BILATERAL COMPARISON OF TEMPERATURE STANDARDS

SIM.T-K9.3
Standard Platinum Resistance Thermometer ITS-90 realizations from the Hg Triple Point to the Zn Freezing Point

FINAL REPORT

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1. INTRODUCTION

This report shows the results of a bilateral comparison of temperature standards between Instituto Nacional de Metrologia, Qualidade e Tecnologia (Inmetro, Brazil), and Trinidad and Tobago Bureau of Standards (TTBS, Trinidad and Tobago), carried out between January and July of 2020. The measurands of this comparison were the $W(t_{90})$ ratios of two Standard Platinum Resistance Thermometers (SPRTs), used as transfer standards, measured at the zinc freezing point (Zn FP, 419.527 °C), tin freezing point (Sn FP, 231.928 °C), gallium melting point (Ga MP, 29.7646 °C), triple point of water (TPW, 0.01 °C) and mercury triple point (Hg TP, -38.8344 °C).

Inmetro is the pilot laboratory of this comparison, which started by measuring the two transfer standards, one provided by each NMI, in TTBS fixed point cells. Both SPRTs were hand-carried to Inmetro, where they were calibrated again from the Zn FP to the Hg TP. The transfer standards, the measurement setups employed, as well as the results of the comparison, are detailed in the sections which follow.

This comparison is aimed at assessing the degree of equivalence between fixed point calibration results of standard platinum resistance thermometers (SPRT) in the range between the triple point of mercury (-38.8344 °C) and the freezing point of zinc (419.527 °C), as performed by both institutes. As a consequence, the results of this comparison will assist TTBS to establish its calibration and measurement capabilities (CMCs) on the BIPM KCDB, by means of a direct link to CCT-K9 key comparison through the results obtained by Inmetro.

2. PARTICIPANTS

The details of the participants of this bilateral comparison are shown below:

Instituto Nacional de Metrologia, Qualidade e Tecnologia – INMETRO

Address:	Laboratório de Termometria (Prédio 04) – Av. Nossa Senhora das Graças, 50 Xerém – Duque de Caxias – RJ – Brasil – CEP: 25250-020
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Trinidad and Tobago Bureau of Standards – TTBS

Address:	1-2 Century Drive, Trincity Industrial Estate, Macoya, Tunapuna Trinidad and Tobago
Contact:	Francis Hamilton
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3. TRANSFER STANDARDS

Each laboratory provided one SPRT to be used as a transfer standard in this comparison. The details of the transfer standards employed are shown in Table 1:

Table 1 – Transfer standards used in the bilateral comparison

Laboratory	INMETRO	TTBS
SPRT ID	SPRT #1	SPRT #2
Manufacturer	Rosemount	Isotech
Model	162CE	670Q
Serial number	3713	234
Nominal resistance at 0 °C	25.5 Ω	25.5 Ω

4. MESAUREMENT SETUPS

Each laboratory calibrated the transfer standards in the Zn FP, Sn FP, Ga MP, TPW and Hg TP. The instrumentation for performing the measurements in both NMIs is summarized in Table 2 below:

Table 2 – Instrumentation employed at the participant laboratories

INMETRO		
Description	**ID/Model**	**Manufacturer**
Zn FP cell	Zn-2019-01	Inmetro
Sn FP cell	Sn-2010-01	Inmetro
WTP cell	13705	Inmetro
Ga MP cell	43073	Fluke
Hg TP cell	Hg36	Isotech
AC Resistance Bridge	F900	ASL
Standard resistor	5685A	Tinsley
3-zone furnace	9114	Fluke
Ga maintenance apparatus	9230	Fluke
Hg maintenance apparatus	ITL M-17924	Isotech
TTBS		
Description	**ID/Model**	**Manufacturer**
Zn FP cell	ITL-M-17671M	Isotech
Sn FP cell	ITL-M-17669	Isotech
Ga MP cell	ITL-M-17401	Isotech
Hg TP cell	K18C	Pond Engineering
WTP Cell	A11-50-270Q	Isotech
Thermometry Bridge	MicroK-70	Isotech
Standard resistor	9334-A	Guildline
3-zone furnace	POTTS-MEDUSA-3 511	Isotech
Single-zone furnace	MEDUSA-1 510	Isotech
Ga maintenance apparatus	RB-5A	Techne
Hg maintenance apparatus	K18M	Pond Engineering

5. PROCEDURES

The transfer standards were calibrated according to each laboratory's own procedure, which corresponded to their best measurement practices. The SPRTs were first calibrated at TTBS and then transported to Inmetro for calibration. Calibration at both laboratories was performed according to the agreed technical protocol in APPENDIX C.

Prior to each calibration, the SPRTs were stabilized in the TPW through furnace annealing. Each laboratory followed its own procedure for stabilizing the standards. For each fixed point, the resistance ratio $W(t_{90}) = R(t_{90})/R(\mathrm{TPW})$ was computed by measuring the resistance of both transfer standards at the fixed point, $R(t_{90})$, and at the water triple point, $R(TPW)$. All measured resistances were corrected for hydrostatic pressure, self-heating and gas pressure, when applicable. One cycle of measurements was performed by each laboratory.

6. RESULTS

Figures 1 and 2 show the measured TPW resistances of both SPRTs during the calibrations at the participant laboratories. The results imply that the drifts due to the transportation between TTBS and Inmetro were relatively small in comparison to the drift observed during the measurements. Both SPRTs were hand-carried between the institutes and the drift due to the travel was almost completely removed by annealing at Inmetro. This is of special importance considering there was only one round of calibrations at each institute (i.e., the comparison loop was left open due to the effects of the pandemic in 2020, when the comparison took place). The TPW resistance drift of the SPRTs is a good metric for checking if there was any damage during the travel. In addition, considering that the uncertainty declared by TTBS for the TPW measurement is 3 mK, as shown in APPENDIX B, it can be seen that the reported values are within this range.

