the 100 V range of the HP3458A DVM that is used to calibrate the ratio of the voltages over reference and unknown resistor.
R_{10M}	10 MΩ reference resistor that is the starting point of the 1 GΩ measurements. The uncertainty is 1 ppm (see the 10 MΩ uncertainty budget)
δR_{1GT}	Temperature effect on the DUT, including non equilibrium temperature of resistor and temperature sensor. Given the total temperature excursion of around 0.1 °C and an estimated temperature coefficient of smaller than 10 ppm/°C (for the NIST resistor), residual effects that are not averaged lead to an uncertainty of at most 0.3 ppm.

This results in the following uncertainty budget for the NIST HR 9106 resistor:

Quantity	**Value**	**Standard Uncertainty**	**Degrees of Freedom**	**Distribution**	**Sensitivity Coefficient**	**Uncertainty Contribution**
r_{1G}	99.9906300	$25.0 \cdot 10^{-6}$	20	normal; A	$10 \cdot 10^{6}$	250
δr_{1G}	0.0	$866 \cdot 10^{-9}$	∞	rect; B	$1.0 \cdot 10^{9}$	870
δr_{leak}	0.0	$1.15 \cdot 10^{-6}$	∞	rect; B	$1.0 \cdot 10^{9}$	1200
δr_{power}	0.0	$577 \cdot 10^{-9}$	∞	rect; B	$1.0 \cdot 10^{9}$	580
δr_{bridge}	0.0	$289 \cdot 10^{-9}$	∞	rect; B	$1.0 \cdot 10^{9}$	290
R_{10M}	10.0087500 MΩ	10.0 Ω	50	normal; A	100	1000
δR_{1GT}	0.0	$173 \cdot 10^{-9}$	∞	rect; B	$-1.0 \cdot 10^{9}$	-170
R_{1G}	$1.00078122 \cdot 10^{9}$	1900	660			

With as final result: $R_{1G\_HR\ 9106}$ = (1.000 781 2 ± 0.000 003.8) GΩ (*k* = 2)

The uncertainty budgets for the other two 1 GΩ resistors (made by MI) are essentially equal. The major difference is the fact that the MI resistors have a significant temperature coefficient. If the measurement data are plotted against temperature for all three 1 GΩ resistors, we observe that the temperature coefficient of the NIST resistor seems less than 10 ppm/°C whereas the MI resistors seem to have a temperature coefficient that is approximately equal to (+60 ± 20) ppm/°C – see Figure 5 below. Thus the contribution of δR_{1GT} becomes larger, resulting in an increased total uncertainty of 4.3 ppm (*k* = 2). Note that this uncertainty comes close to that of the NIST 1 GΩ resistor, when a correction would be applied to the MI 1 GΩ data (using known temperature coefficients of these standards).



Data of the MI 9331S, snr 1100036, 1 GΩ resistor as a function of temperature

6 VMT/PFI

Uncertainty budget for Rx s/n 1100036
Date: 2006.02.11

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution/ method of evaluation (A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$	Degree of freedom υ_i
X1	0	0.58	Rectangular / B	1.0E+01	5.8	infinity
X2	0	10.0000	Normal / B	1.0E+01	100.0	4
X3	0	2.00E+01	Normal / B	1.0E+01	200.0	11
X4	0	3.00E+01	Normal / B	1.0E+01	300.0	23
X5	0	3.00E+01	Normal / B	1.0E+01	300.0	7
X6	100004940.6	4.00E+01	Normal / B	1.0E+01	400.0	7
X7	0	4.33E+01	Rectangular / B	1.0E+01	433.0	infinity
X8	9.999370453	1.24E-07	Normal / A	1.0E+08	12.4	7
X9	0	2.89E-05	Rectangular / B	1.0E+08	2886.9	infinity
X10	0	5.77E-08	Rectangular / B	1.0E+08	5.8	infinity
X11	0	1.00E-05	Normal / A	1.0E+08	1000.0	45
X12	0	1.15E+03	Rectangular / B	1.0E+00	1154.7	infinity
X13	0	2.89E-01	Rectangular / B	1.0E+01	2.9	infinity
Rx	999986448					
		Combined standard uncertainty:			3.4E+03	
		Effective degrees of freedom:			infinity	
		Expanded uncertainty (95% coverage factor):			6.7E+03	

Model function:
Rx = (X1 + X2 + X3 + X4 + X5 + X6 + X7 + X13) * (X8 + X9 + X10 + X11) + X12
where:

X1	Traceability SR104 10 kΩ (Ω)
X2	Stability of SR104 (Ω)
X3	Scaling 10 kΩ to 1 MΩ (Ω)
X4	Stability of 1 MΩ reference (Ω)
X5	Scaling 1 MΩ to 100 MΩ (Ω)
X6	Resistance of 100 MΩ reference (Ω)
X7	Temperature stability of 100 MΩ reference (Ω)
X8	10:1 ratio 1 GΩ unknown / 100 MΩ reference (includes detector resolution, voltage source stability)
X9	Bridge 10:1 ratio error
X10	Bridge linearity error
X11	Repeatability of 10:1 ratio measurements
X12	Leakage (Ω)
X13	Temperature stability of 1 MΩ reference (Ω)

7 MIKES

Budget of uncertainty for 1 GOhm resistor (NIST_901), measured by substitution method with the Keithley 6517A DMM from 1 GOhm Hamon reference.

Mathematical model:
The value R_{10M} of the unknown resistor is obtained from the relationship:
$R_x = R_{ref} * (1 + \delta_{Ref} + K_{Drift} + K_{Temper} + K_{settime}) * k_{Nom}(1 + k_{Det} + k_{leak}) * (1 + k_{Rx})$
where:

R_{Ref} is the value of the reference resistor
δ_{Ref} is the relative error of the reference resistor.
K_{Drift} is the relative error due to drifts and instabilities in reference resistor
K_{Temper} is the relative error due to uncorrected temperature instabilities of reference resistor
$K_{setltime}$ is the relative error due to settling time of Rx and Rs
k_{Nom} is the nominal measured ratio
k_{Det} is the relative error of DMM Keithley readings due to drifts of zero during measurements
k_{leak} is the relative error due to leakage currents
k_{Rx} is the relative error due to temperature effects and drifts of unknown resistor during its stay in laboratory

The relative standard uncertainty is given by :
$u(R_x) / R_x = \sqrt{\{ [u (R_{Ref}) / R_{Ref}]^2 + [u (k_{Nom}) / k_{Nom}]^2 + [u (k_{read}) / k_{read}]^2 \}}$

Where $u(k_{read}) / k_{read}$ is the relative standard deviation of the measurement results.

Table VI. Uncertainty budget for 1 GOhm (NIST_901)

Quantity X_i	Estimate x_I Ohm	Relative standard uncertainty $u(x_i)$, 10^{-6}	Probability distribution / Method of evaluation (A,B)	Sensitivity coefficient c_i	Relative Uncertainty contribution $u_i(Rx)$, (10^{-6})	Degree of Freedom v_i
R_{Ref}	100007900	0	Rect/B	1	0	inf
δ_{Ref}	0	3.0	Rect/B	1	3.0	inf
k_{Drift}	0	1.0	Rect/B	1	1.0	inf
K_{Temper}	0	1.4	Rect/B	1	1.4	inf
$K_{setltime}$	0	1	Rect/B	1	1	inf
k_{Nom}	1	0	Rect/B	1	0	inf
k_{Det}	0	2.5	Rect/B	1	2.5	inf
k_{leak}	0	0.5	rect/B	1	0.5	inf
k_{Rx}	0	0.1	Rect/B	1	0.1	inf
k_{read}	0	0.5	Normal/A	1	0.5	50
R_{1G}	1000775400	Combined standard uncertainty (1 σ)			4.5	6
		RSS of Type A uncertainties			1.0	
		RSS of Type B uncertainties			4.4	

MIKES Budget of uncertainty for 1 GOhm resistor (NIST_901), measured by DCC 6675 Guildline bridge with 10:1 ratio from 100 MOhm reference.

Mathematical model:
When DCC bridge is balanced, the value R_{10M} of the unknown resistor is obtained from the relationship:
$R_x = R_{\mathrm{ref}} * (1 + \delta_{\mathrm{Ref}} + K_{Drift} + K_{Temper} + K_{load}) * k_{\mathrm{DCC}} (1 + k_{\mathrm{br}} + k_{leak} + k_{br/volt})*(1 + k_{\mathrm{Rx}})$
where:

R_{Ref} is the value of reference resistor.
δ_{Ref} is the relative error of the reference resistor.
K_{Drift} is the relative error due to drifts in reference resistor.
K_{Temper} is the relative error due to uncorrected temperature instabilities of reference resistor.
K_{load} is the relative error due to uncorrected loading effects.
k_{DCC} is the nominal ratio of the bridge.
k_{br} is specified 1 σ uncertainty of the bridge ratio for that range.
k_{leak} is the relative error due to leakage currents.
$k_{br/volt}$ is the relative error due to lower then nominal applied test voltage.
k_{Rx} is the relative error due to temperature effects and drifts of unknown resistor during its stay in laboratory

The relative standard uncertainty is given by :
$u(R_x) / R_x = \sqrt{}\{ [u (R_{\mathrm{Ref}}) /R_{\mathrm{Ref}}]^2 + [u (k_{\mathrm{DCC}})/ k_{\mathrm{DCC}}]^2 + [u (k_{\mathrm{read}})/ k_{\mathrm{read}}]^2\}$

Where $u(k_{\mathrm{read}}) / k_{\mathrm{read}}$ is the relative standard deviation of the measurement results.

