Final Report
Interamerican Metrology System (SIM)
Regional Metrology Organization (RMO)
High Value Resistance Comparison

SIM.EM-S11:

- **100 MΩ at 10 V and 100 V.**
- **100 GΩ at 30 V, 100 V and 300 V.**

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2014 Comparison
Pilot Laboratory: National Institute of Standards and Technology, Gaithersburg, Maryland USA

Abstract —This is a report of the results of the Interamerican Metrology System (SIM) comparison on high resistance values, performed for compare the measurement capabilities of NIST and ICE-LMVE and for establishing the degree of equivalence between those laboratories. During February 2014, two resistance standards were used as traveling standards for measurements in those countries, with NIST-USA acting as pilot laboratory. Results for five measurement points are presented as errors relative to a comparison reference value together with their uncertainty.

Index Terms — Comparison, resistance, measurement error, measurement uncertainty.

1 Introduction

At the National Institute of Standards and Technology (NIST), the U.S. representation of the ohm is based on the quantum Hall effect, and it is maintained and disseminated at various resistance levels by working reference groups of standards. NIST provides a calibration service for standard resistors of nominal decade values (i.e., $R = 10^n$ where n is an integer) in the range between 10^{-5} Ω and 10^{12} Ω. In addition, non-decade value standard resistors can be calibrated in the lower resistance ranges, near 10^3 Ω or below. To provide this wide-ranging calibration service, NIST maintains a working reference group at each nominal decade value between 1 Ω and 10^{12} Ω. The working reference groups are calibrated using special ratio techniques.

At the ICE-LMVE, the Costa Rican representation of the ohm is based on a group of resistors, which goes for calibration to another NMI that uses a comparison against reference standards calibrated in terms of the quantized Hall resistance using a potentiometric measurement bridge and a modified Wheatstone bridge. To provide the service, ICE-LMVE use a substation method through a commercial Teraohmmeter.

The objective of this comparison is to compare the measurement capabilities of NIST and ICE-LMVE in the field of high value resistance.

ICE-LMVE has been improving its resistance procedures and personnel training. This action is aimed to determine the improvement degree ICE-LMVE has achieved and support new uncertainties that ICE-LMVE will report to SIM for their inclusion in the CIPM MRA KCDB.

SIM.EM-S11 will be an intercomparison of a 100 MΩ resistance standard and a 100 GΩ resistance standard.

The participant institutes are listed in Table 1.

Table 1. Resistance comparison participants

Country	**Institute**	**Acronym**
Costa Rica	Instituto Costarricense de Electricidad	ICE
United States	National Institute of Standards and Technology	NIST

2 Traveling Standards

2.1 Description of the standards

The traveling standard for the SIM.EM-S11 comparison were

- NIST 100 MΩ Resistor, Model # 9336, SN 69318.
- NIST 100 GΩ Standard, Model # HR, SN HR11206.

This Resistance Standards are designed as very high stability calibration laboratory standards for accurate resistance calibration in air. With a wide laboratory environment requirement from 18 °C to 28 °C, they can be used as working standards or reliable, ruggedized, transportable transfer standards.

2.2 Transport Package Description

A plastic container was filled with polyurethane foam to hold the traveling standards and equipment. NIST personal hand carried the standards from NIST to Costa Rica and then back to NIST.

2.3 Quantities to be measured

Participants measured the 100 MΩ at 10 V and 100 V; and the 100 GΩ at (ICE 30 V vs. NIST 50 V), 100 V and 300 V (ICE 300 V vs. NIST 200 V); both values are presented at 23 °C.

All resistance measurements with corresponding combined standard uncertainties were reported. At least four measurements over three days for each voltage were done.

3 Organization

The National Institute of Standards and Technology (NIST) was the pilot laboratory for the SIM.EM-S11 comparison. NIST used a 100 MΩ Resistor and a NIST designed 100 GΩ resistor as reference standards for the measurements. A direct substitution was used. Measurements were taken on the reference standards at both institutes.

The NIST standards were measured at NIST at the beginning and end of the comparison schedule. The NIST standards travelled to ICE laboratory. ICE calibrated both resistors and sent the results to NIST.

The schedule of measurements is shown in Table 2.

Table 2. Schedule of measurements

Laboratory	Approximate measurement dates
NIST (United States)	Before February 4, 2014
ICE (Costa Rica)	February 10, 2014 to February 14, 2014
NIST (United States)	After February 28, 2014

4 Pilot Laboratory Measurement Results

The pilot laboratory measurement results are listed in Table 1 and shown graphically in Figure 1. Results at each voltage consist only of measurements from a Dual Source Resistance Bridge using Hamon Transfer Standards with substitution methods.

4.1 SIM.EM-S11 100 MΩ results

Table 3. Pilot Lab (NIST) measurements for 100 MΩ

Date	Resistance (MΩ)	Voltage (V)	Expanded Uncertainty μΩ/Ω (*k*=2)
Average data Before 12/01/2014	100.003 959	10	
Average data After 28/02/2014	100.003 977	10	
Mean (04/02/2014)	100.003 968	10	2.2
Average data Before 04/02/2014	100.003 957	100	
Average data After 28/02/2014	100.003 961	100	
Mean (16/02/2014)	100.003 959	100	2.2

