INTER-LABORATORY COMPARISON JOINT PROJECT FOR FIELD THERMOMETRY

Agreed EURAMET Project N° 1338

Comparison of the Standard Platinum Resistance Thermometer (SPRT) in the temperature range from -40 °C and 230 °C

TECHNICAL REPORT

FINAL

Coordinator: Narcisa Arifovic

TUBITAK UME Temperature Laboratory
TÜBITAK Gebze Yerleskesi
P.O Box 54
Barış Mah. Dr.Zeki Acar Cad. No:1
41470 Gebze / KOCAELİ
narcisa.arifovic@tubitak.gov.tr

TABLE OF CONTENTS

1. INTRODUCTION

This project is carried out as the cooperation between National Metrology Institute of Turkey TUBITAK UME and Bosnia and Hercegovina (IMBIH) to conduct a comparison within the framework of the EURAMET 1338 Project on “Comparison of the Standard Platinum Resistance Thermometer (SPRT) in the temperature range from -40 °C and 230 °C.

The objectives of the comparison can be summarized as following:

-provide the opportunity to participating laboratory (IMBIH) to acquire experience in participating in comparisons

- check the measurement capabilities in the field of temperature of the participating laboratory

- provide input for improvement

-prepare the participating laboratory for approvement technically valid calibration measurement capabilities (CMC)

It was agreed that the comparison should be carried out over the temperature range from -40 °C to 230 °C. Each laboratory used its own calibration procedure.

The circulating instrument was one Standart Platinum Resistance Thermometer (SPRT 25 ohm) with a diameter 6 mm and length 600 mm.

As a pilot laboratory TUBITAK UME provided the circulating thermometer. The analysis of the results was performed by TUBITAK UME.

The draft version of comparison protocol was sent to participant laboratory before the comparison to receive its suggestions and opininons.

2. PARTICIPATING LABORATORIES

2.1 Coordinator/Reference laboratory

TURKEY

Participating laboratory: TUBITAK-Ulusal Metroloji Enstitusu (UME)
Contact person: Mrs.Narcisa Arifovic

Address: TUBITAK UME Gebze Yerleşkesi
Barış Mah. Dr.Zeki Acar Cad.No:1
41470 Gebze / KOCAELİ TURKEY
Phone: +90 262 679 50 00 / Ext. 3406
Fax : +90 262 679 50 01
email: narcisa.arifovic@tubitak.gov.tr

2.2 Participating laboratory

The contact details of participant laboratory are given below:

Bosnia and Herzegovina

Participating laboratory: IMBiH, Temperature Laboratory
Contact person: Miss Nedžadeta Hodžić
Address: Dolina 6
71000 Sarajevo / Bosnia and Herzegovina
Phone: +387 61 462 012
Fax: +387 33 568 909

Email: nedzadeta.hodzic@met.gov.ba

3. SCHEDULE OF COMPARİSON

At the beginning of the circulation, UME made the first calibration of the SPRT (see Table 1). Then the SPRT was sent to IMBIH. The time allowed for a calibration over the range -40 °C to 230 °C was three weeks.

Table 1. Schedule of comparison

Period	Task	Lab.
8 September to 27 September, 2014	Selection and calibration of SPRTs	UME
30 September to 3 October, 2014	Starting the circulation of a SPRT	
6 October to 24 October, 2014	Calibration of the circulating SPRT	IMBIH
27 October to 22 November, 2014	Check the stability and Calibration of the circulating SPRT	UME

4. CIRCULATING DEVICE

The information regarding the circulating device employed for the comparison is given in Table 2.

Table 2. Circulating Instrument

Manufacturer	Fluke
Type	SPRT
Model	5680
Serial Number	0668

TUBITAK UME as pilot laboratory carried out the calibration of the thermometer before and after comparison.

3. MEASUREMENTS and RESULTS

The comparison was carried out in the temperature range from -40 °C to 230 °C. The results were presented for nominal temperature points -40 °C, -20 °C, -10 °C, 0,01 °C, 20 °C, 70 °C, 120 °C, 170 °C, 200 °C and 230 °C. IMBIH was requested to use its existing calibration techniques. Measurements were suggested to be taken in the order of decreasing temperatures for the calibration points above 0.01 °C and in the order of increasing temperatures for below 0.01 °C values.