The open loop prevents identifying whether any observed drift is due to any damage suffered during the travel, or if they are due to any systematic effect in the realized temperatures or in the measured electrical resistances. In order to address this, an additional component was included in the model to account for the observed changes in the measured TPW resistances. The uncertainty of this component is bounded by the minimum and maximum measured values with each SPRT at the TPW, with a rectangular distribution, as shown in equations 4 and 5.

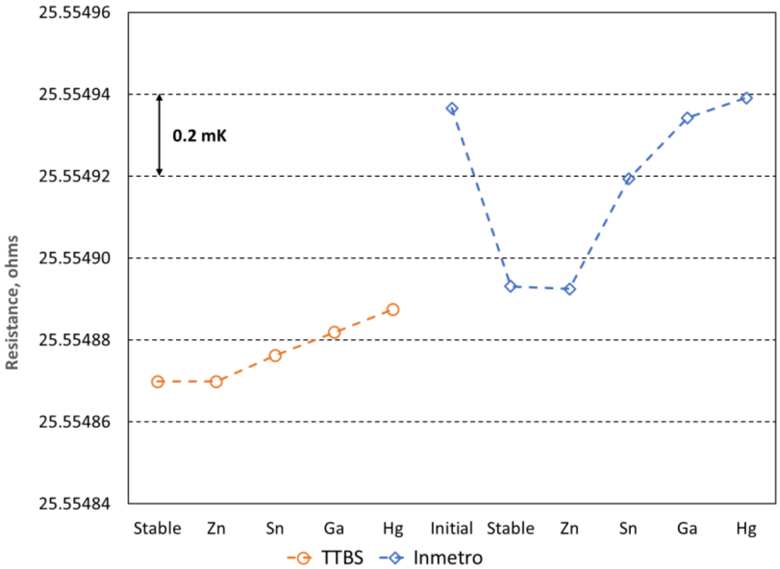

Figure 1 – Measured TPW values at TTBS and Inmetro with SPRT #1. The measurement performed upon arrival of the SPRT at Inmetro is labeled as Initial, while the ones performed after annealing are labeled as Stable.

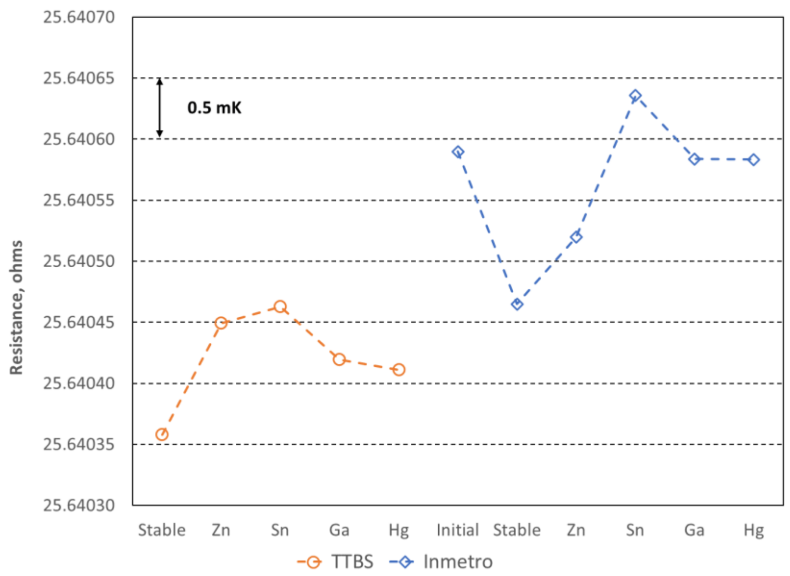

Figure 2 – Measured TPW values at TTBS and Inmetro with SPRT #2. The measurement performed upon arrival of the SPRT at Inmetro is labeled as Initial, while the ones performed after annealing are labeled as Stable.

Table 3 and 4, as well as figures 3 and 4, show the results of TTBS and Inmetro at the fixed points for both SPRTs. The temperature differences Δt_{90} between TTBS and Inmetro, for each SPRT *i*, at each fixed point, are given by eq. 2 of the comparison protocol, i.e.:

$$\Delta t_{90,SPRT\ i} = \frac{W_{TTBS}(t_{90,SPRT\ i}) - W_{Inmetro}\ (t_{90,SPRT\ i})}{dW(t_{90})/dt_{90}} \qquad (1)$$

where *SPRT i* refers to each SPRT (#1 and #2). The measurement uncertainties of each participant laboratory for the fixed point realizations are detailed in APPENDIX B.

Table 3 – Measurement results for SPRT #1

	INMETRO		TTBS			
Fixed point	**W(t_{90})**	**Uncertainty k=2, mK**	**W(t_{90})**	**Uncertainty k=2, mK**	**W_{TTBS}-$W_{Inmetro}$**	**Δt_{90} mK**
Zn	2.568 483 30	2.9	2.568 481 27	10.9	-0.000 002 03	-0.6
Sn	1.892 554 12	1.2	1.892 534 67	10.6	-0.000 019 45	-5.2
Ga	1.118 108 25	0.47	1.118 105 20	6.0	-0.000 003 05	-0.8
Hg	0.844 179 67	0.83	0.844 183 83	5.6	0.000 004 16	1.0