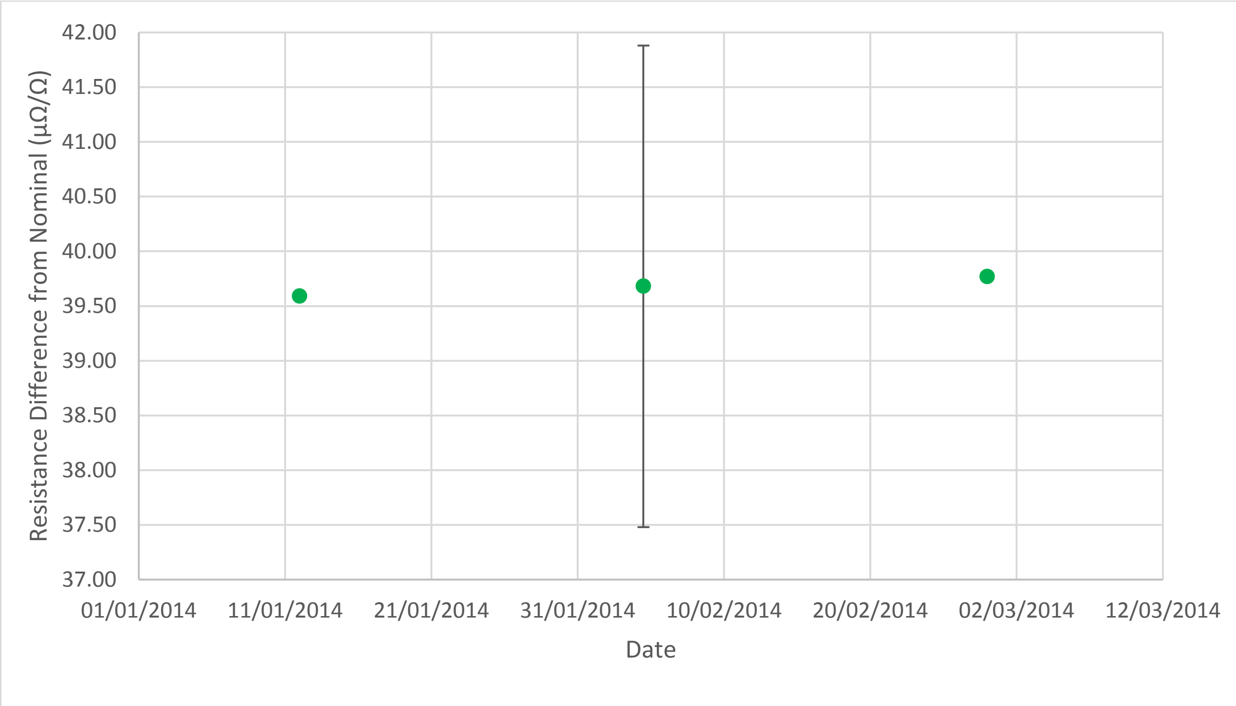

Fig. 1a. Pilot laboratory measurements of NIST 100 MΩ Resistor at 10 V, showing the averages of the before and after measurements. The error bar on the mean value of both averages, showing expanded uncertainty (*k=2*).

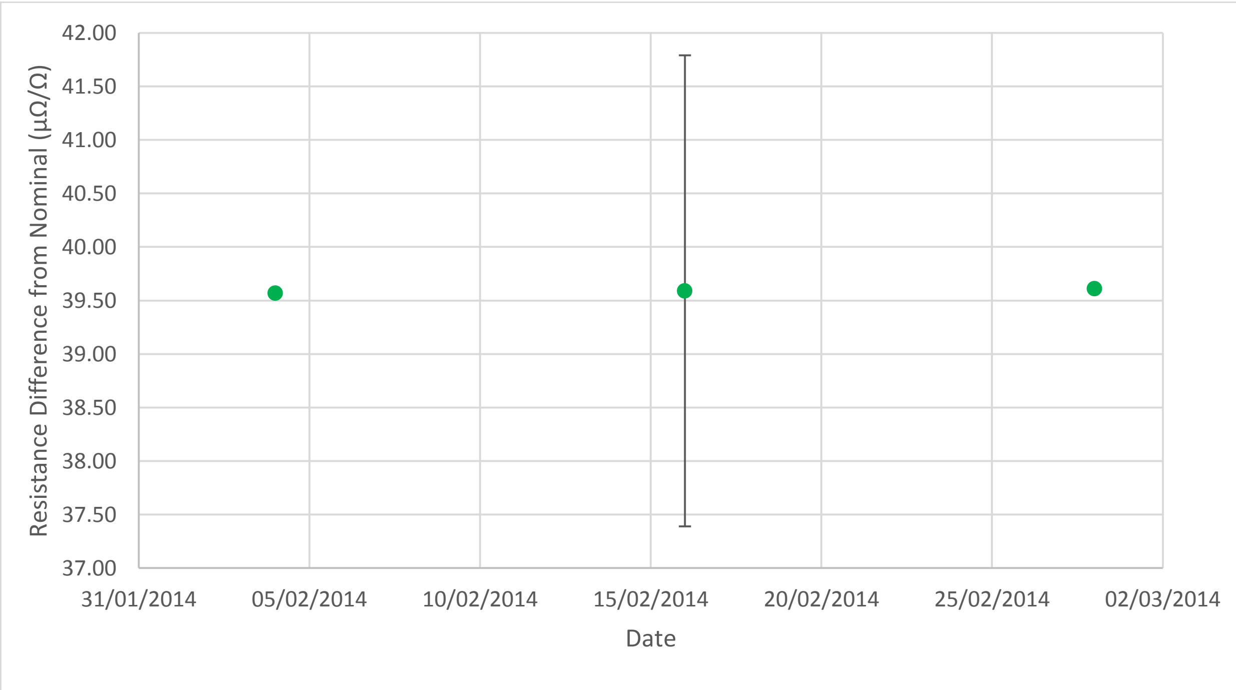

Fig. 1b. Pilot laboratory measurements of NIST 100 MΩ Resistor at 100 V, showing the averages of the before and after measurements. The error bar on the mean value of both averages, showing expanded uncertainty (*k=2*).

4.2 SIM.EM- S11 100 GΩ results

Table 4. Pilot Lab (NIST) measurements for 100 GΩ

Date	Resistance (GΩ)	Voltage (V)	Expanded Uncertainty μΩ/Ω (*k=2*)
Average data Before 04/02/2014	100.262 22	50	
Average data After 28/02/2014	100.262 16	50	
Mean (16/02/2014)	100.262 19	50	12
Average data Before 04/02/2014	100.262 27	100	
Average data After 28/02/2014	100.262 29	100	
Mean (16/02/2014)	100.262 28	100	12
Average data Before 04/02/2014	100.262 42	200	
Average data After 28/02/2014	100.262 45	200	
Mean (16/02/2014)	100.262 43	200	12
Average data Before 04/02/2014	100.262 73	500	
Average data After 28/02/2014	100.262 65	500	
Mean (16/02/2014)	100.262 69	500	8