Table 3. Uncertainty budget for 1 GOhm (NIST_901)

Quantity X_i	Estimate x_I Ohm	Relative standard uncertainty $u(x_i)$, 10^{-6}	Probability distribution / Method of evaluation (A,B)	Sensitivity coefficient c_i	Relative uncertainty contribution $u_i(Rx)$, (10^{-6})	Degree of Freedom v_i
R_{Ref}	99991004.96	0	rect/B	1	0	inf
δ_{Ref}	0	2.1	rect/B	1	2.1	inf
k_{Drift}	0	0.6	rect/B	1	0.6	inf
K_{Temper}	0	1.4	rect/B	1	1.4	inf
K_{load}	0	0.5	rect/B	1	0.5	inf
k_{DCC}	10	0	rect/B	1	0	inf
k_{br}	0	4	rect/B	1	4	inf
$k_{br/volt}$	0	2	rect/B	1	2	inf
k_{leak}	0	0.5	rect/B	1	0.5	inf
k_{Rx}	0	0.3	rect/B	1	0.3	inf
k_{read}	0	1	normal/A	1	1	60
R_{10M}	1000784200	Combined standard uncertainty (1 σ)			5.3	3
		RSS of Type A uncertainties			1	
		RSS of Type B uncertainties			5.2	

MIKES Budget of uncertainty for 1 GOhm resistor (NIST_901), measured by substitution method with Keithley 6517A DMM from 1 GOhm (U1G) reference at 1:1 ratio.

Mathematical model:
The value R_{10M} of the unknown resistor is obtained from the relationship:
$R_x = R_{ref} * (1 + \delta_{Ref} + K_{Drift} + K_{Temper} + K_{settime}) * k_{Nom}(1 + k_{Det} + k_{leak}) * (1 + k_{Rx})$
where:
R_{Ref} is the value of the reference resistor
δ_{Ref} is the relative error of the reference resistor.
K_{Drift} is the relative error due to drifts and instabilities in reference resistor
K_{Temper} is the relative error due to uncorrected temperature instabilities of reference resistor
$K_{setltime}$ is the relative error due to settling time of Rx and Rs
k_{Nom} is the nominal measured ratio
k_{Det} is the relative error of DMM Keithley readings due to drifts of zero during measurements
k_{leak} is the relative error due to leakage currents
k_{Rx} is the relative error due to temperature effects and drifts of unknown resistor during its stay in laboratory

The relative standard uncertainty is given by :
$u(R_x) / R_x = \sqrt{ [u(R_{Ref}) / R_{Ref}]^2 + [u(k_{Nom}) / k_{Nom}]^2 + [u(k_{read}) / k_{read}]^2 }$

Where $u(k_{read}) / k_{read}$ is the relative standard deviation of the measurement results.

Table 4. Uncertainty budget for 1 GOhm (NIST_901)

Quantity X_i	Estimate x_I Ohm	Relative standard uncertainty $u(x_i)$, 10^{-6}	Probability distribution / Method of evaluation (A,B)	Sensitivity coefficient c_i	Relative Uncertainty contribution $u_i(Rx)$, (10^{-6})	Degree of Freedom V_i
R_{Ref}	100009600	0	Rect/B	1	0	Inf
δ_{Ref}	0	5.2	Rect/B	1	5.2	Inf
k_{Drift}	0	0.3	Rect/B	1	0.3	Inf
K_{Temper}	0	0.6	Rect/B	1	0.6	Inf
$K_{setltime}$	0	0.5	Rect/B	1	0.5	Inf
k_{Nom}	1	0	Rect/B	1	0	Inf
k_{Det}	0	2	Rect/B	1	2	Inf
k_{leak}	0	0.5	rect/B	1	0.5	Inf
k_{Rx}	0	0.1	Rect/B	1	0.1	Inf
k_{read}	0	1	Normal/A	1	1	50
R_{1G}	1000775400	Combined standard uncertainty (1 σ)			5.7	3
		RSS of Type A uncertainties			1.0	
		RSS of Type B uncertainties			5.6	

MIKES Budget of uncertainty for 1 GOhm resistor (NIST_901), measured by modified Wheatstone bridge ("Two Calibrator") method from 100 MOhm (U100M) reference.

The result was calculated using following equation:

Model equation:

$Rx=(k_s*K+\delta_{drift})*Rs+\delta_l+\delta_t+\delta_{set}+\delta_{lff}$

Where:

Rx	is the value of the 1 GOhm unknown resistor
k_s	is the correction for measured voltage ratio
K	is the measured voltage ratio;
δ_{drift}	is the relative error due to drift; cumulative measurement time (about 40 min)
Rs	is the value of the reference resistance
δ_l	is the uncertainty due to effect of the leakage current from unguarded Rx and Rs resistor element sections to ground on the final result
δ_t	is the uncertainty due to effect of temperature variations of Rx and Rs to the final result
δ_{set}	is the resolution of ND during the calibrator settings
δ_{lff}	is the 1/f type low frequency fluctuation in ND.

Table 5. Uncertainty budget for 1 GOhm.

Quantity X_I	Estimate x_I Ohm	Relative Standard uncertainty $u(x_i)$, 10^{-6}	Probability distribution / Method of evaluation (A,B)	Sensitivity coefficient c_I	Relative Uncertainty contribution $u_i(Rx)$, (10^{-6})	Degree of Freedom v_i
k_s	1.0000041000	0.08	Rect/B	1	0.08	∞
K	10.00854276	0.48	Norm/A	1	0.48	10
δ_{drift}	0.0	1.44	Rect/B	1	1.44	∞
Rs	$99.991100\cdot10^6$ Ohm	2.1	Norm/B	1	2.1	50
δ_l	0.0 Ohm	0.3	Rect/B	1	0.3	∞
δ_t	0.0 Ohm	0.8	Rect/B	1	0.8	∞
δ_{set}	0.0 Ohm	0.6	Rect/B	1	0.6	∞
δ_{lff}	0.0 Ohm	2.9	Rect/B	1	2.9	∞
Rx = $1.0007693\cdot10^9$ Ohm		Combined standard uncertainty (1 σ)			4.0	1
		RSS of Type A uncertainties, 10^{-6}			0.48	
		RSS of Type B uncertainties, 10^{-6}			3.97	

8 OMH

Uncertainty budget for 1 GΩ No:1100036

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$	Degree of freedom ν_i
100 MΩ working standard	100.0067504 MΩ	2.1 ppm	B normal	1	2.1	inf.
leakage effects	0	2 ppm	B rectangular	1	2	inf.
MI 6000A bridge	0	0.05 ppm	B rectangular	1	0.05	inf.
temperature inhomogeneity	0	0.2°C	B rectangular	12ppm/°C for	2.4	inf.
Ratio measurement	9.999255017	0.36 ppm	A normal	1	0.36	29
R_x	999.993001 MΩ					
		Combined standard uncertainty:			3.8	
		Effective degrees of freedom:			353173	
		Expanded uncertainty (95% coverage factor):			7.6	

9 CMI

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution [GΩ] $u(R_i)$	Degree of freedom ν_i
R_S	1. 000 014 GΩ	3.5 x 10^{-6} GΩ	normal	1.001	3.5 x 10^{-6}	∞
$\delta_{R\ SD}$	+12 x 10^{-6} GΩ	20 x 10^{-6} / √ 3 GΩ	rectangular	1.001	11.5 x 10^{-6}	∞
δ_{p}	5 x 10^{-6} / √ 3	5 x 10^{-6} / √ 3	rectangular	1.000 GΩ	2.9 x 10^{-6}	∞
$\delta_{S\ T\ D}$	0.2 x 10^{-6} / √ 3	0.2 x 10^{-6} / √ 3	rectangular	1.000 GΩ	0.1 x 10^{-6}	∞
$\delta_{R\ T}$	0 GΩ	2 x 10^{-6} / √ 3 GΩ	rectangular	1.001	1.2 x 10^{-6}	∞
$\delta_{R\ RH}$	0 GΩ	2 x 10^{-6} / √ 3 GΩ	rectangular	1.001	1.2 x 10^{-6}	∞
$\delta_{R\ L}$	0 GΩ	10 x 10^{-6} / √ 3 GΩ	rectangular	1.001	5.8 x 10^{-6}	∞
$\delta_{R\ C}$	0 GΩ	10 x 10^{-6} / √ 3 GΩ	rectangular	1.001	5.8 x 10^{-6}	∞
repeatability p	1. 000 776 5	1.2 x 10^{-6}	normal	1.000 GΩ	1.2 x 10^{-6}	14
R_x	1. 000 803 GΩ					
		Combined relative standard uncertainty:			15 x 10^{-6}	
		Effective degrees of freedom:			341 797	
		Expanded relative uncertainty (95% coverage factor):			30 x 10^{-6}	

10 INM

Model equation of the measurement:

The principle of measurement applied was the substitution method. The measurand is described by the equation

$$R_X = R_S + (R_{XM} – R_{SM})$$

If this equation is expanded in order to include relevant deviation of the input quantities, it becomes:

$$R_X = R_S + (R_{XM} – R_{SM}) + \delta R_D + \delta R_{ST} + \delta R_m - \delta R_{XT}$$

To obtain the conventional value and the standard uncertainty of the resistor under test – UUT- **MI 9331S, SN 1100037**, the “driven at a guard potential”variant was used and the following input quantities were considered:

Reference standard (R_S)

Resistance value of the 1 GΩ, Measurement International, type 9331G, serial no 1100184. The calibration certificate for the reference standard gives a resistance value of 0.999998 GΩ and standard uncertainty 15 kΩ at the specified reference temperature of 23 °C.

