Bilateral Comparison of 10 V and 1.018 V Standards between the NML (Forbairt) and the BIPM, April 1998

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A comparison of the reference standards of voltage of the BIPM and the National Metrology Laboratory (NML, Forbairt), Dublin, Ireland was carried out from 26 February to 12 May 1998. Three BIPM Fluke 732B Zener diode-based travelling standards, designated BIPM4, BIPM5 and BIPM7, were shipped by air freight. The BIPM measurements of the 1.018 V outputs of the travelling standards were carried out by comparison with a reference standard cell whose value is known with respect to the BIPM Josephson voltage standard with a combined standard uncertainty of 10 nV. The BIPM measurements of the 10 V outputs of the travelling standards were carried out by dividing the 10 V output down to 1.018 V using a custom-built resistive divider and comparing this with a reference standard cell whose value is known with respect to the BIPM Josephson voltage standard. The combined standard uncertainty of the link from 10 V to the Josephson standard is 0.01 μV and has been verified by measurements using the BIPM 10 V Josephson array voltage standard.

At the NML, the 10V outputs of the travelling standards were measured by comparison with the mean e.m.f. of the laboratory's reference group of electronic voltage standards. The NML reference group is maintained by means of periodic calibrations and comparisons with BIPM and by correction for temporal drift between these comparisons. The voltage differences between the travelling standards and the NML reference devices were measured using a digital nanovoltmeter and a low-thermal scanner. The usual parameter fitting technique was used to arrive at the values assigned to the outputs of the travelling standards. The NML measurements of the 1.018V outputs of the travelling standards were made using a Measurements International model 8000A potentiometer which operates on the binary divider principle and which was standardised against the NML 10V reference group. Results of all measurements were corrected for the dependence of the output voltages on ambient temperature and pressure using coefficients determined in separate measurements at the BIPM.

Figure 1 shows the results of the 10 V measurements of standard BIPM4) in both laboratories. The measurements were analyzed using a linear least-squares fit to the voltages as a function of time. The straight dashed lines on the graph show the predicted values. The results are referenced to the mean date of the NML measurements, 9 April 1998. In this way, the values and uncertainties of the NML measurements are essentially the same whether we use a least-squares fit or a simple average. The BIPM value and uncertainty for the reference date are also calculated from a linear least-squares fit. Figure 2 shows the results for travelling standard BIPM5 at 10 V. Figure 3 shows the results for travelling standard BIPM7 at 10 V. Figure 4 shows the results for BIPM4 1.018 V; Figure 5 shows the results for BIPM5 1.018 V and Figures 6 shows the results for BIPM7 1.018 V. The model that assumes a linear drift in the Zeners as a function of time seems reasonable in all cases.

Table 1 lists the results of the 10 V comparison and the component uncertainty contributions. The components arising from the uncertainties in the BIPM measurements of the temperature and pressure coefficients would lead to a type B uncertainty if only one travelling standard were used. In the case of more than one, we do not expect significant correlation among the corrections for different standards and in our uncertainty table they are treated as type A uncertainties. In combining the uncertainties we apply the usual method of combining variances to calculate the uncertainty of the mean value of the result. Thus, the final result is calculated from the mean of the results from each travelling standard. Its type A variance is the sum of the type A variances of the travelling standards divided by the square of the number of travelling standards. The total variance is the sum of 1) the type A variance, 2) the type B variances and 3) the variance deduced from the transfer uncertainty.

The final results of the comparison are presented as the difference between the value assigned to a 10 V standard by the NML, U_{NML}, and that assigned by the BIPM, U_{BIPM}, on the reference date. The result is

$$\text{at 10 V:} \qquad U_{\mathrm{NML}} - U_{\mathrm{BIPM}} = -2.5\ \mu\mathrm{V}; \qquad u_c = 2.5\ \mu\mathrm{V} \text{ on 1998/04/09,}$$

where u_c is the combined type A and type B standard uncertainty from both laboratories. This difference corresponds to 2.5 parts in 10^7 of the 10 V output.