Table 4 – Measurement results for SPRT #2

	INMETRO		TTBS			
Fixed point	**W(t_{90})**	**Uncertainty k=2, mK**	**W(t_{90})**	**Uncertainty k=2, mK**	**W_{TTBS}-$W_{Inmetro}$**	**Δt_{90} mK**
Zn	2.568 389 26	2.5	2.568 382 96	11.1	-0.000 006 30	-1.8
Sn	1.892 501 81	1.3	1.892 499 11	10.3	-0.000 002 70	-0.7
Ga	1.118 102 62	0.80	1.118 097 66	6.4	-0.000 004 96	-1.2
Hg	0.844 187 07	0.83	0.844 191 56	5,8	0.000 004 49	1.1

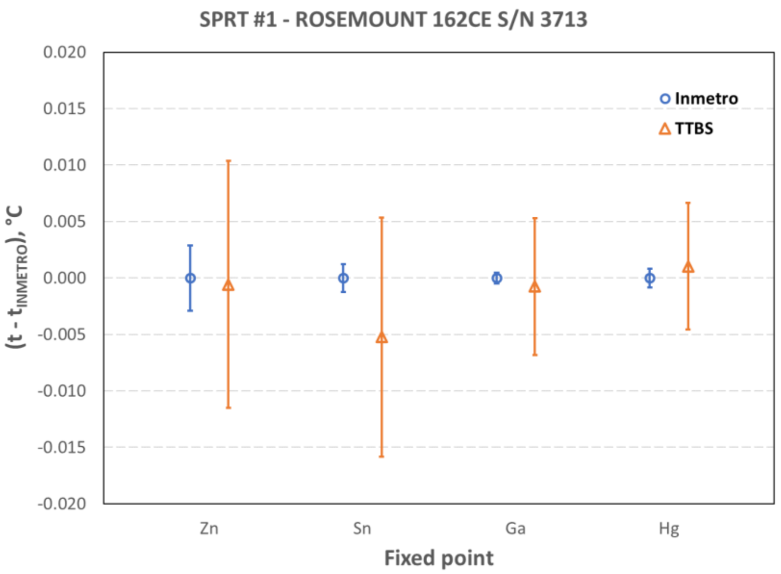

Figure 3 – Comparison results for SPRT #1

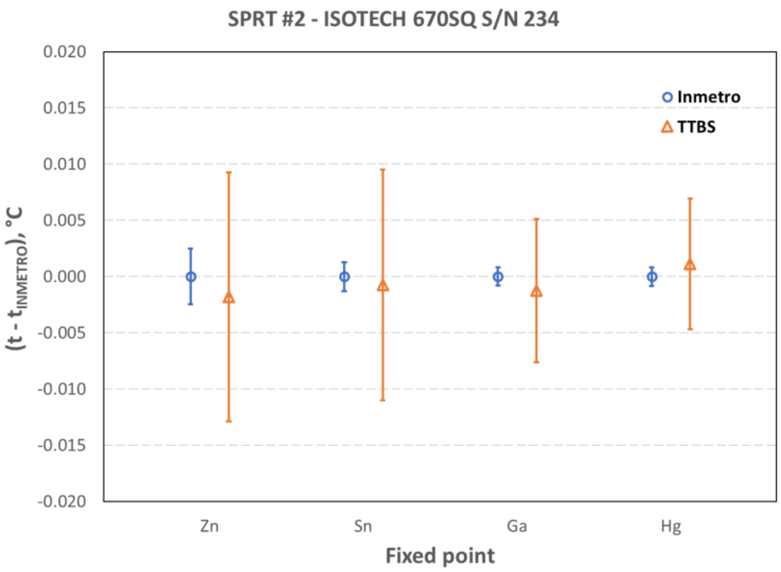

Figure 4 – Comparison results for SPRT #2

The individual SPRT results were used to calculate the overall comparison result. The bilateral temperature difference for each fixed point is given by:

$$\overline{\Delta t_{90}} = \frac{\Delta t_{90\_SPRT\,\#1} + \Delta t_{90\_SPRT\,\#2}}{2} \tag{2}$$

The uncertainties of the bilateral differences, for each fixed point, are calculated as follows:

$$u^2(\overline{\Delta t_{90}}) = \frac{u^2(\Delta t_{90\_SPRT\,\#1}) + u^2(\Delta t_{90\_SPRT\,\#2})}{2^2} + \left(\frac{1}{2}\right) \cdot u(\Delta t_{90\_SPRT\,\#1}) \cdot u(\Delta t_{90\_SPRT\,\#2}) \tag{3}$$

where the measurements performed with both thermometers are assumed as being fully correlated, and:

$$u^2(\Delta t_{90\,SPRT\,i}) = \frac{u^2\left(W_{TTBS}(t_{90\,SPRT\,i})\right) + u^2\left(W_{Inmetro}\,(t_{90\,SPRT\,i})\right)}{\left(\frac{dW(t_{90})}{dt_{90}}\right)^2} + \left(2\cdot\Delta T_{TPW,SPRT\,i}\right)^2 \quad (4)$$

where *SPRT i* refers to each SPRT (#1 and #2), and $\Delta T_{TPW,SPRT\,i}$ accounts for the observed change in the measured TPW resistance values with the *SPRT i* throughout the comparison, being bounded by the minimum and maximum measured resistances at the TPW, scaled with $W(t_{90})$ and with a rectangular distribution. It is given by:

$$\Delta T_{TPW,SPRT\,i} = \left(\frac{R_{TPW,max} - R_{TPW,min}}{2\cdot\sqrt{3}}\right)\cdot\frac{W}{R_{TPW}}\cdot\frac{dt_{90}}{dW(t_{90})} \quad (5)$$

Finally, the Normalized Error (E_n), are given by:

$$E_n = \frac{|\overline{\Delta t_{90}}|}{u(\overline{\Delta t_{90}})} \quad (6)$$

The results of the comparison are the bilateral differences and their associated uncertainties, as summarized in table 5, below. The E_n values are merely illustrative and also shown in the table 5. The expanded uncertainties (for a 95% coverage interval, with k=2) were computed from the uncertainties of the participant laboratories with both transfer standards at the fixed points, and from the drift observed in each SPRT due to the transportation, according to equations 3 and 4.

