FINAL REPORT

EUROMET project no. 429

Comparison of 10 V Electronic Voltage Standards

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Abstract

This report presents the results of a comparison of measurements on four electronic DC reference standards performed by national metrology institutes in the EUROMET region and BIPM. The results of the comparison, in terms of degrees of equivalence, show that there is a good agreement between the measurement results of the participants. The results also show that the time-dependent fluctuations in the output voltages of the traveling standards provide one of the main sources of uncertainty.

1. Introduction

At the EUROMET *Josephson and quantum Hall experts meeting*, held in Lisboa on 27 and 28 May 1997, it was proposed to organise a EUROMET comparison of 10 V DC voltage measurements. At the EUROMET *electricity contact persons meeting*, held in Madrid on 29 and 30 October 1997, this comparison was assigned the status of EUROMET key-comparison (EUROMET.EM.BIPM-K11).

Primary and secondary DC voltage standards are of fundamental importance for the traceability of electrical measurements. The primary standard for DC voltage is formed by the Josephson Array Voltage Standard (JAVS). After the development of 10 V Josephson Arrays, the 10 V level has become the most important and accurately known level to maintain secondary electronic standards. These electronic standards form the starting point for further realisation of the voltage scale and the traceability of electrical calibrations.
Since 1991 most JAVSs of national metrology institutes have been compared bilaterally with the transportable JAVS of the Bureau International des Poids et Mesures (BIPM) [1,2]. These comparisons have provided detailed information about the quality of the JAVSs. The working group on key comparisons of the CCEM has recommended to repeat these comparisons after 10 years. However, not only comparisons at the primary level are important. To gain insight in the quality and compatibility of the results of routine calibration results, calibration results of national measurement institutes on the secondary level should be internationally compared. In the field of DC voltage this implies a comparison of the results of calibrations of electronic DC reference standards, commonly refered to as Zener references. These calibrations are performed either by means of a JAVS or, in the absence of a JAVS, by comparison with a group of Zener references traceable to a JAVS.
A comparison of 10 V calibration results will accelerate the development of measurement strategies within the field of electrical metrology. It will also facilitate the dissemination of experience and knowledge to less favoured regions, by incorporating in the comparison countries from eastern and southern Europe that are building up their facilities and that do not (yet) operate a JAVS as their national standard.
The present document presents the report of the comparison of 10 V calibration results organised in Europe in the period 1998 – 2001. The aim of the comparison was to determine the degrees of equivalence between the results of 10 V calibrations of each of the participants. For this purpose, for each participant the deviation of his result from the EUROMET Reference Value (ERV) and the uncertainty in this deviation at a 95% level of confidence (the so-called degree of equivalence) was determined.

2. Participants and schedule

There were 22 members of EUROMET who participated and BIPM was also included. A complete list is given in Table 1. During the comparison, 2 participants withdrew.

Laboratory		Country
NMi-VSL	NMi Van Swinden Laboratorium – Pilot laboratory	The Netherlands
BIPM	Bureau International des Poids et Mesures	
BNM-LNE(*)	BNM - Laboratoire National d'Essais	France
NPL	National Physical Laboratory	United Kingdom
NML	National Metrology Laboratory	Ireland
UME	Ulusal Metroloji Institüsü	Turkey
DFM	Danish Institute of Fundamental Metrology	Denmark
SP	Swedish National Testing and Research Institute	Sweden
MIKES	Centre for Metrology and Accreditation	Finland
JV	Norwegian Metrology and Accreditation Service	Norway
SMD	Service de la Métrologie	Belgium
CMI	Czech Metrology Institute	Czech Republic
BEV	Bundesamt für Eich- und Vermessungswesen	Austria
SMU	Slovak Institute of Metrology	Slovakia
CEM	Centro Español de Metrologia	Spain
INETI	Instituto Nacional de Engenharia e Tecnologia Industrial	Portugal
METAS (**)	Swiss Federal Office of Metrology and Accreditation	Switzerland
IEN (***)	Istituto Elettrotecnico Nazionale	Italy
PTB	Physikalisch-Technische Bundesanstalt	Germany
GUM (***)	Central Office of Measures	Poland
EIM	Hellenic Institute of Metrology	Greece
SIQ	Slovenian Institute of Quality and Metrology	Slovenia
OMH	National Office of Measures	Hungary
* before 1 July 2001: BNM-LCIE (BNM – Laboratoire Central des Industries Electriques) ** before 1 January 2001: OFMET (Swiss Federal Office of Metrology) *** withdrawn		

Table 1: *List of participants.*

NMi-VSL was responsible for providing and preparing the traveling standards and coordination of the schedule. NMi-VSL was also responsible for collecting and analysing the comparison data and preparing the draft reports.

In appendix A the schedule of the comparison is presented. This schedule is based on the scheme **A**-B-C-**A**-D-E-**A**-…, with A the pilot laboratory (NMi-VSL) and B, C, D, etc. the participating laboratories. This schedule avoids that possible problems with the traveling standards remain unnoticed for too long a period. In two cases, an intervention of the type -**A**-B-C-D-**A**- was necessary as a result of planning and logistic limitations. In one case, an intervention of the type -A-B-A- was necessary due to the withdrawal of a participant. In total, NMi-VSL performed 14 measurements during the course of the comparison. The corresponding measurement results are used to make corrections for the time dependent behaviour of the Zener output voltages (see section 5.1). As a secondary "back-up" pilot laboratory, BIPM performed 5 measurements during the course of the comparison. The corresponding measurement results are used to verify the correctness of the time dependences as determined by NMi-VSL. Arbitrarily, the 8th measurement period of NMi-VSL and the 4th measurement period of BIPM are considered as the periods that NMi-VSL and BIPM participated in the comparison. The data for NMi-VSL and BIPM in the overview of the degrees of equivalence are based on the results of these periods.

Although one week is considered as sufficient for performing the necessary measurements, each participant was normally allowed to keep the traveling standards for two weeks in his laboratory. After return to NMi-VSL, the traveling standards remained for about three weeks at NMi-VSL. In this way the pilot laboratory was able to catch up delays without being forced to adjust the whole future planning. During the course of the comparison some adjustments had to be made to the schedule because of the withdrawal of two participants. Because of late application of three participants the end of the comparison was postponed from June 2000 until February 2001.

3. The traveling standards

3.1 Characterisation

The traveling standards are 4 electronic DC reference standards, type Fluke 732B, property of NMi-VSL. These standards are labeled and identified with VSL-1, VSL-2, VSL-3, and VSL-4. The Fluke 732B has both a 1.018 V and a 10 V output voltage, but in this comparison only the 10 V output voltage was considered. Prior to the start of the comparison, the air-pressure and temperature dependence of each of the traveling standards were determined by BIPM. A measure for the temperature of a Fluke 732B is the value of the internal thermistor resistance. All traveling standards appeared to exhibit a linear dependence on the air pressure p and the thermistor resistance R. For each of the traveling standards the pressure coefficients α_p and the resistance coefficients α_R were measured at BIPM in December 1998 and December 2000. For each standard, the weighted means of these two measurements have been calculated and are given in Table 2. At the end of the comparison, all measurements from all participants have been recalculated by applying these coefficients.

The measured output voltages U are corrected for the air-pressure and thermistor resistance dependence, yielding corrected voltages U_L, using the formula:

$$U_L = U - \alpha_R (R - R_0) - \alpha_p (p - p_0) \quad ,$$

where p_0 is the reference air pressure and R_0 is the reference thermistor resistance. The reference values for each of the traveling standards were calculated as the rounded averages of all participant laboratories. The reference values are also given in Table 2.

ID and s/n	R_0 (kΩ)	α_R (nV/kΩ)		p_0 (hPa)	α_p (nV/hPa)	
		coefficient	uncertainty		coefficient	uncertainty
VSL-1, 6025001	38.70	325	289	1000	16.99	0.52
VSL-2, 6025002	38.73	1453	370	1000	17.20	0.44
VSL-3, 6025003	38.67	2145	549	1000	17.74	0.41
VSL-4, 6025004	38.45	1857	646	1000	18.69	0.83

Table 2: *Overview of the reference thermistor values and reference air-pressure value, and the thermistor and pressure coefficients*

3.2 Transport and status checks

During transport from one participant to another, the standards were always accompanied, to avoid damage to the standards and to avoid delays at the customs. During transport the standards were operated on their internal batteries. After arrival in the participant's laboratory the front panel 'low bat' and 'in cal' indicators had to be checked for voltage drops. In case of a voltage drop the 'low bat' indicator will blink and the 'in cal' indicator goes off. After recharging the first indicator will go on, and the second one will stay off, indicating that a voltage drop has occurred. Before starting the calibrations, the standards had to stabilise for at least three days in a temperature and, possibly, humidity controlled room. When not carrying out measurements, the standards should continuously be connected to the AC line power.

In spite of careful treatment of the standards, the following problems occurred during the course of the comparison. Upon arrival at CEM the 'in cal' indicator of VSL-1 appeared to be extinguished during transport, probably due to a too low capacity of the internal battery in conjunction with the long traveling time from NMi-VSL to CEM. During the measurements at CEM also the 'in cal' indicator of VSL-4 turned off, probably due to failure of the AC line power in the laboratory. After transport from CEM to INETI the 'in cal' indicator of VSL-4 extinguished again, indicating that also the capacity of the internal battery of VSL-4 was too low. After return at NMi-VSL the internal batteries of the traveling standards were replaced.

4. Measurements

4.1 Measurement methods and traceability

The method of calibration of the traveling standards depends on the participant. Most participants performed the measurements using a JAVS with a 10 V Josephson array. This means that their measurements are traceable to an independent representation of the volt. Some other participants performed the measurements using a group of electronic DC reference standards that are traceable to a JAVS. Details of the applied method and the traceability of the participants are given in Table 3.

Laboratory	Reference standard	Traceable to
NMi-VSL	10V JAVS	
BIPM	10V JAVS	
BNM-LNE	10V JAVS	
NPL	10V JAVS	
NML	Group of electronic DC reference standards	BIPM
UME	10V JAVS	
DFM	10V JAVS	
SP	10V JAVS	
MIKES	10V JAVS	
JV	10V JAVS	
SMD	Group of electronic DC reference standards	BIPM
CMI	Group of electronic DC reference standards	BIPM
BEV	10V JAVS	
SMU	10V JAVS	
CEM	10V JAVS	
INETI	Group of electronic DC reference standards	BIPM
METAS	10V JAVS	
PTB	10V JAVS	
EIM	10V JAVS	
SIQ	Group of electronic DC reference standards	NMi-VSL
OMH	Group of electronic DC reference standards	BIPM and BEV

Table 3: *Overview of applied reference standards and traceability.*

4.2 Measurement conditions

Participants were requested to measure the 10 V output voltage of each of the traveling standards, together with the resistance of the respective thermistor, the air pressure, the ambient temperature and the humidity. In Figures 1 to 3 the averaged values, and the minimum and maximum values are shown of the air pressure, the ambient temperature and the humidity as measured by the participants. One institute did not report the air pressure (INETI). One institute did not report the relative humidity (DFM).

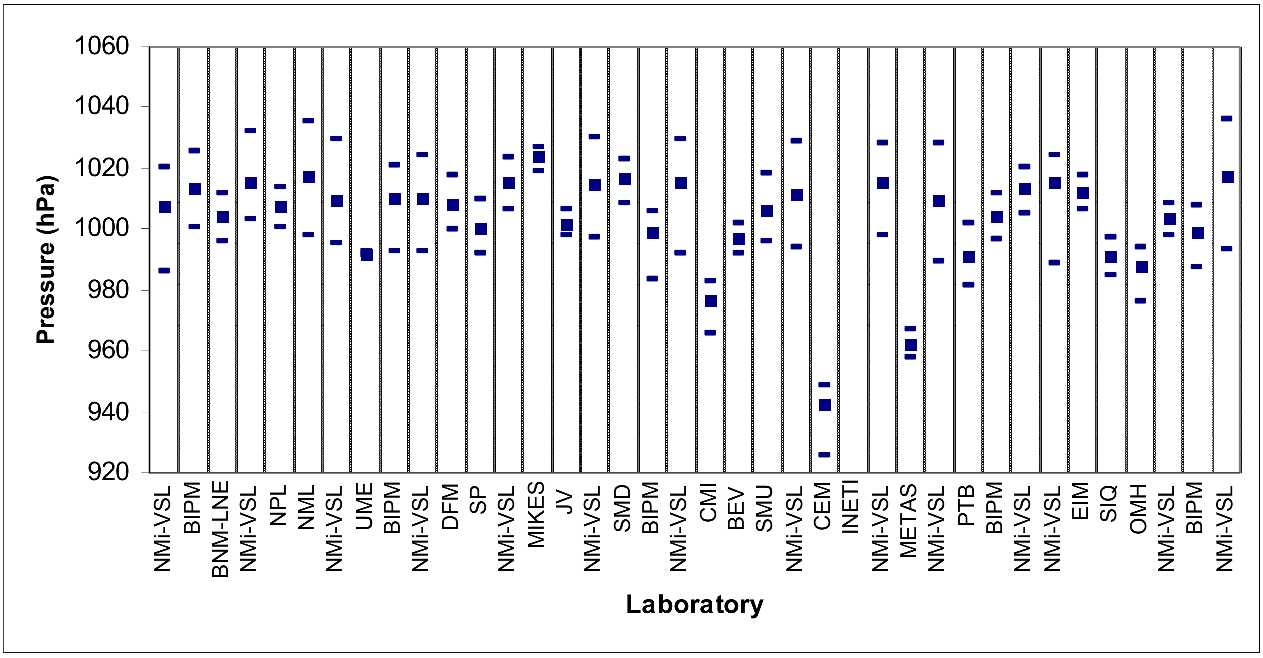

Figure 1: *The air pressure during the comparison. The solid squares indicate the average pressure as measured by each participant. The horizontal dashes above and below the average value indicate the maximum and minimum air pressure respectively during the measurements.*

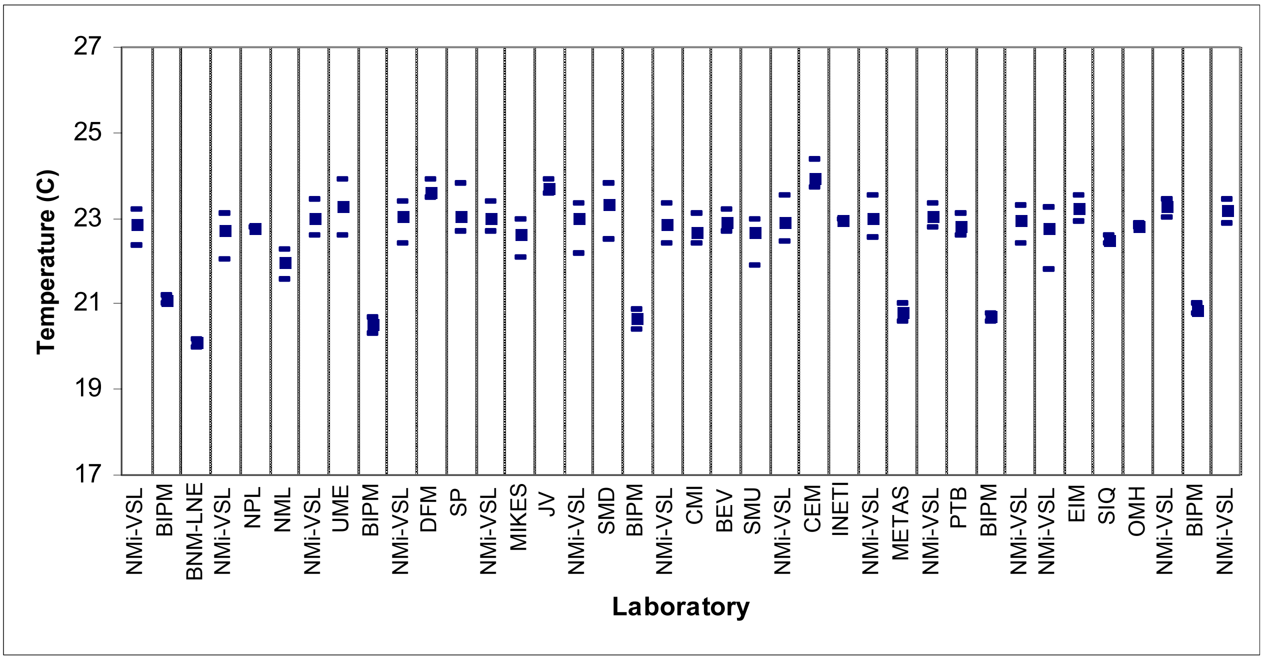

Figure 2: *The ambient temperature during the comparison. The solid squares indicate the average temperature as measured by each participant. The horizontal dashes above and below the average value indicate the maximum and minimum temperature respectively during the measurements.*

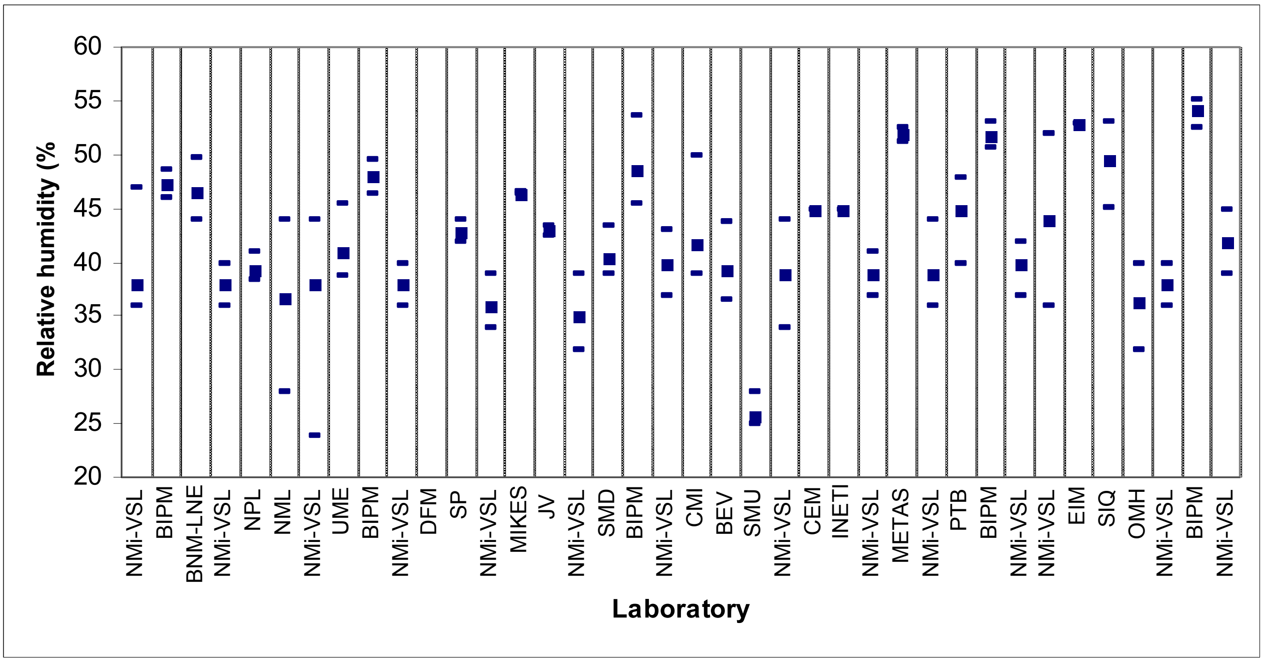

Figure 3: *The relative humidity during the comparison. The solid squares indicate the average humidity as measured by each participant. The horizontal dashes above and below the average value indicate the maximum and minimum humidity respectively during the measurements.*

The resistance of the internal thermistors was measured for each measurement of a 10 V output voltage. The thermistor resistances of the standards have nominal values between 38 kΩ and 39 kΩ (see Table 2). To avoid heating of the thermistor, the test current may not exceed 10 µA. This implies that most DMMs cannot be used in their 100 kΩ range or auto-range setting.
In Figures 4 to 7 the averaged values, and minimum and maximum values, as measured for the thermistor resistances of VSL-1 to VSL-4 are shown. In these figures also the reference value has been indicated.

Preferably, the measurements should be carried out with the standards operated at their internal batteries, i.e., disconnected from the AC line power. To allow the standards to stabilise, battery-operated measurements should not start any sooner than 2 hours after disconnection of the standard from the AC line power. The duration of the disconnection is restricted to 6 hours or less. Only SIQ performed measurements with the standards connected to the AC line power. Therefore, the thermistor resistance values reported by SIQ are lower than the values from other laboratories.
Assuming that the voltage measurements are carried out with the standards disconnected from the AC line power, the front panel GUARD binding post should be connected to the guard of the measuring system and to the front panel CHASSIS binding post. At one point in the measuring system the guard should be connected to ground. When measuring while the standards are powered by the AC line power, the CHASSIS must be disconnected from the GUARD to avoid ground loops.