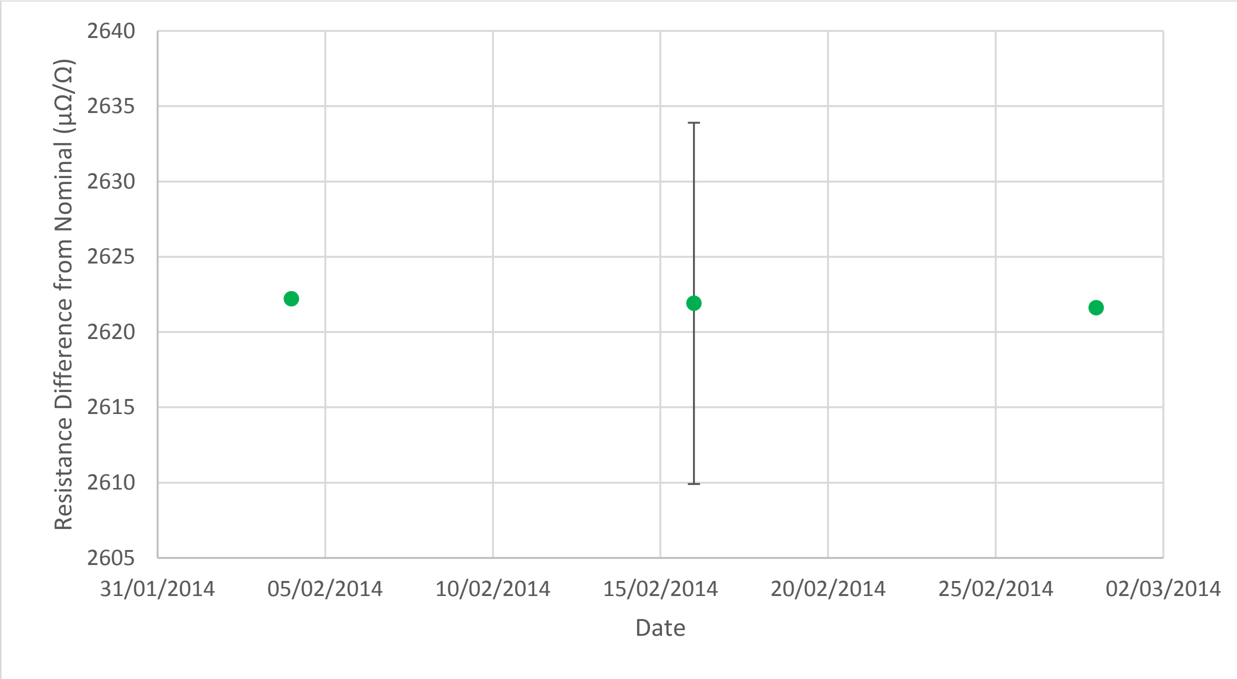

Fig. 2a. Pilot laboratory measurements of NIST 100 GΩ Resistor at 50 V showing the averages of the before and after measurements. The error bar on the mean value of both averages, showing expanded uncertainty (*k=2*).

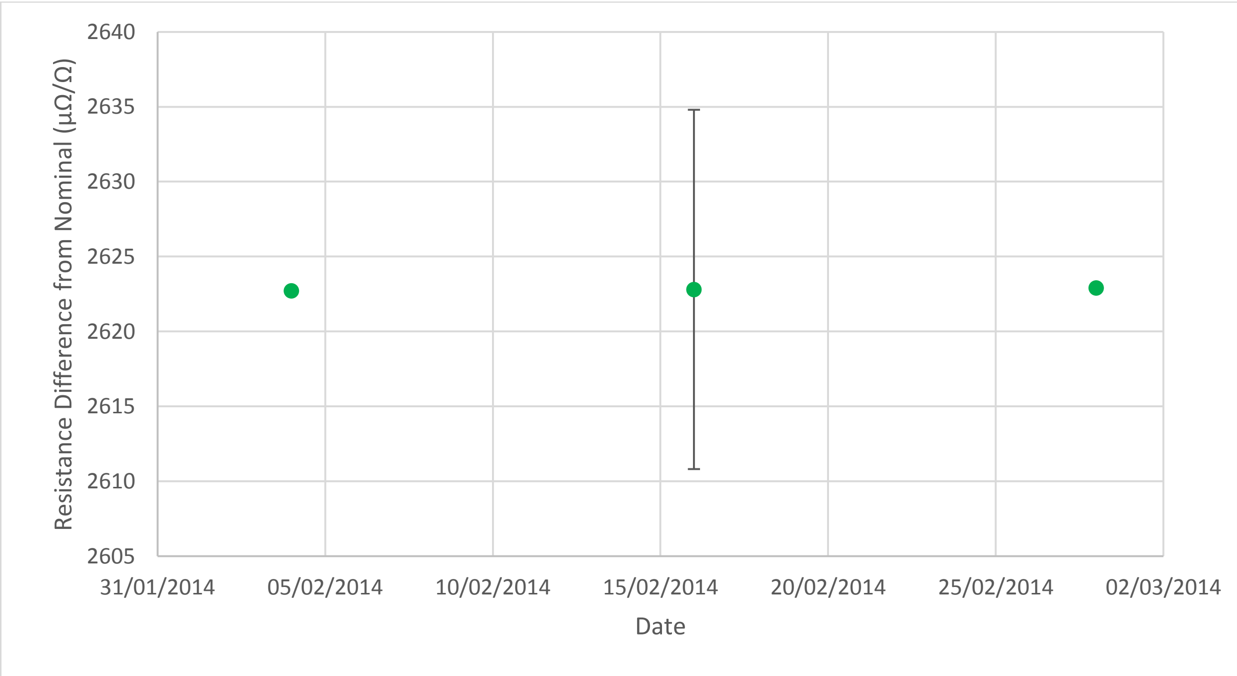

Fig. 2b. Pilot laboratory measurements of NIST 100 GΩ Resistor at 100 V showing the averages of the before and after measurements. The error bar on the mean value of both averages, showing expanded uncertainty (*k=2*).