Difference between measured values of UUT and reference standard (R_{XM} - R_{SM})

R_{XM} and R_{SM} are the indications of the teraohmmeter for each of the two resistors (UUT and standard).

Nineteen observations were made. The mean difference between measured value of UTT and reference standard was -57 kΩ with an estimated associated standard uncertainty: s_0 = 0.4 kΩ (see Table 4).

Drift of the value of the standard (δR_D)

The uncertainty due to the drift of standards value is represented by a rectangular distribution with bounds ± 25 kΩ.

Temperature corrections (δR_{ST}, δR_{XT})

The air bath temperature at the time of calibration was measured with a digital thermometer. The mean value of the temperature was 23,13 °C and the range of variation was 22.91 °C ÷ 23.27 °C. The associated uncertainty was ± 0.08 °C.

For the resistor under test the temperature coefficients are unknown, but the uncertainty of the correction is approximately 2 kΩ (Technical Protocol).

For the standard resistor the maximum change for the 23 °C ± 5 °C are 25 kΩ. The uncertainty of the correction is represented by a rectangular distribution with bounds ± 5 kΩ.

Change of the indicated values caused by disturbances in the power supply line (δR_m)
We estimated the changes of the teraohmmeter indication due to the instabilities in the power supply line with bounds ± 5 kΩ (triangular distribution).

Measurement results

Standard **MI 9331, SN 1100037**

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$	Degree of freedom ν_i
R_S	0.999998 GΩ	15 kΩ	Normal/B	1	15 kΩ	∞
R_{XM} - R_{SM}	-57 kΩ	0.4 kΩ	Normal/A	1	0.4 kΩ	18
δR_{SD}	0	15 kΩ	Rectangular/B	1	15 kΩ	2
δR_{ST}	0	3 kΩ	Rectangular/B	1	3 kΩ	2
δR_m	0	2 kΩ	Triangular/B	1	2 kΩ	50
δR_{XT}	0	2 kΩ	Normal/B	-1	2 kΩ	∞
R_x	0.999941 GΩ					
		Combined standard uncertainty:			22 kΩ	
		Effective degrees of freedom:			9	
		Expanded uncertainty (95% coverage factor):			50 kΩ	

12 NML

The measurement model, containing the significant input quantities is :

$$R_X = r_1 \cdot r_2 \cdot r_3 \cdot R_S \cdot [1 + \alpha \cdot (23 - T)] + \Delta_L + \Delta_R \qquad \ldots(4)$$

where R_X is the resistance of the unknown 1 GΩ resistor;

r_1 is the ratio of the resistance of the unknown 1 GΩ resistor to resistance of the 100 MΩ/step transfer standard in the series configuration;

r_2 is the ratio of the resistance of the 100 MΩ/step transfer standard in the series configuration, to its resistance in the parallel configuration;

r_3 is the ratio of the resistance of the 100 MΩ/step transfer standard in the parallel configuration to the resistance of 1MΩ/step transfer standard in the series configuration;

R_S is the resistance of the 1MΩ/step transfer standard in the series configuration

α is the relative temperature coefficient of R_X;

T is the mean measuring temperature;

Δ_L is the correction due to leakage effects;

Δ_R is the correction due to all effects which change randomly during the measurement.

If we write the resistance values and ratios in terms of their nominal values ($R_X{}^{(N)}, r_1{}^{(N)}, r_2{}^{(N)}, r_3{}^{(N)}, R_S{}^{(N)}$), and fractional deviations from nominal ($\delta_X, \delta_1, \delta_2, \delta_3, \delta_S$) we have :

$$\begin{aligned} R_X &= R_X{}^{(N)} \cdot (1 + \delta_X) \\ r_i &= r_i{}^{(N)} \cdot (1 + \delta_i) \qquad i = 1,2,3 \qquad \ldots(5) \\ R_S &= R_S{}^{(N)} \cdot (1 + \delta_S) \end{aligned}$$

equation (4) reduces to :

$$\delta_X \approx \delta_1 + \delta_2 + \delta_3 + \delta_S + \alpha \cdot (23 - T) + \frac{\Delta_L}{R_X{}^{(N)}} + \frac{\Delta_R}{R_X{}^{(N)}} \qquad \ldots(6)$$

where we have retained only the first order terms of small quantities.

The uncertainty budget for the 1 GΩ measurement is presented in Table 2 below.
In order to simplify the presentation, the standard uncertainties for the input quantities $\delta_X, \delta_1, \delta_2, \delta_3, \delta_S$ include the effects due to calibration, drift, non-linearity, temperature, and other influences. The standard uncertainties of these input quantities are dominated by contributions from systematic effects whose uncertainty contributions are obtained by type B method. Consequently, the number of degrees of freedom associated with these estimates is taken to be infinite. The relative temperature coefficient used in the table is for the NIST type resistor and is taken from Jarrett et al., IEEE Trans Instrum Meas., **52**, Apr 2003, p 475.

Quantity	Estimate	Standard Uncertainty	Method of Evaluation	Sensitivity Coefficient	Uncertainty Contribution	Degrees of Freedom
δ_1	-172.9 µΩ/Ω	20 µΩ/Ω	B	1	20 µΩ/Ω	∞
δ_2	0.0 µΩ/Ω	20 µΩ/Ω	B	1	20 µΩ/Ω	∞
δ_2	+219.2 µΩ/Ω	5 µΩ/Ω	B	1	5 µΩ/Ω	∞
δ_3	+2.5 µΩ/Ω	5 µΩ/Ω	B	1	5 µΩ/Ω	∞
(T-23)	0.00°C	0.10°C	B	-30 µΩ/Ω°C^{-1}	3 µΩ/Ω	∞
Δ_L	0 Ω	10 kΩ	B	10^{-9} Ω^{-1}	10 µΩ/Ω	∞
Δ_R	0 Ω	8 kΩ	A	10^{-9} Ω^{-1}	8 µΩ/Ω	12
δ_X	+48.8 µΩ/Ω					
		Combined Standard Uncertainty			32 µΩ/Ω	
		Effective Degrees of Freedom			>10^3	
		Expanded Uncertainty (95% C.F.)			64 µΩ/Ω	

Table 2 Uncertainty Budget for 1 GΩ Measurement

13 JV

Making a linear approximation in the deviations, the measurement function can be written as:

$$\mathbf{R_X = r \cdot (R_S + \delta R_{DS} + \delta R_{PS} + \delta R_{TS}) + r \cdot R_S \cdot (\delta r_C + \delta r_B + \delta r_{LB} + \delta r_{LG}) - \delta R_{PX} - \delta R_{TX}}$$

where :

$\mathbf{R_X}$ - Value of unknown resistor (object),
$\mathbf{r}$ - Measured ratio r,
$\mathbf{R_S}$ - Resistance of reference standard,
$\mathbf{\delta R_{DS}}$ - Drift/Stability of reference standard,
$\mathbf{\delta R_{PS}}$ - Influence of Pressure on reference standard,
$\mathbf{\delta R_{TS}}$ - Influence of Temperature on reference standard,
$\mathbf{\delta r_C}$ - Correction factor for influence of thermoelectric voltages,
$\mathbf{\delta r_B}$ - Correction factor for Bridge linearity /offset,
$\mathbf{\delta r_{LB}}$ - Correction factor for Leakage currents in Bridge/scanner,
$\mathbf{\delta r_{LG}}$ - Correction factor for Leakage currents in ref. & object (w. active Guard),
$\mathbf{\delta R_{PX}}$ - Influence of Pressure on object,
$\mathbf{\delta R_{TX}}$ - Influence of Temperature on object.

Uncertainty budget 1 GΩ MI.9331S, SN.1100035

Quantity X_i	Estimate x_i	Standard uncertainty u(xi)	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$ (Ω)	Degree of freedom ν_i
r	9,999 551 3	4,33e-6	Norm./ A	1,0e+8 Ω	433	8
R_S	100 003 939 Ω	124,4 Ω	Norm./ B	10	1 244	∞
δR_{DS}	0 Ω	19,0 Ω	Norm./ B	10	190	∞
δR_{PS}	0 Ω	3,0 Ω	Norm./ B	10	30	∞
δR_{TS}	0 Ω	24,2 Ω	Rect./ B	10	242	∞
δr_{LB}	0	6,25e-6	Rect./ B	1,0e+9 Ω	6 250	∞
δr_{LG}	0	577e-9	Norm./ B	1,0e+9 Ω	577	∞
δR_{PX}	0 Ω	30 Ω	Norm./ B	1	30	∞
δR_{TX}	0 Ω	2309 Ω	Rect./ B	1	2 309	∞
δr_C	0	10e-9	Rect./ B	1,0e+9 Ω	10	∞
δr_B	0	200e-9	Rect./ B	1,0e+9 Ω	200	∞
R_x , deviation from nominal value	- 5 483 Ω					
		Combined standard uncertainty:			*6,83E+03 Ω*	
		Effective degrees of freedom:			*492 712*	
		Expanded uncertainty (95% coverage factor):			*14E+03 Ω*	

The use of active guard has a large influence on leakage effects. The leakage is therefore split into two components, one where the active guard is working and another where it is not. The backplane of scanner and bridge are at ground potential. The terminals are not guarded there.