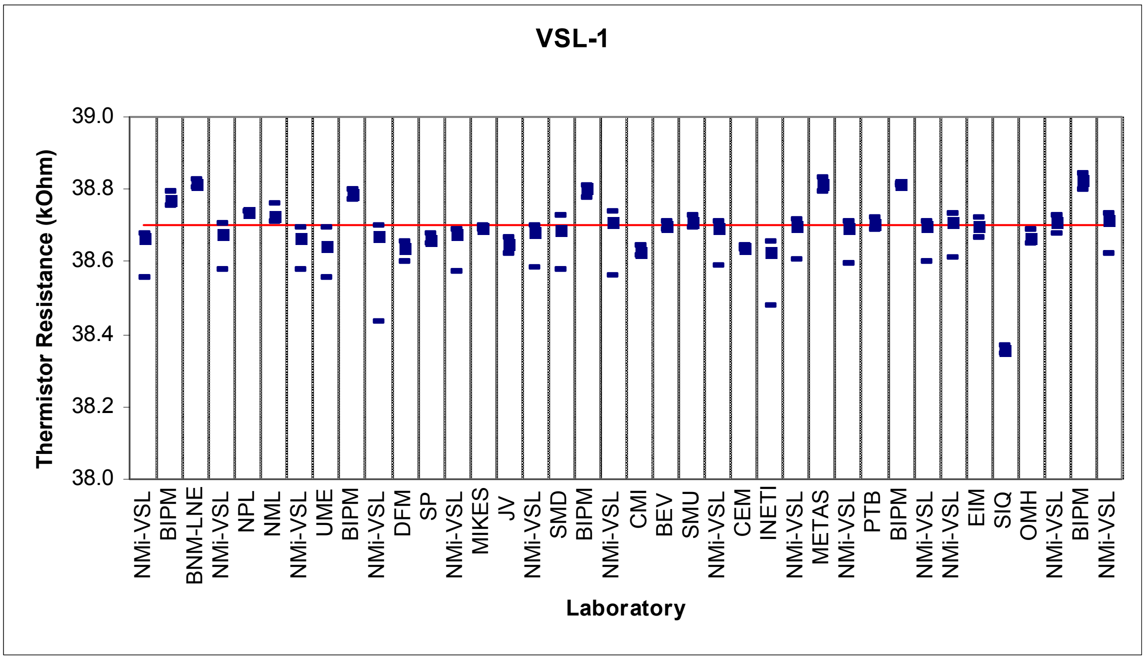

Figure 4: *The thermistor resistance of VSL-1 during the comparison. The solid squares indicate the average resistance as measured by each participant. The horizontal dashes above and below the average value indicate the maximum and minimum resistance respectively during the measurements. The horizontal line indicates the reference resistance value of VSL-1.*

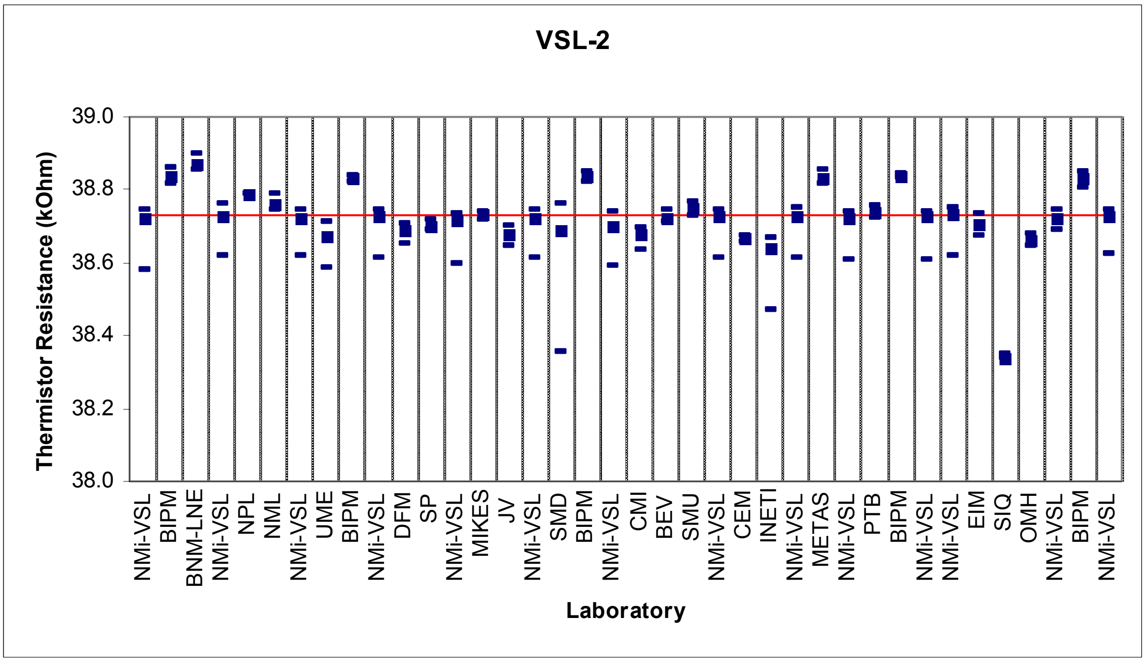

Figure 5: *The thermistor resistance of VSL-2 during the comparison. The solid squares indicate the average resistance as measured by each participant. The horizontal dashes above and below the average value indicate the maximum and minimum resistance respectively during the measurements. The horizontal line indicates the reference resistance value of VSL-2.*

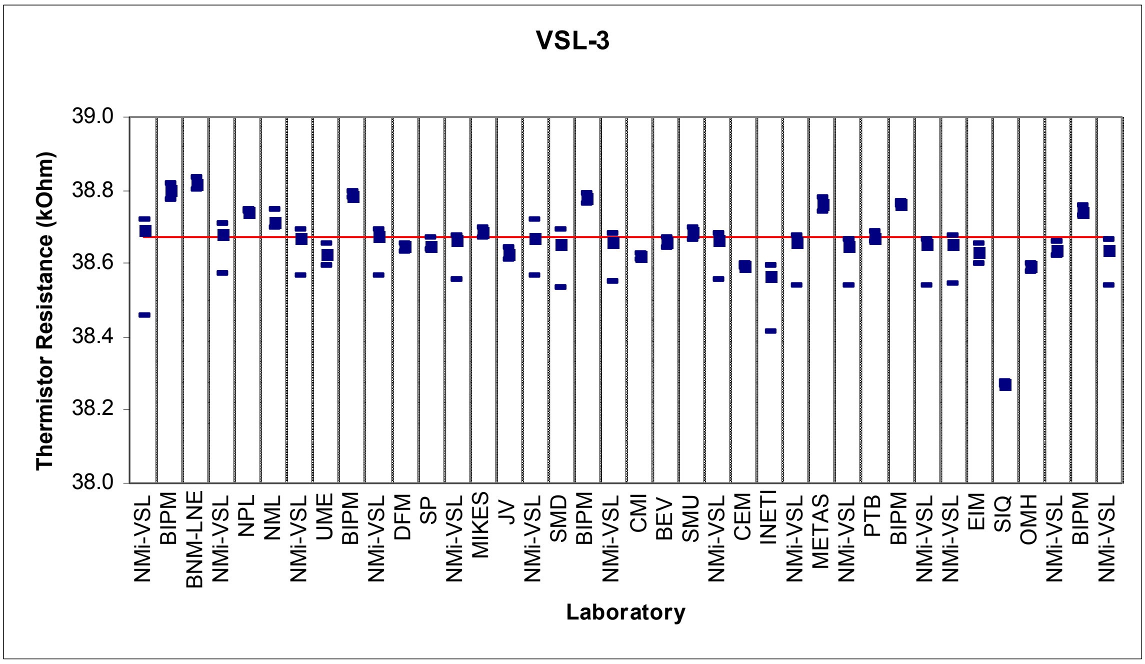

Figure 6: *The thermistor resistance of VSL-3 during the comparison. The solid squares indicate the average resistance as measured by each participant. The horizontal dashes above and below the average value indicate the maximum and minimum resistance respectively during the measurements. The horizontal line indicates the reference resistance value of VSL-3.*

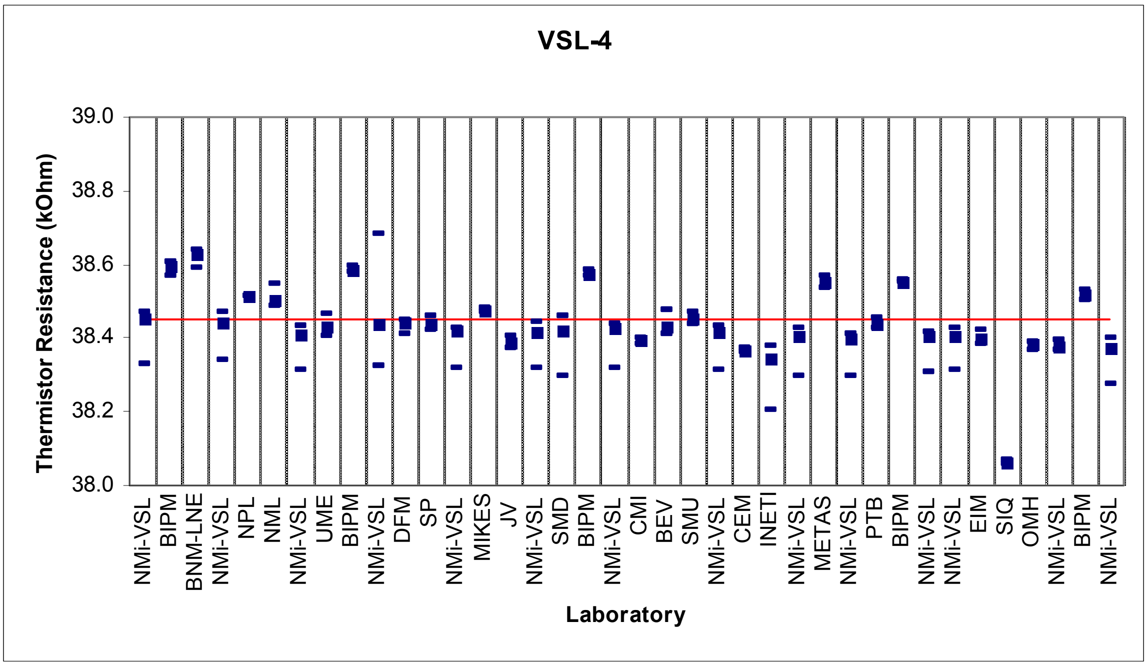

Figure 7: *The thermistor resistance of VSL-4 during the comparison. The solid squares indicate the average resistance as measured by each participant. The horizontal dashes above and below the average value indicate the maximum and minimum resistance respectively during the measurements. The horizontal line indicates the reference resistance value of VSL-4.*

4.3 Behaviour of the Zener output voltages

Figures 8 to 11 show the NMi-VSL and BIPM measurements U_L (deviations from the nominal voltage of 10 V) on the traveling standards during the comparison. In between these measurements, the traveling standards were sent to the other participants for measurements. The data of NMi-VSL have been used to make corrections for the time-dependence of the Zener output voltages (see section 5). From the figures it can be clearly seen that VSL-1 is less stable than the other Zeners.

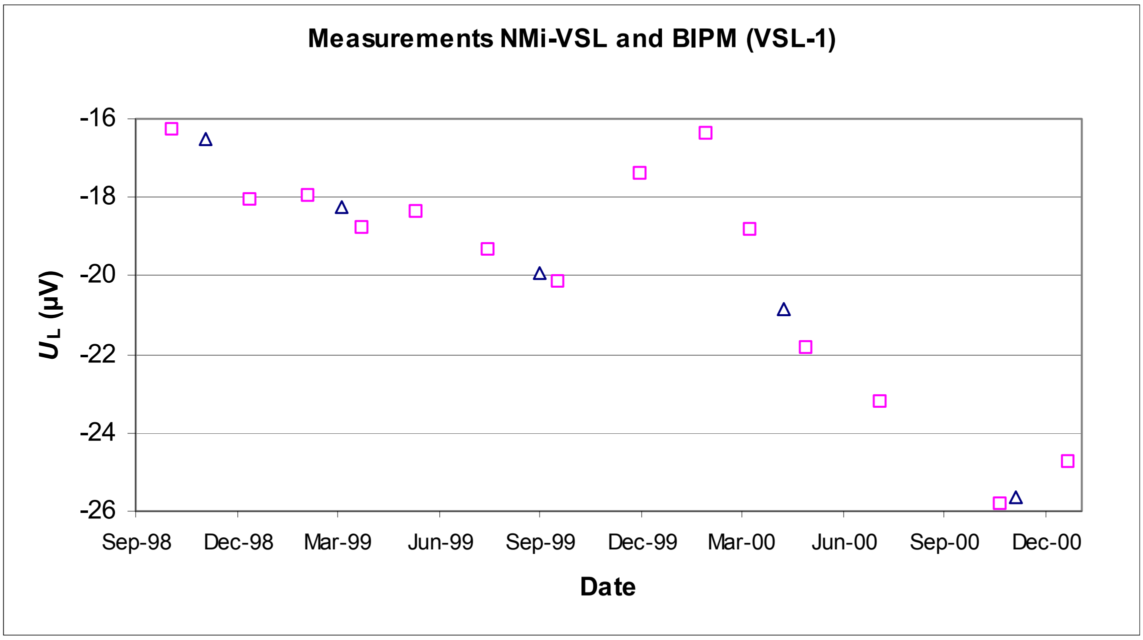

Figure 8: *The output voltage of VSL-1 as measured by NMi-VSL (squares) and BIPM (triangles).*

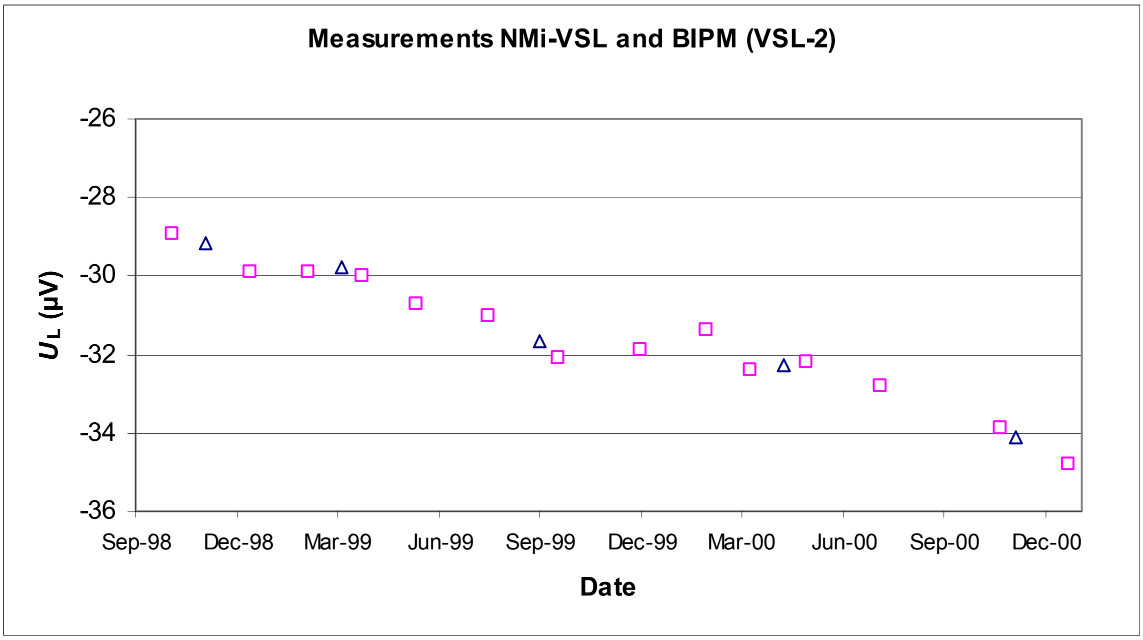

Figure 9: *The output voltage of VSL-2 as measured by NMi-VSL (squares) and BIPM (triangles).*

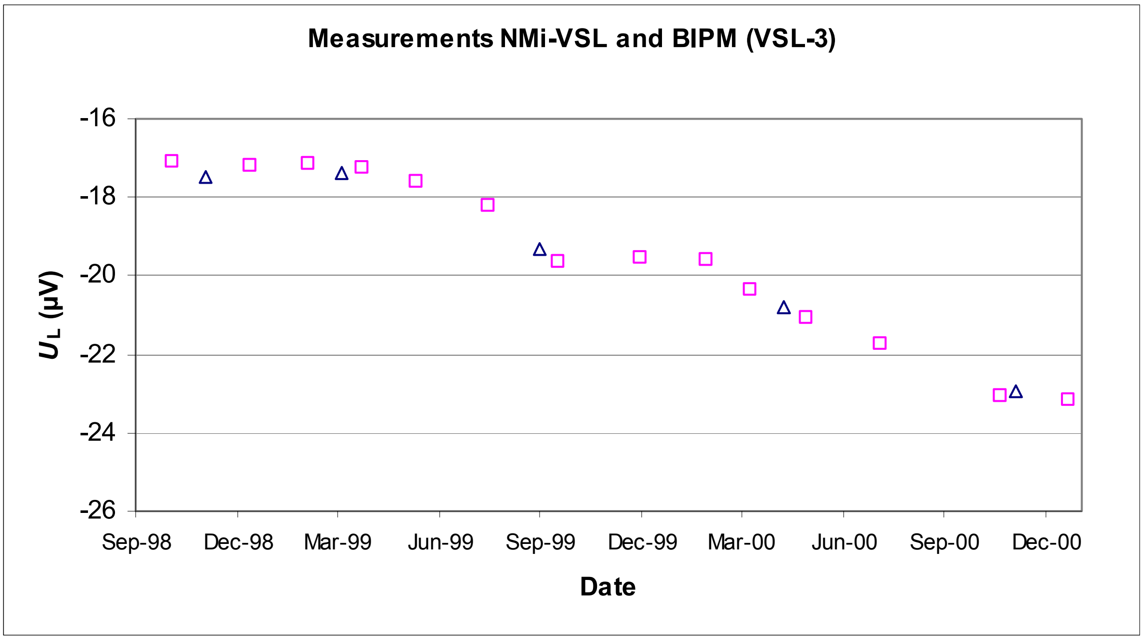

Figure 10: *The output voltage of VSL-3 as measured by NMi-VSL (squares) and BIPM (triangles).*

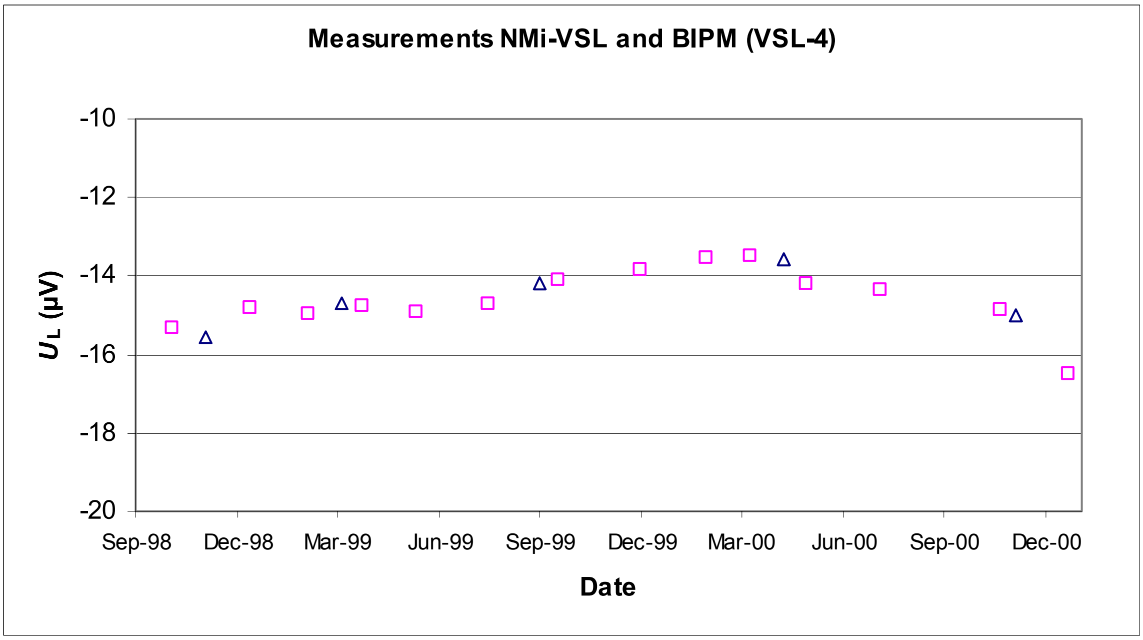

Figure 11: *The output voltage of VSL-4 as measured by NMi-VSL (squares) and BIPM (triangles).*

5. Results

Each laboratory has reported a value U_L (deviation from a nominal voltage of 10 V) for each of the traveling standards measured, also specifying a mean measurement date and a measurement uncertainty, u_L (95% confidence level). The uncertainty has been split in a Zener contribution, u_z and a system contribution, u_s, where:

$$u_L = \sqrt{u_z^2 + u_s^2} \ .$$

As explained in section 3, the value U_L has been corrected for temperature and pressure effects. The value reported by a laboratory is an average of a series of measurements taken in the specific time period that the standards resided in the participants' laboratory.

In Appendix B the values of U_L as reported by the participants are presented for each traveling standard. The uncertainties, u_z, u_s and u_L are also given in Appendix B. The detailed uncertainty budgets of the participants are given in Appendix C.

In Figures 12 to 15 U_L has been plotted versus date of measurement, including all measurements of NMi-VSL and BIPM.

To determine the degrees of equivalence with the EUROMET Reference Value (*ERV*) and the degrees of equivalence between the laboratories, the following steps have to be taken:

- A correction has to be made for the time dependence of the Zener output voltages;
- A weighted mean value has to be calculated for each laboratory;
- A (single value) *ERV* has to be determined;
- The deviations from the *ERV* have to be calculated, along with the deviations between each two participants.