3.1 Equipment at IMBIH

The resistance ratio, between the SPRT resistance and a 100 Ω standard resistor Tinsley 5685 A, was measured with an ASL resistance ratio bridge, model F900. The standard resistor was placed in the maintenance oil bath model 455 Isotec with stability of 1.25 mK.

The WTP cell was placed in the Water Triple Point maintenance bath during the measurements of the resistance ratio. For the measurements in the temperature range from 120 °C to 230 °C the oil bath, from 20 °C to 70 °C the water bath and from -40 °C to -10 °C the alcohol bath was utilised. The information concerning the equipments used by IMBIH is summarized in Table 3.

Table 3. Equipment used by IMBIH

No	Instrument Name	Manufacturer	Model
1	WTP Cell	Isotech	B11-50-270
2	SPRT	Isotech	670SQ
3	AC Bridge	ASL	F900
4	Standard Resistor	Tinsley	5685 A
5	Standard Resistor Maintenance Bath	Isotech	455
6	WTP Maintenance Bath	Isotech	ITL M 18233
7	Oil bath	Isotech	NEPTUNE 915H
8	Water bath	Isotech	NEPTUNE 915LW
9	Alcohol bath	Isotech	NEPTUNE 915LW

3.2 Equipment at TUBITAK UME

The resistance ratio, between the SPRT resistance and a calibrated standard resistor, at the TPW measurements was measured with 6010T model of Measurement International Ltd. The standard resistors Tinsley type 5685A 100 Ω was used for these measurements.The standard resistor was maintained in a water bath at a controlled temperature of 23 ºC (±2 mK).For the measurements at liquid baths the 1590 Model Superthermometer readouts is used for the measurements of reference temperatures. The information concerning the equipments used by UME is summarized in Table 4.

Table 4. Equipment used by TUBITAK UME

No	Instrument Name	Manufacturer	Model
1	WTP Cell	UME	B11-50-270
2	SPRT	Hart Scientific	5680
3	DC Bridge	MI	6010T
4	Super Thermometer	Hart Scientific	1590
5	Standard Resistor	Tinsley	5685 A
6	Standard Resistor Maintenance Bath	Hart Scientific	7008
7	WTP Maintenance Bath	Isotech	ITL M 18233
8	Oil bath	HETO/ Hart Scientific	6024 / 108-3FOH920
9	Water bath	HETO	106-3FOH920
10	Alcohol bath	HETO/ Hart Scientific	7381 / 106-3FOH920

3.3 Measurements at IMBIH

The results of the measurements performed by IMBIH are summarized in Table 5.

Table 5. The results of the measurements performed by IMBIH

Measured Values			**Calculated Values**		
Referance Temperature	**Measured Resistance**	**Nominal Temperature**	**Calculated Resistance**	**Calculated Resistance Ratio**	**Uncertainty (k=2)**
/°C	/ Ω	/°C	/ Ω	/	/°C
0.01	25.58926	0.01	25.58926	1.0000000	0.0003
-39.9395	21.48737	-40	21.48087	0.8394485	0.008
-20.0062	23.54009	-20	23.54089	0.9199518	0.008
-10.0011	24.56443	-10	24.56612	0.9600168	0.008
0.01	25.58926	0.01	25.58927	1.0000000	0.0003
19.9990	27.62260	20	27.62315	1.0794823	0.007
69.6279	32.61914	70	32.65553	1.2761418	0.007
0.01	25.58926	0.01	25.58927	1.0000000	0.0003
119.9995	37.61136	120	37.61103	1.4697973	0.009
169.9975	42.48901	170	42.49020	1.6604698	0.009
199.9938	45.38026	200	45.38135	1.7734527	0.009
229.9864	48.24486	230	48.24542	1.8853773	0.009
0.01	25.58927	0.01	25.58927	1.0000000	0.0003

3.4 Measurements at TUBITAK UME

The results of the measurements performed by TUBITAK UME at the begining of the comparison are summarized in Table 6.