Table 2 lists the results of the 1.018 V comparison and the component uncertainty contributions. The components arising from the uncertainties in the BIPM measurements of the temperature and pressure coefficients would lead to a type B uncertainty if only one travelling standard were used. In combining the uncertainties we apply the usual method of combining variances to calculate the uncertainty of the mean value of the result. Thus, the final result is calculated from the mean of the results from each travelling standard. Its type A variance is the sum of the type A variances of the travelling standards divided by the square of the number of travelling standards. The total variance is the sum of 1) the type A variance, 2) the type B variances and 3) the variance deduced from the transfer uncertainty.

The final results of the comparison are presented as the difference between the value assigned to a 1.018 V standard by the NML, U_{NML}, and that assigned by the BIPM, U_{BIPM}, on the reference date. The result is

$$\text{at 1.018 V:} \qquad U_{\mathrm{NML}} - U_{\mathrm{BIPM}} = -0.30\ \mu\mathrm{V}; \qquad u_c = 0.5\ \mu\mathrm{V} \text{ on 1998/04/09,}$$

where u_c is the combined type A and type B standard uncertainty from both laboratories. This difference corresponds to 2.9 parts in 10^7 of the 1.018 V output.

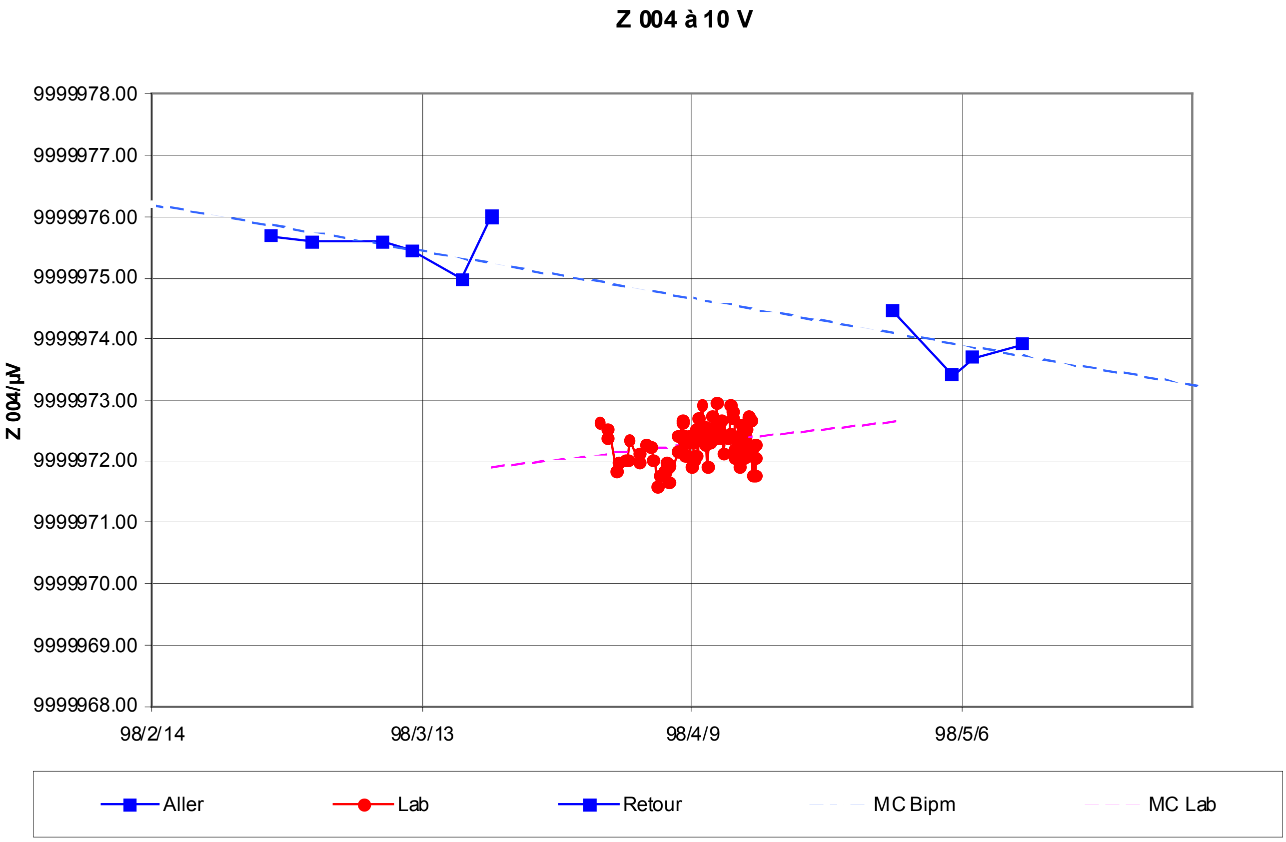

Figure 1. Values assigned to the 10 V output of BIPM4 by the BIPM and the NML during the comparison. The dotted lines are the results of least-squares fits to the BIPM (MC Bipm) and the NML (MC Lab) results.

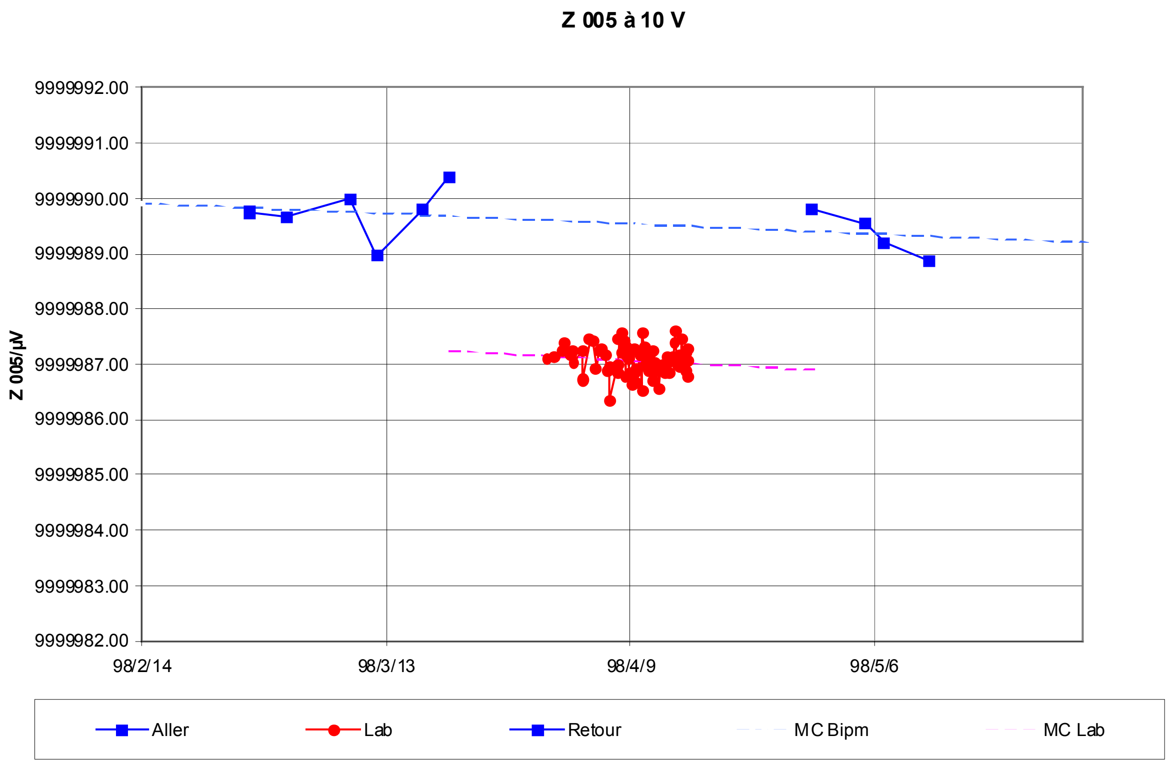

Figure 2. Values assigned to the 10 V output of BIPM5 by the BIPM and the NML during the comparison. The dotted lines are the results of least-squares fits to the BIPM (MC Bipm) and the NML (MC Lab) results.