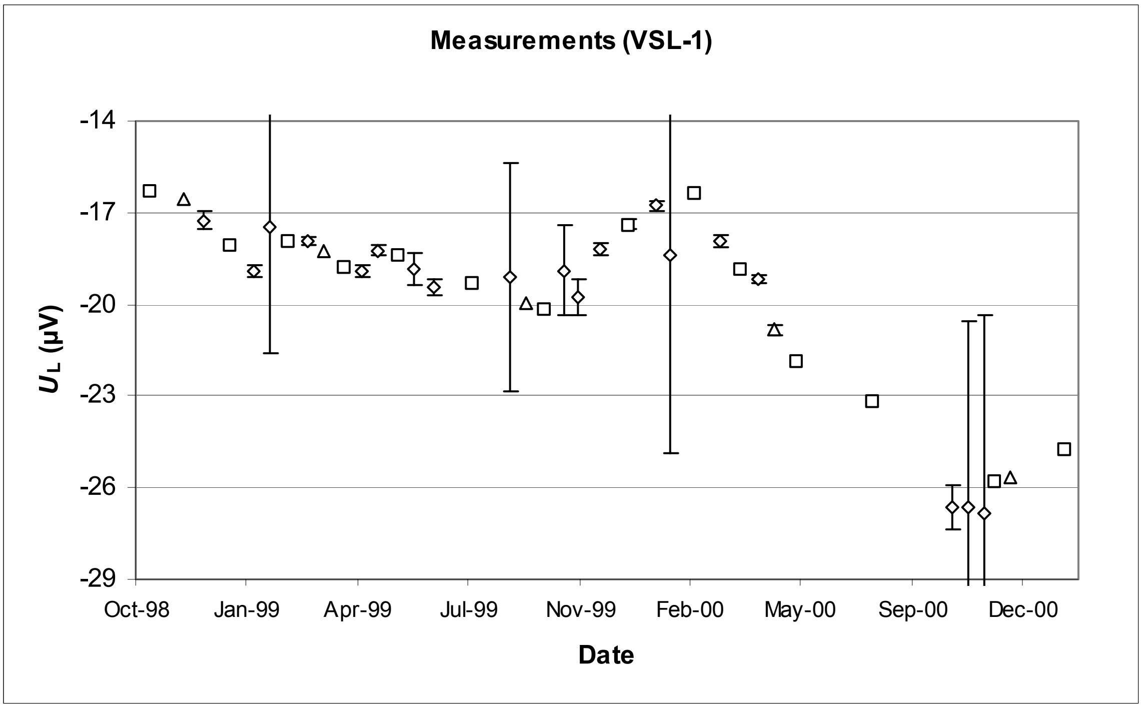

Figure 12: *The output voltage of VSL-1 (deviation from 10 V) as measured by the participants (diamonds). Also all data of NMi-VSL (squares) and BIPM (triangles) have been included. Notice that the 8th period of NMi-VSL coincides with the participation of NMi-VSL. In the same way, the 4th period of BIPM coincides with the participation of BIPM.*

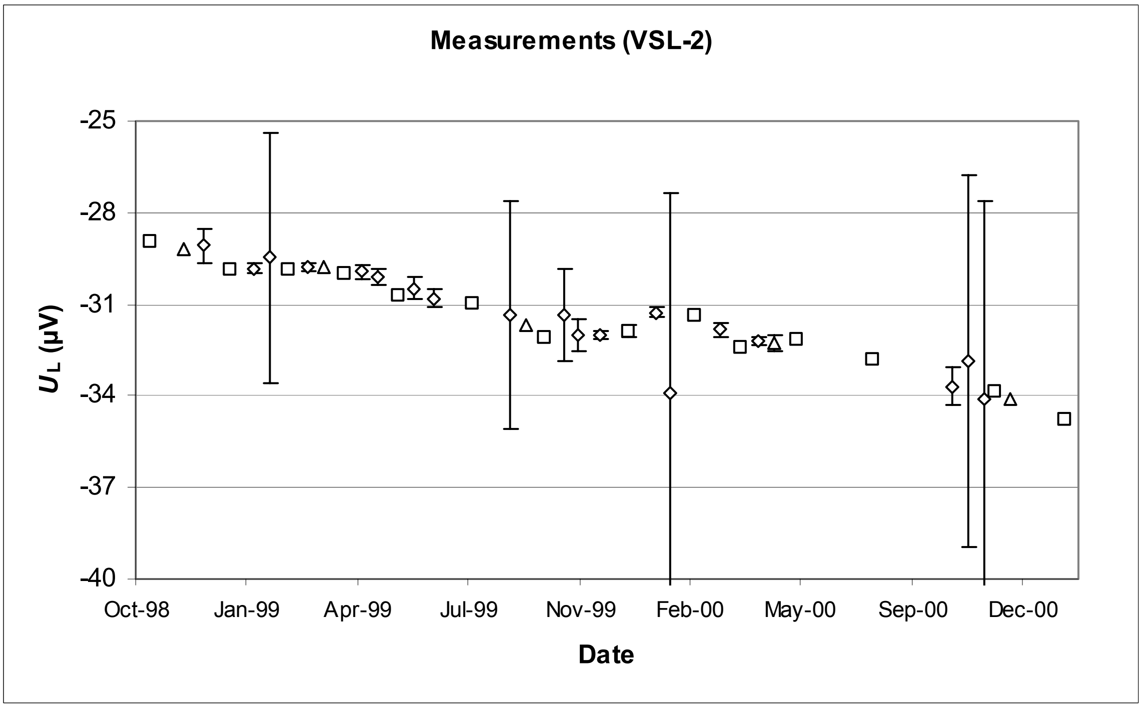

Figure 13: *The output voltage of VSL-2 (deviation from 10 V) as measured by the participants (diamonds). Also all data of NMi-VSL (squares) and BIPM (triangles) have been included. Notice that the 8th period of NMi-VSL coincides with the participation of NMi-VSL. In the same way, the 4th period of BIPM coincides with the participation of BIPM.*

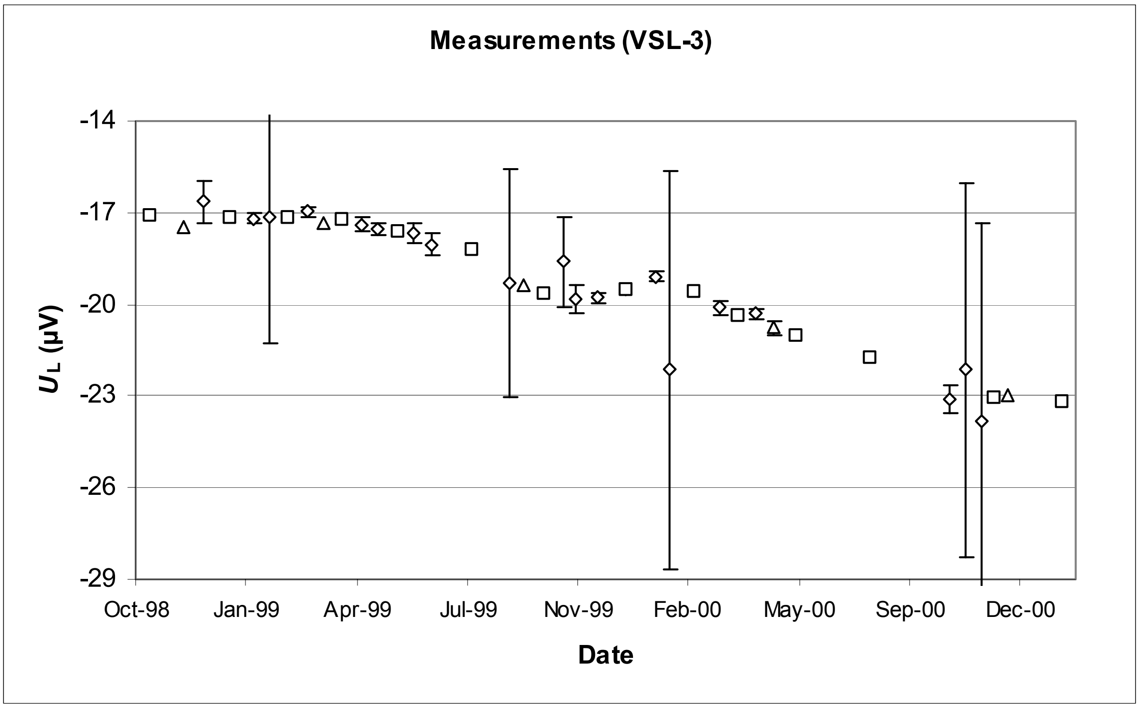

Figure 14: *The output voltage of VSL-3 (deviation from 10 V) as measured by the participants (diamonds). Also all data of NMi-VSL (squares) and BIPM (triangles) have been included. Notice that the 8th period of NMi-VSL coincides with the participation of NMi-VSL. In the same way, the 4th period of BIPM coincides with the participation of BIPM.*

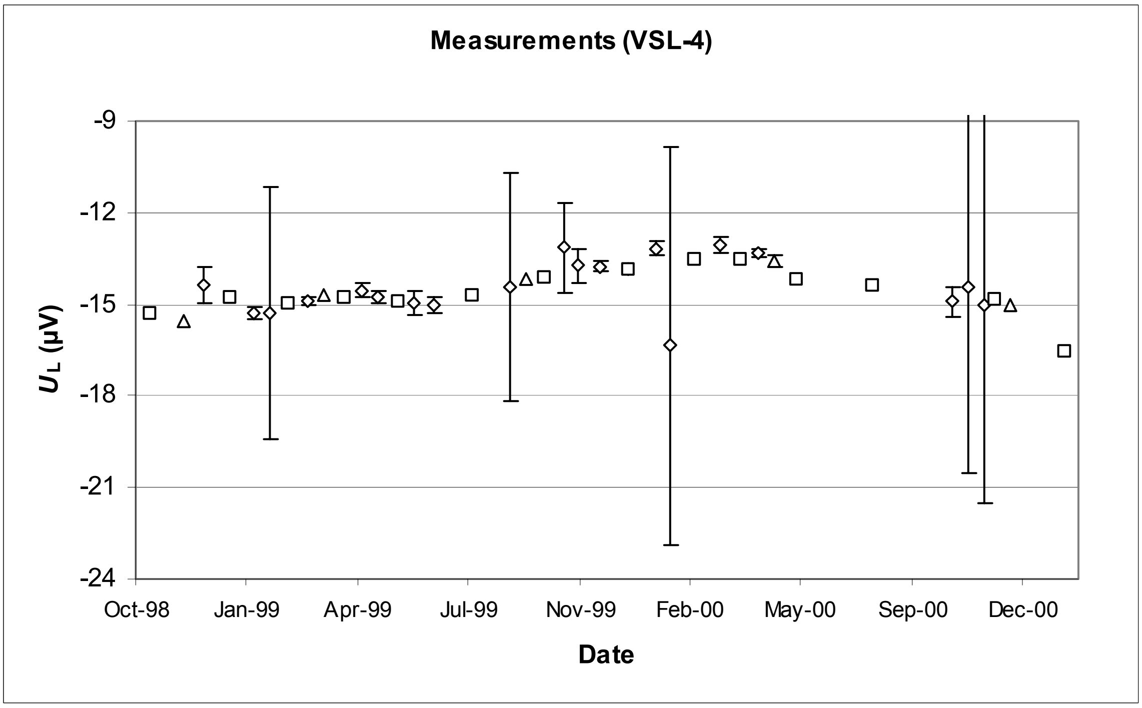

Figure 15: *The output voltage of VSL-4 (deviation from 10 V) as measured by the participants (diamonds). Also all data of NMi-VSL (squares) and BIPM (triangles) have been included. Notice that the 8th period of NMi-VSL coincides with the participation of NMi-VSL. In the same way, the 4th period of BIPM coincides with the participation of BIPM.*

5.1 Correction for time dependence

The results of different participants can only be compared if corrections are made for the time dependence of the Zener output voltages. From Figures 8 to 11 it is clear that the output voltages do exhibit significant time dependences. The behaviour of the standards cannot be described by a simple linear drift over the total course of the comparison. Different methods are available to estimated the behaviour of the standards. For example, recently, a (rather complicated) minimum variance method [3] was published to calculate an estimate in such a case. However, in this report it was chosen to use a more simplified method, in which the NMi-VSL data are considered as to provide the best information about the time-dependence of the standards. For that reason the NMi-VSL measurement results are interpolated to calculate a fictitious NMi-VSL measurement result U_t at the averaged date that a participant performed its measurements. To this end, the behaviour of the Zener output voltages was assumed to be linear between each two measurements of NMi-VSL. As explained in section 2, the 8th measurement period of NMi-VSL and the 4th measurement period of BIPM are arbitrarily considered as the periods that NMi-VSL and BIPM participated in the comparison respectively. The measurement results of these periods are treated in the same way as the results of all other participants, where U_t for the 8th measurement period of NMi-VSL is calculated from the 7th and 9th measurement period of NMi-VSL. The U_t values for CMI, BEV and SMU have been calculated from the 7th and 8th period of NMi-VSL and the U_t values for CEM and INETI were calculated from the 8th and 9th period.

The interpolation uncertainty u_t represents the uncertainty in the knowledge about the behaviour of the standards. It was chosen to consider this uncertainty to be the same for each participant and has been calculated for each Zener separately by using the NMi-VSL measurement data. The uncertainty u_t is found from the root of the mean of squared (rms) deviations of the measurements $U_{\text{NMi-VSL},i}$ from the interpolation between $U_{\text{NMi-VSL},i-1}$ and $U_{\text{NMi-VSL},i+1}$ (i = 2, 3, ..., 13). The values for u_t (95 % confidence level) are given in Table 4.

ID	u_t (µV)
VSL-1	2.044
VSL-2	0.895
VSL-3	0.655
VSL-4	0.644

***Table 4:** Interpolation uncertainties (95 % confidence level)*

The difference Δ_L between the measurement result U_L of a participant and the interpolated fictitious NMi-VSL measurement result is given by:

$$\Delta_{\mathrm{L}} = U_{\mathrm{L}} - U_{\mathrm{t}}$$

with an uncertainty u_Δ:

$$u_\Delta = \sqrt{u_{\mathrm{L}}^2 + u_{\mathrm{t}}^2} \ .$$

The values U_t and Δ_L are given in Appendix B. In the next section, the values of Δ_L and u_Δ will be used to calculate a weighted mean for the group of Zeners, for each participant.

5.2 Calculation of the group results

To compare the results of different participants, each of the participants should have only one single measurement result, which is a combined result of the group of four Zeners. For this purpose a mean value of the group of Zeners was calculated for each laboratory. To reduce the effects of unpredicted behaviour of the Zeners (especially VSL-1) it was decided to use a weighted mean. The weights depend on the uncertainties in the measurement. The system uncertainty u_s of a participant is correlated for all Zeners and therefore it should be excluded from the calculation of the weights.

If the values $\Delta_{L,n}$ are the results of the four Zeners (n = 1 to 4) with uncertainties $u_{\Delta,n}$, then the group value Δ_G of each participant is now found from:

$$\Delta_{\mathrm{G}} = \frac{\sum_{n=1}^{4} g_n \Delta_{\mathrm{L},n}}{\sum_{n=1}^{4} g_n}$$

, with an internal group uncertainty u_{IG} of: $u_{\mathrm{IG}} = \dfrac{1}{\sqrt{\sum_{n=1}^{4} g_n}}$;

where: $g_{\mathrm{n}} = \dfrac{1}{u_{\Delta,\mathrm{n}}^2 - u_{\mathrm{s}}^2}$.

The total uncertainty U_{TG}* of a group result of a participant is found from combining the internal group uncertainty and the system uncertainty:

$$U_{TG} = \sqrt{u_{IG}^2 + u_s^2} \ .$$

The values Δ_G and the uncertainties U_{TG} are given in Appendix B.

The group results for all participants are shown in Figures 16a and 16b.

* Note that U_{TG} , $U_{TG,i}$ and U_{ERV} are used to indicate expanded uncertainties (and not measurement values).

5.3 Determination of the reference value (ERV)

Now that the effects of the time dependences have been removed and each participant, i is represented by a single value $\Delta_{G,i}$ with uncertainty $U_{TG,i}$ the reference value, *ERV* can be determined by calculating the weighted mean of $\Delta_{G,i}$, excluding those participants who do not have an independent realisation of the volt and only taking into account the 8th measurement period of NMi-VSL and the 4th measurement period of BIPM:

$$ERV = \frac{\sum_{i=1}^{N} w_i \Delta_{G,i}}{\sum_{i=1}^{N} w_i} \quad \text{with uncertainty:} \quad U_{ERV} = \frac{1}{\sqrt{\sum_{i=1}^{N} w_i}},$$

with $N = 15$ the number of independent participants. The weighing factor w_i is given by:

$$w_i = \frac{1}{U_{TG,i}^2}.$$

This method does not eliminate self-correlations. If self-correlations are removed, no longer a single *ERV* can be determined. The *ERV* and U_{ERV} are given in Table 5.

***ERV* (µV)**	**U_{ERV} (µV)**
0.067	0.113

Table 5: *The EUROMET Reference Value*

The *ERV* is also shown in Figure 16a and 16b.

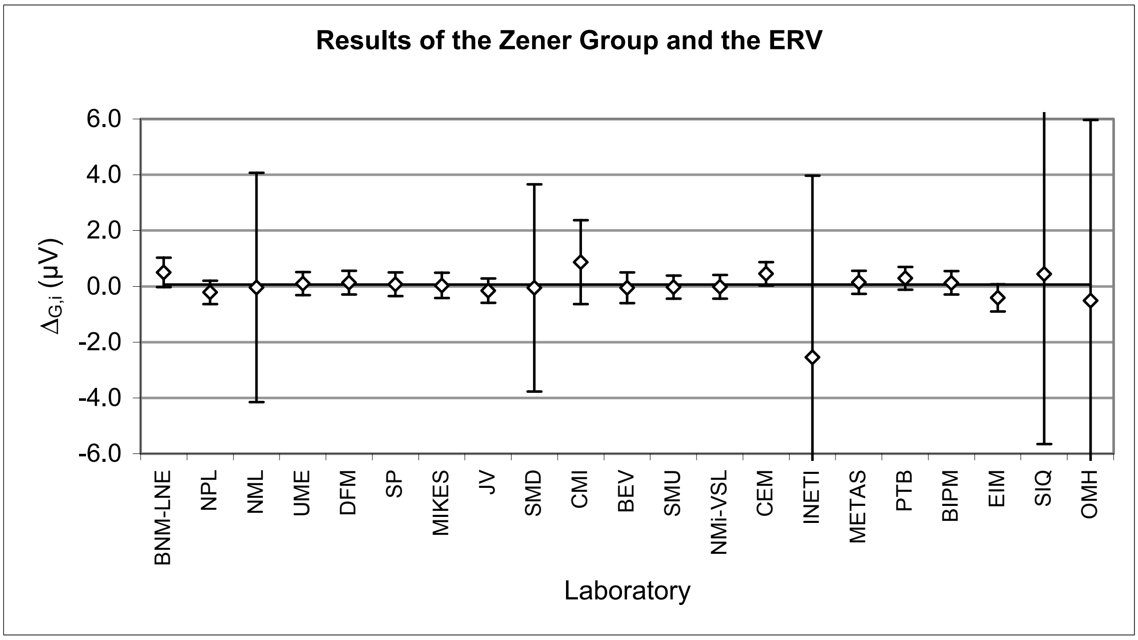

Figure 16a: *Results of the Zener group based on the weighted means of the laboratories (diamonds). The horizontal line indicates the ERV.*

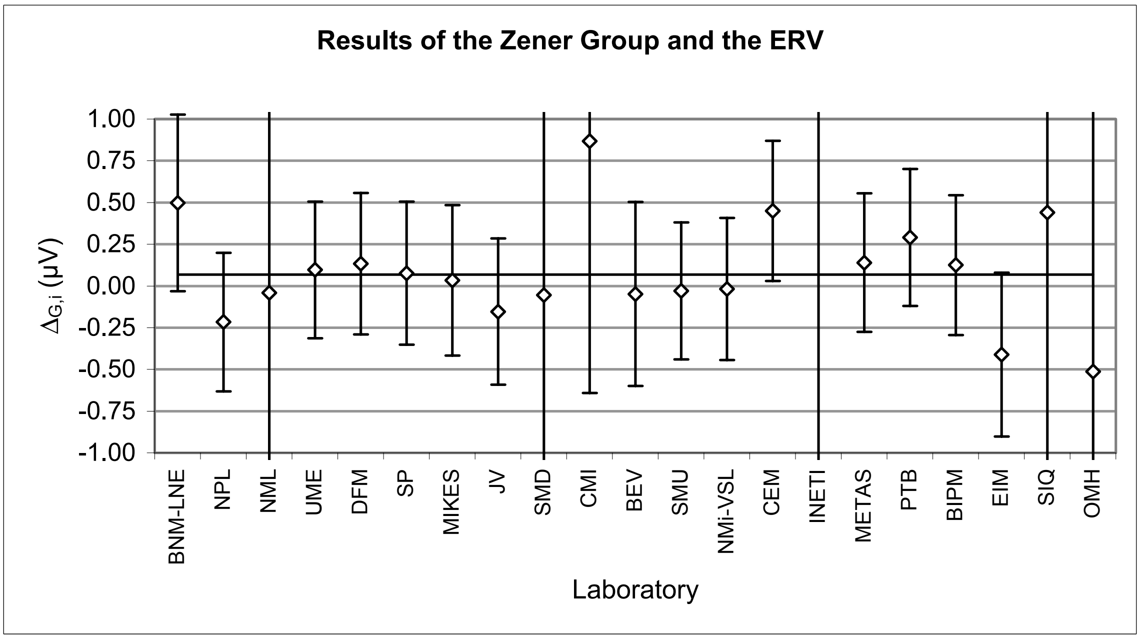

Figure 16b: *The group results (Fig. 16a) in more detail*

5.4 Calculation of the deviation from the ERV

The degrees of equivalence D_i with the *ERV* are calculated by subtracting the *ERV* from $\Delta_{G,i}$, i.e., $D_i = \Delta_{G,i} - ERV$, with the uncertainty given by $\sqrt{U_{TG,i}^2 - U_{ERV}^2}$ for those laboratories participating in the weighted mean and $\sqrt{U_{TG,i}^2 + U_{ERV}^2}$ for laboratories that do not participate in the weighted mean [4]. Similarly, the degree of equivalence between participant i and participant j is approximated by $D_{ij} = \Delta_{G,i} - \Delta_{G,j}$, with an uncertainty $\sqrt{U_{TG,i}^2 + U_{TG,j}^2}$. Correlations between different laboratories, such as those caused by the thermistor dependences and the air-pressure dependence, are not taken into account by these calculations. From Table 4 and Appendix C, it can be seen that, for participants who use a JAVS, the uncertainties are dominated by the noise in the measurements and the interpolation uncertainties. For participants who don't use a JAVS, the uncertainty is dominated by the reference voltage source. So, in any case, the correlated terms have only a small contribution to the total uncertainties, which means that taking into account these correlations would only have a very small effect on the uncertainties of the degrees of equivalence. In Figures 17a and 17b the degrees of equivalence with the *ERV* have been plotted for each of the participants. In appendix D the full D_i table has been included, also representing the matrix D_{ij} of the degrees of equivalence between every two participants.