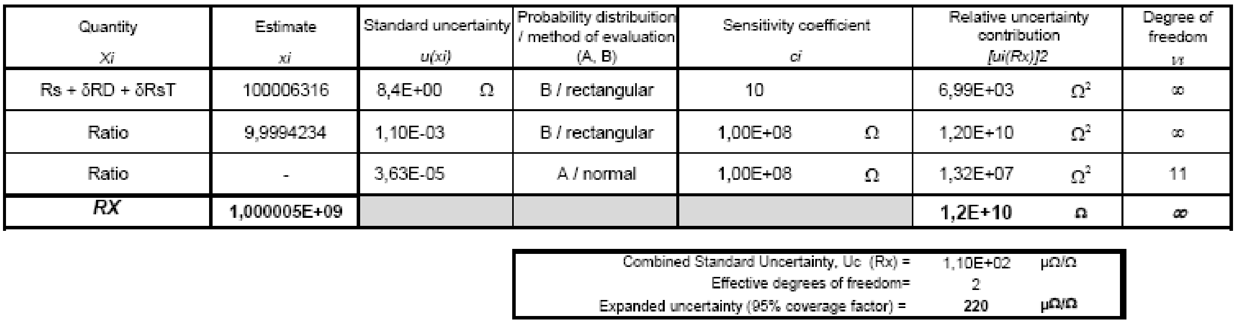
14 INETI

The resistance R_x of the unknown resistor was obtained from the relationship:

$$R_x = \left(R_s + \delta \mathrm{R_D} + \delta \mathrm{R_{TS}}\right) * Ratio$$

where: R_S – is the value of the reference resistance and the component of the uncertainty includes the drift of the resistance, δR_D, and it's variation with temperature, δR_{TS};

Ratio – is the ratio measured by the Wheatstone bridge.



Quantity Xi	Estimate xi	Standard uncertainty u(xi)	Probability distribuition / method of evaluation (A, B)	Sensitivity coefficient ci	Relative uncertainty contribution [ui(Rx)]2	Degree of freedom νi
Rs + δRD + δRsT	100006316	8,4E+00 Ω	B / rectangular	10	6,99E+03 Ω^2	∞
Ratio	9,9994234	1,10E-03	B / rectangular	1,00E+08 Ω	1,20E+10 Ω^2	∞
Ratio	-	3,63E-05	A / normal	1,00E+08 Ω	1,32E+07 Ω^2	11
RX	**1,000005E+09**				**1,2E+10 Ω**	**∞**

Combined Standard Uncertainty, Uc (Rx) = 1,10E+02 μΩ/Ω
Effective degrees of freedom= 2
Expanded uncertainty (95% coverage factor) = **220** **μΩ/Ω**

16 NPL

The uncertainty contributions of the bridge consist of the ratio error ε_{CCC}, error due to the combining network ε_{cn}, and the error due to non-linearity of the SQUID readout ε_{SQUID} in the case of the measurement without SQUID servo (i.e. only in the 1 GΩ measurement).

1 GΩ Uncertainty Budget

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$	Degree of freedom ν_i
ε_{CCC}	-	0.012 ppm	Rectangular/B	1	0.012 μΩ/Ω	Inf
ε_{cn}	-	< 0.1 ppb	Rectangular/B	1	< 0.0001μΩ/Ω	Inf
ε_{SQUID}	-	0.58		1	0.58 μΩ/Ω	Inf
$R_{standard}$	10 MΩ	0.027 μΩ/Ω	Normal/A	1	0.027μΩ/Ω	4
$R_{standard}$	10 MΩ	0.087 μΩ/Ω	Rectangular/B	1	0.087μΩ/Ω	Inf
$T_{standard}$	20°C	0.1 °C	Rectangular/B	0.5 ppm/°C	0.050 μΩ/Ω	Inf
R_x	1 GΩ	1.426 μΩ/Ω	Normal/A	1	1.426 μΩ/Ω	4
R_x	1 GΩ					
		Combined standard uncertainty:			**1.54 μΩ/Ω**	
		Effective degrees of freedom:			**5.5**	
		Expanded uncertainty (95% coverage factor):			**3.98 μΩ/Ω**	

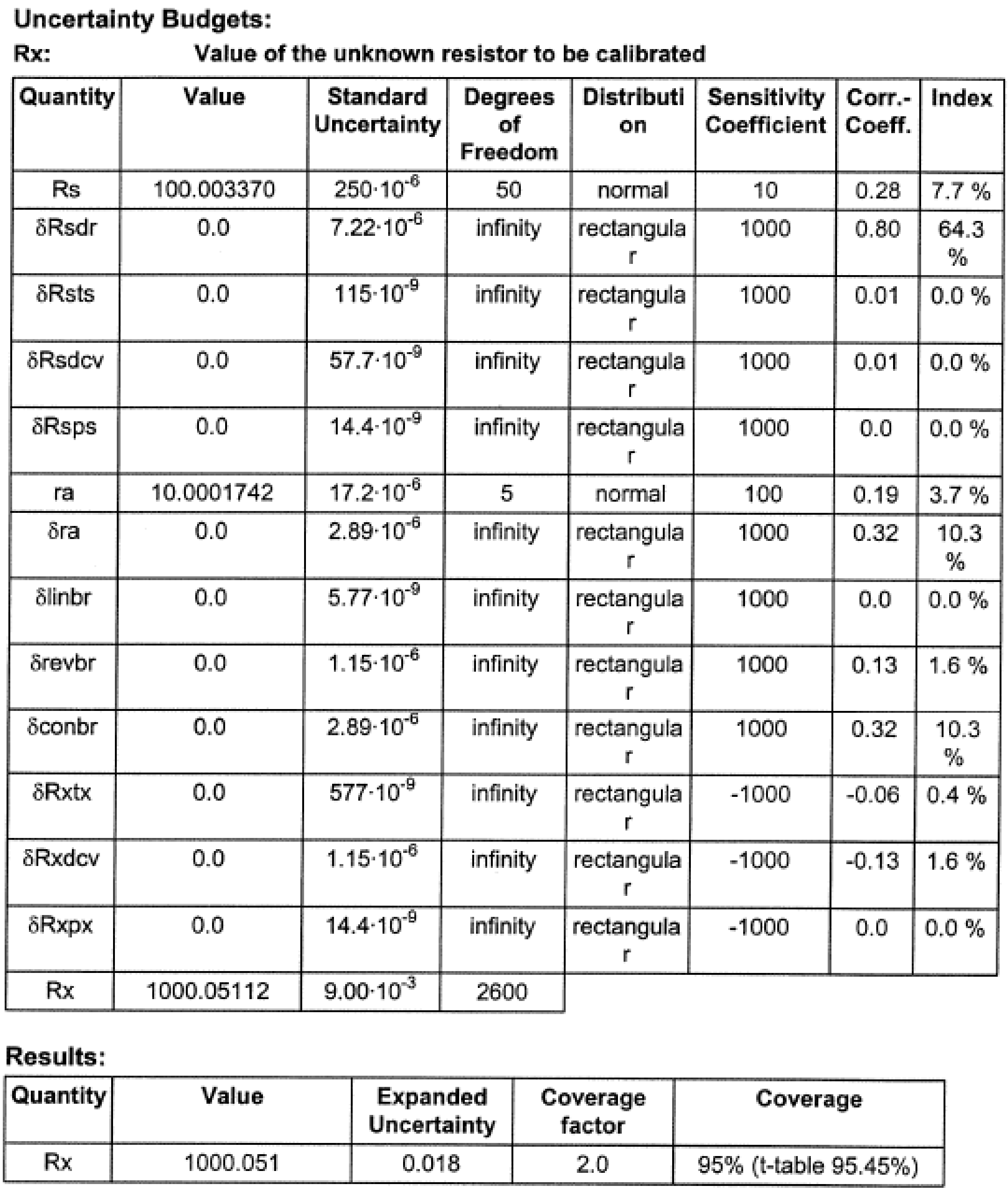
17 SMD

The uncertainty calculations were made using commercially available software developed according the rules of the GUM [2], [3] and [4]. The following mathematical models were used:

$$R_x = R_s \times (1 + \delta Rsdr + \delta Rsts + \delta Rsdcv + \delta Rsps) \times r_a \times (1 + \delta r_a + \delta linbr + \delta conbr) / (1 + \delta Rxtx + \delta Rxdcv + \delta Rxpx)$$

The following components were taken into account:

- $\boldsymbol{R_x}$ = value of the unknown resistor.
- $\boldsymbol{R_s}$ = value of the reference resistor calibrated by SMD and corrected for the temperature difference.
- ***δRsdr*** : uncertainty on the value of the correction for the drift of Rs.
- ***δRsts*** = uncertainty of Rs due to the uncertainty on the exact knowledge of the temperature of this resistor. This is due to the short-term stability of the climatic test chamber.
- ***δRsdcv*** = influence of the applied voltage on Rs
- ***δRsps*** = uncertainty due to the possible influence of atmospheric pressure on Rs.
- $\boldsymbol{r_a}$: successively means of measurement results recorded the ratios R_s/R_x or R_x/R_s.
- $\boldsymbol{\delta r_a}$ = correction for the ratios R_s/R_x or R_x/R_s.
- ***δlinbr*** : uncertainty coming from the non-linearity of the bridge.
- ***δconbr***: uncertainty coming from the influence of the limited insulation of the bridge and of the connecting leads, the guarding, grounding and shielding, the thermal emfs, the electromagnetic interference,…
- ***δRxtx*** : uncertainty on Rx due to the uncertainty on the exact knowledge of the temperature of the unknown resistor. This due to the short-term instability of the climatic test chamber.
- ***δRxdcv*** = influence of the applied voltage on Rx
- ***δRxpx*** : uncertainty due to influence of the atmospheric pressure on Rx.