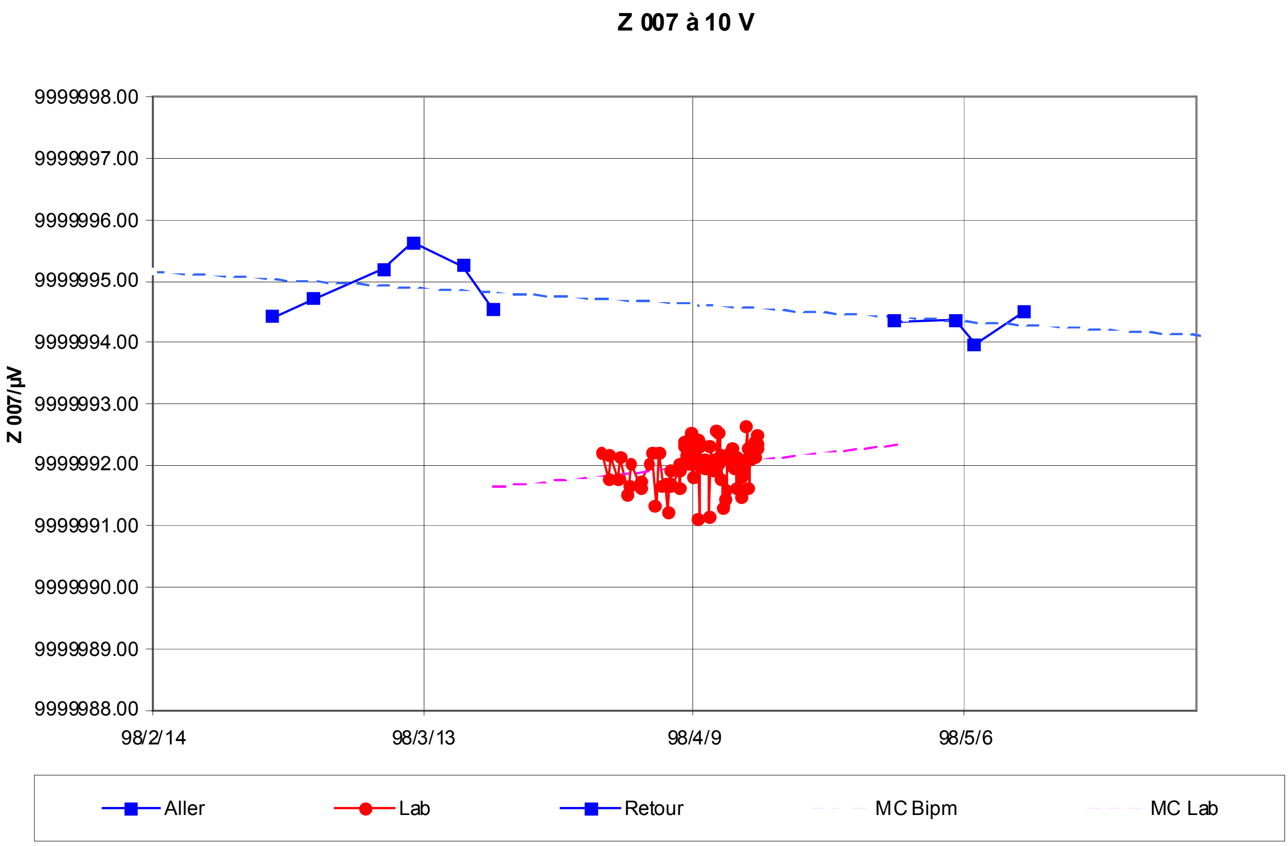

Figure 3. Values assigned to the 10 V output of BIPM7 by the BIPM and the NML during the comparison. The dotted lines are the results of least-squares fits to the BIPM (MC Bipm) and the NML (MC Lab) results.