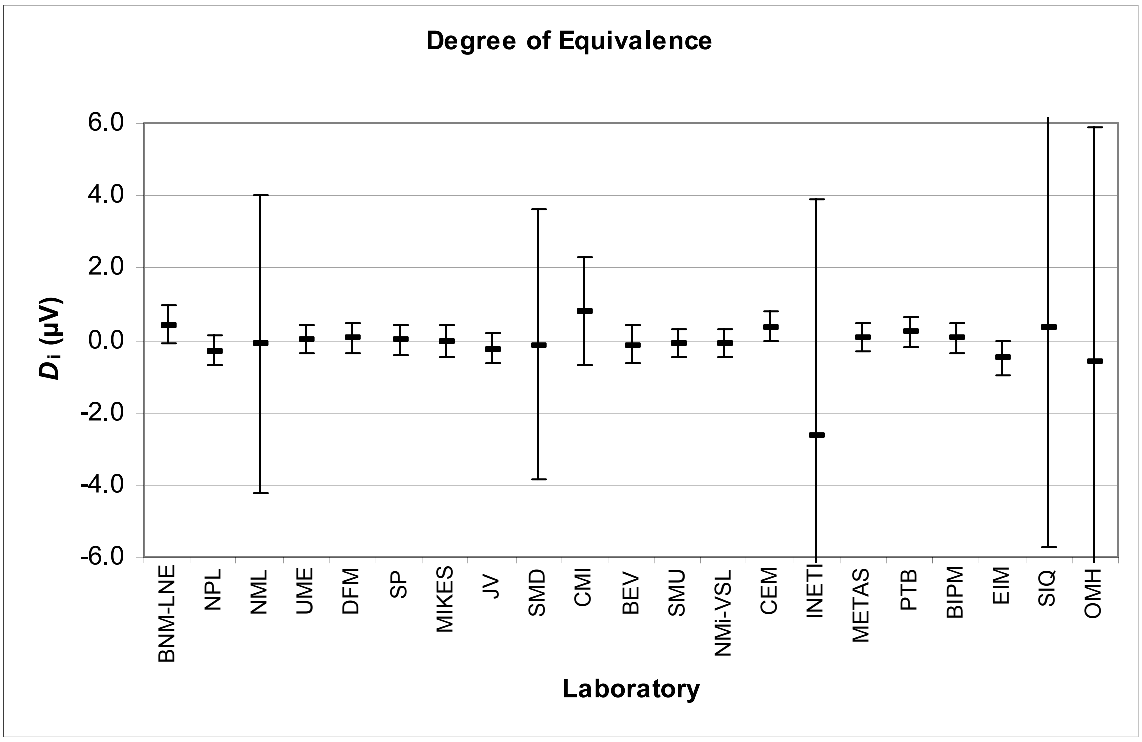

Figure 17a: *Degree of equivalence with the ERV based on group results* $\Delta_{G,i}$

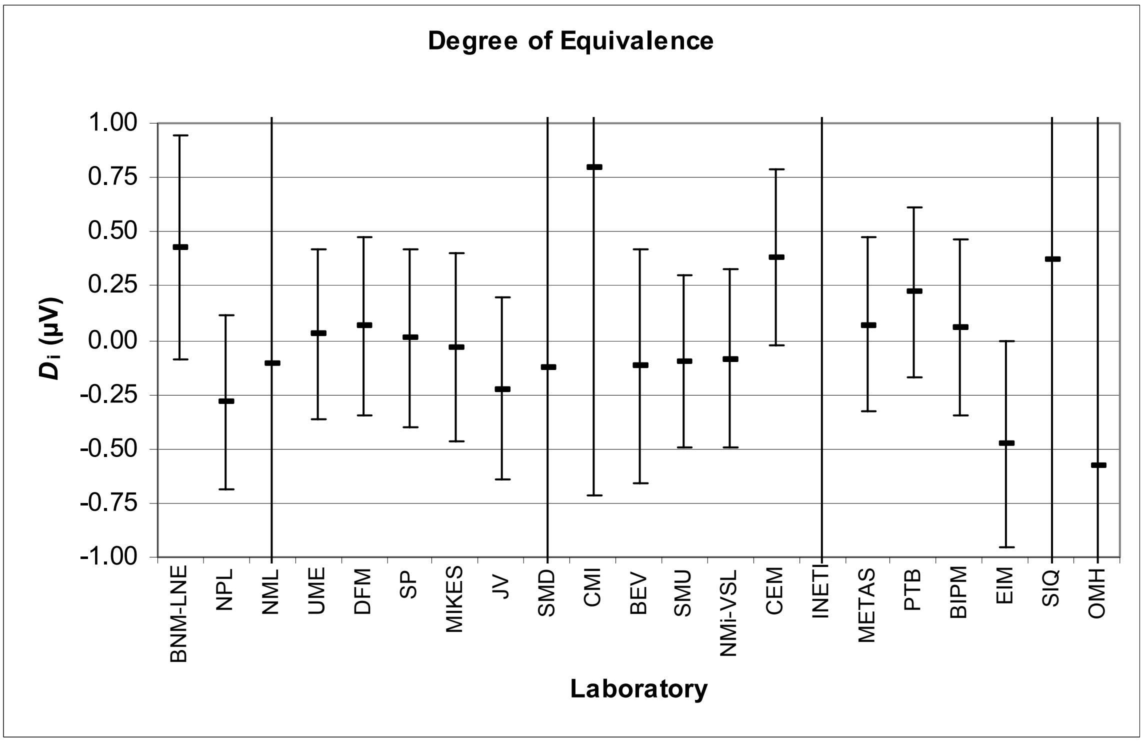

Figure 17b: *Degrees of equivalence (Fig. 17a) in more detail*

6. Discussion of the measurement results

The Figures 17 and Appendix C show that the degrees of equivalence with the *ERV* and the degrees of equivalence between the participants are reasonable. For those laboratories which have a JAVS, the uncertainty budgets are dominated by the interpolation uncertainty, u_t which can be seen as a measure for the "mean" term variations of the traveling standards. For laboratories which do not have a JAVS, the main source of uncertainty is the value of their DC reference standards.

Figures 17a and 17b confirm that in general the results of all participants are near the *ERV*. The largest deviation occurs for INETI, but it is well within the reported uncertainty. For the participants who have a JAVS, all deviations as seen in Figure 17b can well be caused by unpredicted fluctuations of one or more of the traveling standards rather than by systematic deviations in participant's measurement setup. From Figures 8 to 11, it can be seen that VSL-1 shows larger fluctuations than the other traveling standards. Effects of these fluctuations have been reduced by calculating the group results of the laboratories as the weighted means of the results of the four Zeners. Participants who have doubts about their results could be advised to arrange an additional bilateral comparison.

As explained in the previous section, the method of analysis introduces correlations between individual measurement results and the *ERV*. A refinement of the method of analysis [3] could be considered. However, it is not expected that such refinement will change the conclusions.
(It can be shown that the best estimate of the behaviour of the Zeners would be obtained from a minimum variance method in which $1/f^2$ noise is assumed, but it should be noted that the method of analysis used in this report is nearly just as good. These calculations are not available to the authors, but will be published elsewhere.)

Only some of the participants reported an estimate of the effective degrees of freedom of the standard uncertainty associated with the measured voltages. It was chosen not to report the degrees of freedom in this document, but to make sure that the coverage factor $k = 2$ as applied in Appendix C corresponds to a coverage probability of about 95 %, the following approach has been used. A distinction is made between two cases:

1) For laboratories which do not use a JAVS, the uncertainty in the measured voltages is dominated by contributions estimated by a type B evaluation. It is common practice to carry out type B evaluations in such a way that any underestimation is avoided. Under this assumption, the degrees

of freedom of the standard uncertainty $u(x_i)$ obtained from a type B evaluation may be taken to be $\nu_i \to \infty$.

2) For laboratories which use a JAVS, the uncertainty in the measured voltages is dominated by contributions estimated by a type A evaluation. The pilot laboratory has checked the raw measurement data of the participants and noticed that for all participants, the type A evaluations were based on more than 10 independent observations. Therefore it can be assumed that these type A evaluations are sufficiently reliable to ensure that a coverage factor $k = 2$ corresponds to a coverage probability of about 95 %.

So, for both case 1) and 2) the use of a Student t-factor is not required.

7. Conclusion

This comparison has established a relationship between the voltage calibrations of laboratories within the regional metrology organisation EUROMET. The results show reasonable degrees of equivalence between the participants. The Zener based traveling standards exhibit fluctuations which, for low frequencies, are dominated by $1/f$ or $1/f^2$ noise rather than white noise. This makes a reliable analysis troublesome and limits the overall accuracy of this comparison.

8. References

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Acknowledgements

The authors would like to thank Jan van der Beek for his assistance in the preparation of the traveling standards and carrying out measurements on the traveling standards at NMi-VSL. Furthermore, all participants are acknowledged for respecting the time schedules and sending us the requested information within due time. Also thanks, for the valuable comments during the preparations of this report.

Special thanks to Panu Helistö for offering to apply a different method of analysis to the comparison results. We're all looking forward to compare both methods.

APPENDIX A: Measurement periods

The shaded area of this table indicates the second part of the comparison. This part was originally not foreseen in the schedule.

Period of measurements			**Participant**	**Country**
Year	**Start**	**End**		
1998	24 September	4 November	NMi-VSL	The Netherlands
	9 November	20 November	BIPM	
	23 November	10 December	BNM-LNE	France
1999	14 December	6 January	NMi-VSL	The Netherlands
	12 January	20 January	NPL	United Kingdom
	25 January	4 February	NML	Ireland
	8 February	25 February	NMi-VSL	The Netherlands
	1 March	11 March	UME	Turkey
	16 March	25 March	BIPM	
	29 March	15 April	NMi-VSL	The Netherlands
	19 April	28 April	DFM	Denmark
	3 May	12 May	SP	Sweden
	19 May	3 June	NMi-VSL	The Netherlands
	8 June	11 June	MIKES	Finland
	22 June	1 July	JV	Norway
	6 July	26 August	NMi-VSL	The Netherlands
	31 August	9 September	SMD	Belgium
	13 September	23 September	BIPM	
	28 September	12 October	NMi-VSL	The Netherlands
	20 October	25 October	CMI	Czech Republic
	28 October	11 November	BEV	Austria
	22 November	26 November	SMU	Slovakia
2000	2 December	5 January	NMi-VSL	The Netherlands
	11 January	18 January	CEM	Spain
	20 January	3 February	INETI	Portugal

	7 February	25 February	NMi-VSL	The Netherlands
	7 March	17 March	METAS	Switzerland
	22 March	5 April	NMi-VSL	The Netherlands
	10 April	18 April	PTB	Germany
	25 April	5 May	BIPM	
	9 May	31 May	NMi-VSL	The Netherlands
	21 June	1 September	NMi-VSL	The Netherlands
	2 October	11 October	EIM	Greece
	18 October	25 October	SIQ	Slovenia
	2 November	9 November	OMH	Hungary
	13 November	16 November	NMi-VSL	The Netherlands
	20 November	7 December	BIPM	
2001	19 December	15 February	NMi-VSL	The Netherlands

APPENDIX B: Measurement results

The uncertainties are expanded uncertainties (k = 2)

VSL-1							
Lab	**Date of measurement**	U_L (µV)	U_t (µV)	Δ_L (µV)	u_z (µV)	u_s (µV)	u_L (µV)
BNM-LNE	December 2, 1998	-17.265	-17.454	0.189	0.296	0.002	0.296
NPL	January 16, 1999	-18.927	-18.012	-0.915	0.182	0.052	0.190
NML	January 30, 1999	-17.459	-17.987	0.528	0.405	4.087	4.107
UME	March 6, 1999	-17.930	-18.243	0.313	0.144	0.005	0.144
DFM	April 24, 1999	-18.912	-18.621	-0.291	0.223	0.035	0.226
SP	May 8, 1999	-18.226	-18.511	0.285	0.143	0.115	0.183
MIKES	June 9, 1999	-18.836	-18.557	-0.279	0.542	0.025	0.542
JV	June 27, 1999	-19.418	-18.810	-0.608	0.246	0.072	0.257
SMD	September 5, 1999	-19.106	-19.756	0.650	0.660	3.676	3.735
CMI	October 23, 1999	-18.888	-19.506	0.618	0.326	1.443	1.479
BEV	November 4, 1999	-19.779	-19.054	-0.725	0.502	0.296	0.583
SMU	November 24, 1999	-18.188	-18.314	0.126	0.199	0.039	0.203
NMi-VSL	December 19, 1999	-17.384	-18.048	0.664	0.141	0.116	0.183
CEM	January 14, 2000	-16.783	-16.945	0.162	0.156	0.071	0.171
INETI	January 27, 2000	-18.359	-16.742	-1.617	0.165	6.501	6.503
METAS	March 12, 2000	-17.944	-17.809	-0.135	0.160	0.010	0.160
PTB	April 14, 2000	-19.159	-19.776	0.617	0.146	0.010	0.147
BIPM	April 30, 2000	-20.841	-20.698	-0.143	0.156	0.003	0.156
EIM	October 7, 2000	-26.639	-24.884	-1.755	0.696	0.023	0.697
SIQ	October 22, 2000	-26.647	-25.241	-1.406	0.241	6.081	6.086
OMH	November 5, 2000	-26.850	-25.579	-1.271	0.520	6.465	6.486

Table B2: Measurement results for Zener VSL-1: measured value U_L as the deviation from nominal, interpolated value U_t based on measurements of the pilot-laboratory, deviation from interpolation Δ_L, uncertainty contribution from the traveling standard u_z, uncertainty contribution from the measurement system u_s, combined uncertainty of u_z and u_s, u_L.

VSL-2							
Lab	**Date of measurement**	**U_L (µV)**	**U_t (µV)**	**Δ_L (µV)**	**u_z (µV)**	**u_s (µV)**	**u_L (µV)**
BNM-LNE	December 2, 1998	-29.073	-29.559	0.486	0.560	0.002	0.560
NPL	January 16, 1999	-29.821	-29.866	0.045	0.149	0.052	0.158
NML	January 30, 1999	-29.484	-29.861	0.377	0.414	4.087	4.108
UME	March 6, 1999	-29.775	-29.903	0.128	0.146	0.005	0.146
DFM	April 24, 1999	-29.938	-30.236	0.298	0.225	0.035	0.228
SP	May 8, 1999	-30.106	-30.439	0.333	0.222	0.115	0.250
MIKES	June 10, 1999	-30.484	-30.774	0.289	0.342	0.025	0.343
JV	June 27, 1999	-30.797	-30.844	0.047	0.269	0.072	0.279
SMD	September 5, 1999	-31.382	-31.578	0.196	0.661	3.676	3.735
CMI	October 23, 1999	-31.356	-32.046	0.690	0.326	1.443	1.479
BEV	November 4, 1999	-32.002	-32.012	0.010	0.435	0.296	0.526
SMU	November 24, 1999	-32.013	-31.957	-0.056	0.143	0.039	0.148
NMi-VSL	December 19, 1999	-31.887	-31.677	-0.210	0.141	0.116	0.183
CEM	January 14, 2000	-31.264	-31.650	0.386	0.156	0.071	0.171
INETI	January 27, 2000	-33.895	-31.541	-2.354	0.229	6.501	6.505
METAS	March 12, 2000	-31.835	-31.954	0.119	0.164	0.010	0.164
PTB	April 14, 2000	-32.207	-32.318	0.111	0.147	0.010	0.147
BIPM	April 30, 2000	-32.277	-32.251	-0.026	0.240	0.003	0.240
EIM	October 7, 2000	-33.699	-33.461	-0.238	0.632	0.023	0.633
SIQ	October 22, 2000	-32.890	-33.606	0.716	0.320	6.081	6.090
OMH	November 5, 2000	-34.075	-33.742	-0.333	0.522	6.465	6.486

Table B3: Measurement results for Zener VSL-2: measured value U_L as the deviation from nominal, interpolated value U_t based on measurements of the pilot-laboratory, deviation from interpolation Δ_L, uncertainty contribution from the traveling standard u_z, uncertainty contribution from the measurement system u_s, combined uncertainty of u_z and u_s, u_L.

VSL-3							
Lab	**Date of measurement**	U_L (µV)	U_t (µV)	Δ_L (µV)	u_z (µV)	u_s (µV)	u_L (µV)
BNM-LNE	December 2, 1998	-16.641	-17.132	0.491	0.669	0.002	0.669
NPL	January 16, 1999	-17.178	-17.138	-0.040	0.164	0.052	0.172
NML	January 30, 1999	-17.172	-17.129	-0.043	0.427	4.087	4.110
UME	March 6, 1999	-16.977	-17.155	0.178	0.148	0.005	0.148
DFM	April 24, 1999	-17.390	-17.348	-0.042	0.231	0.035	0.234
SP	May 8, 1999	-17.528	-17.452	-0.076	0.143	0.115	0.183
MIKES	June 9, 1999	-17.691	-17.714	0.022	0.323	0.025	0.324
JV	June 27, 1999	-18.032	-17.870	-0.162	0.334	0.072	0.341
SMD	September 5, 1999	-19.281	-18.948	-0.333	0.660	3.676	3.735
CMI	October 23, 1999	-18.612	-19.598	0.986	0.328	1.443	1.480
BEV	November 4, 1999	-19.840	-19.582	-0.258	0.342	0.296	0.452
SMU	November 24, 1999	-19.783	-19.555	-0.228	0.143	0.039	0.148
NMi-VSL	December 19, 1999	-19.521	-19.583	0.062	0.143	0.116	0.184
CEM	January 15, 2000	-19.085	-19.535	0.450	0.169	0.071	0.183
INETI	January 27, 2000	-22.155	-19.541	-2.614	0.191	6.501	6.504
METAS	March 12, 2000	-20.109	-20.008	-0.101	0.176	0.010	0.176
PTB	April 14, 2000	-20.311	-20.556	0.245	0.148	0.010	0.148
BIPM	April 30, 2000	-20.778	-20.772	-0.006	0.229	0.003	0.229
EIM	October 7, 2000	-23.100	-22.598	-0.502	0.468	0.023	0.469
SIQ	October 22, 2000	-22.149	-22.779	0.630	0.456	6.081	6.098
OMH	November 5, 2000	-23.804	-22.949	-0.855	0.527	6.465	6.486

Table B4: Measurement results for Zener VSL-3: measured value U_L as the deviation from nominal, interpolated value U_t based on measurements of the pilot-laboratory, deviation from interpolation Δ_L, uncertainty contribution from the traveling standard u_z, uncertainty contribution from the measurement system u_s, combined uncertainty of u_z and u_s, u_L.

VSL-4							
Lab	**Date of measurement**	U_L (µV)	U_t (µV)	Δ_L (µV)	u_z (µV)	u_s (µV)	u_L (µV)
BNM-LNE	December 2, 1998	-14.390	-14.955	0.565	0.597	0.002	0.597
NPL	January 16, 1999	-15.313	-14.855	-0.458	0.183	0.052	0.191
NML	January 30, 1999	-15.275	-14.899	-0.376	0.427	4.087	4.110
UME	March 6, 1999	-14.899	-14.878	-0.021	0.142	0.005	0.142
DFM	April 24, 1999	-14.543	-14.805	0.262	0.237	0.035	0.240
SP	May 8, 1999	-14.782	-14.853	0.071	0.175	0.115	0.210
MIKES	June 10, 1999	-14.942	-14.870	-0.072	0.385	0.025	0.386
JV	June 27, 1999	-15.018	-14.813	-0.205	0.237	0.072	0.247
SMD	September 5, 1999	-14.459	-14.375	-0.084	0.662	3.676	3.735
CMI	October 23, 1999	-13.148	-14.033	0.885	0.333	1.443	1.481
BEV	November 4, 1999	-13.733	-13.990	0.257	0.475	0.296	0.560
SMU	November 24, 1999	-13.761	-13.920	0.159	0.143	0.039	0.148
NMi-VSL	December 19, 1999	-13.832	-13.765	-0.067	0.149	0.116	0.189
CEM	January 15, 2000	-13.174	-13.689	0.515	0.200	0.071	0.212
INETI	January 27, 2000	-16.346	-13.623	-2.723	0.383	6.501	6.512
METAS	March 12, 2000	-13.078	-13.498	0.420	0.204	0.010	0.204
PTB	April 14, 2000	-13.316	-13.712	0.396	0.149	0.010	0.149
BIPM	April 30, 2000	-13.567	-13.924	0.357	0.196	0.003	0.196
EIM	October 7, 2000	-14.918	-14.687	-0.231	0.468	0.023	0.469
SIQ	October 22, 2000	-14.431	-14.755	0.324	0.518	6.081	6.103
OMH	November 5, 2000	-14.996	-14.820	-0.176	0.527	6.465	6.486

Table B5: Measurement results for Zener VSL-4: measured value U_L as the deviation from nominal, interpolated value U_t based on measurements of the pilot-laboratory, deviation from interpolation Δ_L, uncertainty contribution from the traveling standard u_z, uncertainty contribution from the measurement system u_s, combined uncertainty of u_z and u_s, u_L.

VSL Zener Group			
Lab	**Date of measurement**	**Δ_G (µV)**	**U_{TG} (µV)**
BNM-LNE	December 2, 1998	0.497	0.529
NPL	January 16, 1999	-0.217	0.416
NML	January 30, 1999	-0.042	4.114
UME	March 6, 1999	0.097	0.409
DFM	April 24, 1999	0.134	0.424
SP	May 8, 1999	0.076	0.428
MIKES	June 9, 1999	0.034	0.450
JV	June 27, 1999	-0.154	0.438
SMD	September 5, 1999	-0.055	3.716
CMI	October 23, 1999	0.867	1.509
BEV	November 4, 1999	-0.048	0.551
SMU	November 24, 1999	-0.030	0.411
NMi-VSL	December 19, 1999	-0.019	0.425
CEM	January 15, 2000	0.449	0.420
INETI	January 27, 2000	-2.549	6.515
METAS	March 12, 2000	0.140	0.415
PTB	April 14, 2000	0.291	0.410
BIPM	April 30, 2000	0.125	0.419
EIM	October 7, 2000	-0.411	0.490
SIQ	October 22, 2000	0.439	6.100
OMH	November 5, 2000	-0.513	6.484

Table B6: Results for the group of Zeners Δ_G calculated as the weighted means of the Δ_L values, with the uncertainty in the group value, U_{TG}.

APPENDIX C: Uncertainty analysis

In this appendix for each participant the details of the uncertainty analysis are presented. Each participant performed this analysis himself, making his own judgement concerning the relevant sources of uncertainty and their impact. In total 15 sources of uncertainty have been recognised, but not each participant did consider each source as relevant. Moreover, the relevance of a source also depends on the measurement method.
For each participant the presented values correspond with the traveling standard for which this participant has reported the lowest uncertainty in the averaged value.

Explanation of the uncertainty budget tables as provided by the participants

Each participant provided an overview of the sources of uncertainty that he considers as relevant for his measurement. This overview includes the following information:

Quantity	=	Description of the source of uncertainty
Uncertainty	=	The uncertainty associated with the quantity mentioned in the first column
Type	=	Indication of type of analysis (A or B)
Distribution	=	Indication of type of distribution (normal, rectangular, triangle, etc.)
Standard uncertainty	=	The standard uncertainty as calculated from the uncertainty in combination with the type of distribution
Sensitivity	=	Influence factor of the quantity on a single measurement result
Uncertainty contribution	=	The effect of the quantity on the total uncertainty u_L (by multiplying the standard uncertainty with the sensitivity coefficient).

For each participant only one uncertainty analysis is shown, i.e., only for the traveling standard for which the participant claims the lowest measurement uncertainty.

METHOD 1: Josephson Array Voltage Standard

The basic equation to calculate the measurement result U_L is given by:

$$U_L = U - \alpha_R (R - R_0) - \alpha_p (p - p_0) \quad ,$$

with

$$U = \frac{Nf}{K_{J-90}}(1 - E_{leak}) + V_{dvm}(1 - E_{gain}) - V_{off} = \frac{Nf}{K_{J-90}} + V_{dvm} - U_{leak} - U_{gain} - V_{off} \quad .$$

In Table C1 an explanation is given of the parameters that determine the final measurement result U_L and its uncertainty. In this table it is also indicated to which sources of uncertainty a parameter corresponds, using the ID number as given in the tables with the uncertainty analysis.