Table 6. The results of the measurements performed by TUBITAK UME at the begining of the comparison

Referance Temperature	Measured Resistance	Nominal Temperature	Calculated Resistance	Calculated Resistance Ratio	Uncertainty (k=2)
/°C	/ Ω	/°C	/ Ω	/	/°C
0.010	25.58923	0.010	25.58923	1.0000000	0.0002
-39.9991	21.48156	-40	21.48185	0.8394720	0.007
-20.0033	23.54091	-20	23.54108	0.9199647	0.007
-9.9985	24.56650	-10	24.56629	0.9600235	0.007
0.010	25.58926	0.010	25.58926	1.0000000	0.0002
20.0078	27.62371	20	27.62253	1.0794712	0.007
70.0078	32.65494	70	32.65498	1.2761320	0.007
120.0662	37.61744	120	37.61072	1.4697947	0.008
170.0023	42.49094	170	42.49084	1.6604857	0.008
200.0040	45.38260	200	45.38224	1.7734849	0.008
230.0005	48.24666	230	48.24640	1.8854295	0.008
0.010	25.58926	0.010	25.58926	1.0000000	0.0002

The results of the measurements performed by TUBITAK UME at the end of the comparison are summarized in Table 7.

Table 7. The results of the measurements performed by TUBITAK UME at the end of the comparison

Referance Temperature	Measured Resistance	Nominal Temperature	Calculated Resistance	Calculated Resistance Ratio	Uncertainty (k=2)
/°C	/ Ω	/°C	/ Ω	/	/°C
0.010	25.58917	0.010	25.58923	1.0000000	0.0002
-39.9964	21.48185	-40	21.48185	0.8394880	0.007
-20.0012	23.54108	-20	23.54108	0.9199603	0.007
-10.0009	24.56629	-10	24.56629	0.9600243	0.007
0.010	25.58916	0.010	25.58926	1.0000000	0.0002
19.9960	27.62253	20	27.62253	1.0794579	0.007
70.0037	32.65498	70	32.65498	1.2761204	0.007
119.9990	37.61072	120	37.61072	1.4697853	0.008
170.0048	42.49084	170	42.49084	1.6604948	0.008
200.0004	45.38224	200	45.38224	1.7734876	0.008
229.9994	48.24640	230	48.24640	1.8854158	0.008
0.010	25.58915	0.010	25.58926	1.0000000	0.0002

The mean value calculated as simple mean of the results of the measurements performed by TUBITAK UME at the begining and at the end of the comparison are summarized in Table 8.

Table 8. The results of the measurements performed by TUBITAK UME at the end of the comparison

Nominal Temperature / °C	Calculated Mean Resistance Ratio	Uncertainty (k=2) / °C
-40	0.8394800	0.007
-20	0.9199625	0.007
-10	0.9600239	0.007
0.010	1.0000000	0.0002
20	1.0794646	0.007
70	1.2761262	0.007
120	1.4697903	0.008
170	1.6604903	0.008
200	1.7734862	0.008
230	1.8854226	0.008

3.5 Uncertainty budget

The uncertainty sources included repeatability of measurements, inhomogeneity and stability of the calibration bath, the uncertainty of the reference temperature measurement system and its drift, the uncertainty of reading of SPRT, and the uncertainty due to self-heating of the thermometer. The total uncertainty U was calculated as the quadrature sum of all uncertainty contributions.

The uncertainty budget for each temperature point is reported in Tables 9,10 and 11.