Table 5 – Final results of this comparison

Fixed point	**Bilateral difference $\overline{\Delta t_{90}}$ (Inmetro – TTBS) mK**	**Uncertainty $u(\overline{\Delta t_{90}})$, k=2 mK**	**E_n**
Zn	-1.2	11.8	**0.1**
Sn	-3.0	10.8	**0.3**
Ga	-1.0	6.4	**0.2**
Hg	1.1	5,9	**0.2**

7. LINKAGE TO CCT-K9

This comparison is intended to be linked to CCT-K9 results, since Inmetro has taken part of this comparison. The temperature differences between the TTBS ITS-90 realization temperature and the CCT-K9 key comparison reference value (KCRV), for each fixed point, are given by:

$$t_{90}(TTBS) - t_{90}(K9_{KCRV}) = \overline{\Delta t_{90}} + \left(t_{90}(Inmetro) - t_{90}(K9_{KCRV})\right) \quad (7)$$

where $t_{90}(K9_{KCRV})$ refers to the CCT-K9 KCRV and $\overline{\Delta t_{90}}$ is the temperature difference of this comparison, for a particular fixed point. The uncertainty is then given by:

$$\mathrm{u}^2\left(\mathrm{t}_{90}(\mathrm{TTBS}) - \mathrm{t}_{90}(\mathrm{K9}_{\mathrm{KCRV}})\right) = \mathrm{u}^2(\overline{\Delta \mathrm{t}_{90}}) + \mathrm{u}^2\left(\mathrm{t}_{90}(\mathrm{Inmetro}) - \mathrm{t}_{90}(\mathrm{K9}_{\mathrm{KCRV}})\right) \quad (8)$$

Inmetro’s results in CCT-K9 are shown in table 6, while the results of the linkage of the results of this SIM.T-K9.3 comparison to the CCT-K9 is shown in table 7. Once more, the uncertainties are reported for a 95% coverage interval.

Table 6 – Inmetro’s CCT-K9 results

Fixed point	$\Delta t_{90}(Inmetro - K9_{KCRV})$ **mK**	**Uncertainty, k=2 mK**
Zn	-0.69	1.37
Sn	-0.91	0.84
Ga	0.29	0.34
Hg	-0.11	0.41

Table 7 – TTBS’s results after link to the CCT-K9 comparison

Fixed point	$\Delta t_{90}(TTBS - K9_{KCRV})$ **mK**	**Uncertainty, k=2 mK**
Zn	-1.9	11.9
Sn	-3.9	10.8
Ga	-0.7	6.4
Hg	1.0	5,9

8. CONCLUSION

This report described a bilateral comparison between Inmetro and TTBS performed in the year of 2020. The results shown confirms the equivalence between the ITS-90 temperature realizations performed by Inmetro and TTBS. Furthermore, it provides a proper linkage to CCT-K9 KCRV values.

9. REFERENCES

[1] Measurement comparisons in the CIPM MRA, CIPM MRA-D-05 version 1.6, BIPM, Paris.

[2] JCGM 100:2008 - *Evaluation of measurement data – Guide to the expression of uncertainty in measurement*, www.bipm.org

[3] CCT/BIPM - *Guide to the Realization of the ITS-90*, www.bipm.org

[4] T. Herman and M. Chojnacky, “ITS-90 SPRT calibration from the Ar TP to the Zn FP”, *Metrologia* 60 03001, 2023

APPENDIX A – MEASUREMENT REPORTS

Identification

Laboratory :	TRINIDAD & TOBAGO BUREAU OF STANDARDS
Contact :	FRANCIS HAMILTON
e-mail :	Francis.Hamilton@ttbs.org.tt

Transfer standard information :

SPRT ID :	SPRT #1		
Manufacturer :	Rosemount		
Model :	162CE		
Serial number :	3713		
Date of transfer standard arrival :	1/12/2020		
Initial value of R(TPW) (ohms) :	25.55486984	±	0.00046
Final value of R(TPW) (ohms) :	25.55488745	±	0.00046

Calibration results :

Fixed point	*W(t90)*	Expanded uncertainty (°C)	Effective Degrees of Freedom
Zn	2.568481275	0.0109	3.27E+08
Sn	1.892534673	0.0106	3.16E+08
Ga	1.118105198	0.0060	1.09E+08
Hg	0.844183831	0.0056	2.16E+08

Identification

Laboratory :	TRINIDAD & TOBAGO BUREAU OF STANDARDS
Contact :	FRANCIS HAMILTON
e-mail :	Francis.Hamilton@ttbs.org.tt

Transfer standard information :

SPRT ID :	SPRT #2		
Manufacturer :	Isotech		
Model :	670SQ		
Serial number :	256		
Date of transfer standard arrival :	1/12/2020		
Initial value of R(TPW) (ohms) :	25.64035786	±	0.00048
Final value of R(TPW) (ohms) :	25.64041115	±	0.00048

Calibration results :

Fixed point	*W(t90)*	Expanded uncertainty (°C)	Effective Degrees of Freedom
Zn	2.568382962	0.0111	3.44E+08
Sn	1.892499110	0.0103	5.40E+08
Ga	1.118097662	0.0064	1.38E+08
Hg	0.844191560	0.0058	4.44E+08