Parameter	**Description**	**Sources**
N	Step number to which the Josephson array is set. This parameter has no uncertainty.	x
K_{J-90}	The Josephson constant, equal to 483597.9 GHz/V. The uncertainty (relative 4 x 10^{-7}) has not been taken into account as it is common to all participants.	x
V_{dvm}	The voltage difference between the Josephson array and the traveling standard as measured with the digital voltmeter or null-detector. This voltage is subject to time-dependent fluctuations. The resolution of the meter limits the measurement accuracy.	1,2
E_{gain} or U_{gain}	The gain error of the digital voltmeter or null-detector (E_{gain}) or the corresponding voltage deviation (U_{gain}).	3
V_{off}	Residual offset voltages due to thermal EMF's in the leads, thermal EMF's in the applied scanner/switch or rectification induced by electromagnetic interference.	4, 5, 6
f	The frequency of the applied microwave power.	7
E_{leak} or U_{leak}	The leakage error (E_{leak}) or corresponding leakage voltage drop (U_{leak}) due to the finite resistance of the leads and the leakage resistance between the leads.	8
p	The ambient air pressure.	9
R	The resistance of the thermistor.	10
α_p	The pressure coefficient.	11
α_R	The resistance coefficient.	12
R_0	The thermistor reference value. This parameter has no uncertainty.	x
p_0	The pressure reference value. This parameter has no uncertainty.	x

Table C1: Description of the parameters that define the measurement result when using a JAVS.

METHOD 2: Electronic DC reference standards

The basic equation to calculate the measurement result U_L is given by:

$$U_L = U - \alpha_R (R - R_0) - \alpha_p (p - p_0) \quad ,$$

with

$$U = U_{reference}(1 - E_{leak}) + V_{dvm}(1 - E_{gain}) - V_{off} = U_{reference} + V_{dvm} - U_{leak} - U_{gain} - V_{off} \quad .$$

In Table C2 an explanation is given of the parameters that determine the final measurement result U_L and its uncertainty. In this table it is also indicated to which sources of uncertainty a parameter corresponds, using the ID number as given in the tables with the uncertainty analysis.

Parameter	Description	Sources
V_{dvm}	The voltage difference between the electronic DC reference standards and the traveling standard as measured with the digital voltmeter or null-detector. This voltage is subject to time-dependent fluctuations. The resolution of the meter limits the measurement accuracy.	1,2
E_{gain} or U_{gain}	The gain error of the digital voltmeter or null-detector (E_{gain}) or the corresponding voltage deviation (U_{gain}).	3
V_{off}	Residual offset voltages due to thermal EMF's in the leads, thermal EMF's in the applied scanner/switch or rectification induced by electromagnetic interference.	4, 5, 6
E_{leak} or U_{leak}	The leakage error (E_{leak}) or corresponding leakage voltage drop (U_{leak}) due to the finite resistance of the leads and the leakage resistance between the leads.	8
p	The ambient air pressure.	9
R	The resistance of the thermistor.	10
α_p	The pressure coefficient.	11
α_R	The resistance coefficient.	12
R_0	The thermistor reference value. This parameter has no uncertainty.	x
p_0	The pressure reference value. This parameter has no uncertainty.	x
$U_{reference}$	The value of the (group of) reference standard(s), including corrections due to drift, temperature or pressure.	13

Table C2: Description of the parameters that define the measurement result when using a (group of) electronic DC reference standards.

Fluctuation in the Zener output voltage

The value reported by each participant is an averaged value of measurements that were performed during one or two weeks. In addition to the uncertainty in a single measurement also the day-to-day fluctuations in the Zener output voltages should thus be taken into account when calculating the uncertainty in this averaged value. Often, the standard deviation of the mean (equal to the standard deviation of a single observation divided by the square root of n, the number of measurements) is used as an estimate for day-to-day fluctuation. However, it is known that this approach is only valid when the fluctuations are dominated by "white" noise. From extensive research on Zener based voltage standards it has been found that the day-to-day fluctuations in the output voltage are dominated by $1/f$ noise. It has been shown that in such a case the fluctuations are well described by the Allan deviation of the measurement results [5, 6]. From these studies it can be seen that for this type of Zeners the Allan deviation gives a lower limit ($1/f$ noise floor) to the random uncertain associated with the measurement of an "ideal" Zener (no drift and no environmental influences). A typical value for this lower limit is about 70 nV. This floor value has been implemented in the participants' uncertainty budget as follows. The random day-to-day fluctuations are denoted by u_A, which is found from:

$$u_A = \max(u_f, u_{std}) \quad ,$$

where u_f is the $1/f$ floor value and u_{std} is the standard deviation as given by the participants.

When the uncertainty associated with a single measurement is denoted by u_1 (resulting from the sources no. 1 to 13) and the day-to-day fluctuations are given by u_A (source no. 14 and 15), the best (conservative) estimation of the total uncertainty u_L is given by:

$$u_L = \sqrt{u_1^2 + u_A^2} \quad .$$

Zener / System uncertainties

The uncertainty budgets as given by the participants have been divided in contributions that result from the traveling standards, u_z and contributions that result from the measurement system, u_s. This separation was made for two purposes:

- It makes it easier to analyse the results and compare the results from different laboratories.
- It is required to calculate the weighted mean of the Zener group as shown in section 5.2.

Table C3 gives a summary of which contribution are attributed to u_z and which are attributed to u_s.

	Quantity	u_z / u_s
1	Null detector	u_s
2	DVM resoltion	u_s
3	Gain error and linearity	u_s
4	Offset voltages	u_s
5	Scanner/switch irreversibility	u_s
6	Electromagnetic interference	u_s
7	Frequency	u_s
8	Leakage error	u_s
9	Ambient pressure	u_z
10	Thermistor resistance	u_z
11	Pressure coefficient	u_z
12	Thermistor coefficient	u_z
13	Reference standard	u_s
14 or 15	Standard deviation or Noise floor	u_z

Table C3: Zener vs. system uncertainties

The combined uncertainties, u_z and u_s are calculated as the square root of the sum of the squared individual components.

Main sources of uncertainty

In general, from the uncertainty budgets it can be seen that for participants using a JAVS, the contribution of the traveling standards, u_z is dominant and for participants that don't use a JAVS, the system contribution, u_s is dominant.
For measurements with a JAVS the main source of uncertainty is the instability of the Zener output voltages. In a few cases, the thermistor coefficient or the pressure coefficient has a significant contribution, but for none of the participants these coefficients are actually dominant.
In the cases where the traveling standards are compared with electronic DC reference standards, the calibration uncertainty of these reference standards provides a dominant contribution to the uncertainty budget.

BNM-LNE, France **VSL-1**

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector	1 nV	B	rectangular	0.6 nV	1	0.6 nV
2	DVM resolution						
3	Gain error and linearity						
4	Offset voltages	1 nV	B	rectangular	0.6 nV	1	0.6 nV
5	Scanner/switch irreversibility						
6	Electromagnetic interference						
7	Frequency	0.1 nV	B	rectangular	0.1 nV	1	0.1 nV
8	Leakage error	0.1 nV	B	rectangular	0.1 nV	1	0.1 nV
9	Ambient pressure	0.12 hPa	B	rectangular	0.07 hPa	16.99 nV/hPa	1.2 nV
10	Thermistor resistance	4.0 Ω	B	rectangular	2.3 Ω	325 nV/kΩ	0.8 nV
11	Pressure coefficient	0.52 nV/hPa	A	normal	0.52 nV/hPa	-5 hPa	2.6 nV
12	Thermistor coefficient	289 nV/kΩ	A	normal	289 nV/kΩ	-0.119 kΩ	34.4 nV
13	Reference standard						
14	Standard deviation	144 nV	A	normal	144 nV	1	144.0 nV
15	Noise floor	70 nV	B	normal	70 nV	1	
u_{tot} (k = 1)							148 nV
Expanded uncertainty, u_L (k = 2)							**296 nV**
Zener contribution, u_z (k = 1)							148 nV
System contribution, u_s (k = 1)							1 nV

Measurement method: 10 V JAVS

Remarks: The uncertainty associated with the thermistor coefficient is significant because the environmental temperature at BNM-LNE amounts 20 °C whereas for most of the participants the thermistor values are based on an environmental temperature of 23 °C.

NPL, United Kingdom **VSL-2**

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector	23 nV	A	normal	23 nV	1	23.0 nV
2	DVM resolution						
3	Gain error and linearity	9 nV	B	rectangular	5.20 nV	1	5.2 nV
4	Offset voltages	3 nV	B	rectangular	1.73 nV	1	1.7 nV
5	Scanner/switch irreversibility	19 nV	B	rectangular	11.0 nV	1	11.0 nV
6	Electromagnetic interference						
7	Frequency	16 Hz	B	rectangular	9.24 Hz	0.1307 nV/Hz	1.2 nV
8	Leakage error	1 nV	B	rectangular	0.58 nV	1	0.6 nV
9	Ambient pressure	0.53 hPa	B	normal	0.53 hPa	17.2 nV/hPa	9.1 nV
10	Thermistor resistance	0.3 Ω	B	normal	0.3 Ω	1453 nV/kΩ	0.4 nV
11	Pressure coefficient	0.44 nV/hPa	A	normal	0.44 nV/hPa	-8 hPa	3.5 nV
12	Thermistor coefficient	370 nV/kΩ	A	normal	370 nV/kΩ	-0.063 kΩ	23.3 nV
13	Reference standard						
14	Standard deviation	60 nV	A	normal	60 nV	1	
15	Noise floor	70 nV	B	normal	70 nV	1	70.0 nV
u_{tot} (k = 1)							79 nV
Expanded uncertainty, u_L (k = 2)							**158 nV**
Zener contribution, u_z (k = 1)							74 nV
System contribution, u_s (k = 1)							26 nV

Measurement method: 10 V JAVS

Remarks: None

NML, Ireland **VSL-1**

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector	300 nV	A	normal	300 nV	1	300.0 nV
2	DVM resolution						
3	Gain error and linearity	500 nV	B	rectangular	289 nV	1	288.7 nV
4	Offset voltages	100 nV	B	rectangular	57.7 nV	1	57.7 nV
5	Scanner/switch irreversibility						
6	Electromagnetic interference						
7	Frequency						
8	Leakage error						
9	Ambient pressure	3 hPa	B	rectangular	1.73 hPa	16.99 nV/hPa	29.4 nV
10	Thermistor resistance	50.0 Ω	B	rectangular	28.9 Ω	325 nV/kΩ	9.4 nV
11	Pressure coefficient	0.52 nV/hPa	A	normal	0.52 nV/hPa	-18 hPa	9.4 nV
12	Thermistor coefficient	289 nV/kΩ	A	normal	289 nV/kΩ	-0.028 kΩ	8.1 nV
13	Reference standard	2000 nV	B	normal	2000 nV	1	2000.0 nV
14	Standard deviation	200 nV	A	normal	200 nV	1	200.0 nV
15	Noise floor	70 nV	B	normal	70 nV	1	
u_{tot} (k = 1)							2054 nV
Expanded uncertainty, u_L (k = 2)							**4107 nV**
Zener contribution, u_z (k = 1)							203 nV
System contribution, u_s (k = 1)							2044 nV

Measurement method: Electronic DC Reference standards

Remarks: None

UME, Turkey VSL-4

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector						
2	DVM resolution						
3	Gain error and linearity	$0.04 \cdot 10^{-9}$	B	normal	$0.04 \cdot 10^{-9}$	10 V	0.4 nV
4	Offset voltages	1 nV	B	normal	1.0 nV	1	1.0 nV
5	Scanner/switch irreversibility	1 nV	B	normal	1 nV	1	1.0 nV
6	Electromagnetic interference						
7	Frequency	3 Hz	B	rectangular	1.7 Hz	0.13 nV/Hz	0.2 nV
8	Leakage error	2 nV	B	nornal	2.0 nV	1	2.0 nV
9	Ambient pressure	0.4 hPa	B	rectangular	0.23 hPa	18.69 nV/hPa	4.3 nV
10	Thermistor resistance	0.3 Ω	B	rectangular	0.2 Ω	1857 nV/kΩ	0.3 nV
11	Pressure coefficient	0.83 nV/hPa	A	normal	0.83 nV/hPa	7.9 hPa	6.6 nV
12	Thermistor coefficient	646 nV/kΩ	A	normal	646 nV/kΩ	0.014 kΩ	9.0 nV
13	Reference standard						
14	Standard deviation	17.3 nV	A	normal	17.3 nV	1	
15	Noise floor	70 nV	B	normal	70 nV	1	70.0 nV
u_{tot} (k = 1)							71 nV
Expanded uncertainty, u_L (k = 2)							**142 nV**
Zener contribution, u_z (k = 1)							71 nV
System contribution, u_s (k = 1)							2 nV

Measurement method: 10 V JAVS

Remarks: None

DFM, Denmark **VSL-1**

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector	15 nV	A	normal	15 nV	1	15.0 nV
2	DVM resolution						
3	Gain error and linearity	$1.0 \cdot 10^{-6}$	B	normal	$1.0 \cdot 10^{-6}$	2.5 mV	2.5 nV
4	Offset voltages	15 nV	B	rectangular	8.7 nV	1	8.7 nV
5	Scanner/switch irreversibility						
6	Electromagnetic interference						
7	Frequency	$0.1 \cdot 10^{-9}$	B	normal	$0.1 \cdot 10^{-9}$	10 V	1.0 nV
8	Leakage error	$0.1 \cdot 10^{-9}$	B	normal	$0.1 \cdot 10^{-9}$	10 V	1.0 nV
9	Ambient pressure	5 hPa	B	normal	5.0 hPa	16.99 nV/hPa	85.0 nV
10	Thermistor resistance	10.0 Ω	B	normal	10.0 Ω	325 nV/kΩ	3.3 nV
11	Pressure coefficient	0.52 nV/hPa	A	normal	0.52 nV/hPa	-9 hPa	4.7 nV
12	Thermistor coefficient	289 nV/kΩ	A	normal	289 nV/kΩ	0.057 kΩ	16.5 nV
13	Reference standard						
14	Standard deviation	56 nV	A	normal	56 nV	1	
15	Noise floor	70 nV	B	normal	70 nV	1	70.0 nV
u_{tot} (k = 1)							113 nV
Expanded uncertainty, u_L (k = 2)							**226 nV**
Zener contribution, u_z (k = 1)							111 nV
System contribution, u_s (k = 1)							18 nV

Measurement method: 10 V JAVS

Remarks: None

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector	98 nV	A	rectangular	56.6 nV	1	56.6 nV
2	DVM resolution						
3	Gain error and linearity	10 nV	B	normal	10.0 nV	1	10.0 nV
4	Offset voltages	2 nV	B	normal	2.0 nV	1	2.0 nV
5	Scanner/switch irreversibility						
6	Electromagnetic interference						
7	Frequency	7 Hz	B	normal	7 Hz	0.13 nV/Hz	0.9 nV
8	Leakage error	0.3 nV	B	normal	0.3 nV	1	0.3 nV
9	Ambient pressure	0.5 hPa	B	normal	0.5 hPa	16.99 nV/hPa	8.5 nV
10	Thermistor resistance	1.0 Ω	B	normal	1.0 Ω	325 nV/kΩ	0.3 nV
11	Pressure coefficient	0.52 nV/hPa	A	normal	0.52 nV/hPa	-1 hPa	0.5 nV
12	Thermistor coefficient	289 nV/kΩ	A	normal	289 nV/kΩ	0.037 kΩ	10.7 nV
13	Reference standard						
14	Standard deviation	70 nV	A	normal	70 nV	1	70.0 nV
15	Noise floor	70 nV	B	normal	70 nV	1	
u_{tot} (k = 1)							92 nV
Expanded uncertainty, u_L (k = 2)							**183 nV**
Zener contribution, u_z (k = 1)							71 nV
System contribution, u_s (k = 1)							58 nV

Measurement method: 10 V JAVS

Remarks: None

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector						
2	DVM resoltion						
3	Gain error and linearity	$1.5\ 10^{-7}$	B	normal	$1.5\ 10^{-7}$	10 mV	1.5 nV
4	Offset voltages	8.7 nV	B	rectangular	5.0 nV	1	5.0 nV
5	Scanner/switch irreversibility						
6	Electromagnetic interference	11.3 nV	B	normal	11.3 nV	1	11.3 nV
7	Frequency	2.47 nV	B	normal	2.5 nV	1	2.5 nV
8	Leakage error	0.02 nV	B	normal	0.02 nV	1	0.0 nV
9	Ambient pressure	1.7 hPa	B	rectangular	1.0 hPa	17.74 nV/hPa	17.7 nV
10	Thermistor resistance	1.7 Ω	B	rectangular	1.0 Ω	2145 nV/kΩ	2.1 nV
11	Pressure coefficient	0.41 nV/hPa	A	normal	0.41 nV/hPa	-25.34 hPa	10.4 nV
12	Thermistor coefficient	549 nV/kΩ	A	normal	549 nV/kΩ	-0.017 kΩ	9.3 nV
13	Reference standard						
14	Standard deviation	160 nV	A	normal	160 nV	1	160.0 nV
15	Noise floor	70 nV	B	normal	70 nV	1	
u_{tot} (k = 1)							162 nV
Expanded uncertainty, u_L (k = 2)							**323 nV**
Zener contribution, u_z (k = 1)							162 nV
System contribution, u_s (k = 1)							13 nV

Measurement method: 10 V JAVS

Remarks: None

JV, Norway **VSL-4**

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector	30 nV	A	normal	30.0 nV	1	30.0 nV
2	DVM resolution	5 nV	B	rectangular	2.9 nV	1	2.9 nV
3	Gain error and linearity	16 nV	B	normal	16.0 nV	1	16.0 nV
4	Offset voltages	3 nV	B	normal	3.0 nV	1	3.0 nV
5	Scanner/switch irreversibility						
6	Electromagnetic interference						
7	Frequency	11 nV	B	normal	11.0 nV	1	11.0 nV
8	Leakage error	1 nV	B	normal	1.0 nV	1	1.0 nV
9	Ambient pressure	0.5 hPa	B	normal	0.5 hPa	18.69 nV/hPa	9.3 nV
10	Thermistor resistance	1.0 Ω	B	normal	1.0 Ω	1857 nV/kΩ	1.9 nV
11	Pressure coefficient	0.83 nV/hPa	A	normal	0.83 nV/hPa	-1 hPa	0.8 nV
12	Thermistor coefficient	646 nV/kΩ	A	normal	646 nV/kΩ	0.057 kΩ	36.8 nV
13	Reference standard						
14	Standard deviation	112 nV	A	normal	112 nV	1	112.0 nV
15	Noise floor	70 nV	B	normal	70 nV	1	
u_{tot} (k = 1)							124 nV
Expanded uncertainty, u_L (k = 2)							**247 nV**
Zener contribution, u_z (k = 1)							118 nV
System contribution, u_s (k = 1)							36 nV

Measurement method: 10 V JAVS

Remarks: None

SMD, Belgium **VSL-1**

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector						
2	DVM resolution						
3	Gain error and linearity	1118 nV	B	rectangular	645 nV	1	645.5 nV
4	Offset voltages						
5	Scanner/switch irreversibility	200 nV	B	rectangular	115 nV	1	115.5 nV
6	Electromagnetic interference	300 nV	B	rectangular	173 nV	1	173.2 nV
7	Frequency						
8	Leakage error	250 nV	B	rectangular	144 nV	1	144.3 nV
9	Ambient pressure	0.1 hPa	B	normal	0.1 hPa	16.99 nV/hPa	1.7 nV
10	Thermistor resistance	1.0 Ω	B	normal	1.0 Ω	325 nV/kΩ	0.3 nV
11	Pressure coefficient	0.52 nV/hPa	A	normal	0.52 nV/hPa	-17 hPa	8.8 nV
12	Thermistor coefficient	289 nV/kΩ	A	normal	289 nV/kΩ	0.011 kΩ	3.2 nV
13	Reference standard	1702 nV	B	normal	1702 nV	1	1702.0 nV
14	Standard deviation	330 nV	A	normal	330 nV	1	330.0 nV
15	Noise floor	70 nV	B	normal	70 nV	1	
u_{tot} (k = 1)							1867 nV
Expanded uncertainty, u_L (k = 2)							**3735 nV**
Zener contribution, u_z (k = 1)							330 nV
System contribution, u_s (k = 1)							1838 nV

Measurement method: Electronic DC reference standards

Remarks: None

CMI, Czech Republic **VSL-2**

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector	50 nV	A	normal	50 nV	1	50.0 nV
2	DVM resolution						
3	Gain error and linearity	260 nV	B	rectangular	150 nV	1	150.1 nV
4	Offset voltages	170 nV	B	rectangular	98 nV	1	98.1 nV
5	Scanner/switch irreversibility						
6	Electromagnetic interference	260 nV	B	rectangular	150 nV	1	150.1 nV
7	Frequency						
8	Leakage error	350 nV	B	rectangular	202 nV	1	202.1 nV
9	Ambient pressure	1.2 hPa	B	normal	1.2 hPa	17.2 nV/hPa	20.6 nV
10	Thermistor resistance	3.7 Ω	B	normal	3.7 Ω	1453 nV/kΩ	5.4 nV
11	Pressure coefficient	0.44 nV/hPa	A	normal	0.44 nV/hPa	22.9 hPa	10.1 nV
12	Thermistor coefficient	370 nV/kΩ	A	normal	370 nV/kΩ	0.05 kΩ	18.5 nV
13	Reference standard	650 nV	B	normal	650 nV	1	650.0 nV
14	Standard deviation	160 nV	A	normal	160 nV	1	160.0 nV
15	Noise floor	70 nV	B	normal	70 nV	1	
u_{tot} ($k = 1$)							740 nV
Expanded uncertainty, u_L ($k = 2$)							**1479 nV**
Zener contribution, u_z ($k = 1$)							163 nV
System contribution, u_s ($k = 1$)							721 nV

Measurement method: Electronic DC reference standards

Remarks: None

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector	148 nV	A	normal	148 nV	1	148.0 nV
2	DVM resolution						
3	Gain error and linearity						
4	Offset voltages						
5	Scanner/switch irreversibility						
6	Electromagnetic interference						
7	Frequency	$0.22 \cdot 10^{-9}$	B	rectangular	$0.13 \cdot 10^{-9}$	10 V	1.3 nV
8	Leakage error	$0.44 \cdot 10^{-9}$	B	rectangular	$0.25 \cdot 10^{-9}$	10 V	2.5 nV
9	Ambient pressure	1 hPa	B	rectangular	0.58 hPa	17.74 nV/hPa	10.2 nV
10	Thermistor resistance	10.0 Ω	B	rectangular	5.8 Ω	2145 nV/kΩ	12.4 nV
11	Pressure coefficient	0.41 nV/hPa	A	normal	0.41 nV/hPa	2.3 hPa	0.9 nV
12	Thermistor coefficient	549 nV/kΩ	A	normal	549 nV/kΩ	0.011 kΩ	6.0 nV
13	Reference standard						
14	Standard deviation	170 nV	A	normal	170 nV	1	170.0 nV
15	Noise floor	70 nV	B	normal	70 nV	1	
u_{tot} (k = 1)							226 nV
Expanded uncertainty, u_L (k = 2)							**452 nV**
Zener contribution, u_z (k = 1)							171 nV
System contribution, u_s (k = 1)							148 nV

Measurement method: 10 V JAVS

Remarks: The type-A uncertainty reported for the Null detector does also include instability of the microwave frequency and offset from the locked frequency, uncertainty due to electromagnetic interference, null detector gain error, null detector offset and noise, and uncompensated offset voltages.