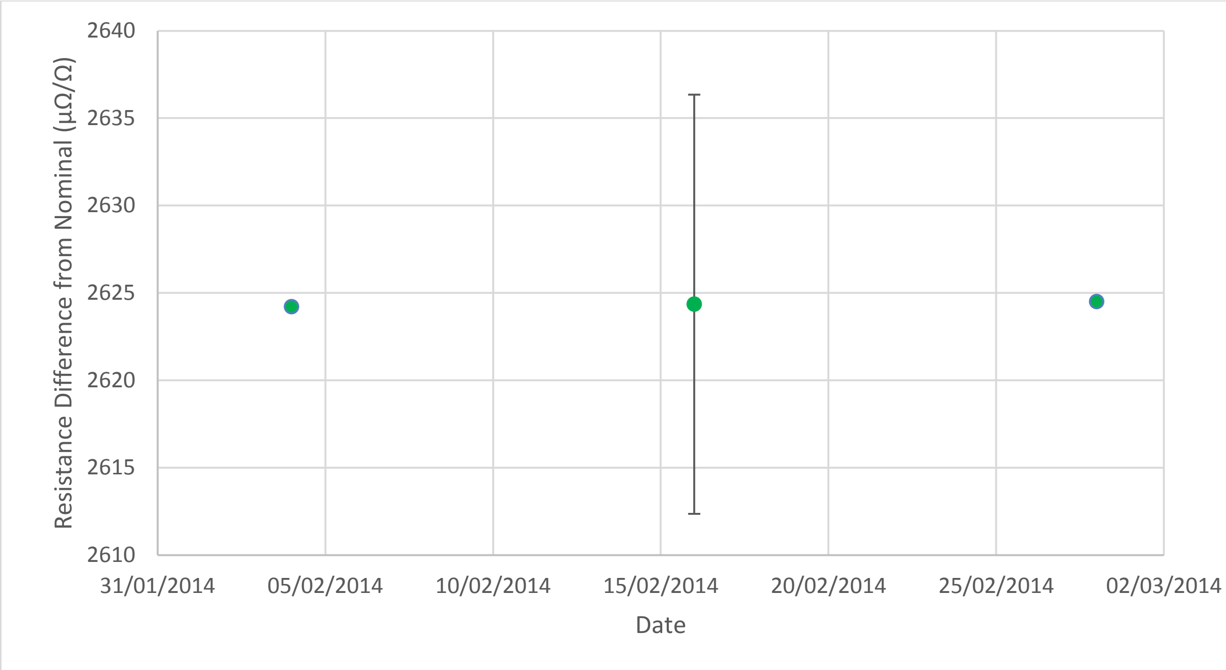

Fig. 2c. Pilot laboratory measurements of NIST 100 GΩ Resistor at 200 V showing the averages of the before and after measurements. The error bar on the mean value of both averages, showing expanded uncertainty (*k=2*).

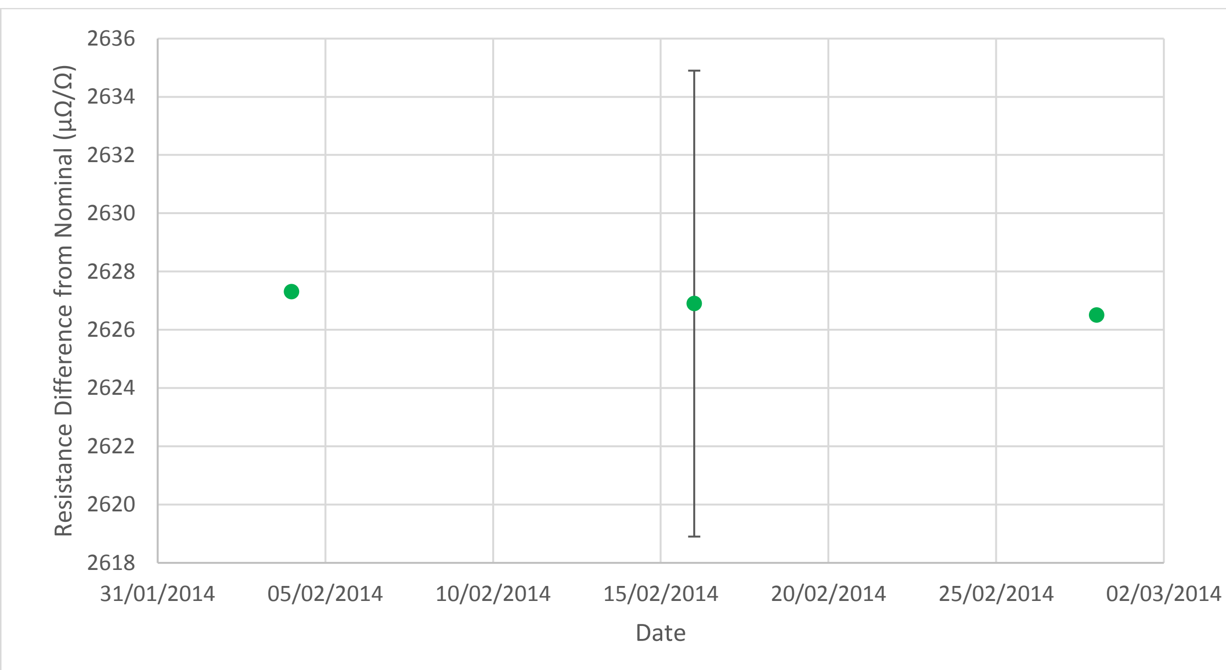

Fig. 2d. Pilot laboratory measurements of NIST 100 GΩ Resistor at 500 V showing the averages of the before and after measurements. The error bar on the mean value of both averages, showing expanded uncertainty (*k=2*).

5 Reported Results of Comparisons

5.1 SIM.EM-S11 100 MΩ results

Table 5. ICE measurements for 100 MΩ

Date	Resistance (MΩ)	Voltage (V)	Expanded Uncertainty μΩ/Ω (*k*=*2*)
11/02/2014	100.003 41	10	
11/02/2014	100.003 48	10	
12/02/2014	100.003 19	10	
12/02/2014	100.003 29	10	
Mean (12/02/2014)	100.003 34	10	5.6
11/02/2014	100.003 80	100	
11/02/2014	100.003 94	100	
12/02/2014	100.003 92	100	
12/02/2014	100.003 94	100	
Mean (12/02/2014)	100.003 90	100	7.0