Uncertainty Budgets:

Rx: Value of the unknown resistor to be calibrated

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Distribution	Sensitivity Coefficient	Corr.-Coeff.	Index
Rs	100.003370	$250 \cdot 10^{-6}$	50	normal	10	0.28	7.7 %
δRsdr	0.0	$7.22 \cdot 10^{-6}$	infinity	rectangular	1000	0.80	64.3 %
δRsts	0.0	$115 \cdot 10^{-9}$	infinity	rectangular	1000	0.01	0.0 %
δRsdcv	0.0	$57.7 \cdot 10^{-9}$	infinity	rectangular	1000	0.01	0.0 %
δRsps	0.0	$14.4 \cdot 10^{-9}$	infinity	rectangular	1000	0.0	0.0 %
ra	10.0001742	$17.2 \cdot 10^{-6}$	5	normal	100	0.19	3.7 %
δra	0.0	$2.89 \cdot 10^{-6}$	infinity	rectangular	1000	0.32	10.3 %
δlinbr	0.0	$5.77 \cdot 10^{-9}$	infinity	rectangular	1000	0.0	0.0 %
δrevbr	0.0	$1.15 \cdot 10^{-6}$	infinity	rectangular	1000	0.13	1.6 %
δconbr	0.0	$2.89 \cdot 10^{-6}$	infinity	rectangular	1000	0.32	10.3 %
δRxtx	0.0	$577 \cdot 10^{-9}$	infinity	rectangular	-1000	-0.06	0.4 %
δRxdcv	0.0	$1.15 \cdot 10^{-6}$	infinity	rectangular	-1000	-0.13	1.6 %
δRxpx	0.0	$14.4 \cdot 10^{-9}$	infinity	rectangular	-1000	0.0	0.0 %
Rx	1000.05112	$9.00 \cdot 10^{-3}$	2600				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
Rx	1000.051	0.018	2.0	95% (t-table 95.45%)

18 UME

The model function of uncertainty can be written as below

$$R_X = \frac{(R_S + \delta R_{Sdrf} + \delta R_{STemp} + \delta R_{Svolt}) \times (E_{Xappl} + \delta E_{Xdrf})}{(E_{Sappl} + \delta E_{Sdrf})} - \delta R_{xTemp}$$

R_S , reference resistance value.

u_{Rcal}, calibration uncertainty of the reference resistance value. It's always given 2σ and has got normal distribution.

$u_{\delta Rsdrf}$, drift of the reference resistance of the reference since its last calibration. This value is added to the uncertainty calculation as rectangular distribution.

$u_{\delta Rstemp}$, temperature related resistance variation of the reference. This value is added to the uncertainty calculation as rectangular distribution.

$u_{\delta Rsvolt}$, power related resistance variation of the reference. This value is added to the uncertainty calculation as rectangular distribution.

E_{Xappl}, applied voltage value.

u_{Excal}, calibration uncertainty of the voltage value. It's always given 2σ and has normal distribution.

$u_{\delta Exdrf}$, drift of the voltage of the reference since its last calibration. This value is added to the uncertainty calculation as rectangular distribution.
E_{Sappl}, applied voltage value

u_{Escal}, calibration uncertainty of the voltage value. It's always given 2σ and has normal distribution.

u_{Esdrf}, drift of the reference voltage since its last calibration. This value is added to the uncertainty calculation as rectangular distribution.

R_X , calibrated resistance value.

$u_{\delta Rxtemp}$, temperature related resistance variation of the unknown. This value is added to the uncertainty calculation as rectangular distribution.

u_{Rstd}, standard deviation of the measurement and it has normal distribution.

Proposed scheme for an uncertainty budget for R_X (S/N: 1100035 , 1GΩ)

Quantity X_i	Estimate x_i	Relative standard uncertainty $u(x_i)$	Probability distribution	Sensitivity coefficient c_i	Relative uncertainty contribution $u_i(R_x)$
Reference resistance value (R_S)	1E+08	$1x10^{-5}$	Normal , k=2	10	$5\ x10^{-6}$
Reference Resistance Drift (δR_{Sdrf})		$1,5x10^{-6}$	Rectangular	10	$0,87x10^{-6}$
Ref.Resistance temperature effect (δR_{Stemp})		$0,5x10^{-6}$	Rectangular	10	$0,29x10^{-6}$
Ref.Resistance Voltage effect (δR_{Svolt})		$0,02x10^{-6}$	Rectangular	10	$0,012x10^{-6}$
Applied voltage (E_{Xappl})	100	$1x10^{-6}$	Normal, k=2	1E+07	$0,5x10^{-6}$
Drift of the voltage (δE_{Xdrf})		$1x10^{-6}$	Rectangular	1E+07	$0,58x10^{-6}$
Applied voltage (E_{Sappl})	10	$1x10^{-6}$	Normal, k=2	1E+08	$0,5x10^{-6}$
Drift of the voltage (δE_{Sdrf})		$1x10^{-6}$	Rectangular	1E+08	$0,58x10^{-6}$
Calibrated Res.Temperature effect (δR_{Xtemp})		0	Rectangular	-1	0
Repeatability (R_{std})		$1,64x10^{-6}$	Normal	1	$1,64x10^{-6}$
					$10,9x10^{-6}$
R_X	**999998500 Ω**	u_c			≈12 μΩ/Ω

19 LNE

EQUATION

When the bridge is balanced (*dm = 0*) :

$$\boxed{Rx = \frac{R.(1+\delta)}{\frac{Q}{P} - \left(1+\frac{Q}{P}\right).\frac{dm}{U}}} \quad \text{Equation 1}$$

where, $\delta = \frac{-R}{g}.\left(\frac{1}{R_{Xn}} + \frac{1}{\rho} + \frac{1}{R}\right)$

g : open loop gain of amplifier
R_{Xn} : nominal value of Rx
ρ : input resistance of the amplifier
U : measurement voltage (100 V)

UNCERTAINTY BUDGET

From Equation 1,

$$\boxed{u(R_X) = \sqrt{\left(\frac{P.R}{Q}\right)^2.u^2(\delta) + \left(\frac{R}{Q}\right)^2.u^2(P) + \left(\frac{P}{Q}\right)^2.u^2(R) + \left(\frac{P.R}{Q^2}\right)^2.u^2(Q) + \left(\frac{Rx.(P+Q)}{Q.U-(P+Q).dm}\right)^2.u^2(dm)}}$$

Component	Probability distribution /method of evaluation	Standard uncertainty value	Sensitivity coefficient	Uncertainty contribution	Degrees of freedom
Calibration of P	Normal/B	25 Ω	100	2,5 kΩ	500
Calibration of R	Normal/B	25 Ω	100	2,5 kΩ	500
Calibration of Q	Normal/B	250 mΩ	10^4	2,5 kΩ	500
Temperature effect on P	Rectangular/B	11 Ω	100	1,1 kΩ	500
Temperature effect on R	Rectangular/B	600 mΩ	100	60 Ω	500
Temperature effect on Q	Rectangular/B	6 mΩ	10^4	60 Ω	500
Input Impedance and of open loop gain of amplifier (δ)	Rectangular/B	510.10^{-9}	10^9 Ω	510 Ω	500
Sensibility and noise (dm)	Rectangular/B	1,5 µV	$1{,}01.10^9$ Ω V^{-1}	1,52 kΩ	500
Leakage resistances	Rectangular/B	50 mΩ	100	5 Ω	500
Combined uncertainty (k=1)				**$4{,}8.10^{-6}$.R**	
Combined uncertainty (k=2)				**$9{,}5.10^{-6}$.R**	

20 EIM

1G	HR9101									
Quantity X_i	Estimate χ_i		Standard uncertainty $u(\chi_i)$		Probability Dist. (Type A/B)	Sensitivity coefficient c_i		Uncertainty contribution $u(R_i)$		Deg of free ν_i
Reference resistor value	100 004 477	Ω	708	Ω	B	10		7080	Ω	∞
Electrometer uncertainty	7.E-13	A	1.E-14	A	B	-7.E+15	Ω/A	70	Ω	∞
Bridge linearity	7.E-13	A	9.E-14	A	B	-7.E+15	Ω/A	630	Ω	∞
Leakages	7.E-13	A	6.E-14	A	B	-7.E+15	Ω/A	420	Ω	∞
Calibrator	10	V	3.E-05	V	B	-7.E+07	Ω/V	1960	Ω	∞
Reproducibility	1000 057 340	Ω	6165	Ω	A	1		6165	Ω	5
Rx	1000 057 340	Ω								

Combined standard uncertainty:	9620	Ω
Effective degrees of freedom:	30	
Expanded uncertainty (95 % conerage factor):	19241	Ω

21 BEV

The following sources of uncertainty as stated in the respective tables are taken into account:

- $R_{\text{ref,cal}}$: This is the calibration uncertainty of the standard resistors of BEV which were used for this comparison. These calibration uncertainties are calculated for each standard resistor of BEV when the internal calibration procedure is done. The largest calibration uncertainty is used for calculating the uncertainty budget of this comparison.
  The value of the estimate is given in the respective table e.g. “10 MΩ” as an example for a measurement against a 10 MΩ standard resistor of BEV. At the 10 MΩ-level the drift of the standards since the last calibration are included in this contribution.
- $\delta R_{\text{ref,drift}}$: This is the uncertainty associated with the standard resistors of BEV due their drift within the time since the last internal calibration. This contribution is considered at the 1 GΩ level.
- δR_{6675}: This is the uncertainty associated with the measuring bridge.
- $\delta R_{6675\text{,res}}$: This is the contribution from the resolution of the bridge.
- δR_{temp}: This is the uncertainty of the temperature measurement. The following contributions are taken into account: calibration uncertainty, type A uncertainty, uncertainty of temperature measuring bridge, uncertainty due to temperature instabilities within the bath.
- δR_{meas}: This is the type A uncertainty of the measurements.
- δR_{wire}: This is the contribution from the measurement wires because of the two-wire-measurement method.
- $\delta R_{\text{offsetNull}}$: This is the contribution from not compensated offset effects of the null detector.
- δR_{thermo}: This is the contribution from not compensated thermal emfs.
- $\delta R_{\text{DVMratio}}$: This is the contribution from the ratio voltmeter according to the manufacturer specification.
- δR_{TkRs}: This is the contribution from the temperature coefficient of the standard resistors from manufacturer specification.
- δR_{TkRx}: This is the contribution from a rough estimation of the temperature coefficient of the DUT resistor.
- δR_{VkRs}: This is the contribution from an estimation of the voltage coefficient of the standard resistor.