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector	6 nV	A	normal	6.0 nV	1	6.0 nV
2	DVM resolution						
3	Gain error and linearity	5 nV	B	normal	5.0 nV	1	5.0 nV
4	Offset voltages	18 nV	B	normal	10.4 nV	1	10.4 nV
5	Scanner/switch irreversibility						
6	Electromagnetic interference						
7	Frequency	2 nV	B	normal	2.0 nV	1	2.0 nV
8	Leakage error	1.7 nV	B	rectangular	1.0 nV	1	1.0 nV
9	Ambient pressure	1 hPa	B	rectangular	0.58 hPa	18.69 nV/hPa	10.8 nV
10	Thermistor resistance	2.4 Ω	B	rectangular	1.4 Ω	1857 nV/kΩ	2.6 nV
11	Pressure coefficient	0.83 nV/hPa	A	normal	0.83 nV/hPa	-7 hPa	5.8 nV
12	Thermistor coefficient	646 nV/kΩ	A	normal	646 nV/kΩ	-0.007 kΩ	4.5 nV
13	Reference standard						
14	Standard deviation	57 nV	A	normal	57 nV	1	
15	Noise floor	70 nV	B	normal	70 nV	1	70.0 nV
u_{tot} ($k = 1$)							74 nV
Expanded uncertainty, u_L ($k = 2$)							**148 nV**
Zener contribution, u_z ($k = 1$)							71 nV
System contribution, u_s ($k = 1$)							20 nV

Measurement method: 10 V JAVS

Remarks: None

NMi-VSL, The Netherlands VSL-1

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector	50 nV	A	normal	50 nV	1	50.0 nV
2	DVM resolution						
3	Gain error and linearity	$2 \cdot 10^{-6}$	B	rectangular	$1.15 \cdot 10^{-6}$	3.05 mV	3.5 nV
4	Offset voltages	10 nV	B	rectangular	5.8 nV	1	5.8 nV
5	Scanner/switch irreversibility						
6	Electromagnetic interference						
7	Frequency	0.8 Hz	B	normal	0.8 Hz	0.13 nV/Hz	0.1 nV
8	Leakage error	$5 \cdot 10^{-9}$	B	rectangular	$2.89 \cdot 10^{-9}$	10 V	28.9 nV
9	Ambient pressure	0.2 hPa	B	rectangular	0.12 hPa	16.99 nV/hPa	2.0 nV
10	Thermistor resistance	10.0 Ω	B	rectangular	5.8 Ω	325 nV/kΩ	1.9 nV
11	Pressure coefficient	0.52 nV/hPa	A	normal	0.52 nV/hPa	-12 hPa	6.2 nV
12	Thermistor coefficient	289 nV/kΩ	A	normal	289 nV/kΩ	0.006 kΩ	1.7 nV
13	Reference standard						
14	Standard deviation	38 nV	A	normal	38 nV	1	
15	Noise floor	70 nV	B	normal	70 nV	1	70.0 nV
u_{tot} (k = 1)							91 nV
Expanded uncertainty, u_L (k = 2)							**183 nV**
Zener contribution, u_z (k = 1)							70 nV
System contribution, u_s (k = 1)							58 nV

Measurement method: 10 V JAVS

Remarks: None

CEM, Spain **VSL-2**

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector	6 nV	A	normal	6.0 nV	1	6.0 nV
2	DVM resolution						
3	Gain error and linearity	$17.4 \cdot 10^{-6}$	B	rectangular	$10.0 \cdot 10^{-6}$	2 mV	20.1 nV
4	Offset voltages	34.8 nV	B	rectangular	20.1 nV	1	20.1 nV
5	Scanner/switch irreversibility						
6	Electromagnetic interference						
7	Frequency	2 nV	B	normal	2.0 nV	1	2.0 nV
8	Leakage error	34.8 nV	B	rectangular	20.1 nV	1	20.1 nV
9	Ambient pressure	0.2 hPa	B	normal	0.2 hPa	17.2 nV/hPa	3.4 nV
10	Thermistor resistance	2.0 Ω	B	normal	2.0 Ω	1453 nV/kΩ	2.9 nV
11	Pressure coefficient	0.44 nV/hPa	A	normal	0.44 nV/hPa	57.5 hPa	25.3 nV
12	Thermistor coefficient	370 nV/kΩ	A	normal	370 nV/kΩ	0.061 kΩ	22.6 nV
13	Reference standard						
14	Standard deviation	30 nV	A	normal	30 nV	1	
15	Noise floor	70 nV	B	normal	70 nV	1	70.0 nV
u_{tot} (k = 1)							86 nV
Expanded uncertainty, u_L (k = 2)							**171 nV**
Zener contribution, u_z (k = 1)							78 nV
System contribution, u_s (k = 1)							35 nV

Measurement method: 10 V JAVS

Remarks:
- During the stay at CEM, the 'in cal' indicators of VSL-1 and VSL-4 went off, because the capacity of the internal batteries had become too low.
- The uncertainty in the pressure coefficients is an important contribution, due to the altitude of the CEM laboratory.

INETI, Portugal **VSL-1**

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector	25 nV	A	rectangular	14.4 nV	1	14.4 nV
2	DVM resolution						
3	Gain error and linearity						
4	Offset voltages	1 nV	B	rectangular	0.6 nV	1	0.6 nV
5	Scanner/switch irreversibility	100 nV	B	rectangular	57.7 nV	1	57.7 nV
6	Electromagnetic interference						
7	Frequency						
8	Leakage error						
9	Ambient pressure						
10	Thermistor resistance	4.1 Ω	B	rectangular	2.4 Ω	325 nV/kΩ	0.8 nV
11	Pressure coefficient						
12	Thermistor coefficient	289 nV/kΩ	A	normal	289 nV/kΩ	0.068 kΩ	19.7 nV
13	Reference standard	3250 nV	B	normal	3250 nV	1	3250.0 nV
14	Standard deviation	80 nV	A	normal	80 nV	1	80.0 nV
15	Noise floor	70 nV	B	normal	70 nV	1	
u_{tot} (k = 1)							3252 nV
Expanded uncertainty, u_L (k = 2)							**6503 nV**
Zener contribution, u_z (k = 1)							82 nV
System contribution, u_s (k = 1)							3251 nV

Measurement method: Electronic DC reference standards

Remarks: None

METAS, Switzerland **VSL-1**

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector	5 nV	A	normal	5.0 nV	1	5.0 nV
2	DVM resoltion						
3	Gain error and linearity	0.6 nV	B	normal	0.6 nV	1	0.6 nV
4	Offset voltages						
5	Scanner/switch irreversibility						
6	Electromagnetic interference						
7	Frequency	0.7 nV	B	normal	0.7 nV	1	0.7 nV
8	Leakage error	1 nV	B	normal	1.0 nV	1	1.0 nV
9	Ambient pressure	0.1 hPa	A	normal	0.10 hPa	16.99 nV/hPa	1.7 nV
10	Thermistor resistance	1.0 Ω	A	normal	1.0 Ω	325 nV/kΩ	0.3 nV
11	Pressure coefficient	0.52 nV/hPa	A	normal	0.52 nV/hPa	37.2 hPa	19.3 nV
12	Thermistor coefficient	289 nV/kΩ	A	normal	289 nV/kΩ	-0.116 kΩ	33.5 nV
13	Reference standard						
14	Standard deviation	40 nV	A	normal	40 nV	1	
15	Noise floor	70 nV	B	normal	70 nV	1	70.0 nV
u_{tot} ($k = 1$)							80 nV
Expanded uncertainty, u_L ($k = 2$)							**160 nV**
Zener contribution, u_z ($k = 1$)							80 nV
System contribution, u_s ($k = 1$)							5 nV

Measurement method: 10 V JAVS

Remarks: - The combined effect of the null meter bias current, input impedance, non linearity and noise, of the uncorrected thermal voltages in the measurement loop, of the rectification of the reference frequency, and of the effect of electromagnetic interference have been evaluated as a type A uncertainty of a short circuit measurement. The uncertainty obtained with this method is 5 nV with a degree of freedom of 5.

- The uncertainty associated with the thermistor coefficient is significant because the environmental temperature at METAS amounts 20 °C whereas for most of the participants the thermistor values are based on an environmental temperature of 23 °C.

PTB, Germany **VSL-1**

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector	5 nV	A	normal	5.0 nV	1	5.0 nV
2	DVM resolution						
3	Gain error and linearity						
4	Offset voltages	1 nV	B	rectangular	0.6 nV	1	0.6 nV
5	Scanner/switch irreversibility						
6	Electromagnetic interference						
7	Frequency	10 Hz	B	rectangular	5.8 Hz	0.133 nV/Hz	0.8 nV
8	Leakage error	1 nV	B	rectangular	0.6 nV	1	0.6 nV
9	Ambient pressure	1.2 hPa	B	normal	1.2 hPa	16.99 nV/hPa	20.4 nV
10	Thermistor resistance	7.9 Ω	B	rectangular	4.6 Ω	325 nV/kΩ	1.5 nV
11	Pressure coefficient	0.83 nV/hPa	A	normal	0.83 nV/hPa	8.3 hPa	4.3 nV
12	Thermistor coefficient	646 nV/kΩ	A	normal	646 nV/kΩ	-0.008 kΩ	2.3 nV
13	Reference standard						
14	Standard deviation	52 nV	A	normal	52 nV	1	
15	Noise floor	70 nV	B	normal	70 nV	1	70.0 nV
u_{tot} (k = 1)							73 nV
Expanded uncertainty, u_L (k = 2)							**147 nV**
Zener contribution, u_z (k = 1)							73 nV
System contribution, u_s (k = 1)							5 nV

Measurement method: 10 V JAVS

Remarks: None

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector	0.5 nV	A	normal	0.5 nV	1	0.5 nV
2	DVM resolution						
3	Gain error and linearity						
4	Offset voltages	1.5 nV	B	normal	1.5 nV	1	1.5 nV
5	Scanner/switch irreversibility						
6	Electromagnetic interference						
7	Frequency	0.3 nV	B	normal	0.3 nV	1	0.3 nV
8	Leakage error	0.2 nV	B	normal	0.2 nV	1	0.2 nV
9	Ambient pressure	0.1 hPa	B	normal	0.1 hPa	16.99 nV/hPa	1.7 nV
10	Thermistor resistance	1.0 Ω	B	normal	1.0 Ω	325 nV/kΩ	0.3 nV
11	Pressure coefficient	0.52 nV/hPa	A	normal	0.52 nV/hPa	-5 hPa	2.6 nV
12	Thermistor coefficient	289 nV/kΩ	A	normal	289 nV/kΩ	-0.118 kΩ	34.1 nV
13	Reference standard						
14	Standard deviation	67 nV	A	normal	67 nV	1	
15	Noise floor	70 nV	B	normal	70 nV	1	70.0 nV
u_{tot} (k = 1)							78 nV
Expanded uncertainty, u_L (k = 2)							**156 nV**
Zener contribution, u_z (k = 1)							78 nV
System contribution, u_s (k = 1)							2 nV

Measurement method: 10 V JAVS

Remarks: The uncertainty associated with the thermistor coefficient is significant because the environmental temperature at BIPM amounts 20 °C whereas for most of the participants the thermistor values are based on an environmental temperature of 23 °C.

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector	10 nV	A	normal	10.0 nV	1	10.0 nV
2	DVM resolution						
3	Gain error and linearity						
4	Offset voltages						
5	Scanner/switch irreversibility						
6	Electromagnetic interference						
7	Frequency	2 nV	B	rectangular	1.2 nV	1	1.2 nV
8	Leakage error	10 nV	B	rectangular	5.8 nV	1	5.8 nV
9	Ambient pressure	0.2 hPa	B	normal	0.20 hPa	17.74 nV/hPa	3.5 nV
10	Thermistor resistance	1.1 Ω	B	normal	1.1 Ω	2145 nV/kΩ	2.4 nV
11	Pressure coefficient	0.41 nV/hPa	A	normal	0.41 nV/hPa	-13 hPa	5.3 nV
12	Thermistor coefficient	549 nV/kΩ	A	normal	549 nV/kΩ	0.039 kΩ	21.4 nV
13	Reference standard						
14	Standard deviation	233 nV	A	normal	233 nV	1	233.0 nV
15	Noise floor	70 nV	B	normal	70 nV	1	
u_{tot} (k = 1)							234 nV
Expanded uncertainty, u_L (k = 2)							**469 nV**
Zener contribution, u_z (k = 1)							234 nV
System contribution, u_s (k = 1)							12 nV

Measurement method: 10 V JAVS

Remarks: The uncertainty reported for uncompensated offset voltages includes all uncertainties except that arising from noise from the traveling standard, frequency, and leakage.
The contribution from uncompensated offset voltages includes uncertainties due to:

- the DVM offset, gain, input impedance, non-linearity, and noise.
- uncorrected thermal voltages in the measurement loop.
- rectification of the reference frequency current.
- any effect of electromagnetic interference (EMI).
- sloped steps resulting in a bias dependent Josephson voltage.

SIQ, Slovenia **VSL-1**

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector						
2	DVM resolution						
3	Gain error and linearity	50 nV	B	rectangular	29 nV	1	28.9 nV
4	Offset voltages	100 nV	B	rectangular	58 nV	1	57.7 nV
5	Scanner/switch irreversibility						
6	Electromagnetic interference						
7	Frequency						
8	Leakage error						
9	Ambient pressure						
10	Thermistor resistance						
11	Pressure coefficient	0.52 nV/hPa	A	normal	0.52 nV/hPa	8.3 hPa	4.3 nV
12	Thermistor coefficient	289 nV/kΩ	A	normal	289 nV/kΩ	0.34 kΩ	98.3 nV
13	Reference standard	3040 nV		normal	3040 nV	1	3040.0 nV
14	Standard deviation	49 nV	A	normal	49 nV	1	
15	Noise floor	70 nV	B	normal	70 nV	1	70.0 nV
u_{tot} ($k = 1$)							3043 nV
Expanded uncertainty, u_L ($k = 2$)							**6086 nV**
Zener contribution, u_z ($k = 1$)							121 nV
System contribution, u_s ($k = 1$)							3041 nV

Measurement method: Electronic DC reference standards

Remarks: The traveling standards were connected to AC line power.

OMH, Hungary **VSL-2**

	Quantity	Uncertainty	Type	Distribution	Standard Uncertainty	Sensitivity	Uncertainty Contribution
1	Null detector	50 nV	A	normal	50.0 nV	1	50.0 nV
2	DVM resolution						
3	Gain error and linearity	104 nV	B	rectangular	60.0 nV	1	60.0 nV
4	Offset voltages	86.6 nV	B	rectangular	50.0 nV	1	50.0 nV
5	Scanner/switch irreversibility	49 nV	B	triangle	20.0 nV	1	20.0 nV
6	Electromagnetic interference						
7	Frequency						
8	Leakage error						
9	Ambient pressure	0.12 hPa	B	triangle	0.05 hPa	17.2 nV/hPa	0.8 nV
10	Thermistor resistance	2.4 Ω	B	triangle	1.0 Ω	1453 nV/kΩ	1.4 nV
11	Pressure coefficient	0.44 nV/hPa	A	normal	0.44 nV/hPa	11.5 hPa	5.1 nV
12	Thermistor coefficient	370 nV/kΩ	A	normal	370 nV/kΩ	0.063 kΩ	23.3 nV
13	Reference standard	3231 nV	B	normal	3231 nV	1	3231.0 nV
14	Standard deviation	260 nV	A	normal	260 nV	1	260.0 nV
15	Noise floor	70 nV	B	normal	70 nV	1	
u_{tot} (k = 1)							3243 nV
Expanded uncertainty, u_L (k = 2)							**6486 nV**
Zener contribution, u_z (k = 1)							261 nV
System contribution, u_s (k = 1)							3232 nV

Measurement method: Electronic DC reference standards

Remarks: None

APPENDIX D: Degrees of equivalence

			Lab *j*													
			BNM-LNE		**NPL**		**NML**		**UME**		**DFM**		**SP**		**MIKES**	
Lab *i*	D_i (µV)	U_i (µV)	D_{ij} (µV)	U_{ij} (µV)	D_{ij} (µV)	U_{ij} (µV)	D_{ij} (µV)	U_{ij} (µV)	D_{ij} (µV)	U_{ij} (µV)	D_{ij} (µV)	U_{ij} (µV)	D_{ij} (µV)	U_{ij} (µV)	D_{ij} (µV)	U_{ij} (µV)
BNM-LNE	0.43	0.52	-	-	0.71	0.67	0.54	4.15	0.40	0.67	0.36	0.68	0.42	0.68	0.46	0.69
NPL	-0.28	0.40	-0.71	0.67	-	-	-0.17	4.14	-0.31	0.58	-0.35	0.59	-0.29	0.60	-0.25	0.61
NML	-0.11	4.12	-0.54	4.15	0.17	4.14	-	-	-0.14	4.13	-0.18	4.14	-0.12	4.14	-0.08	4.14
UME	0.03	0.39	-0.40	0.67	0.31	0.58	0.14	4.13	-	-	-0.04	0.59	0.02	0.59	0.06	0.61
DFM	0.07	0.41	-0.36	0.68	0.35	0.59	0.18	4.14	0.04	0.59	-	-	0.06	0.60	0.10	0.62
SP	0.01	0.41	-0.42	0.68	0.29	0.60	0.12	4.14	-0.02	0.59	-0.06	0.60	-	-	0.04	0.62
MIKES	-0.03	0.44	-0.46	0.69	0.25	0.61	0.08	4.14	-0.06	0.61	-0.10	0.62	-0.04	0.62	-	-
JV	-0.22	0.42	-0.65	0.69	0.06	0.60	-0.11	4.14	-0.25	0.60	-0.29	0.61	-0.23	0.61	-0.19	0.63
SMD	-0.12	3.72	-0.55	3.75	0.16	3.74	-0.01	5.54	-0.15	3.74	-0.19	3.74	-0.13	3.74	-0.09	3.74
CMI	0.80	1.51	0.37	1.60	1.08	1.57	0.91	4.38	0.77	1.56	0.73	1.57	0.79	1.57	0.83	1.57
BEV	-0.12	0.54	-0.55	0.76	0.17	0.69	-0.01	4.15	-0.15	0.69	-0.18	0.70	-0.13	0.70	-0.08	0.71
SMU	-0.10	0.40	-0.53	0.67	0.19	0.58	0.01	4.13	-0.13	0.58	-0.16	0.59	-0.11	0.59	-0.06	0.61
NMi-VSL	-0.09	0.41	-0.52	0.68	0.20	0.59	0.02	4.14	-0.12	0.59	-0.15	0.60	-0.10	0.60	-0.05	0.62
CEM	0.38	0.40	-0.05	0.68	0.67	0.59	0.49	4.14	0.35	0.59	0.32	0.60	0.37	0.60	0.42	0.62
INETI	-2.62	6.52	-3.05	6.54	-2.33	6.53	-2.51	7.71	-2.65	6.53	-2.68	6.53	-2.63	6.53	-2.58	6.53
METAS	0.07	0.40	-0.36	0.67	0.36	0.59	0.18	4.13	0.04	0.58	0.01	0.59	0.06	0.60	0.11	0.61
PTB	0.22	0.39	-0.21	0.67	0.51	0.58	0.33	4.13	0.19	0.58	0.16	0.59	0.21	0.59	0.26	0.61
BIPM	0.06	0.40	-0.37	0.68	0.34	0.59	0.17	4.14	0.03	0.59	-0.01	0.60	0.05	0.60	0.09	0.61
EIM	-0.48	0.48	-0.91	0.72	-0.19	0.64	-0.37	4.14	-0.51	0.64	-0.54	0.65	-0.49	0.65	-0.44	0.67
SIQ	0.37	6.10	-0.06	6.12	0.66	6.11	0.48	7.36	0.34	6.11	0.31	6.11	0.36	6.12	0.41	6.12
OMH	-0.58	6.49	-1.01	6.51	-0.30	6.50	-0.47	7.68	-0.61	6.50	-0.65	6.50	-0.59	6.50	-0.55	6.50

Table D7: Degrees of equivalence with the *ERV*, D_i with the expanded uncertainties, U_i and degrees of equivalence between pairs of laboratories, D_{ij} with the expanded uncertainties, U_{ij}.