Table 9. The uncertainty budget of the measurements performed by IMBIH

Uncertainty Component	-40 °C	-20 °C	-10 °C	20 °C	70 °C
	/ mK	/ mK	/ mK	/ mK	/ mK
Reference SPRT: Repeatability	0.257	0.130	0.114	0.537	0.909
Reference SPRT : Certificate	1.000	1.000	1.000	1.000	1.000
Reference SPRT : Annual drift	1.443	1.443	1.443	1.445	1.445
Homogeneity of the liquid bath	3.200	3.200	3.200	2.758	2.758
Thermometer under test: Repeatibility	0.162	0.048	0.368	0.212	0.350
Resistance Bridge	0.002	0.002	0.002	0.003	0.003
Resolution of the resistance bridge	0.002	0.002	0.002	0.002	0.003
Standard Resistor:Certificate	0.100	0.100	0.100	0.100	0.100
Drift of Standard Resistor	0.026	0.026	0.026	0.026	0.026
Stability of the maintenance bath	0.001	0.001	0.001	0.001	0.001
Selfheating effect	0.018	0.018	0.018	0.018	0.018
Combined Uncertainty (k=1)	3.66	3.65	3.67	3.32	3.41
Expanded Uncertainty (k=2)	7.32	7.30	7.34	6.64	6.82
Rounded Value	8.00	8.00	8.00	7.00	7.00

Table 10. The uncertainty budget of the measurements performed by IMBIH

Uncertainty Component	120 °C	170 °C	200 °C	230 °C
	/ mK	/ mK	/ mK	/ mK
Reference SPRT:Repeatability	0.072	0.450	0.592	0.913
Reference SPRT : Certificate	1.000	1.000	1.000	1.000
Reference SPRT : Annual drift	1.445	1.445	1.445	1.445
Homogeneity of the liquid bath	3.000	3.000	3.757	3.757
Thermometer under test: Repeatibility	0.214	1.555	0.743	0.612
Resistance Bridge	0.004	0.004	0.005	0.005
Resolution of the resistance bridge	0.003	0.004	0.004	0.004
Standard Resistor: Certificate	0.100	0.100	0.100	0.100
Drift of Standard Resistor	0.026	0.026	0.026	0.001
Stability of the maintenance bath of resistors	0.001	0.001	0.001	0.026
Selfheating effect	0.018	0.018	0.018	0.018
Combined Uncertainty (k=1)	3.49	3.84	4.26	4.29
Expanded Uncertainty (k=2)	6.98	7.68	8.52	8.58
Rounded Value	7.00	8.00	9.00	9.00

Table 11. The uncertainty budget of the TPW measurements performed by IMBIH

Uncertainty Components (k=1)	WTP
Repeatability	0.059
Isotopic analyses	0.020
Impurities	0.020
Selfheating	0.036
Hydrostatic effect	0.051
Heat flux	0.083
Resistance Bridge	0.003
Resolution of the resistance bridge	0.001
Standard Resistor:Certificate	0.100
Drift of Standard Resistor	0.026
Stability of the maintenance bath	0.001
Combined Uncertainty (k=1)	0.16
Expanded Uncertainty (k=2)	0.32
Rounded Value	0.3

3.6 Stability of circulating SPRT

The uncertainty parameter arising from the instability of the circulating instrument has been included into the comparison uncertainty budget as calculated in Table 3. The stability of the SPRT was calculated under hypotesis of not symmetrical rectangular distribution because of its drift (Equation 1):

$$U_{stability} = \frac{|\,W\,UME_{end} - W\,UME_{start}\,|}{\sqrt{3}} \times \frac{\delta T}{\delta W} \qquad (1)$$

Table 3. Stability of the Circulating SPRT

Temperature / °C	W UME$_{start}$	Uncertainty /°C	W UME$_{end}$	Uncertainty /°C	W_{end}-W_{start}	W_{end}-W_{start} /mK	$U_{stability}$ /mK
-40	0.8394720	0.007	0.8394880	0.007	0.0000160	0.004	2.31
-20	0.9199647	0.007	0.9199604	0.007	-0.0000044	-0.001	0.63
-10	0.9600235	0.007	0.9600243	0.007	0.0000008	0.0002	0.11
20	1.0794712	0.007	1.0794579	0.007	-0.0000133	-0.003	1.96
70	1.2761320	0.007	1.2761204	0.007	-0.0000116	-0.003	1.72
120	1.4697947	0.008	1.4697853	0.008	-0.0000094	-0.002	1.40
170	1.6604857	0.008	1.6604948	0.008	0.0000091	0.002	1.38
200	1.7734849	0.008	1.7734876	0.008	0.0000027	0.001	0.42
230	331.8854295	0.008	1.8854158	0.008	-0.0000137	-0.004	2.15

The stability of the SPRT is shown in the Figure 1.