NIST standard, SN HR 9101

Quantity **X_i**	**Estimate** **x_i** **[▯]**	**Rel. stand. uncert.** **$u(x_i)$**		**Probability dist/method of evaluation (A,B)**	**Sens. coeff.** **c_i**		**Relative uncert. cont.** **$u(y_i)$**	**Deg. of freedom** **ν_i**
$R_{ref,cal}$	1000 000 000.	5	μΩ/Ω	normal/B	1.0		5.000	50
$R_{ref,drift}$	0	2.309	μΩ/Ω	rect/B	1.0		2.309	infinite
δR_{wire}	0	0.006	μΩ/Ω	rect/B	1.0		0.006	infinite
$\delta R_{offsetNull}$	0	0.127	μΩ/Ω	rect/B	1.0		0.127	infinite
δR_{thermo}	0	0.013	μΩ/Ω	rect/B	1.0		0.013	infinite
$\delta R_{DVMRatio}$	0	2.500	μΩ/Ω	normal/B	1.0		2.500	50
δR_{TkRs}	0	0.400	K	rect/B	1.0	(μΩ/Ω)/K	0.400	infinite
δR_{TkRx}	0	0.400	K	rect/B	5.0	(μΩ/Ω)/K	1.998	infinite
δR_{VkRs}	0	57.735	V	rect/B	0.100	(μΩ/Ω)/V	5.774	infinite
δR_{meas}	1000 074 016.	3.934	μΩ/Ω	normal/A	1.0		3.934	3
					combined uncertainty [μΩ/Ω], k=1		9.464	
Deviation from nominal value [μΩ/Ω]	74.016				expanded uncertainty [μΩ/Ω], k=2		18.927	
					Effective degree of freedom $\nu_{i,eff}$			86.16

22 CEM

In the analysis of uncertainty for this comparison, the following mathematical model is considered. For the 1 GΩ standards:

$$R_{x1G} = r_{x2} R_{100\mathrm{M}} \left(1 + \delta_{10} + \alpha \delta_T\right) \tag{3}$$

, where the symbols have the following meanings:

- R_{x1G}: Value of the 1 GΩ travelling standard, relative to Quantum Hall Resistance.
- r_{x2}: Measured ratio of 1 GΩ to 100 MΩ standard resistor.
- $R_{100\mathrm{M}}$: Value of 100 MΩ standard.
- α: Temperature coeficient of 100 MΩ standard.
- δ_T: Temperature difference between measure

With th following expression for uncertainty:

$$\frac{u^2\left(R_{x1G}\right)}{\left(R_{x1G}\right)^2} = \frac{u^2\left(r_{x2}\right)}{\left(r_{x2}\right)^2} + \frac{u^2\left(R_{100\mathrm{M}}\right)}{\left(R_{100\mathrm{M}}\right)^2} + \frac{u^2\left(\delta_{10}\right)}{\left(1+\delta_{10}+\alpha\delta_T\right)^2} + \frac{\delta_T{}^2 u^2(\alpha)}{\left(1+\delta_{10}+\alpha\delta_T\right)^2} + \frac{\alpha^2 u^2\left(\delta_T\right)}{\left(1+\delta_{10}+\alpha\delta_T\right)^2} \tag{4}$$

The results individualized for every resistor are presented in separated tables.

Uncertainty budget for HR9101 1 GΩ $R_{\mathrm{X\,1\,G}}$

Quantity X_i	Estimate x_i	Relative standard uncertainty $u(x_\mathrm{i})$	Probability distribution /method of evaluation (A. B)	Sensitivity coefficient c_i	Relative uncertainty contribution $u(R_\mathrm{i})$	Degree of freedom ν_i
r_{x2}	9.897 653 3	4.4×10^{-7}	A	1	4.4×10^{-7}	25
$R_{100\mathrm{M}}$	101.039 54 MΩ	2×10^{-6}	B	1	2×10^{-6}	10
δ_{10}	0	3.2×10^{-7}	B	1	3.2×10^{-7}	∞
α	-29.3×10^{-6}/ºC	2.4×10^{-6}/ºC	A	0.017 ºC	4.2×10^{-8}	10
δ_T	0.017 ºC	0.004 ºC	A	-29.3×10^{-6}/ºC	1×10^{-7}	25
R_{x1G}	1,000 054 3 GΩ					
		Combined relative standard uncertainty:			2.1×10^{-6}	
		Effective degrees of freedom:			12	
		Expanded relative uncertainty (95% coverage factor):			4.6×10^{-6}	

23 VNIIM

The model for the measurement of 1 GΩ standard is:

$R\,(1G)_x = R_{s2}\cdot N_{H2}\cdot(1 + \delta_{drift} + \delta_{leak2} + \delta_{Wb2} + \delta_{Wbarm} + \delta_{t2})$

The components are:

$R(1G)_x$:	the unknown resistor,
$R_{s2} = R(10M)$:	the standard resistor of 10 MΩ.
N_{H2} :	the ratio of the parallel- series transfer of the Hamon device No. 2 (10 ×100 MΩ).
δ_{drift}:	the relative uncertainty due to short term drift of the 10 MΩ standard resistors,
δ_{leak2}:	the relative uncertainty due to leakage resistance from node points of the Wheatstone bridge (Wb),
δ_{Wb2}:	the relative uncertainty due to Wb balancing for 1 GΩ resistors (sensitivity, reproducibility),
δ_{Wbarm}:	the relative uncertainty due to the stability of the Wb arms (100 kΩ).
δ_{t2}:	the relative uncertainty due to instability temperature of the resistors.

The relative standard uncertainty is then given by :

$$\frac{u(R(1G)_x)}{R(1G)_x} = \sqrt{\left(\frac{u(R_{s2})}{R_{s2}}\right)^2 + \left(\frac{u(N_{H2})}{N_{H2}}\right)^2 + \sum_1^5 \left(\delta_j^2\right)}$$

Uncertainty budget for the 1 GΩ Standard NIST S/N. HR9101

Quantity X_i	Estimate x_i	Relative standard uncertainty, 10^{-6} $U(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Relative uncertainty contribution, 10^{-6} $u(R_i)$	Degree of freedom ν_i
$R_{s2} = R(10M)$	10 MΩ	0.9	Normal/B	1.0	0.9	50
N_{H2}	100	1.5	Normal/B	1.0	1.5	12
δ_{drift}	0	0.2	Normal/A	1.0	0.2	12
δ_{leak2}	0	0.8	Rectangular/ B	1.0	0.8	Inf.
δ_{Wb2}	0	1.0	Normal/A	1.0	1.0	11
δ_{Wbarm}	0	0.5	Normal/B	1.0	0.5	12
δ_{t2}	0	0.6	Normal/B	1.0	0.6	8
R_x	1000.142 MΩ					
		Relative combined standard uncertainty:			$2.3\cdot 10^{-6}$	
		Effective degrees of freedom:			51	
		Relative expanded uncertainty (95% coverage factor):			$4.7\cdot10^{-6}$ (k = 2.05)	

Annex D

RMO Key Comparison EUROMET.EM-K2
Comparison of Resistance Standards at 10 MΩ and 1 GΩ

TECHNICAL PROTOCOL

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Contents

1. Introduction

The Mutual Recognition Arrangement (MRA) states that its technical basis is a set of results obtained in a course of time through key comparisons carried out by the Consultative Committees (CCs) of the CIPM, the BIPM and the Regional Metrology Organisations (RMOs). As part of this process, the CIPM Consultative Committee for Electricity and Magnetism (CCEM) carried out the key comparison CCEM-K2 of resistance standards at 10 MΩ and 1 GΩ. This comparison was piloted by the National Institute for Standards and Technology and approved by the CCEM for full equivalence in January 2002 [1, 2].

In order to link the National Metrology Institutes organised in EUROMET to the key comparison CCEM-K2, the EUROMET Technical Committee for Electricity and Magnetism decided at its October 2004 meeting to organise the corresponding RMO key comparison EUROMET.EM-K2.

The procedures outlined in this document should allow for a clear and unequivocal comparison of the measurement results. The protocol was prepared following the CCEM guidelines for planning, organizing, conducting and reporting key, supplementary and pilot comparisons.