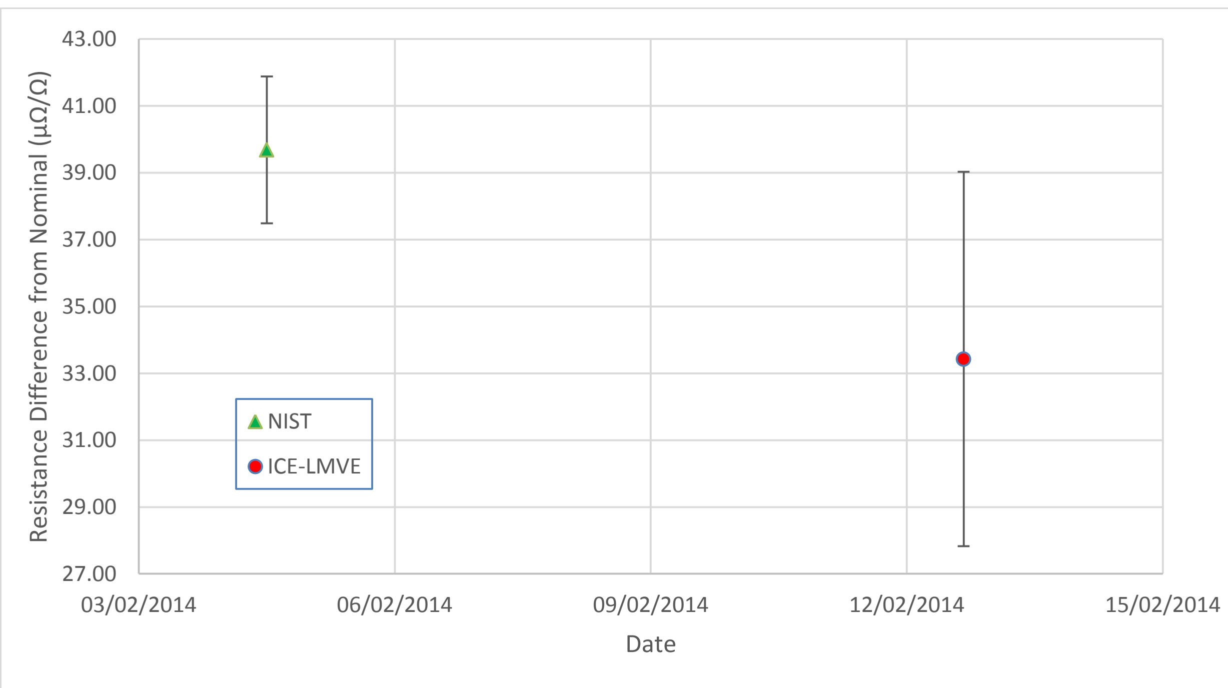

Fig. 3a. Participant results of measurement of NIST 100 MΩ Resistor at 10 V with error bar on the mean value, showing expanded uncertainty (*k*=*2*).
NIST mean value corresponds to the average of before and after measurements. ICE-LMVE mean value corresponds to the average of four measurements.

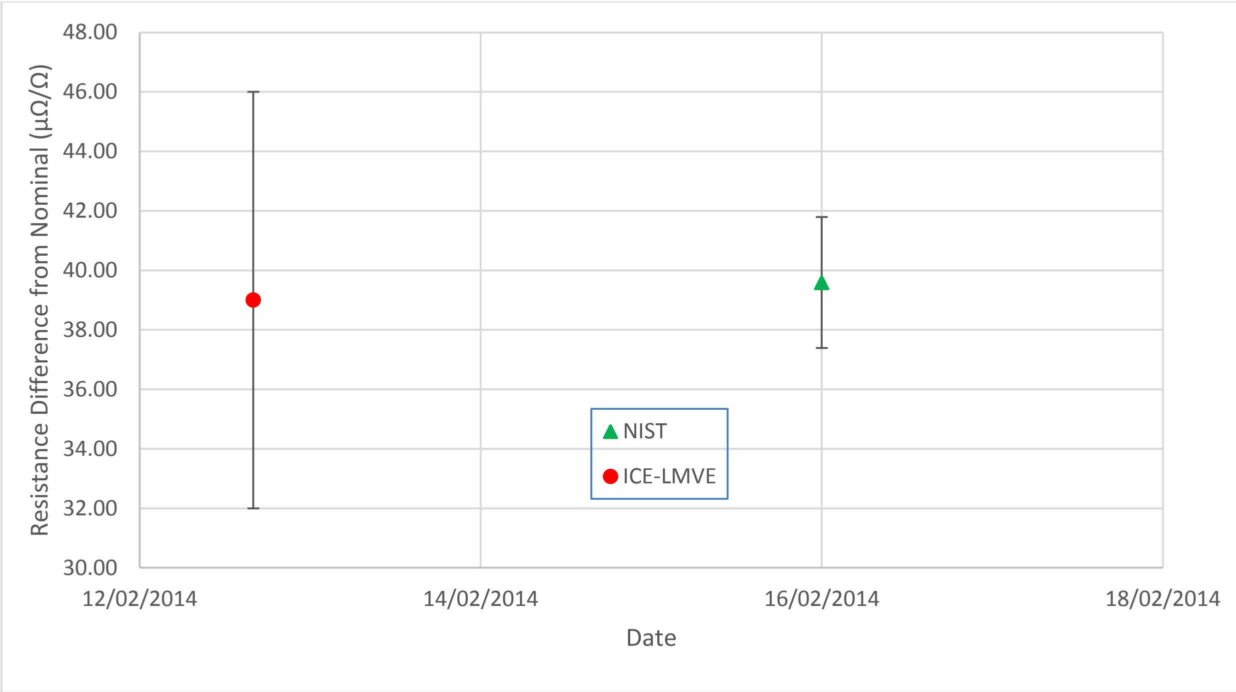

Fig. 3b. Participant results of measurement of NIST 100 MΩ Resistor at 100 V with error bar on the mean value, showing expanded uncertainty (*k=2*).

NIST mean value corresponds to the average of before and after measurements. ICE-LMVE mean value corresponds to the average of four measurements.