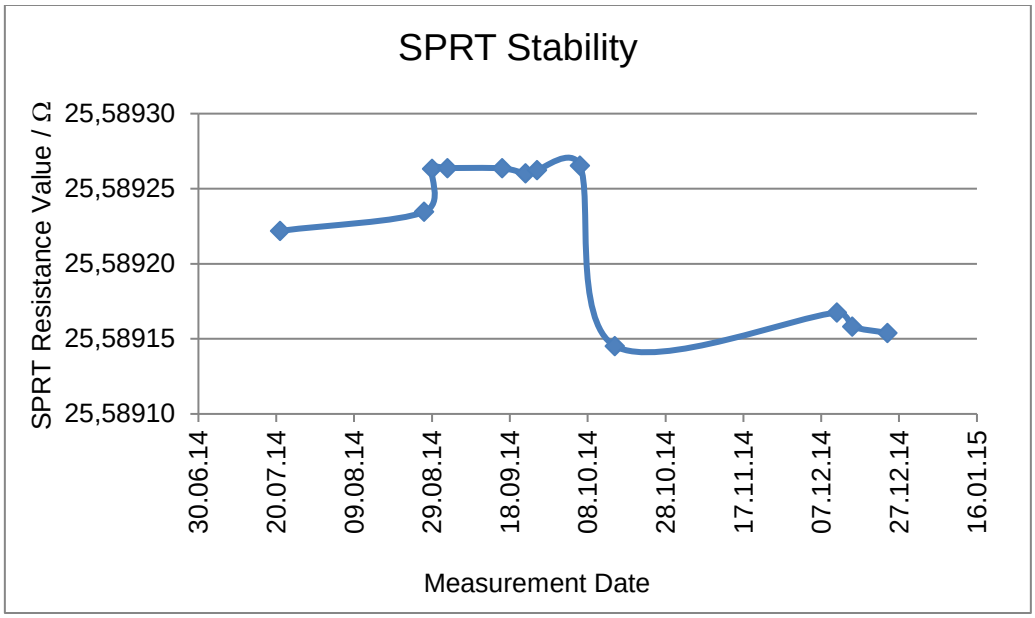

Figure 1. Stability of the SPRT

The resistance value of SPRT at Triple Point of Water Cell (TPW) has been changed by 1.1 mK after the measurements were performed in IMBIH (Table 4). The stability of the SPRT at the WTP calculated in Table 5 contain this drift and is expressed as difference in resistance since the ratio value does not include this information.

Table 4. Resistance of the Circulating SPRT at TPW

Date	Resistance / Ω	Measured by
21.07.2014	25.58922	UME
27.08.2014	25.58923	UME
29.08.2014	25.58926	UME
02.09.2014	25.58926	UME
16.09.2014	25.58926	IMBIH
22.09.2014	25.58926	IMBIH
25.09.2014	25.58926	IMBIH
06.10.2014	25.58927	IMBIH
11.12.2014	25.58917	UME
15.12.2014	25.58916	UME
24.12.2014	25.58915	UME

Table 5. Stability of the Circulating SPRT at TPW

Temperature / °C	R UME$_{start}$	Uncertainty /°C	R UME$_{end}$	Uncertainty /°C	R_{end}-R_{start}	R_{end}-R_{start} /mK	$U_{stability}$ /mK
0.01	25.58926	0.00015	25.58915	0.00015	-0.00011	-1.1	0.7

4. RESULTS OF COMPARISON

During evaluation, TUBITAK UME values obtained at nominal temperatures were taken as reference values (t_{ref}) and the deviations of IMBIH were calculated on this basis. Reference values of the comparison were calculated to be the mean of the begining and the final resistance values obtained at nominal comparison points during the measurements at UME.

$$T_{IMBIH} - T_{UME} = (W_{IMBIH} - W_{UME}) \times \frac{\delta T}{\delta W}$$

The comparison uncertainty was calculated according to the Equation 3 and includes the uncertainty on the reference value, uncertainty on the participant laboratory's value and uncertainty due to instability of the circulating equipment.