2. Travelling standards

2.1 Description of the standards

10 MΩ

Two different types of travelling standards (three resistors each) are used:

1. NIST type wire-wound resistors. The resistance elements are hermetically sealed in metal containers. The two resistor terminations of the standards are coaxial BPO connectors mounted on grooved PTFE circular plates on the top panel of the enclosures. The resistor containers are electrically isolated from the enclosures and electrically connected to the shield of one of the coaxial connectors. This allows the resistor container of the standard to be operated either in floating mode, a grounded mode, or driven at a guard potential.
2. Standards manufactured by Measurements International (CA), Model 9331. The resistance elements are hermetically sealed in metal containers. The four resistor terminations of the standards are tellurium copper binding posts. A separate ground terminal is included for screening.

1 GΩ

Two different types of travelling standards (three resistors each) are used:

1. NIST film-type resistors. The mounting of the resistance elements is the same as for the 10 MΩ standards.
2. Standards manufactured by Measurements International (CA), Model 9331S (based on NIST design). The resistance elements are housed in a double shielded enclosure. The two resistor terminations of the standards are BPO coaxial connectors mounted directly on the outer enclosure. The inner enclosure containing the resistive element is isolated from the external enclosure. It is connected to the guard terminal and may be operated either in floating mode, a grounded mode, or driven at a guard potential.

In order to keep a reasonable time scale for the comparison, the measurement will be carried out in two separate loops. In each loop, three 10 MΩ and three 1 GΩ standards will be circulated:

Loop A

- 10 MΩ: NIST standard, SN HR 7550
  NIST standard, SN HR7552
  MI 9331, SN 1050109
- 1 GΩ: NIST standard, SN HR 9106
  MI 9331S, SN 1100036
  MI 9331S, SN 1100037

Loop B

- 10 MΩ: NIST standard, SN HR 7551
  MI 9331, SN 1050110
  MI 9331, SN 1050111
- 1 GΩ: NIST standard, SN HR 9101
  NIST standard, SN HR 9102
  MI 9331S, SN 1100035

2.2 Quantities to be measured

- Resistance of the 10 MΩ standards at the following conditions:
  test voltage: $V_{\text{test}} \leq 100$ V; preferably 10 V
  ambient temperature: (23 ± 0.2) °C
  relative humidity: (50 ± 10) %

- Resistance of the 1 GΩ standards at the following conditions:
  test voltage: $V_{\text{test}} \leq 100$ V; preferably 100 V
  ambient temperature: (23 ± 0.2) °C
  relative humidity: (50 ± 10) %

If not possible otherwise, the measurements may also be performed at an ambient temperature of (20 ± 0.2) °C. In such a case, the results will be corrected to 23 °C using the temperature coefficients determined by the pilot laboratory. The uncertainty of the correction is approximately 0.2 µΩ/Ω for the 10 MΩ standards and 2 µΩ/Ω for 1 GΩ respectively.

2.3 Method of computation of the Reference value

The comparison reference value (CRV) will be evaluated following the principles laid down in [3]. A generalized version of the procedure described in [4] will be applied to account for the drift of the travelling standards. The proposed principles of the analysis are:

- The results obtained by the pilot laboratory will be used to determine the drift behaviour of the travelling standards and to link the two loops A and B of the comparison;
- The results provided by the participants will be corrected to the nominal temperature (23 °C) and nominal test voltages (10 V for 10 MΩ standards and 100 V for 1 GΩ) using the sensitivity coefficients determined by the pilot laboratory;
- For the calculation of the CRV, the weighted mean over the laboratories will be used;
- If for a result, the uncertainty contribution due to the traceability to another NMI amounts to a substantial part of the overall uncertainty value, the result is not taken into account in the calculation of the CRV.

3. Organisation

3.1 Co-ordinator and members of the support group

The pilot laboratory for the comparison is the Swiss Federal Office of Metrology and Accreditation (METAS).

Co-ordinator and contact person for technical questions:
Dr Beat Jeckelmann
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Organizational matters:
Mrs Beatrice Steiner
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Support group:
Dr Bernd Schumacher, Physikalisch-Technische Bundesanstalt (PTB), DE;
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Dr Gert Rietveld, NMi Van Swinden Laboratorium (NMi-VSL), NL:
e-mail: grietveld@nmi.nl

3.2 Participants

The participating institutes are listed in the following table. The contact details are given in Appendix A1.

No	Country	Institute	Acronym
1	Austria	Bundesamt für Eich- und Vermessungswesen	BEV
2	Belgium	Service de la Métrologie	SMD
3	Czech Republic	Czech Metrology Institute	CMI
4	Finland	Centre for Metrology and Accreditation	MIKES
5	France	Laboratoire National d'Essais	LNE*)
6	Germany	Physikalisch-Technische Bundesanstalt	PTB*)
7	Greece	Hellenic Institute of Metrology	EIM
8	Hungary	National Office of Measures	OHM
9	Ireland	National Metrology Laboratory	NML
10	Latvia	Latvian National Metrology Centre	LNMC
11	Lithuania	State Metrology Service/ Institute for Semiconductor Physics	VMT/ PFI
12	Netherlands	NMi Van Swinden Laboratorium B.V.	NMi-VSL*)
13	Norway	Norwegian Metrology and Accreditation Service	JV
14	Poland	Central Office of Measures	GUM
15	Portugal	Instituto Nacional de Engenharia, Tecnologia e Inovação	INETI /LME
16	Romania	National Institute of Metrology	INM
17	Russia	D.I. Mendeleyev Institute for Metrology	VNIIM*)
18	Slovakia	Slovak Institute of Metrology	SMU

No	Country	Institute	Acronym
19	Slovenia	Slovenian Institute of Quality and Metrology	SIQ
20	South Africa	CSIR- National Metrology Laboratory	CSIR-NML
21	Spain	Centro Español de Metrologia	CEM
22	Switzerland	Swiss Federal Office of Metrology and Accreditation	METAS*)
23	Turkey	Ulusal Metroloji Enstitüsü	UME
24	United Kingdom	National Physical Laboratory	NPL*)

*) These laboratories participated in CCEM-K2 and will assure the link to this CCEM key comparison.

Table 1: Participants

3.3 Time schedule

The comparison is carried out in two parallel loops (loop A and loop B). The circulation of the standards starts in July 2005 and is planned to end in August 2006. The detailed time schedule for the comparison is given in Appendix A2.

A period of four weeks is allowed for the measurements in each laboratory, including the time necessary for transportation. It is intended to re-measure the standards at certain intervals in the pilot laboratory to establish a drift rate for the standards and to detect transport problems. The time period in the pilot laboratory is extended to cover small delays in the circulation of the standards.

In agreeing with the proposed circulation time schedule, each participating laboratory confirms that it is capable to perform the measurements in the limited time period allocated in the time schedule. If, for some reasons, the measurement facility is not ready or custom clearance should take too much time, the laboratory is requested to contact immediately the co-ordinator in the pilot laboratory. According to the arrangement made in this special case the travelling standards must be eventually sent directly to the next participant before the measurement has been finished or even without performing any measurements. In such a case, there is a possibility to carry out the measurements at the end of the comparison.

If delay occurs, the pilot laboratory shall inform the participants and revise - if necessary - the time schedule, or skip one country and put it at the end of the circulation.

3.4 Transportation

- Transportation is at each laboratory’s own responsibility and cost. Due to the time constraints, a recognised courier service (e.g. UPS, DHL..) guaranteeing an adequate delivery time, inclusive of the time for customs procedure, should be used. Where appropriate, customs procedures have to be examined in advance of the transport. *The courier service has to be informed that the transport case should not be exposed to extreme temperatures or mechanical shock*s.
- In some countries, the case will be transported with an ATA carnet for customs clearance. Upon each movement of the package, the person organising the transit must ensure that the carnet is presented to customs on leaving the country, and upon its arrival in the country of destination. When the package is sent unaccompanied, the carnet must be included with the other forwarding documents so that the handling agent can obtain customs clearance. *In no case should the carnet be packed inside the case*. In some cases it is possible to attach the carnet to the case. The carnet must be stored in the laboratory very carefully because a loss of the carnet may cause a serious delay in the comparison schedule.

- On receipt of the case, the participant shall inform the pilot laboratory by sending the receipt form given in Appendix A5 by fax or e-mail.
- Immediately after the completion of the measurements, the case is to be transported to the next participant. It is advisable to organise this transport beforehand. The pilot laboratory has to be informed through the form given in Appendix A6 about the dispatch of the case. The next participant should be informed as well.

3.5 Unpacking, handling, packing

The transport cases contain the following items:

Packing list, loop A

- Three 10 MΩ standard resistors:
    - NIST, SN HR7550
    - NIST, SN HR7552
    - MI 9331, SN 1050109
- Three 1 GΩ standard resistors:
    - NIST, SN HR9106
    - MI 9331S, SN 1100036
    - MI 9331S, SN 1100037
- 10 BPO-BNC adapters
- Ambient conditions recorder. This recorder is used to monitor the temperature of the standards during transport and to monitor vibrations and shocks.
- Instruction manual

Packing list, loop B

- Three 10 MΩ standard resistors:
    - NIST, SN HR 7551
    - MI 9331, SN 1050110
    - MI 9331, SN 1050111
- Three 1 GΩ standard resistors:
    - NIST, SN HR 9101
    - NIST, SN HR 9102
    - MI 9331S, SN 1100035
- 8 BPO-BNC adapters
- Ambient conditions recorder. This recorder is used to monitor the temperature of the standards during transport and to monitor vibrations and shocks.
- Instruction manual

On receipt of the case, unpack the standards carefully and check for any damage and the completeness of the audit pack according to the packing list. The ambient conditions recorder should not be removed from the transport case. If possible, the transport case should be stored in the laboratory. Any damage of the standards or missing item shall be reported on the receipt form to be sent to the co-ordinator.