5.2 SIM.EM- S11 100 GΩ results

Table 6. ICE measurements for 100 GΩ

Date	Resistance (GΩ)	Voltage (V)	Expanded Uncertainty μΩ/Ω (*k=2*)
11/02/2014	100.265 0	30	
11/02/2014	100.264 4	30	
12/02/2014	100.265 5	30	
12/02/2014	100.265 2	30	
Mean (12/02/2014)	100.265 0	30	84
11/02/2014	100.276 9	100	
11/02/2014	100.276 9	100	
12/02/2014	100.277 1	100	
12/02/2014	100.277 0	100	
Mean (12/02/2014)	100.277 0	100	71
11/02/2014	100.273 3	300	
11/02/2014	100.273 8	300	
12/02/2014	100.273 7	300	
12/02/2014	100.273 7	300	
Mean (12/02/2014)	100.273 6	300	90

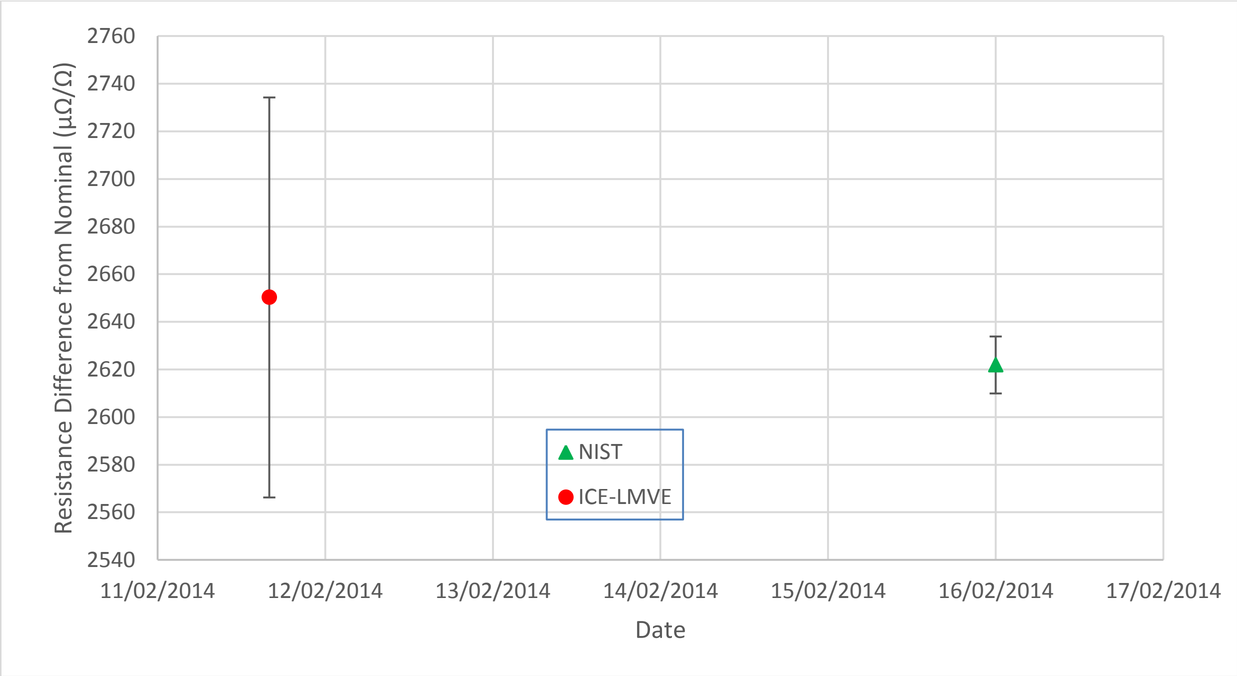

Fig. 4a. Participant results of measurement of NIST 100 GΩ Standard Resistor at 30 V with error bar on the mean value, showing expanded uncertainty (*k=2*).
Comparison with Pilot value at 50 V. NIST mean value corresponds to the average of before and after measurements. ICE-LMVE mean value corresponds to the average of four measurements.

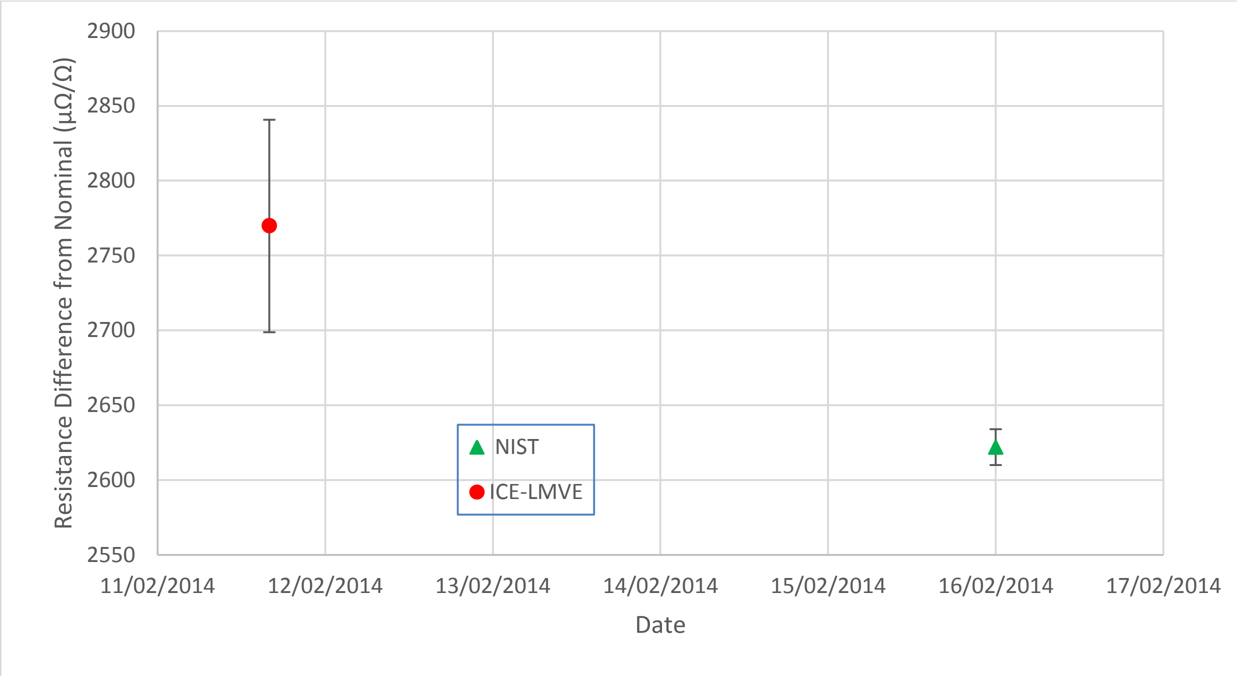

Fig. 4b. Participant results of measurement of NIST 100 GΩ Standard Resistor at 100 V with error bar on the mean value, showing expanded uncertainty (*k=2*).
NIST mean value corresponds to the average of before and after measurements. ICE-LMVE mean value corresponds to the average of four measurements.