$$U_{D_i} = \sqrt{(U_{Lab})^2 + (U_{ref})^2 + (U_{stability})^2} \qquad (3)$$

The evaluation of results was carried out on the basis of E_n number, which is expressed by the Equation 2:

$$E_n = \frac{t_{Lab} - t_{ref}}{\sqrt{(U_{Lab})^2 + (U_{ref})^2}} \qquad (2)$$

where t_{lab} is the participant's result, t_{ref} is the reference value, U_{lab} is the expanded (k=2) uncertainty of a participant's result and U_{ref} is the expanded (k=2) uncertainty of the reference value with criteria for the performance evaluation is based on statistical determination for E_n number:

If $|E_n| \leq 1$ then the results are accepted to be satisfactory.

If $|E_n| > 1$ then the results are evaluated as unsatisfactory.

The resistance ratio values with associated uncertainties (k=2, in K) obtained at nominal comparison points by UME and IMBIH as well as the differences from reference values in terms of resistance ratio and temperature (K) associated with comparison uncertainty and the E_n values were calculated and given in the Table 6.

Table 6. Results for Fluke SPRT Serial No:0668

Temperature / °C	W_{UME}	U_{UME} (k=2) / K	W_{IMBIH}	U_{IMBIH} (k=2) / K	$D_{IMBIH-UME}$	$D_{IMBIH-UME}$ / K	U_D / K	En
-40	0.8394800	0.007	0.8394485	0.008	-0.00003145	-0.008	0.011	-0.7
-20	0.9199625	0.007	0.9199518	0.008	-0.00001070	-0.003	0.011	-0.3
-10	0.9600239	0.007	0.9600168	0.008	-0.00000712	-0.002	0.011	-0.2
0.01	1.0000000	0.00015	1.0000000	0.00032	0.00000000	0.000	0.001	0.0
20	1.0794646	0.007	1.0794823	0.007	0.00001768	0.005	0.010	0.5
70	1.2761262	0.007	1.2761419	0.007	0.00001568	0.004	0.010	0.4
120	1.4697900	0.008	1.4697973	0.009	0.00000730	0.002	0.012	0.2
170	1.6604903	0.008	1.6604698	0.009	-0.00002043	-0.005	0.012	-0.4
200	1.7734862	0.008	1.7734527	0.009	-0.00003356	-0.009	0.012	-0.7
230	1.8854226	0.008	1.8853773	0.009	-0.00004537	-0.012	0.012	-1.0

The deviations from reference values with associated uncertainties (k=2, in K) for each temperature are presented in the Figure 2.

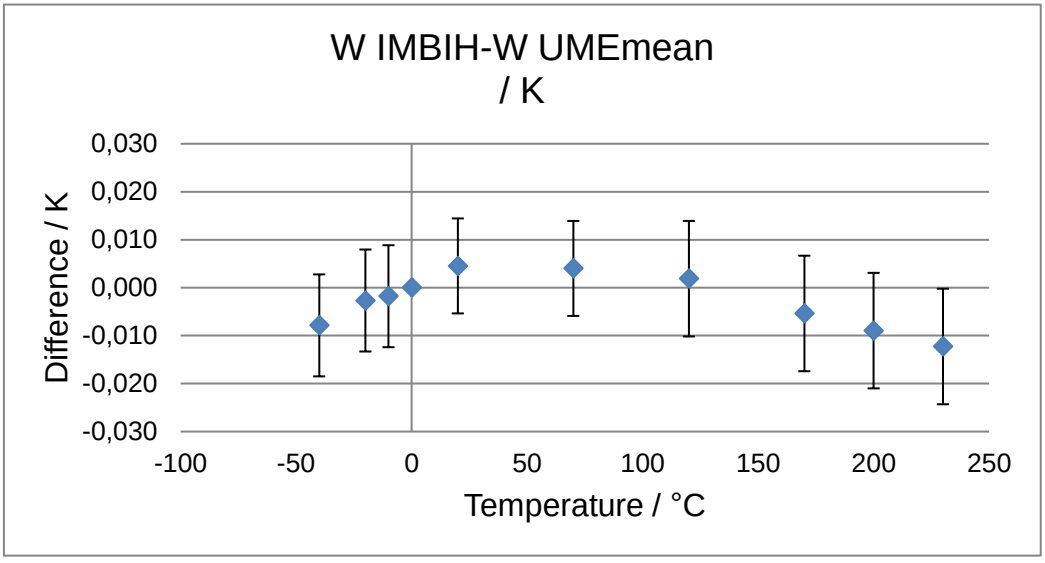

Figure 2. The deviation from reference values with associated uncertainties

The E_n values for each temperature are presented in the Figure 3.