Identification

Laboratory :	Inmetro
Contact :	Klaus Quelhas
e-mail :	knquelhas@inmetro.gov.br

Transfer standard information :

SPRT ID :	SPRT #1		
Manufacturer :	Rosemount		
Model :	162CE		
Serial number :	3713		
Date of transfer standard arrival :	1/27/2020		
Initial value of R(TPW) (ohm) :	25.554 879	±	0.000 022
Final value of R(TPW) (ohm) :	25.554 925	±	0.000 012

Calibration results :

Fixed point	*W(t90)*	Expanded uncertainty (°C)	Effective Degrees of Freedom
Zn	2.568 483 30	0.0029	2.52E+07
Sn	1.892 554 12	0.0012	4.03E+06
Ga	1.118 108 25	0.00047	1.72E+05
Hg	0.844 179 67	0.00083	1.19E+07

Identification

Laboratory :	Inmetro
Contact :	Klaus Quelhas
e-mail :	knquelhas@inmetro.gov.br

Transfer standard information :

SPRT ID :	SPRT #2		
Manufacturer :	Isotech		
Model :	670SQ		
Serial number :	256		
Date of transfer standard arrival :	1/27/2020		
Initial value of R(TPW) (ohm) :	25.640 451	±	0.000 025
Final value of R(TPW) (ohm) :	25.640 570	±	0.000 011

Calibration results :

Fixed point	*W(t90)*	Expanded uncertainty (°C)	Effective Degrees of Freedom
Zn	2.568 389 26	0.0025	9.50E+06
Sn	1.892 501 81	0.0013	1.20E+06
Ga	1.118 102 62	0.00080	1.31E+06
Hg	0.844 187 07	0.00083	1.17E+07

TTBS / SPRT #1

Fixed Point :	Zn

Description	**Uncertainty Estimate** x_i	**Unit**	**Probability distribution**	**Standard uncertainty** u_{xi}	**Sensitivity coefficient** c_i	**Unit**	**Contribution to uncertainty, mK** $c_i \cdot u_{xi}$	**Degrees of freedom** ν_i
Repeatability of test thermometer readings	0.000005	ohm	Normal	0.000005	11400	mK/ohm	0.05	100
Fixed point cell temperature uncertainty	6.0	mK	Normal	3.0	1.00	-	3.00	∞
Resistance readout uncertainty	2.395E-05	ohm	Normal	1.198E-05	11400	mK/Ohm	0.14	∞
Standard resistor uncertainty	7.77E-05	ohm	Normal	3.89E-05	7410	mK/ohm	0.29	∞
Hydrostatic head correction	0.014	m	Rectangular	0.0081	2.70	mK/m	0.02	∞
Gas pressure correction*	1.70	mK	Rectangular	0.981	1	-	0.98	∞
Heat flux	0.396	mK	Rectangular	0.229	1	-	0.23	∞
Self-heating correction	0.000098	ohm	Rectangular	0.000057	11400	mK/ohm	0.64	∞
TPW measurement uncertainty	3.0	mK	Normal	1.50	2.93	-	4.40	9.25E+07
W stability	0.000010	-	Rectangular	0.00000577	28610	mK	0.17	∞

* Estimate given by Appendix 1 of part 2 of the Guide to the Realization of the ITS-90 [3]

Combined uncertainty =	5.47
Effective degrees of freedom =	3.27E+08
k =	2.0
Expanded uncertainty =	10.93

Fixed Point :	Sn							
Description	**Uncertainty Estimate** *xi*	**Unit**	**Probability distribution**	**Standard uncertainty** *uxi*	**Sensitivity coefficient** *ci*	**Unit**	**Contribution to uncertainty, mK** *ci · uxi*	**Degrees of freedom** *νι*
Repeatability of test thermometer readings	0.000011	ohm	Normal	0.000011	10800	mK/ohm	0.11	100
Fixed point cell temperature uncertainty	7.0	mK	Normal	3.50	1.0	-	3.50	∞
Resistance readout uncertainty	2.40E-05	ohm	Normal	1.20E-05	10800	mK/Ohm	0.13	∞
Standard resistor uncertainty	7.77E-05	ohm	Normal	3.89E-05	5076	mK/ohm	0.20	∞
Hydrostatic head correction	0.014	m	Rectangular	0.0081	2.20	mK/m	0.02	∞
Gas pressure correction*	0.70	mK	Rectangular	0.404	1.0	-	0.40	∞
Heat flux	0.345	mK	Rectangular	0.199	1.0	-	0.20	∞
Self-heating correction	0.00040	ohm	Rectangular	0.000230	10800	mK/ohm	2.49	∞
TPW measurement uncertainty	3.0	mK	Normal	1.50	2.03	-	3.05	9.25E+07
W stability	0.000010	-	Rectangular	0.00000577	26930.00	mK	0.16	∞

* Estimate given by Appendix 1 of part 2 of the Guide to the Realization of the ITS-90 [3]

Combined uncertainty =	5.29
Effective degrees of freedom =	3.16E+08
k =	2.0
Expanded uncertainty =	10.58