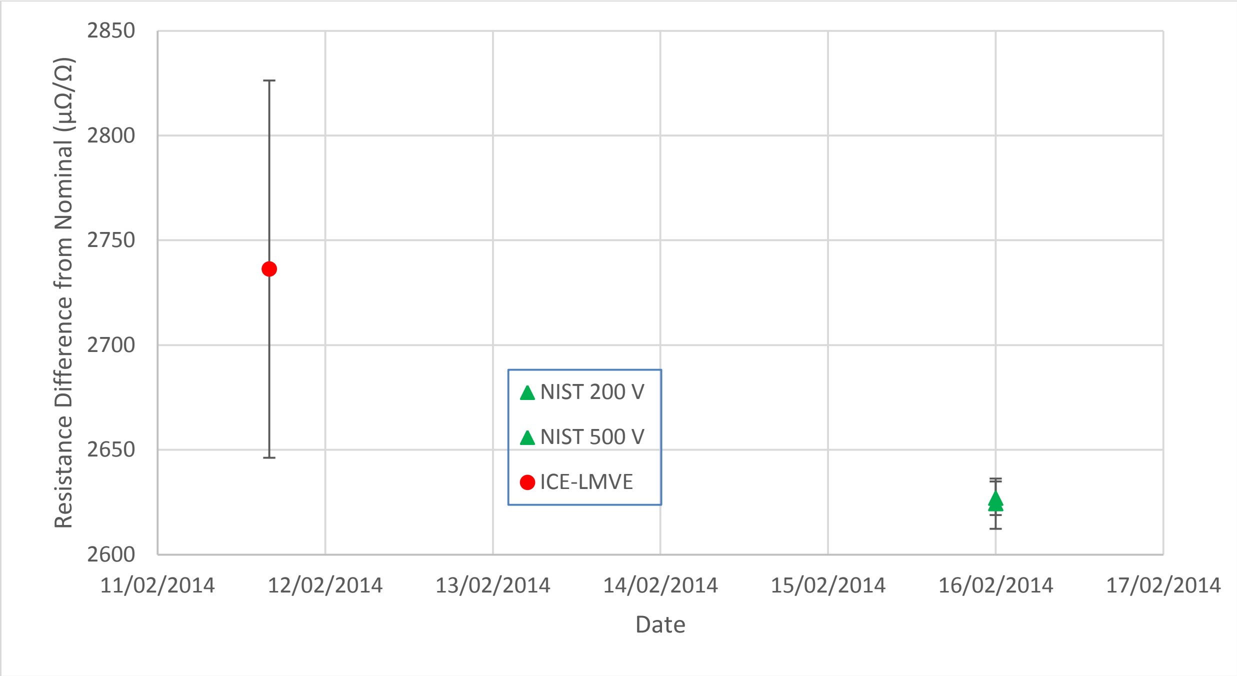

Fig. 4c. Participant results of measurement of NIST 100 GΩ Standard Resistor at 300 V with error bar on the mean value, showing expanded uncertainty (*k=2*).
Comparison with Pilot value at 200 V and 500 V.
NIST mean value corresponds to the average of before and after measurements. ICE-LMVE mean value corresponds to the average of four measurements.

6 References

[1] ISO/IEC 17043:2010 Conformity assessment -- General requirements for proficiency testing

[2] CIPM MRA-D-05 Measurement comparisons in the CIPM MRA. Version 1.5

[3] CIPM MRA-D-04 - Calibration and Measurement Capabilities in the context of the CIPM MRA. Version 4.

Appendix A: Analysis Procedure

The bilateral comparisons consist of two related resistance comparisons between ICE and NIST. SIM.EM-S11 is a comparison of a NIST 100 MΩ Resistor, Model # 9336 and a NIST 100 GΩ Standard, Model # HR11206. The two participant laboratories each measured both traveling standards for one measurement period. The period at NIST was approximately 30 days, resulting in one reported mean value. The period at ICE was five days.

In order to determine if ICE-LMVE is proficient for this particular measurement discipline, the normalized error (E_n) is calculated.

The E_n performance statistic is found in ISO/IEC 17043-2010 and the A2LA document "A2LA Proficiency Testing Requirements for Accredited Testing and Calibration Laboratories" and in other documents is given in equation (1):

$$|E_n| = \left| \frac{x - X}{\sqrt{U_{lab}^2 + U_{ref}^2}} \right|$$

where:

E_n = normalized error

x = participant's measurement result

X = assigned value of the artifact

U_{lab} = uncertainty of the participant's measurement results

U_{ref} = uncertainty of the reference laboratory's assigned value

The normalized error can fluctuate between a positive or negative value. If a participant gets normalized error values between -1 and +1, with an acceptable estimate of their uncertainties, it can be concluded that the laboratory has a satisfactory, reliable and competent performance.

The normalized error criterion is:

$|En| \leq 1.0$ for satisfactory performance and

$|En| > 1.0$ for unsatisfactory performance.

Note: U_{lab} and U_{ref} are both the expanded uncertainty with k = 2.

Appendix B: Analysis Results

1. **Measurements for 100 MΩ at 10 V and 100 V**

   From Table 5 in the main text above, ICE's measurement was 100.003 3 4 MΩ at 10 V with standard uncertainty (*k=2*) of 5.6 μΩ/Ω and 100.003 90 MΩ at 100 V with standard uncertainty (*k=2*) of 7.0 μΩ/Ω.

   NIST's measurement was 100.003 968 MΩ at 10 V with a standard uncertainty (*k=2*) of 2.2 μΩ/Ω and 100.003 959 MΩ at 100 V with standard uncertainty (*k=2*) of 2.2 μΩ/Ω.

Table B1. Calculated normalized error for each measurement

Test Voltage (V)	Normalized Error for ICE's measurements	Result
10	1.04E+00	Unsatisfactory performance
100	8.04E-02	Satisfactory performance

2. **Measurements for 100 GΩ at (ICE 30 V vs. NIST 50 V), 100 V and (ICE 300 V vs. NIST 200 V).**

   From Table 6 in the main text above, ICE's measurement was 100.2650 GΩ at 30 V with standard uncertainty (*k=2*) of 84 μΩ/Ω; 100.2770 GΩ at 100 V with standard uncertainty (*k=2*) of 71 μΩ/Ω and 100.2736 GΩ at 300 V with standard uncertainty (*k=2*) of 90 μΩ/Ω.