Before sending the case out, check the packing list and ensure everything is enclosed. The standards should be packed in the original transport case as illustrated in the instruction manual. *Ensure that the ATA carnet (where applicable) is packed outside the case for easy access by customs*.

3.6 Failure of the travelling standard

Should one of the standards be damaged during the comparison, the pilot laboratory has to be informed immediately.

3.7 Financial aspects, insurance

Each participating laboratory covers the costs of the measurements, transportation and eventual customs formalities as well as for any damage that may occur within its country. The overall costs for the organisation of the comparison are covered by the organising pilot laboratory. The pilot laboratory has no insurance for any loss or damage of the standards during transportation.

4. Measurement instructions

4.1 Test before measurements

No initial tests are required. However, depending on the measurement set-up it may be necessary to measure the isolation resistance between the resistive elements and the case of the standards.

4.2 Measurement performance

Pre- conditioning:	The standards should be installed in a thermostatic air bath, regulated at the chosen working temperature, at least 24 h before staring the measurements.
Measurand:	Resistance value of the travelling standards at DC, expressed in terms of the conventional value of the von Klitzing constant $R_{K\text{-}90}$ = 25812.807 Ω.
Test voltage:	10 MΩ: $V_{test} \leq 100$ V; preferably 10 V 1 GΩ: $V_{test} \leq 100$ V; preferably 100 V
Temperature:	(23 ± 0.2) °C ((20 ± 0.2) °C in exceptional cases; see Sect. 2.2); the temperature should not exceed the given limits.
Humidity:	(50 ± 10) %.
Measurements:	The measurements should be repeated several times during the whole period allocated to the participating laboratory.

4.3 Method of measurement

The measurement method is not specified. It is assumed that every participant uses its normal measurement method. The method and the traceability scheme have to be described in the measurement report (see below).

The choice of the ground/guard configuration is left to the participants. Sect. 2.1 describes the internal configuration of the ground/guard terminals in the resistance standards.

5. Uncertainty of measurement

5.1 Main uncertainty components

A detailed uncertainty budget in accordance with the ISO Guide to the Expression of Uncertainty in Measurement shall be reported for one resistor of each nominal value.

To have a comparable uncertainty evaluation, a list of principal uncertainty contributions is given. Depending on the measuring methods, this list may vary:

- Step-up procedure
- Reference standard (drift, temperature and voltage dependence)
- Measuring set-up (stability, gain and offset-effects, configuration)
- Leakage effects
- Temperature
- Reproducibility

5.2 Scheme to report the uncertainty budget

A proposed scheme for the uncertainty budget is given in Annex A3.

6. Measurement report

Each participant is asked to submit a printed and signed report by mail within 6 weeks after completing the measurements. A copy of the report may also be sent by e-mail. In the case of differences between electronic and paper versions of the report, the signed paper form is considered to be the valid version. The report should contain at least the following (see also Appendix A4):

- Description of the measuring set-up including the ground/guard configuration. (If a two-terminal method is used in the case of the MI standards, the connection scheme should be reported);
- Traceability scheme. If the traceability to the SI is provided by another NMI, the name of the NMI has to be stated (needed to identify possible sources of correlation);
- Description of the measurement procedure;
- The measurement results: Mean resistance value for every standard and the corresponding mean date of measurement; individual results in the form described in Appendix A4;
- The test voltages chosen for the measurements;
- The ambient conditions of the measurement: the temperature and humidity with limits of variation;
- A complete uncertainty budget in accordance with the principles of the ISO Guide to the Expression of Uncertainty in Measurement, including degrees of freedom for every component and calculation of the coverage factor. Such an analysis is a prerequisite to be considered in the calculation of the comparison reference value. It is also an essential part of the final report which will appear in the BIPM Key Comparison Database.

The pilot laboratory will inform a participating laboratory if there is a large deviation between the results of the laboratory and the preliminary reference values. No other information will be communicated before the completion of the circulation.

7. Report of the comparison

The pilot laboratory will prepare the draft A report within three months after completion of the circulation. This report will be prepared with the aid of the support group and will be sent to all participants for comments.

References

[1] R.F. Dziuba and D. G. Jarett, Final report on key comparison CCEM-K2 of resistance standards at 10 MΩ and 1 GΩ, Metrologia, 39, Tech. Suppl., 01001, 2002.

[2] N. F. Zhang, N. Sedransk and D. G. Jarrett, Statistical uncertainty analysis of key comparison CCEM-K2, IEEE Trans. Instrum, Meas., 52, pp. 491-4, 2003.

[3] M. G. Cox, The evaluation of key comparison data, Metrologia, 39, pp. 589-95, 2002.

[4] N. F. Zhang, H.-K. Liu, N. Sedransk and W. E. Straderman, Statistical analysis of key comparisons with linear trends, Metrologia, 41, pp. 231-7, 2004.

Annexes

A1 Detailed list of participants

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A2 Schedule of the measurements

Loop A

Institute	Country	Start date	Time for measurements and transport
Pilot (metas)	Switzerland	until July 2005	
PTB	Germany	August 2005	4 weeks
SIQ	Slovenia	September 2005	4 weeks
SMU	Slovak Republic	October 2005	4 weeks
NMi-VSL	Netherlands	November 2005	4 weeks
Pilot (metas)	Switzerland	December 05 to January 2006	8 weeks
SPI	Lithuania	February 2006	4 weeks
MIKES	Finland	March 2006	4 weeks
OMH	Hungary	April 2006	4 weeks
CMI	Czech Republic	Mai 2006	4 weeks
GUM	Poland	June 2006	4 weeks
INM	Romania	July 2006	4 weeks
CSIR-NML	South-Africa	August 2006	4 weeks
INM (2nd measurement)	Romania	October 2006	4 weeks
GUM (2nd measurement)	Poland	November 2006	4 weeks
Pilot (metas)	Switzerland	December 2006	4 weeks

Loop B

Institute	Country	Start date	Time for measurements and transport
Pilot (metas)	Switzerland	until July 2005	
NML	Ireland	August 2005	4 weeks
JV	Norway	September 2005	4 weeks
INETI/LME	Portugal	October 2005	4 weeks
LNMC	Latvia	November 2005	4 weeks
Pilot (metas)	Switzerland	December 2005	4 weeks
NPL	United Kingdom	January 2006	4 weeks
SMD	Belgium	February 2006	4 weeks
UME	Turkey	March 2006	4 weeks
LNE	France	April 2006	4 weeks
EIM	Greece	September 2006	4 weeks
BEV	Austria	October 2006	4 weeks
CEM	Spain	November 2006	4 weeks
VNIIM	Russia	December 2006	4 weeks
Pilot (metas)	Switzerland	January 2007	4 weeks

A3 Typical scheme for an uncertainty budget

Quantity X_{i}	Estimate x_{i}	Standard uncertainty $u(x_{\mathrm{i}})$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_{i}	Uncertainty contribution $u(R_{\mathrm{i}})$	Degree of freedom ν_{i}
R_{x}						
		Combined standard uncertainty:				
		Effective degrees of freedom:				
		Expanded uncertainty (95% coverage factor):				

The detailed uncertainty has to be provided in this form for one standard of each nominal value.

A4 Layout of the measurement report

1. Measurand
2. Measurement set-up and traceability scheme
3. Measurement procedure
4. Results
    a. Ambient conditions
    Temperature: mean value, uncertainty and range of variation
    Humidity: mean value, uncertainty and range of variation
    b. Test voltage
    c. Mean date of measurement
    d. Mean resistance value, combined standard uncertainty
5. Detailed uncertainty budget

Appendix: Detailed results

Standard Serial No

Date	Temperature *T* (°C)	Stand. Uncert. *T* (°C)	Test voltage (V)	Measurement result: Deviation from nominal value (μΩ/Ω)	Type A uncertainty (μΩ/Ω)

A5 Confirmation note of receipt

Telefax Telefax Telefax

(Please pass on immediately!)

To: Swiss Federal Office of Metrology and Accreditation
attn.: Mrs. Beatrice Steiner

Lindenweg 50, CH-3003 Bern-Wabern, Switzerland

FAX No. : +41 31 323 3210
e-mail: beatrice.steiner@metas.ch

From: (participating laboratory):

....

....

....

Fax: International +

Pages (total): 1

In the case of faulty reproduction, please call:

Re: Euromet key comparison Euromet.EM-K2 - Receipt of travelling standards

Date: ....

We confirm having received the travelling standards of the Euromet.EM-K2 key comparison

on ....

After visual inspection:

☐ No damage of the suitcase and the travelling standards has been noticed

☐ the following damage(s) must be reported(if possible add a picture):

....

....

....

Date: .... Signature: ....

A6 Confirmation note of dispatch

Telefax Telefax Telefax

(Please pass on immediately!)

To: Swiss Federal Office of Metrology and Accreditation
attn.: Mrs. Beatrice Steiner

Lindenweg 50, CH-3003 Bern-Wabern, Switzerland

FAX No. : +41 31 323 3210
e-mail: beatrice.steiner@metas.ch

From: (participating laboratory):

....

....

....

Fax: International +

Pages (total): 1

In the case of faulty reproduction, please call:

Re: Euromet key comparison Euromet.EM-K2 - Dispatch of travelling standards

Date: ....

We have informed the next participant on..............................that we will send the travelling standards to them.

We confirm having sent the travelling standards of the EUROMET.EM-K2 key comparison on................................to the next participant.

Additional informations:

....

....

....

Date: .... Signature: ....