Fixed Point :	Ga

Description	**Uncertainty Estimate** *xi*	**Unit**	**Probability distribution**	**Standard uncertainty** *uxi*	**Sensitivity coefficient** *ci*	**Unit**	**Contribution to uncertainty, mK** *ci · uxi*	**Degrees of freedom** *νι*
Repeatability of test thermometer readings	0.000009	ohm	Normal	0.000009	10100	mK/ohm	0.09	100
Fixed point cell temperature uncertainty	5.0	mK	Normal	2.50	1.0	-	2.50	∞
Resistance readout uncertainty	2.40E-05	ohm	Normal	1.20E-05	10100	mK/Ohm	0.12	∞
Standard resistor uncertainty	7.77E-05	ohm	Normal	3.89E-05	2828	mK/ohm	0.11	∞
Hydrostatic head correction	0.025	m	Rectangular	0.014	-1.20	mK/m	-0.02	∞
Gas pressure correction	5000	Pa	Rectangular	2886.8	2.0E-05	mK/Pa	0.06	∞
Heat flux	0.075	mK	Rectangular	0.043	1.0	-	0.04	∞
Self-heating correction	0.000013	ohm	Rectangular	0.000008	10100	mK/ohm	0.08	∞
TPW measurement uncertainty	3.0	mK	Normal	1.50	1.13	-	1.69	9.25E+07
W stability	0.000010	-	Rectangular	0.00000577	25220.00	mK	0.15	∞

Combined uncertainty =	3.02
Effective degrees of freedom =	1.09E+08
k =	2.0
Expanded uncertainty =	6.05

Fixed Point :	Hg

Description	Uncertainty Estimate x_i	Unit	Probability distribution	Standard uncertainty u_{xi}	Sensitivity coefficient c_i	Unit	Contribution to uncertainty, mK $c_i \cdot u_{xi}$	Degrees of freedom ν_i
Repeatability of test thermometer readings	0.000008	ohm	Normal	0.000008	9900	mK/ohm	0.07	100
Fixed point cell temperature uncertainty	5.0	mK	Normal	2.50	1.0	-	2.50	∞
Resistance readout uncertainty	2.40E-05	ohm	Normal	1.20E-05	9900	mK/Ohm	0.12	∞
Standard resistor uncertainty	7.77E-05	ohm	Normal	3.89E-05	2079	mK/ohm	0.08	∞
Hydrostatic head correction	0.018	m	Rectangular	0.010	7.10	mK/m	0.07	∞
Gas pressure correction	0	Pa	Rectangular	0	5.4E-05	mK/Pa	0.00	∞
Heat flux	-0.176	mK	Rectangular	-0.102	1.0	-	-0.10	∞
Self-heating correction	0.00003	ohm	Rectangular	0.000	9900	mK/ohm	0.18	∞
TPW measurement uncertainty	3.0	mK	Normal	1.50	0.83	-	1.25	9.25E+07
W stability	0.000010	-	Rectangular	0.00000577	24770.00	mK	0.14	∞

Combined uncertainty =	2.81
Effective degrees of freedom =	2.16E+08
k =	2.0
Expanded uncertainty =	5.62

TTBS / SPRT #2

Fixed Point :	Zn

Description	**Uncertainty Estimate** *xi*	**Unit**	**Probability distribution**	**Standard uncertainty** *uxi*	**Sensitivity coefficient** *ci*	**Unit**	**Contribution to uncertainty, mK** *ci · uxi*	**Degrees of freedom** *νι*
Repeatability of test thermometer readings	0.000010	ohm	Normal	0.000010	11400	mK/ohm	0.11	100
Fixed point cell temperature uncertainty	6.0	mK	Normal	3.00	1.0	-	3.00	∞
Resistance readout uncertainty	2.40E-05	ohm	Normal	1.20E-05	11400	mK/Ohm	0.14	∞
Standard resistor uncertainty	7.77E-05	ohm	Normal	3.89E-05	7410	mK/ohm	0.29	∞
Hydrostatic head correction	0.014	m	Rectangular	0.0081	2.70	mK/m	0.02	∞
Gas pressure correction*	1.70	mK	Rectangular	0.981	1	-	0.98	∞
Heat flux	0.296	mK	Rectangular	0.171	1.0	-	0.17	∞
Self-heating correction	-0.000167	ohm	Rectangular	0.000097	11400	mK/ohm	1.10	∞
TPW measurement uncertainty	3.0	mK	Normal	1.50	2.93	-	4.40	2.03E+08
W stability	0.000010	-	Rectangular	0.00000577	28610.00	mK	0.17	∞

* Estimate given by Appendix 1 of part 2 of the Guide to the Realization of the ITS-90 [3]

Combined uncertainty =	5.54
Effective degrees of freedom =	3.44E+08
k =	2.0
Expanded uncertainty =	11.08

Fixed Point :	Sn							
Description	**Uncertainty Estimate** *xi*	**Unit**	**Probability distribution**	**Standard uncertainty** *uxi*	**Sensitivity coefficient** *ci*	**Unit**	**Contribution to uncertainty, mK** *ci · uxi*	**Degrees of freedom** *νι*
Repeatability of test thermometer readings	0.000009	ohm	Normal	0.000009	10800	mK/ohm	0.10	100
Fixed point cell temperature uncertainty	7.0	mK	Normal	3.50	1.0	-	3.50	∞
Resistance readout uncertainty	2.40E-05	ohm	Normal	1.20E-05	10800	mK/Ohm	0.13	∞
Standard resistor uncertainty	7.77E-05	ohm	Normal	3.89E-05	5076	mK/ohm	0.20	∞
Hydrostatic head correction	0.014	m	Rectangular	0.0081	2.20	mK/m	0.02	∞
Gas pressure correction*	0.70	mK	Rectangular	0.404	1.0	-	0.40	∞
Heat flux	-2.8	mK	Rectangular	1.618	1.0	-	-1.62	∞
Self-heating correction	0.00022	ohm	Rectangular	0.000128	10800	mK/ohm	1.38	∞
TPW measurement uncertainty	3.0	mK	Normal	1.50	2.03	-	3.05	2.03E+08
W stability	0.000010	-	Rectangular	0.00000577	26930.00	mK	0.16	∞

* Estimate given by Appendix 1 of part 2 of the Guide to the Realization of the ITS-90 [3]