   NIST's measurement was 100.262 19 GΩ at 50 V with standard uncertainty (*k=2*) of 12 μΩ/Ω; 100.262 28 GΩ at 100 V with standard uncertainty (*k=2*) of 12 μΩ/Ω, 100.262 43 GΩ at 200 V with standard uncertainty (*k=2*) of 12 μΩ/Ω and 100.262 69 GΩ at 500 V with standard uncertainty (*k=2*) of 8 μΩ/Ω

Table B2. Calculated normalized error for each measurement

Test Voltage (V)	Normalized Error for ICE's measurements	Result
30	3.30E-01	Satisfactory performance
100	2.04E+00	Unsatisfactory performance
300	1.23E+00	Unsatisfactory performance

Appendix C: Uncertainty Budgets for 100 MΩ

Table C1. ICE-LMVE 100 MΩ at 10 V Uncertainty Budget

Quantity	**Type**	**Uncertainty (μΩ/Ω)**	**Sensitivity coefficient**	**Standard uncertainty (μΩ/Ω)**
Reference Standard	Combined	7.61E-08	1	7.61E-08
Test Standard	Type A	1.50E-10	1	1.50E-10
Test Standard	Type B	8.35E-16	1	8.35E-16
Other	Type B	-	-	3.54E-10
Combined Standard Uncertainty	*k =2*			5.56E+00

Table C2. ICE-LMVE 100 MΩ at 100 V Uncertainty Budget

Quantity	**Type**	**Uncertainty (μΩ/Ω)**	**Sensitivity coefficient**	**Standard uncertainty (μΩ/Ω)**
Reference Standard	Combined	1.20E-07	1	1.20E-07
Test Standard	Type A	2.88E-11	1	2.88E-11
Test Standard	Type B	8.35E-16	1	8.35E-16
Other	Type B	-	-	3.54E-10
Combined Standard Uncertainty	*k = 2*			6.98E+00

Table C3. NIST 100 MΩ Uncertainty Budget

Quantity	**Type**	**Standard uncertainty (μΩ/Ω) at 10 V**	**Standard uncertainty (μΩ/Ω) at 100 V**
Reference Standard	Type B	0.10	0.10
Short-Term Stability	Type B	0.50	0.50
Substitution Error	Type B	1.00	1.00
Combined Standard Uncertainty	*k = 2*	2.2	2.2

Appendix D: Uncertainty Budgets for 100 GΩ

Table D1. ICE-LMVE 100 GΩ at 30 V Uncertainty Budget

Quantity	**Type**	**Uncertainty (μΩ/Ω)**	**Sensitivity coefficient**	**Standard uncertainty (μΩ/Ω)**
Reference Standard	Combined	1.67E-05	1	1.67E-05
Test Standard	Type A	1.53E-15	1	1.53E-15
Test Standard	Type B	8.35E-16	1	8.35E-16
Other	Type B	-	-	8.86E-07
Combined Standard Uncertainty				8.43E+01

Table D2. ICE-LMVE 100 GΩ at 100 V Uncertainty Budget

Quantity	**Type**	**Uncertainty (μΩ/Ω)**	**Sensitivity coefficient**	**Standard uncertainty (μΩ/Ω)**
Reference Standard	Combined	1.17E-05	1	1.17E-05
Test Standard	Type A	6.27E-17	1	6.27E-17
Test Standard	Type B	8.35E-16	1	8.35E-16
Other	Type B	-	-	8.86E-07
Combined Standard Uncertainty				7.13E+01

Table D3. ICE-LMVE 100 GΩ at 300 V Uncertainty Budget

Quantity	**Type**	**Uncertainty (μΩ/Ω)**	**Sensitivity coefficient**	**Standard uncertainty (μΩ/Ω)**
Reference Standard	Combined	1.90E-05	1	1.90E-05
Test Standard	Type A	3.63E-16	1	3.63E-16
Test Standard	Type B	8.35E-16	1	8.35E-16
Other	Type B	-	-	8.86E-07
Combined Standard Uncertainty				8.97E+01

Table D4. NIST 100 GΩ Uncertainty Budget

Quantity	**Type**	**Standard uncertainty (μΩ/Ω) at 30 V**	**Standard uncertainty (μΩ/Ω) at 100 V**	**Standard uncertaint y (μΩ/Ω) at 300 V**
Reference Standard	Type B	2	2	2
Short-Term Stability	Type B	1	1	1
Substitution Error	Type B	5	5	3
Combined Standard Uncertainty	*k = 2*	12	12	8

Appendix E: Corrective Actions and Results

ICE-LMVE provided post-comparison corrections to their comparison results. The corrections could not be included in the comparison results but are shown below.

The ICE results were corrected based upon an improved calibration, performed by METAS in March 2014, of the reference standards used by ICE in the comparison. The corrected results are shown in Table E1 and Table E2.

Table E1. ICE measurements for 100 MΩ

Date	Resistance (MΩ)	Voltage (V)	Expanded Uncertainty μΩ/Ω (*k=2*)
11/02/2014	100.003 41	10	
11/02/2014	100.003 48	10	
12/02/2014	100.003 19	10	
12/02/2014	100.003 29	10	
Mean (12/02/2014)	100.003 34	10	15.0
11/02/2014	100.003 80	100	
11/02/2014	100.003 94	100	
12/02/2014	100.003 92	100	
12/02/2014	100.003 94	100	
Mean (12/02/2014)	100.003 90	100	15.0

Table E2. ICE measurements for 100 GΩ

Date	Resistance (GΩ)	Voltage (V)	Expanded Uncertainty μΩ/Ω (*k=2*)
11/02/2014	100.265 0	30	
11/02/2014	100.264 4	30	
12/02/2014	100.265 5	30	
12/02/2014	100.265 2	30	
Mean (12/02/2014)	100.265 0	30	150
11/02/2014	100.276 9	100	
11/02/2014	100.276 9	100	
12/02/2014	100.277 1	100	
12/02/2014	100.277 0	100	
Mean (12/02/2014)	100.277 0	100	150
11/02/2014	100.273 3	300	

11/02/2014	100.273 8	300	
12/02/2014	100.273 7	300	
12/02/2014	100.273 7	300	
Mean (12/02/2014)	100.273 6	300	150