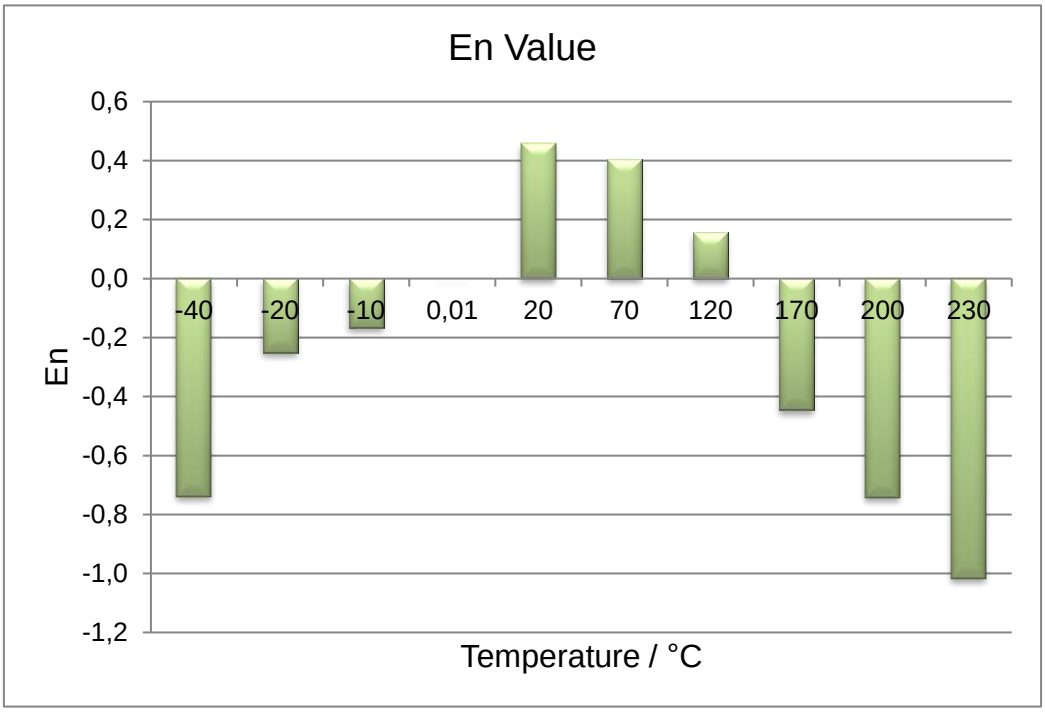

Figure 3. E_n values obtained for SPRT

4. CONCLUSION

1338 EURAMET Comparison was organized to compare the realisations of the SPRT calibrations in the temperature range from -40 °C and 230 °C by comparison method. This comparison was coordinated by TUBITAK UME as Turkish National Laboratory. Participating laboratory was the Temperature Laboratory of National Metrology Institute of Bosnia and Hercegovina (IMBIH).

In order to have sufficient information about a possible drift of the SPRTs, UME as pilot laboratory performed a calibration over the full temperature range at the beginning and at the end of the comparison.

The results of the comparison were analysed by the pilot laboratory. The reference values used during the evaluation were the mean value of the values measured at the begining and at the end of the comparison by the pilot laboratory.

Since there was a 1.1 mK drift of the SPRT at the TPW cell, the stability of the SPRT during the comparison has beeen calculated for each temperaturte point (Tables 3 and 6) and added to the uncetrainty (k=2, in K) of the comparison in Table 6.

It may be concluded that all the measurements were within expected limits and uncertainties. The only E_n value equal to -1 is calculated for the measurement at 230 °C.