Combined uncertainty =	5.13
Effective degrees of freedom =	5.40E+08
k =	2.0
Expanded uncertainty =	10.26

Fixed Point :	Ga

Description	**Uncertainty Estimate** *xi*	**Unit**	**Probability distribution**	**Standard uncertainty** *uxi*	**Sensitivity coefficient** *ci*	**Unit**	**Contribution to uncertainty, mK** *ci · uxi*	**Degrees of freedom** *νι*
Repeatability of test thermometer readings	0.000009	ohm	Normal	0.000009	10100	mK/ohm	0.09	100
Fixed point cell temperature uncertainty	5.0	mK	Normal	2.50	1.0	-	2.50	∞
Resistance readout uncertainty	2.40E-05	ohm	Normal	1.20E-05	10100	mK/Ohm	0.12	∞
Standard resistor uncertainty	7.77E-05	ohm	Normal	3.89E-05	2828	mK/ohm	0.11	∞
Hydrostatic head correction	0.025	m	Rectangular	0.014	-1.20	mK/m	-0.02	∞
Gas pressure correction	5000	Pa	Rectangular	2886.8	2.0E-05	mK/Pa	0.06	∞
Heat flux	-0.272	mK	Rectangular	0.157	1.0	-	0.16	∞
Self-heating correction	0.00017	ohm	Rectangular	0.000096	10100	mK/ohm	0.97	∞
TPW measurement uncertainty	3.000000	mK	Normal	1.50	1.13	-	1.69	2.03E+08
W stability	0.000010	-	Rectangular	0.00000577	25220.00	mK	0.15	∞

Combined uncertainty =	3.18
Effective degrees of freedom =	1.38E+08
k =	2.0
Expanded uncertainty =	6.36

Fixed Point :	Hg

Description	**Uncertainty Estimate** *xi*	**Unit**	**Probability distribution**	**Standard uncertainty** *uxi*	**Sensitivity coefficient** *ci*	**Unit**	**Contribution to uncertainty, mK** *ci · uxi*	**Degrees of freedom** *νι*
Repeatability of test thermometer readings	0.000007	ohm	Normal	0.000007	9900	mK/ohm	0.06	100
Fixed point cell temperature uncertainty	5.0	mK	Normal	2.50	1.0	-	2.50	∞
Resistance readout uncertainty	2.40E-05	ohm	Normal	1.20E-05	9900	mK/Ohm	0.12	∞
Standard resistor uncertainty	7.77E-05	ohm	Normal	3.89E-05	2079	mK/ohm	0.08	∞
Hydrostatic head correction	0.018	m	Rectangular	0.010	7.10	mK/m	0.07	∞
Gas pressure correction	0	Pa	Rectangular	0	5.4E-05	mK/Pa	0.00	∞
Heat flux	-0.120	mK	Rectangular	0.069	1.0	-	0.07	∞
Self-heating correction	0.00014	ohm	Rectangular	0.000079	9900	mK/ohm	0.79	∞
TPW measurement uncertainty	3.0	mK	Normal	1.5000000	0.83	-	1..25	2.03E+08
W stability	0.000010	-	Rectangular	0.00000577	24770.00	mK	0.14	∞

Combined uncertainty =	2.91
Effective degrees of freedom =	4.44E+08
k =	2.0
Expanded uncertainty =	5.81

Inmetro / SPRT #1

Fixed Point :	Zn

Description	**Uncertainty Estimate** *xi*	**Unit**	**Probability distribution**	**Standard uncertainty** *uxi*	**Sensitivity coefficient** *ci*	**Unit**	**Contribution to uncertainty, mK** *ci · uxi*	**Degrees of freedom** *νι*
Repeatability of test thermometer readings	4.5E-06	ohm	Normal	4.5E-06	11444.00	mK/ohm	0.05	45
Fixed point cell temperature uncertainty	1.14	mK	Normal	1.14	1.00	-	1.14	∞
Resistance readout	0.05	ppm	Normal	0.05	0.75	mK	0.04	∞
Standard resistor	3.7E-05	ohm	Normal	3.7E-05	7511.50	mK/ohm	0.28	∞
Hydrostatic head correction	0.03	m	Rectangular	0.014	2.70	mK/m	0.04	∞
Gas pressure correction	1500	Pa	Rectangular	866	4.3E-05	mK/Pa	0.04	∞
Heat flux	0.06	mK	Normal	0.06	1.00	-	0.06	∞
Self-heating correction	4.5E-06	ohm	Normal	4.5E-06	11444.00	mK/ohm	0.05	∞
TPW measurement	0.22	mK	Normal	0.22	2.93	-	0.64	1.03E+07
W stability	3.7E-06	adm.	Rectangular	2.16E-06	286100.00	mK	0.61	∞

Combined uncertainty =	1.47
Effective degrees of freedom =	2.52E+07
k =	2.0
Expanded uncertainty =	2.95

Fixed Point :	Sn

Description	**Uncertainty Estimate** *xi*	**Unit**	**Probability distribution**	**Standard uncertainty** *uxi*	**Sensitivity coefficient** *ci*	**Unit**	**Contribution to uncertainty, mK** *ci · uxi*	**Degrees of freedom** *νι*
Repeatability of test thermometer readings	3.3E-06	ohm	Normal	3.3E-06	10772.00	mK/ohm	0.04	45
Fixed point cell temperature uncertainty	0.40	mK	Normal	0.40	1.00	-	0.40	∞
Resistance readout	0.05	ppm	Normal	0.05	0.52	mK	0.03	∞
Standard resistor	3.7E-05	ohm	Normal	3.7E-05	5209.76	mK/ohm	0.19	∞
Hydrostatic head correction	0.02	m	Rectangular	0.01	2.20	mK/m	0.03	∞
Gas pressure correction	1500	Pa	Rectangular	866	3.3E-05	mK/Pa	0.03	∞
Heat flux	0.35	mK	Normal	0.35	1.00	-	0.35	∞
Self-heating correction	3.3E-06	ohm	Normal	3.3E-06	10772.00	mK/ohm	0.04	∞
TPW measurement	0.11	mK	Normal	0.11	2.03	-	0.23	1.03E+07
W stability	6.8E-07	adm.	Rectangular	3.9E-07	269300.00	mK	0.11	∞