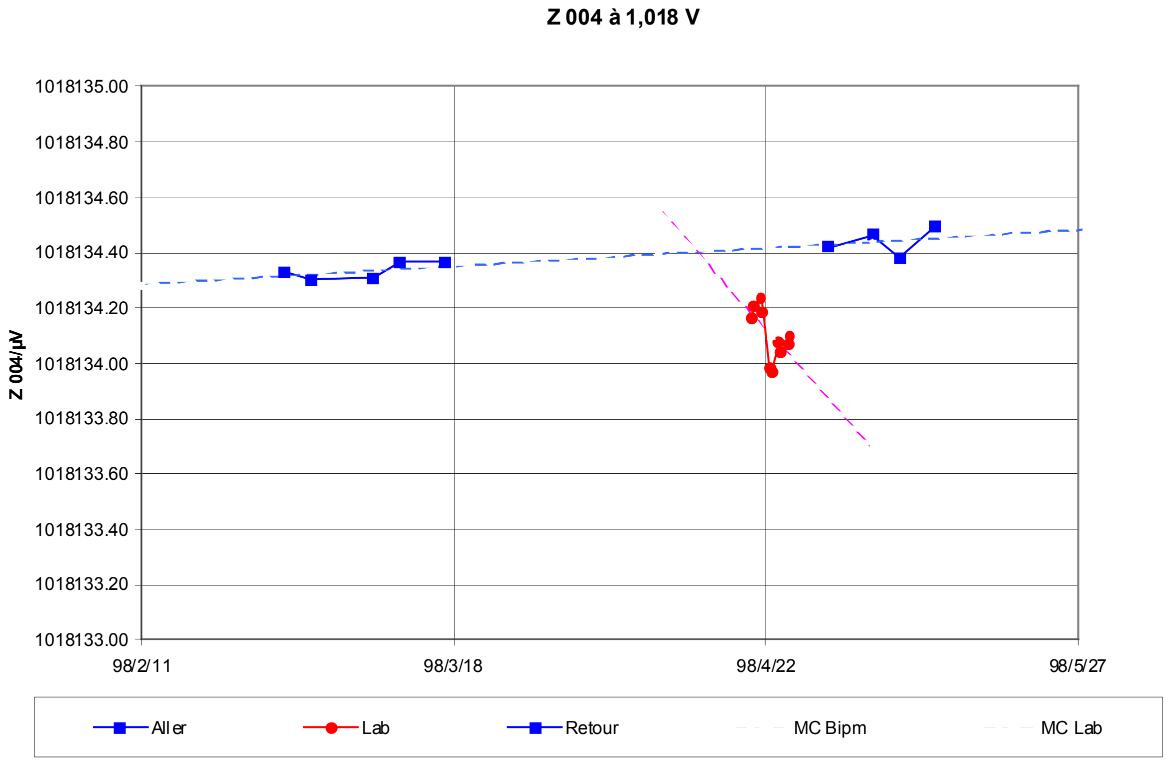

Figure 4. Values assigned to the 1.018 V output of Zener BIPM4 by the NML (Lab) and the BIPM. Dashed lines are the result of linear least-squares fits (MC).