	Lab *j*													
	JV		**SMD**		**CMI**		**BEV**		**SMU**		**NMi-VSL**		**CEM**	
Lab *i*	D_{ij} (μV)	U_{ij} (μV)	D_{ij} (μV)	U_{ij} (μV)	D_{ij} (μV)	U_{ij} (μV)	D_{ij} (μV)	U_{ij} (μV)	D_{ij} (μV)	U_{ij} (μV)	D_{ij} (μV)	U_{ij} (μV)	D_{ij} (μV)	U_{ij} (μV)
BNM-LNE	0.65	0.69	0.55	3.75	-0.37	1.60	0.55	0.76	0.53	0.67	0.52	0.68	0.05	0.68
NPL	-0.06	0.60	-0.16	3.74	-1.08	1.57	-0.17	0.69	-0.19	0.58	-0.20	0.59	-0.67	0.59
NML	0.11	4.14	0.01	5.54	-0.91	4.38	0.01	4.15	-0.01	4.13	-0.02	4.14	-0.49	4.14
UME	0.25	0.60	0.15	3.74	-0.77	1.56	0.15	0.69	0.13	0.58	0.12	0.59	-0.35	0.59
DFM	0.29	0.61	0.19	3.74	-0.73	1.57	0.18	0.70	0.16	0.59	0.15	0.60	-0.32	0.60
SP	0.23	0.61	0.13	3.74	-0.79	1.57	0.13	0.70	0.11	0.59	0.10	0.60	-0.37	0.60
MIKES	0.19	0.63	0.09	3.74	-0.83	1.57	0.08	0.71	0.06	0.61	0.05	0.62	-0.42	0.62
JV	-	-	-0.10	3.74	-1.02	1.57	-0.11	0.70	-0.12	0.60	-0.14	0.61	-0.60	0.61
SMD	0.10	3.74	-	-	-0.92	4.01	-0.01	3.76	-0.02	3.74	-0.04	3.74	-0.50	3.74
CMI	1.02	1.57	0.92	4.01	-	-	0.92	1.61	0.90	1.56	0.89	1.57	0.42	1.57
BEV	0.11	0.70	0.01	3.76	-0.92	1.61	-	-	-0.02	0.69	-0.03	0.70	-0.50	0.69
SMU	0.12	0.60	0.02	3.74	-0.90	1.56	0.02	0.69	-	-	-0.01	0.59	-0.48	0.59
NMi-VSL	0.14	0.61	0.04	3.74	-0.89	1.57	0.03	0.70	0.01	0.59	-	-	-0.47	0.60
CEM	0.60	0.61	0.50	3.74	-0.42	1.57	0.50	0.69	0.48	0.59	0.47	0.60	-	-
INETI	-2.39	6.53	-2.49	7.50	-3.42	6.69	-2.50	6.54	-2.52	6.53	-2.53	6.53	-3.00	6.53
METAS	0.29	0.60	0.19	3.74	-0.73	1.57	0.19	0.69	0.17	0.58	0.16	0.59	-0.31	0.59
PTB	0.44	0.60	0.35	3.74	-0.58	1.56	0.34	0.69	0.32	0.58	0.31	0.59	-0.16	0.59
BIPM	0.28	0.61	0.18	3.74	-0.74	1.57	0.17	0.69	0.16	0.59	0.14	0.60	-0.32	0.59
EIM	-0.26	0.66	-0.36	3.75	-1.28	1.59	-0.36	0.74	-0.38	0.64	-0.39	0.65	-0.86	0.65
SIQ	0.59	6.12	0.49	7.14	-0.43	6.28	0.49	6.12	0.47	6.11	0.46	6.11	-0.01	6.11
OMH	-0.36	6.50	-0.46	7.47	-1.38	6.66	-0.46	6.51	-0.48	6.50	-0.49	6.50	-0.96	6.50

Table D8: Degrees of equivalence between pairs of laboratories, D_{ij} with the expanded uncertainties, U_{ij} (continued)

Lab i	Lab j INETI D_{ij} (μV)	INETI U_{ij} (μV)	METAS D_{ij} (μV)	METAS U_{ij} (μV)	PTB D_{ij} (μV)	PTB U_{ij} (μV)	BIPM D_{ij} (μV)	BIPM U_{ij} (μV)	EIM D_{ij} (μV)	EIM U_{ij} (μV)	SIQ D_{ij} (μV)	SIQ U_{ij} (μV)	OMH D_{ij} (μV)	OMH U_{ij} (μV)
BNM-LNE	3.05	6.54	0.36	0.67	0.21	0.67	0.37	0.68	0.91	0.72	0.06	6.12	1.01	6.51
NPL	2.33	6.53	-0.36	0.59	-0.51	0.58	-0.34	0.59	0.19	0.64	-0.66	6.11	0.30	6.50
NML	2.51	7.71	-0.18	4.13	-0.33	4.13	-0.17	4.14	0.37	4.14	-0.48	7.36	0.47	7.68
UME	2.65	6.53	-0.04	0.58	-0.19	0.58	-0.03	0.59	0.51	0.64	-0.34	6.11	0.61	6.50
DFM	2.68	6.53	-0.01	0.59	-0.16	0.59	0.01	0.60	0.54	0.65	-0.31	6.11	0.65	6.50
SP	2.63	6.53	-0.06	0.60	-0.21	0.59	-0.05	0.60	0.49	0.65	-0.36	6.12	0.59	6.50
MIKES	2.58	6.53	-0.11	0.61	-0.26	0.61	-0.09	0.61	0.44	0.67	-0.41	6.12	0.55	6.50
JV	2.39	6.53	-0.29	0.60	-0.44	0.60	-0.28	0.61	0.26	0.66	-0.59	6.12	0.36	6.50
SMD	2.49	7.50	-0.19	3.74	-0.35	3.74	-0.18	3.74	0.36	3.75	-0.49	7.14	0.46	7.47
CMI	3.42	6.69	0.73	1.57	0.58	1.56	0.74	1.57	1.28	1.59	0.43	6.28	1.38	6.66
BEV	2.50	6.54	-0.19	0.69	-0.34	0.69	-0.17	0.69	0.36	0.74	-0.49	6.12	0.46	6.51
SMU	2.52	6.53	-0.17	0.58	-0.32	0.58	-0.16	0.59	0.38	0.64	-0.47	6.11	0.48	6.50
NMi-VSL	2.53	6.53	-0.16	0.59	-0.31	0.59	-0.14	0.60	0.39	0.65	-0.46	6.11	0.49	6.50
CEM	3.00	6.53	0.31	0.59	0.16	0.59	0.32	0.59	0.86	0.65	0.01	6.11	0.96	6.50
INETI	-	-	-2.69	6.53	-2.84	6.53	-2.67	6.53	-2.14	6.53	-2.99	8.93	-2.04	9.19
METAS	2.69	6.53	-	-	-0.15	0.58	0.01	0.59	0.55	0.64	-0.30	6.11	0.65	6.50
PTB	2.84	6.53	0.15	0.58	-	-	0.17	0.59	0.70	0.64	-0.15	6.11	0.80	6.50
BIPM	2.67	6.53	-0.01	0.59	-0.17	0.59	-	-	0.54	0.65	-0.31	6.11	0.64	6.50
EIM	2.14	6.53	-0.55	0.64	-0.70	0.64	-0.54	0.65	-	-	-0.85	6.12	0.10	6.50
SIQ	2.99	8.93	0.30	6.11	0.15	6.11	0.31	6.11	0.85	6.12	-	-	0.95	8.90
OMH	2.04	9.19	-0.65	6.50	-0.80	6.50	-0.64	6.50	-0.10	6.50	-0.95	8.90	-	-

Table D9: Degrees of equivalence between pairs of laboratories, D_{ij} with the expanded uncertainties, U_{ij} (continued)

APPENDIX E: Comparison Summary

Comparison: **EUROMET.EM.BIPM-K11**

Measurand: **DC Voltage at 10 V**

Pilot laboratory: **NMi-VSL**

Δ_G the result of a participant for its voltage measurements on a group of electronic DC voltage standards. This result is calculated as the weighted mean of the voltage differences between the participant's measured values and interpolated values based on the measurements of the pilot laboratory.

U_{TG} the expanded uncertainty ($k = 2$) in a participant's measurement result for the group of traveling standards.

Table E10: Measurement results and expanded uncertainties (k = 2)

VSL Zener Group			
Lab	**Date of measurement**	**Δ_G (μV)**	**U_{TG} (μV)**
BNM-LNE	December 2, 1998	0.497	0.529
NPL	January 16, 1999	-0.217	0.416
NML	January 30, 1999	-0.042	4.114
UME	March 6, 1999	0.097	0.409
DFM	April 24, 1999	0.134	0.424
SP	May 8, 1999	0.076	0.428
MIKES	June 9, 1999	0.034	0.450
JV	June 27, 1999	-0.154	0.438
SMD	September 5, 1999	-0.055	3.716
CMI	October 23, 1999	0.867	1.509
BEV	November 4, 1999	-0.048	0.551
SMU	November 24, 1999	-0.030	0.411
NMi-VSL	December 19, 1999	-0.019	0.425
CEM	January 15, 2000	0.449	0.420
INETI	January 27, 2000	-2.549	6.515
METAS	March 12, 2000	0.140	0.415
PTB	April 14, 2000	0.291	0.410
BIPM	April 30, 2000	0.125	0.419
EIM	October 7, 2000	-0.411	0.490
SIQ	October 22, 2000	0.439	6.100
OMH	November 5, 2000	-0.513	6.484

The comparison reference value, *ERV* is obtained from the weighted mean of the results of those participants, i, who have an independent realisation of the volt by means of a Josephson Array Voltage Standard (JAVS). In Table E3a, these laboratories are indicated by (*). The reference value, *ERV* and the expanded uncertainty, U_{ERV} in this reference value are given by:

$$ERV = \frac{\sum_{\mathrm{i=1}}^{\mathrm{N}} w_{\mathrm{i}} \Delta_{\mathrm{G,i}}}{\sum_{\mathrm{i=1}}^{\mathrm{N}} w_{\mathrm{i}}} \qquad \text{with uncertainty } (k = 2): \qquad U_{\mathrm{ERV}} = \frac{1}{\sqrt{\sum_{\mathrm{i=1}}^{\mathrm{N}} w_{\mathrm{i}}}} \quad ,$$

with $N = 15$ the number of independent participants. The weighing factor w_{i} is given by:

$$w_i = \frac{1}{U_{TG,i}^2} \; .$$

The values of *ERV* and U_{ERV} are given in Table E2.

Table E11: The EUROMET Reference Value and its expanded uncertainty ($k = 2$)

***ERV* (µV)**	**U_{ERV} (µV)**
0.067	0.113

The degree of equivalence D_{i} of each laboratory with respect to the reference value is given by:

$$D_{\mathrm{i}} = \Delta_{\mathrm{G,i}} - ERV \; ,$$

with the expandanded uncertainty:

$$U_{\mathrm{i}} = \sqrt{U_{\mathrm{TG,i}}^2 - U_{\mathrm{ERV}}^2} \quad \text{for independent laboratories and}$$

$$U_{\mathrm{i}} = \sqrt{U_{\mathrm{TG,i}}^2 + U_{\mathrm{ERV}}^2} \quad \text{for laboratories that do not have an independent realisation of the volt.}$$

The degree of equivalence D_{ij} between any pair of laboratories i and j is given by:

$$D_{\mathrm{ij}} = \Delta_{\mathrm{G,i}} - \Delta_{\mathrm{G,j}} \, ,$$

with an expanded uncertainty:

$$U_{\mathrm{ij}} = \sqrt{U_{\mathrm{TG,i}}^2 + U_{\mathrm{TG,j}}^2} \; .$$

Correlations between laboratories are not taken into account by this last equation, because they are expected to be negligible.

Table E12a: Degrees of equivalence and expanded uncertainties. (Laboratories indicated with * have an independent realisation of the volt).

			Lab *j*													
			BNM-LNE		NPL		NML		UME		DFM		SP		MIKES	
Lab *i*	D_i (µV)	U_i (µV)	D_{ij} (µV)	U_{ij} (µV)	D_{ij} (µV)	U_{ij} (µV)	D_{ij} (µV)	U_{ij} (µV)	D_{ij} (µV)	U_{ij} (µV)	D_{ij} (µV)	U_{ij} (µV)	D_{ij} (µV)	U_{ij} (µV)	D_{ij} (µV)	U_{ij} (µV)
BNM-LNE*	0.43	0.52	-	-	0.71	0.67	0.54	4.15	0.40	0.67	0.36	0.68	0.42	0.68	0.46	0.69
NPL*	-0.28	0.40	-0.71	0.67	-	-	-0.17	4.14	-0.31	0.58	-0.35	0.59	-0.29	0.60	-0.25	0.61
NML	-0.11	4.12	-0.54	4.15	0.17	4.14	-	-	-0.14	4.13	-0.18	4.14	-0.12	4.14	-0.08	4.14
UME*	0.03	0.39	-0.40	0.67	0.31	0.58	0.14	4.13	-	-	-0.04	0.59	0.02	0.59	0.06	0.61
DFM*	0.07	0.41	-0.36	0.68	0.35	0.59	0.18	4.14	0.04	0.59	-	-	0.06	0.60	0.10	0.62
SP*	0.01	0.41	-0.42	0.68	0.29	0.60	0.12	4.14	-0.02	0.59	-0.06	0.60	-	-	0.04	0.62
MIKES*	-0.03	0.44	-0.46	0.69	0.25	0.61	0.08	4.14	-0.06	0.61	-0.10	0.62	-0.04	0.62	-	-
JV*	-0.22	0.42	-0.65	0.69	0.06	0.60	-0.11	4.14	-0.25	0.60	-0.29	0.61	-0.23	0.61	-0.19	0.63
SMD	-0.12	3.72	-0.55	3.75	0.16	3.74	-0.01	5.54	-0.15	3.74	-0.19	3.74	-0.13	3.74	-0.09	3.74
CMI	0.80	1.51	0.37	1.60	1.08	1.57	0.91	4.38	0.77	1.56	0.73	1.57	0.79	1.57	0.83	1.57
BEV*	-0.12	0.54	-0.55	0.76	0.17	0.69	-0.01	4.15	-0.15	0.69	-0.18	0.70	-0.13	0.70	-0.08	0.71
SMU*	-0.10	0.40	-0.53	0.67	0.19	0.58	0.01	4.13	-0.13	0.58	-0.16	0.59	-0.11	0.59	-0.06	0.61
NMi-VSL*	-0.09	0.41	-0.52	0.68	0.20	0.59	0.02	4.14	-0.12	0.59	-0.15	0.60	-0.10	0.60	-0.05	0.62
CEM*	0.38	0.40	-0.05	0.68	0.67	0.59	0.49	4.14	0.35	0.59	0.32	0.60	0.37	0.60	0.42	0.62
INETI	-2.62	6.52	-3.05	6.54	-2.33	6.53	-2.51	7.71	-2.65	6.53	-2.68	6.53	-2.63	6.53	-2.58	6.53
METAS*	0.07	0.40	-0.36	0.67	0.36	0.59	0.18	4.13	0.04	0.58	0.01	0.59	0.06	0.60	0.11	0.61
PTB*	0.22	0.39	-0.21	0.67	0.51	0.58	0.33	4.13	0.19	0.58	0.16	0.59	0.21	0.59	0.26	0.61
BIPM*	0.06	0.40	-0.37	0.68	0.34	0.59	0.17	4.14	0.03	0.59	-0.01	0.60	0.05	0.60	0.09	0.61
EIM*	-0.48	0.48	-0.91	0.72	-0.19	0.64	-0.37	4.14	-0.51	0.64	-0.54	0.65	-0.49	0.65	-0.44	0.67
SIQ	0.37	6.10	-0.06	6.12	0.66	6.11	0.48	7.36	0.34	6.11	0.31	6.11	0.36	6.12	0.41	6.12
OMH	-0.58	6.49	-1.01	6.51	-0.30	6.50	-0.47	7.68	-0.61	6.50	-0.65	6.50	-0.59	6.50	-0.55	6.50

Table E3b: Degrees of equivalence and expanded uncertainties

Lab *j*	JV		SMD		CMI		BEV		SMU		NMi-VSL		CEM	
Lab *i*	D_{ij} (µV)	U_{ij} (µV)	D_{ij} (µV)	U_{ij} (µV)	D_{ij} (µV)	U_{ij} (µV)	D_{ij} (µV)	U_{ij} (µV)	D_{ij} (µV)	U_{ij} (µV)	D_{ij} (µV)	U_{ij} (µV)	D_{ij} (µV)	U_{ij} (µV)
BNM-LNE	0.65	0.69	0.55	3.75	-0.37	1.60	0.55	0.76	0.53	0.67	0.52	0.68	0.05	0.68
NPL	-0.06	0.60	-0.16	3.74	-1.08	1.57	-0.17	0.69	-0.19	0.58	-0.20	0.59	-0.67	0.59
NML	0.11	4.14	0.01	5.54	-0.91	4.38	0.01	4.15	-0.01	4.13	-0.02	4.14	-0.49	4.14
UME	0.25	0.60	0.15	3.74	-0.77	1.56	0.15	0.69	0.13	0.58	0.12	0.59	-0.35	0.59
DFM	0.29	0.61	0.19	3.74	-0.73	1.57	0.18	0.70	0.16	0.59	0.15	0.60	-0.32	0.60
SP	0.23	0.61	0.13	3.74	-0.79	1.57	0.13	0.70	0.11	0.59	0.10	0.60	-0.37	0.60
MIKES	0.19	0.63	0.09	3.74	-0.83	1.57	0.08	0.71	0.06	0.61	0.05	0.62	-0.42	0.62
JV	-	-	-0.10	3.74	-1.02	1.57	-0.11	0.70	-0.12	0.60	-0.14	0.61	-0.60	0.61
SMD	0.10	3.74	-	-	-0.92	4.01	-0.01	3.76	-0.02	3.74	-0.04	3.74	-0.50	3.74
CMI	1.02	1.57	0.92	4.01	-	-	0.92	1.61	0.90	1.56	0.89	1.57	0.42	1.57
BEV	0.11	0.70	0.01	3.76	-0.92	1.61	-	-	-0.02	0.69	-0.03	0.70	-0.50	0.69
SMU	0.12	0.60	0.02	3.74	-0.90	1.56	0.02	0.69	-	-	-0.01	0.59	-0.48	0.59
NMi-VSL	0.14	0.61	0.04	3.74	-0.89	1.57	0.03	0.70	0.01	0.59	-	-	-0.47	0.60
CEM	0.60	0.61	0.50	3.74	-0.42	1.57	0.50	0.69	0.48	0.59	0.47	0.60	-	-
INETI	-2.39	6.53	-2.49	7.50	-3.42	6.69	-2.50	6.54	-2.52	6.53	-2.53	6.53	-3.00	6.53
METAS	0.29	0.60	0.19	3.74	-0.73	1.57	0.19	0.69	0.17	0.58	0.16	0.59	-0.31	0.59
PTB	0.44	0.60	0.35	3.74	-0.58	1.56	0.34	0.69	0.32	0.58	0.31	0.59	-0.16	0.59
BIPM	0.28	0.61	0.18	3.74	-0.74	1.57	0.17	0.69	0.16	0.59	0.14	0.60	-0.32	0.59
EIM	-0.26	0.66	-0.36	3.75	-1.28	1.59	-0.36	0.74	-0.38	0.64	-0.39	0.65	-0.86	0.65
SIQ	0.59	6.12	0.49	7.14	-0.43	6.28	0.49	6.12	0.47	6.11	0.46	6.11	-0.01	6.11
OMH	-0.36	6.50	-0.46	7.47	-1.38	6.66	-0.46	6.51	-0.48	6.50	-0.49	6.50	-0.96	6.50

Table E3c: Degrees of equivalence and expanded uncertainties

Lab *i*	Lab *j*: INETI		METAS		PTB		BIPM		EIM		SIQ		OMH	
	D_{ij} (μV)	U_{ij} (μV)	D_{ij} (μV)	U_{ij} (μV)	D_{ij} (μV)	U_{ij} (μV)	D_{ij} (μV)	U_{ij} (μV)	D_{ij} (μV)	U_{ij} (μV)	D_{ij} (μV)	U_{ij} (μV)	D_{ij} (μV)	U_{ij} (μV)
BNM-LNE	3.05	6.54	0.36	0.67	0.21	0.67	0.37	0.68	0.91	0.72	0.06	6.12	1.01	6.51
NPL	2.33	6.53	-0.36	0.59	-0.51	0.58	-0.34	0.59	0.19	0.64	-0.66	6.11	0.30	6.50
NML	2.51	7.71	-0.18	4.13	-0.33	4.13	-0.17	4.14	0.37	4.14	-0.48	7.36	0.47	7.68
UME	2.65	6.53	-0.04	0.58	-0.19	0.58	-0.03	0.59	0.51	0.64	-0.34	6.11	0.61	6.50
DFM	2.68	6.53	-0.01	0.59	-0.16	0.59	0.01	0.60	0.54	0.65	-0.31	6.11	0.65	6.50
SP	2.63	6.53	-0.06	0.60	-0.21	0.59	-0.05	0.60	0.49	0.65	-0.36	6.12	0.59	6.50
MIKES	2.58	6.53	-0.11	0.61	-0.26	0.61	-0.09	0.61	0.44	0.67	-0.41	6.12	0.55	6.50
JV	2.39	6.53	-0.29	0.60	-0.44	0.60	-0.28	0.61	0.26	0.66	-0.59	6.12	0.36	6.50
SMD	2.49	7.50	-0.19	3.74	-0.35	3.74	-0.18	3.74	0.36	3.75	-0.49	7.14	0.46	7.47
CMI	3.42	6.69	0.73	1.57	0.58	1.56	0.74	1.57	1.28	1.59	0.43	6.28	1.38	6.66
BEV	2.50	6.54	-0.19	0.69	-0.34	0.69	-0.17	0.69	0.36	0.74	-0.49	6.12	0.46	6.51
SMU	2.52	6.53	-0.17	0.58	-0.32	0.58	-0.16	0.59	0.38	0.64	-0.47	6.11	0.48	6.50
NMi-VSL	2.53	6.53	-0.16	0.59	-0.31	0.59	-0.14	0.60	0.39	0.65	-0.46	6.11	0.49	6.50
CEM	3.00	6.53	0.31	0.59	0.16	0.59	0.32	0.59	0.86	0.65	0.01	6.11	0.96	6.50
INETI	-	-	-2.69	6.53	-2.84	6.53	-2.67	6.53	-2.14	6.53	-2.99	8.93	-2.04	9.19
METAS	2.69	6.53	-	-	-0.15	0.58	0.01	0.59	0.55	0.64	-0.30	6.11	0.65	6.50
PTB	2.84	6.53	0.15	0.58	-	-	0.17	0.59	0.70	0.64	-0.15	6.11	0.80	6.50
BIPM	2.67	6.53	-0.01	0.59	-0.17	0.59	-	-	0.54	0.65	-0.31	6.11	0.64	6.50
EIM	2.14	6.53	-0.55	0.64	-0.70	0.64	-0.54	0.65	-	-	-0.85	6.12	0.10	6.50
SIQ	2.99	8.93	0.30	6.11	0.15	6.11	0.31	6.11	0.85	6.12	-	-	0.95	8.90
OMH	2.04	9.19	-0.65	6.50	-0.80	6.50	-0.64	6.50	-0.10	6.50	-0.95	8.90	-	-

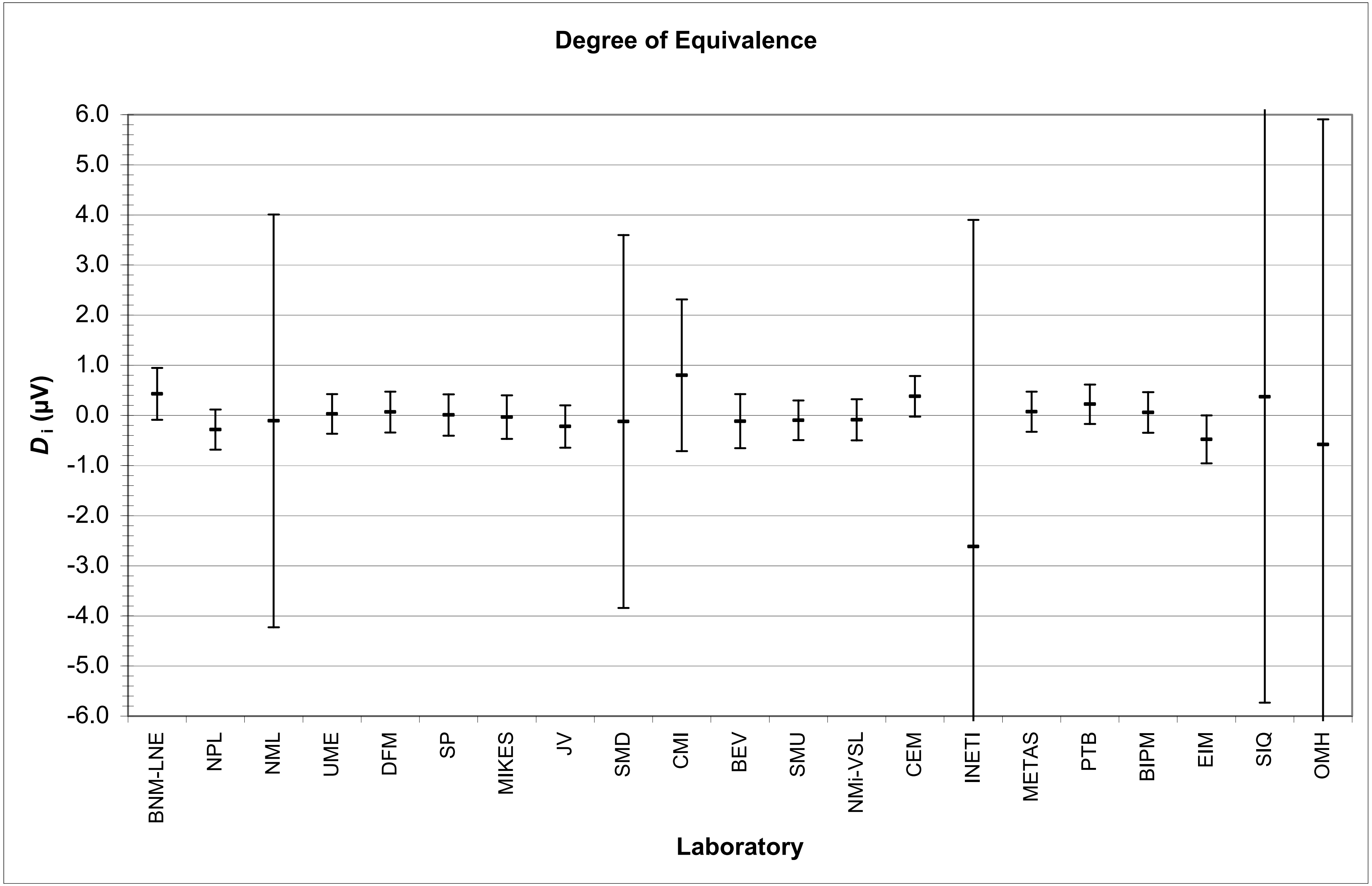

Figure E2a: Degree of equivalence with respect to the *ERV* for each laboratory

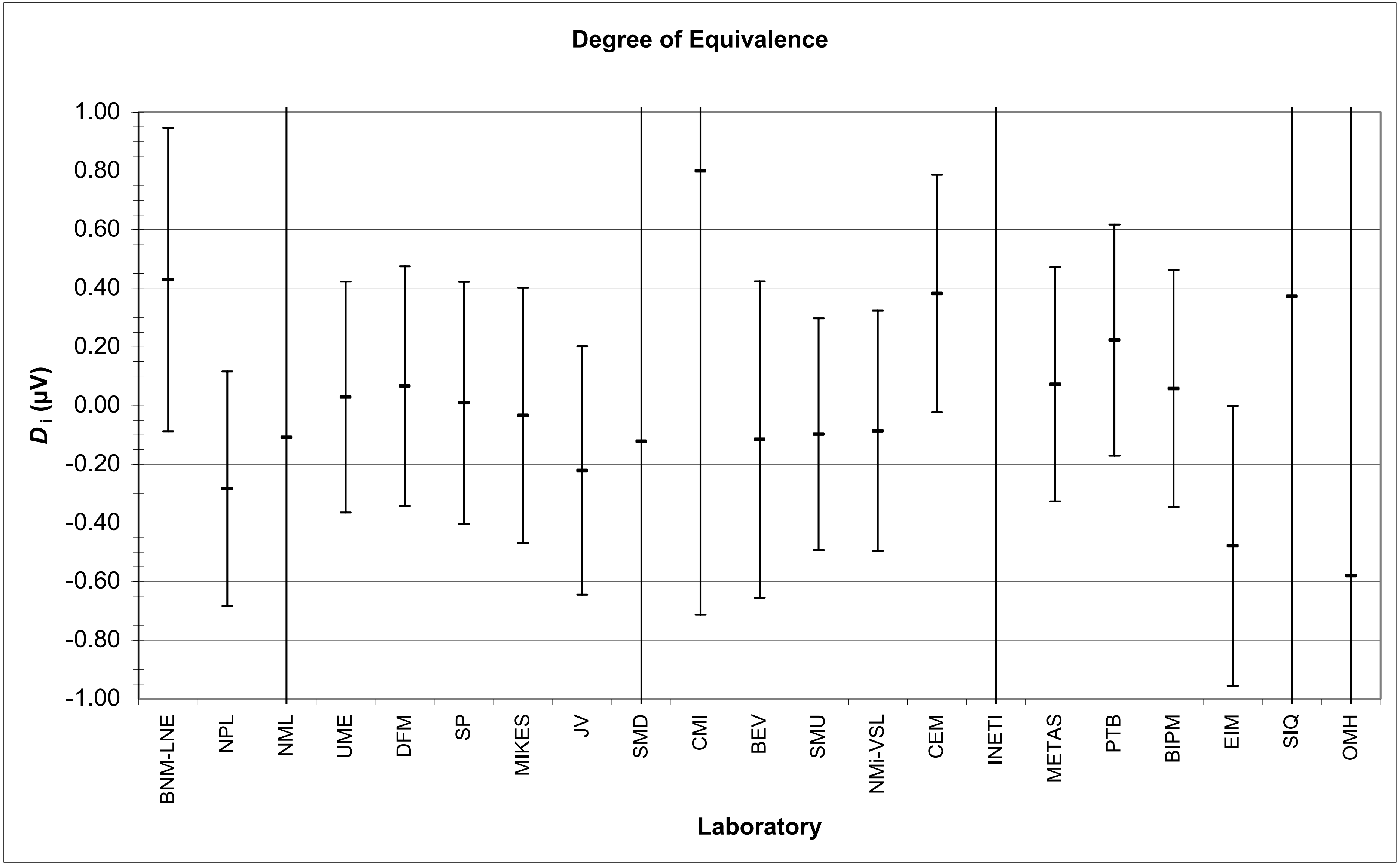

Figure E1b: Degree of equivalence with respect to the *ERV* for each laboratory (in a detailed picture)

APPENDIX F: Technical Protocol

EUROMET PROJECT NO. 429: COMPARISON ON 10 V DC VOLTAGE

Technical protocol

(September 2000)

CONTENTS

1. PURPOSE

At the Euromet *JAVS and QHRS experts meeting*, held in Lisbon on 27 and 28 May 1997, it was proposed to organize an Euromet comparison on 10 V DC voltage. At the Euromet *Electricity Contact Persons meeting*, held in Madrid on 29 and 30 October 1997, the comparison on 10 V DC voltage was assigned the status of Euromet key comparison.

Primary and secondary DC voltage standards are of fundamental importance for the traceability of electrical measurements. The primary standard for DC voltage is formed by the Josephson Array Voltage Standard (JAVS). Due to the development of 10 V Josephson Arrays, the 10 V level has recently become the most important and accurately-known level to maintain secondary, electronic standards. These electronic standards form the main starting point for further realisation of the voltage scale and the traceability of other electrical units.
The JAVSs of the National Metrology Laboratories have been, or will be, compared with the transportable JAVS of the Bureau International des Poids et Mesures (BIPM). No European comparison has yet been organised to compare the results of routine 10 V calibration measurements on secondary electronic standards by using JAVSs (or other national standards).
Such comparison of 10 V calibration results, contributing to the system of ‘key comparisons’, will accelerate the development of measurement strategies within the field of electrical metrology. It will also facilitate the dissemination of experience and knowledge to less favoured regions, by incorporating in the comparison countries from Eastern and Southern Europe that are building up their facilities and that do not (yet) operate a JAVS as their national standard.

2. THE PACKAGE

The package contains the following items:

<u>Transit case no. 1:</u>

- Fluke 732B electronic DC reference standard — s/n 6025001
- Fluke 732B electronic DC reference standard — s/n 6025002
- AC line power cord (2x)
- Cord for thermistor resistance measurement (2x)
- Hanwell Humbug logger for temperature and humidity — s/n 00399
- ATA carnet for non European-Union countries (optional)

<u>Transit case no. 2:</u>

- Fluke 732B electronic DC reference standard — s/n 6025003
- Fluke 732B electronic DC reference standard — s/n 6025004
- AC line power cord (2x)
- Cord for thermistor resistance measurement (2x)
- ATA carnet for non European-Union countries (optional)

3. THE STANDARDS

Description of the standard

The standards, four Fluke 732B electronic DC reference standards, have an identification as follows:

VSL-1	s/n 6025001
VSL-2	s/n 6025002
VSL-3	s/n 6025003
VSL-4	s/n 6025004

The dimensions of each of these standards are (height x width x depth) 13.4 cm x 9.8 cm x 40.6 cm, with a weight of 5.9 kg.

The Fluke 732 B electronic DC reference standard, henceforth denoted by *the standard*, has two output voltages, nominally 1.018 V and 10 V respectivally. Within the comparison, only the 10 V output will be measured.

Powering of the standard

If not carrying out measurements on the standards, **the standards must continue to receive uninterrupted voltage from the AC line power** (230 V, 50 Hz). Check that the front panel **AC PWR** indicator lights when the standard is connected to the AC line power.

During measurements, the standard should be operated at its internal battery, i.e., disconnected from the AC line power (see section 6). If the battery voltage drops low, the front panel LOW BAT indicator starts blinking and the standard must be plugged into the AC line power immediately to allow for recharging of the battery and to avoid extinguishing the IN CAL indicator.

Front panel indicators

- **AC PWR**
  The AC PWR indicator lights whenever the standard is connected to AC line power (230 V, 50 Hz).

- **IN CAL**
  The IN CAL indicator goes out after excessive drops in battery operating voltage or gross changes in oven temperature.
  If the IN CAL indicator doesn't light, you must immediately contact the pilot laboratory, which will give specific instructions how to proceed.

- **CHARGE**
  The CHARGE indicator lights when the standard is connected to the AC line power and the internal battery is in the charging mode. When the battery is near full charge, the CHARGE indicator goes off.

- **LOW BAT**
  The LOW BAT indicator blinks when approximately 5 hours of battery operation time remains.
  When LOW BAT blinks, plug the standard into the AC line power immediately to avoid extinguishing the IN CAL indicator. The battery is recharged in less than 24 hours with the self-contained automatic battery charger.

Characteristics of the standards

In table 1 an overview is given of the temperature and pressure coefficients of the output voltages $U_{measured}$ of the travelling standards as determined by the BIPM. The temperature effect is expressed in terms of the environmental temperature (α_T) and in terms of the oven thermistor resistance (α_R). The coefficient α_R will be used to make corrections for temperature effects (see measurement procedure).

Standard	Reference thermistor resistance R_0 (kΩ)	Temperature coefficient α_T ($10^{-9} \cdot U_{measured}$ K^{-1})	Temperature coefficient α_R ($10^{-9} \cdot U_{measured}$ Ω^{-1})	Pressure coefficient α_p ($10^{-9} \cdot U_{measured}$ hPa^{-1})
VSL-1	38.55	-1.1 ± 1.9	0.026 ± 0.042	1.67 ± 0.05
VSL-2	38.60	-6.8 ± 2.3	0.159 ± 0.054	1.70 ± 0.03
VSL-3	38.60	-6.9 ± 2.5	0.161 ± 0.058	1.77 ± 0.02
VSL-4	38.40	-4.2 ± 2.6	0.089 ± 0.056	1.94 ± 0.05

Table 13: Temperature and pressure coefficients of $U_{measured}$.

The resistance of the oven temperature thermistor, which is an indicator for the temperature of the zener reference, can be measured via the MONITOR/EXT BAT IN connector at the rear panel of the standard. A special cable is supplied with the standards to measure the two-terminal thermistor resistance with a resistance meter (see measurement procedure).

4. SCHEDULE AND TRANSPORTATION

The comparison will be organized in loops of two or three laboratories in order to allow close monitoring of the behavior of the standard. The package is preferably tranported by car or train. Details concerning the transport will be discussed bilaterally with the participants. In any case, extreme temperature, humidity or pressure changes as well as violent impacts must be avoided. The standards will normally be accompanied by an ATA carnet for non European-Union countries. Each participant is expected to ship or to carry the standard to the next scheduled laboratory.

During transport and stay at the participant's laboratory, the environmental temperature and humidity will be measured continuously by the datalogger in transit case no. 1. Please keep the datalogger with the standards, also during the measurements in your laboratory.

Each arrival and departure of the standards must be communicated to the pilot laboratory using the forms that will be provided. In case of damage or evident malfunctioning of the standards, the laboratory will report immediately to the pilot laboratory, that will give specific instructions.

If unforeseen circumstances prevent a laboratory from carrying out the measurements within the time allocated, it should send the standards without delay to the laboratory next in the schedule. If time allows, the laboratory will get the possibility to carry out the measurements at a later time.

Each laboratory will have two weeks available for its participation to the comparison. This includes the measurements and the transportation of the standards to the next participant. After arrival in the participant's laboratory, the standards should be allowed to stabilise in a temperature and, possibly, humidity controlled room for at least three days before use.

As usual each participating laboratory is responsible for its own costs for the measurements, transportation and any customs charges as well as any damage that may occur within its country.

5. MEASUREMENT INSTRUCTIONS

Precautions

- Do not short the output voltages.
- Make sure not to disconnect the standard from the AC line power for too long a period.
- Avoid extreme temperature, humidity or pressure changes as well as violent impacts.

Stabilization of the standards

After arrival in the participant's laboratory, the standards should be allowed to stabilise in a temperature and, possibly, humidity controlled room for at least three days before use. Don't place the standards too close to each other, this to avoid heating of the standards.

Powering of the standard during the measurements

When not carrying out measurements, the standards must be connected continuously to the AC line power.
Measurements should be carried out with the standard operated at its internal battery, i.e., disconnected from the AC line power. To allow the standard for stabilization, battery-operated measurements should not start any sooner than 2 hours after disconnection of the standard from the AC line power. Restrict the disconnection to 6 hours or less.

In addition to the battery-operated measurements, measurements can be made (and submitted to the pilot laboratory) with the standards connected to the AC line power. Notice that connection to the AC line power during measurement will (probably) have consequences for the connection of guard and/or ground.

Guarding

Assuming that you carry out the voltage measurements with the standards disconnected from the AC line power, the front panel GUARD binding post should be connected to the guard of your measuring system and to the front panel CHASSIS binding post. At one point in your system the guard should be connected to ground.

If measuring while the standards are powered by the AC line power, the CHASSIS must be disconnected from the GUARD to avoid earth loops.

Measuring the internal thermistor resistance

The internal thermistor resistance must be measured for each measurement of a 10 V output voltage. The thermistor resistances of the standards have nominal values between 38 kΩ and 39 kΩ (see Table 1). To avoid heating of the thermistor, the test current should not exceed 10 µA. This implies that most DMMs can not be used in their 100 kΩ range or auto-range setting.

Environmental conditions

The ambient temperature, humidity and pressure must be measured. Corrections must be made for temperature and pressure effects (see next section). Preferably, the measurements should be carried out at nominally 23 °C and 40 % RH.

Making corrections for temperature and pressure effects

The measured voltages U_{measured} should be corrected for temperature and pressure effects. The temperature effect is taken into account through the thermistor resistance R. The following formula should be used to calculate the corrected voltages $U_{\text{corrected}}$:

$$U_{\text{corrected}} = U_{\text{measured}} - \alpha_R \cdot (R - R_0) - \alpha_p \cdot (p - p_0) \quad ,$$

with α_P and α_p the temperature and pressure coefficients as given in Table 1, with p the ambient air pressure, and p_0 = 1013.25 hPa the reference air pressure. The reference thermistor resistances R_0 depend on the specific standard and are given in Table 1.

Obviously, the uncertainties of both the thermistor resistance measurement and the air pressure measurement contribute to the total uncertainty of measurement.

6. CALCULATION OF THE MEASUREMENT UNCERTAINTY

The uncertainty calculations must comply with the requirements of the 'Guide to the Expression of Uncertainty in Measurement' (issued by the International Organization for Standardization, first edition 1993, ISBN 92-67-10188-9). Foreseen sources of uncertainty:

- Type A
- DVM or null-detector gain-error uncertainty
- Uncertainty due to irreversibility of scanner or switch
- Leakage-error uncertainty
- Uncertainty due to uncompensated offset voltages
- Microwave-frequency uncertainty
- Uncertainty due to EMI
- Calibration uncertainty of measurement equipment (e.g., for measuring the thermistor resistance, pressure, etc.)

This is not a complete list and should be extended with uncertainty contributions that are specific for the participant’s measurement system.

7. PARTICIPANT'S REPORT

Software

The participant's report must be sent to NMi-VSL within two months from the completion of his measurements. Reports can also be submitted electronically, using the following software (or lower versions):

- Word 97 or Word Perfect 6.1 for the report including the participant's results
- Excel 97 or Quattro Pro 6.0 for the raw data

Contents of report

The report must contain:

- **The results of the measurement**
  For each reported value the following information must be provided:
  - identification of standard
  - method of powering the standard
  - date and time of measurement
  - time of disconnection from AC line power
  - measured voltage
  - thermistor resistance
  - ambient temperature, humidity, and pressure
  - values of correction for temperature and pressure effects
  - measured voltage corrected for temperature and pressure effects
  - the Type A standard uncertainty
  - the expanded uncertainty of measurement (for $k = 2$)
  - number of averages and degrees of freedom

- **Uncertainty budget and calculation**
  The uncertainty analysis should include a list of all sources of Type B uncertainty, together with the associated standard uncertainties as well as their evaluation method. For clarity, it is recommended to present the uncertainty budget in the form of a table (see, e.g., chapter 4 of the EAL-R2 document 'Expression of the Uncertainty of Measurement in Calibration').
  For each reported value, the expanded uncertainty of measurement, obtained by multiplying the combined standard uncertainty by a coverage factor $k = 2$, must be given.

- **Description of the method of measurement**
  This includes information on:
  - the method applied for correction of offset voltages
    (manual or automatic switching, reversal of null-detector or not, etc.)
  - the method applied for guarding and shielding, and connection to earth
  - method applied for biasing the Josephson array
    (bias on or off during measurement)
  - method for Josephson step number adjustment and maximum value of null voltage
  - 'bandwidth' of the voltage measurement (null-detector analog or digital filtering, number of samples, averaging, etc.)

- **A statement of traceability**
  This is only required if the national standard is not considered to be a primary standard.

8. FINAL REPORT OF THE COMPARISON

The draft version of the final report will be issued within four months after completion of the comparison. The draft report will be sent to the participants and will be discussed during a general project meeting. The final report will be prepared within three months after this meeting.
The whole procedure will be based on Euromet Guidance document no. 3.

9. COORDINATOR AND COMMUNICATIONS

The NMi Van Swinden Laboratorium will coordinate the comparison, provide the standards, and act as reference laboratory.

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A list of participants, including their addresses, can be found in Appendix B.

APPENDIX A: Schedule for Euromet project no. 429

Final version (September 1998)				
Period			**Laboratory**	**Country**
Year	**Week No.**	**Date**		
			NMi-VSL PILOT laboratory	The Netherlands
1998	46 - 47	9 Nov - 20 Nov	BIPM	
	48 - 49	23 Nov - 4 Dec	BNM-LCIE	France
	50 - 1	7 Dec - 8 Jan	NMi-VSL PILOT laboratory	The Netherlands
1999	2 - 3	11 Jan - 22 Jan	NPL	UK
	4 - 5	25 Jan - 5 Feb	NML	Ireland
	6 - 8	8 Feb - 26 Feb	NMi-VSL PILOT laboratory	The Netherlands
	9 - 10	1 Mar - 12 Mar	UME	Turkey
	11 - 12	15 Mar - 26 Mar	BIPM	
	13 - 15	29 Mar - 16 Apr	NMi-VSL PILOT laboratory	The Netherlands
	16 - 17	19 Apr – 30 Apr	DFM	Denmark
	18 - 19	3 May - 14 May	SP	Sweden
	20 - 22	17 May - 4 Jun	NMi-VSL PILOT laboratory	The Netherlands
	23 - 24	7 Jun - 18 Jun	VTT	Finland
	25 - 26	21 Jun - 2 Jul	JV	Norway
	27 - 34	5 Jul - 27 Aug	NMi-VSL PILOT laboratory	The Netherlands
	35 - 36	30 Aug - 10 Sep	BMS	Belgium
	37 - 38	13 Sep - 24 Sep	BIPM	
	39 - 41	27 Sep - 15 Oct	NMi-VSL PILOT laboratory	The Netherlands
	42 - 43	18 Oct - 29 Oct	CMI	Czech Republic
	44 - 45	1 Nov - 12 Nov	BEV	Austria
	46 - 47	15 Nov - 26 Nov	SMU	Slovakia
	49 - 1	29 Nov - 7 Jan	NMi-VSL PILOT laboratory	The Netherlands
2000	2 - 3	10 Jan - 21 Jan	CEM	Spain
	4 - 5	24 Jan - 4 Feb	INETI	Portugal
	6 - 8	7 Feb - 25 Feb	NMi-VSL PILOT laboratory	The Netherlands
	9 - 10	28 Feb - 10 Mar	OFMET	Switzerland
	11 - 12	13 Mar - 24 Mar	IEN	Italy
	13 - 15	27 Mar - 14 Apr	NMi-VSL PILOT laboratory	The Netherlands
	16 - 17	17 Apr - 28 Apr	PTB	Germany
	18 - 19	1 May - 12 May	BIPM	
	20 - 22	15 May - 2 Jun	NMi-VSL PILOT laboratory	The Netherlands
	23 - 24	5 Jun - 16 Jun	GUM	Poland

APPENDIX B: List of participants Euromet project no. 429

- **Bundesamt für Eich- und Vermessungswesen (BEV)**

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