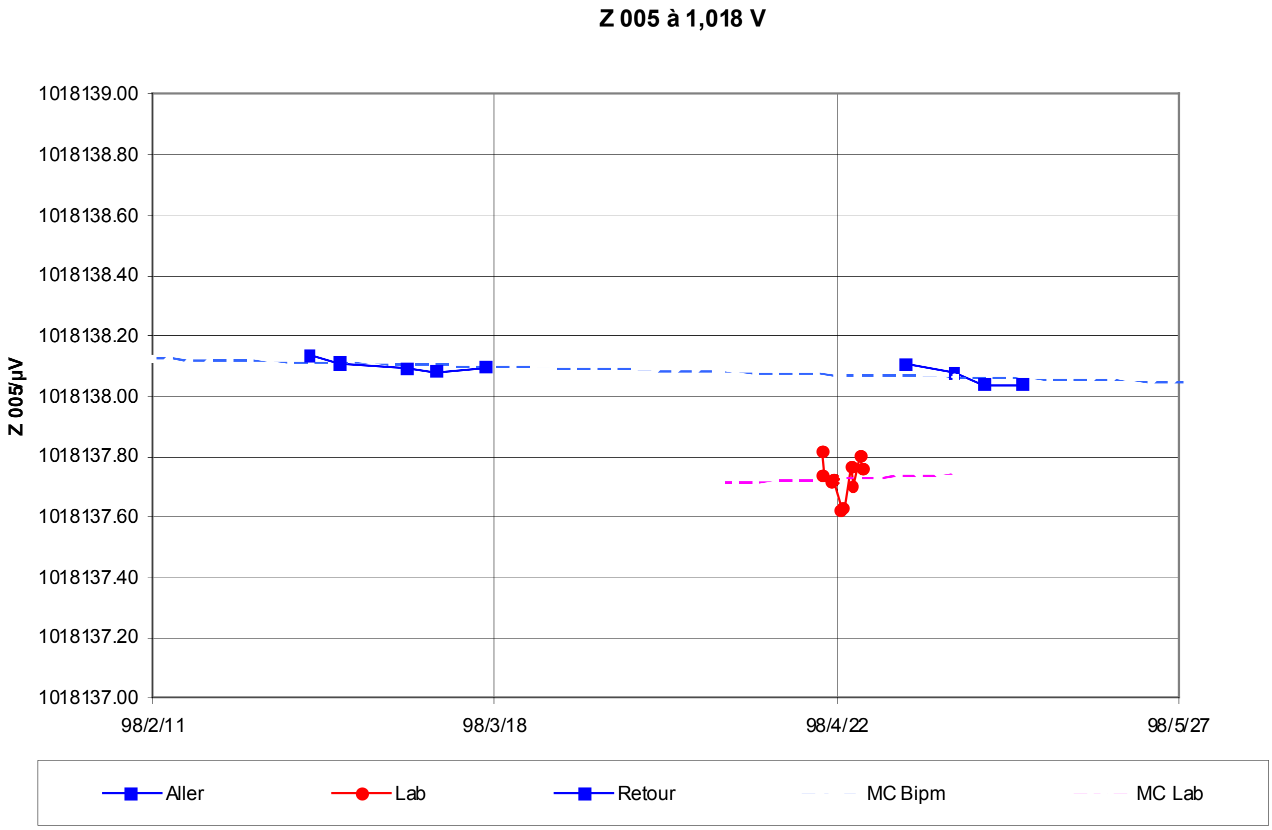

Figure 5. Values assigned to the 1.018 V output of Zener BIPM5 by the NML (Lab) and the BIPM. Dashed lines are the result of linear least-squares fits (MC).

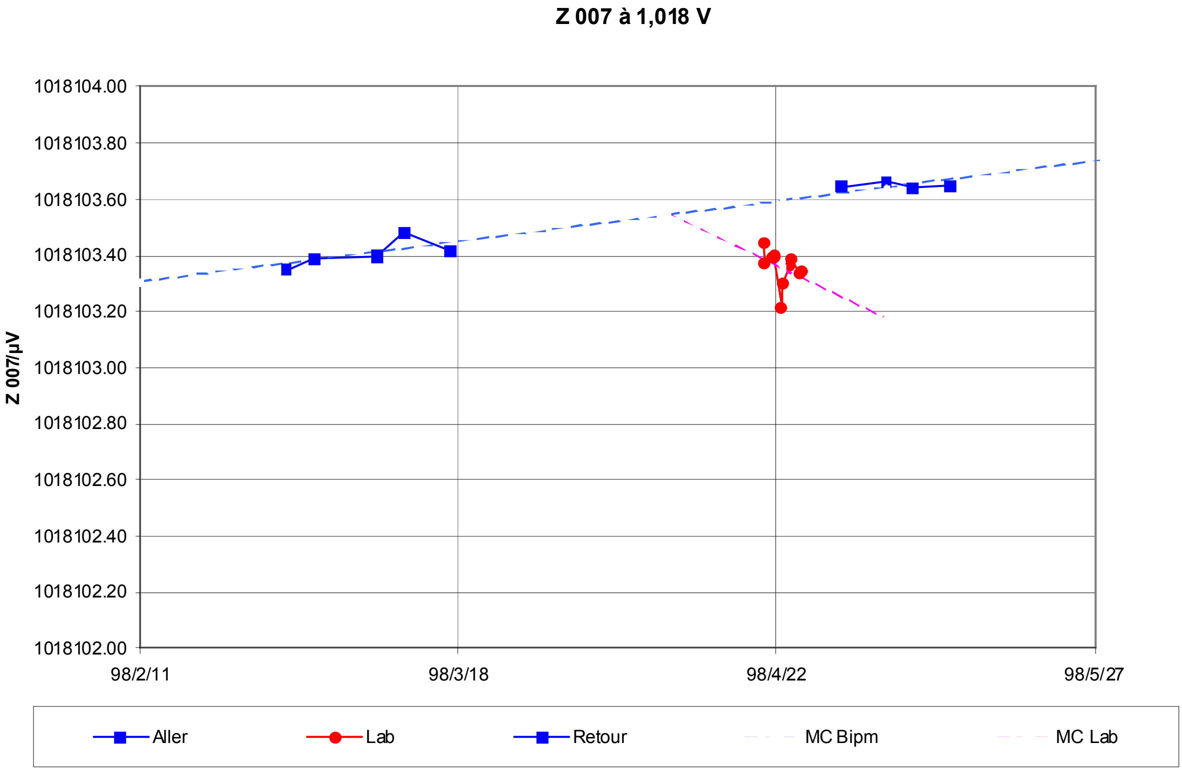

Figure 6. Values assigned to the 1.018 V output of Zener BIPM7 by the NML (Lab) and the BIPM. Dashed lines are the result of linear least-squares fits (MC).

Table 1. Results of the NML/BIPM bilateral comparison of 10V standards using Zener travelling standards. Mean Date: 9 April 1998.

10 V comparison: units are µV

		Z.4 at 10 V	Z.5 at 10 V	Z.7 at 10 V
1	NML value, drift model	9999972.29	9999987.06	9999991.99
2	NML unc (A), drift model	0.03	0.03	0.04
3	NML unc (B)	2.5	2.5	2.5
4	BIPM value, drift model	9999974.65	9999989.54	9999994.61
5	BIPM unc (A), drift model	0.27	0.15	0.16
6	BIPM unc (B)	0.01	0.01	0.01
7	U_{NML} -U_{BIPM}	-2.36	-2.48	-2.62
8	Unc (A) of U_{NML} -U_{BIPM}	0.06		0.08
9	mean U_{NML} -U_{BIPM}	-2.49		
10	unc of transfer	0.08		
11	Total unc of comparison	2.5		
12	mean date yy/mm/dd	98/04/9		

References to Table 1.

1. Results from a linear least-squares fit to the NML data.
2. The type A standard uncertainty following from the least-squares fit to the NML data.
3. The type B uncertainty estimated by the NML.

4-6. Same as 1-3. But for the BIPM results.

7. The comparison result following from each travelling standard.
8. The combined type A uncertainty in 7; the root-sum-square of the contributions from both laboratories.
9. The mean of the results on line 7.
10. The standard deviation of the mean of the results from the three travelling standards.
11. The root-sum-square combination of items in lines 3,6,8 and 10.
12. The mean date of the comparison, the mean date of the NML measurements.

Table 2. Results of the NML/BIPM bilateral comparison of 1.018 V standards using Zener travelling standards. Mean Date: 22 April 1998.

1.018 V comparison: units are μV

		Z.4 at 1.018 V	Z.5 at 1.018 V	Z.7 at 1.018 V
1	NML value, drift model	1018134.104	1018137.727	1018103.355
2	NML unc (A), drift model	0.03	0.02	0.02
3	NML unc (B)	0.5	0.5	0.5
4	BIPM value, drift model	1018134.418	1018138.071	1018103.596
5	BIPM unc (A), drift model	0.04	0.02	0.08
6	BIPM unc (B)	0.01	0.01	0.01
7	U_{NML} - U_{BIPM}	-0.314	-0.344	-0.241
8	Unc (A) of U_{NML} - U_{BIPM}			
9	mean U_{NML} - U_{BIPM}	-0.300		
10	unc of transfer	0.03		
11	Total unc of comparison	0.5		
12	mean date yy/mm/dd	98/04/22		

References to Table 1.
1. Results from a linear least-squares fit to the NML data.
2. The type A standard uncertainty following from the least-squares fit to the NML data.
3. The type B uncertainty estimated by the NML.
4-6. Same as 1-3. But for the BIPM results.
7. The comparison result following from each travelling standard.
8. The combined type A uncertainty in 7; the root-sum-square of the contributions from both laboratories.
9. The mean of the results on line 7.
10. The standard deviation of the mean of the results from the three travelling standards.
11. The root-sum-square combination of items in lines 3,6,8 and 10.
12. The mean date of the comparison, the mean date of the NML measurements.