Combined uncertainty =	0.62
Effective degrees of freedom =	4.03E+06
k =	2.0
Expanded uncertainty =	1.24

Fixed Point :	Ga

Description	**Uncertainty Estimate** *xi*	**Unit**	**Probability distribution**	**Standard uncertainty** *uxi*	**Sensitivity coefficient** *ci*	**Unit**	**Contribution to uncertainty, mK** *ci · uxi*	**Degrees of freedom** *νι*
Repeatability of test thermometer readings	3.0E-06	ohm	Normal	3.0E-06	10088.00	mK/ohm	0.03	45
Fixed point cell temperature uncertainty	0.11	mK	Normal	0.11	1.00	-	0.11	∞
Resistance readout	0.05	ppm	Normal	0.05	0.29	mK	0.02	∞
Standard resistor	3.7E-05	ohm	Normal	3.7E-05	2882.45	mK/ohm	0.11	∞
Hydrostatic head correction	0.03	m	Rectangular	0.01	1.20	mK/m	0.02	∞
Gas pressure correction	5000	Pa	Rectangular	2887	2.0E-05	mK/Pa	5.8E-02	∞
Heat flux	0.01	mK	Normal	0.01	1.00	-	0.01	∞
Self-heating correction	3.0E-06	ohm	Normal	3.0E-06	10088.00	mK/ohm	0.03	∞
TPW measurement	0.14	mK	Normal	0.14	1.13	-	0.16	3.83E+06

Combined uncertainty =	0.24
Effective degrees of freedom =	1.72E+05
k =	2.0
Expanded uncertainty =	0.47

Fixed Point :	Hg

Description	Uncertainty Estimate *xi*	Unit	Probability distribution	Standard uncertainty *uxi*	Sensitivity coefficient *ci*	Unit	Contribution to uncertainty, mK *ci · uxi*	Degrees of freedom *νι*
Repeatability of test thermometer readings	1.8E-06	ohm	Normal	1.8E-06	9908.00	mK/ohm	0.02	45
Fixed point cell temperature uncertainty	0.38	mK	Normal	0.38	1.00	-	0.38	∞
Resistance readout	0.05	ppm	Normal	0.05	0.21	mK	0.01	∞
Standard resistor	3.7E-05	ohm	Normal	3.7E-05	2137.45	mK/ohm	0.08	∞
Hydrostatic head correction	0.03	m	Rectangular	0.01	7.10	mK/m	0.10	∞
Gas pressure correction	0	Pa	Rectangular	0	5.4E-05	mK/Pa	0.0E+00	∞
Heat flux	0.05	mK	Normal	0.05	1.00	-	0.05	∞
Self-heating correction	1.8E-06	ohm	Normal	1.8E-06	9908.00	mK/ohm	0.02	∞
TPW measurement	0.12	mK	Normal	0.12	0.83	-	0.10	3.99E+05

Combined uncertainty =	0.42
Effective degrees of freedom =	1.19E+07
k =	2
Expanded uncertainty =	0.83

Inmetro / SPRT #2

Fixed Point :	Zn

Description	Uncertainty Estimate *xi*	Unit	Probability distribution	Standard uncertainty *uxi*	Sensitivity coefficient *ci*	Unit	Contribution to uncertainty, mK *ci · uxi*	Degrees of freedom *νι*
Repeatability of test thermometer readings	5.0E-06	ohm	Normal	5.0E-06	11444.00	mK/ohm	0.06	45
Fixed point cell temperature uncertainty	1.14	mK	Normal	1.14	1.00	-	1.14	∞
Resistance readout	0.05	ppm	Normal	0.05	0.75	mK	0.04	∞
Standard resistor	3.7E-05	ohm	Normal	3.7E-05	7536.40	mK/ohm	0.28	∞
Hydrostatic head correction	0.03	m	Rectangular	0.02	2.70	mK/m	0.04	∞
Gas pressure correction	1500	Pa	Rectangular	866	4.3E-05	mK/Pa	0.04	∞
Heat flux	0.06	mK	Normal	0.06	1.00	-	0.06	∞
Self-heating correction	5.0E-06	ohm	Normal	5.0E-06	11444.00	mK/ohm	0.06	∞
TPW measurement	0.15	mK	Normal	0.15	2.93	-	0.43	3.26E+07
W stability	-1.4E-07	adm.	Rectangular	7.8E-08	286100.00	mK	0.02	∞

Combined uncertainty =	1.26
Effective degrees of freedom =	9.50E+06
k =	2.0
Expanded uncertainty =	2.51

Fixed Point :	Sn							
Description	**Uncertainty Estimate** *xi*	**Unit**	**Probability distribution**	**Standard uncertainty** *uxi*	**Sensitivity coefficient** *ci*	**Unit**	**Contribution to uncertainty, mK** *ci · uxi*	**Degrees of freedom** *νι*
Repeatability of test thermometer readings	4.7E-06	ohm	Normal	4.7E-06	10772.00	mK/ohm	0.05	45
Fixed point cell temperature uncertainty	0.40	mK	Normal	0.40	1.00	-	0.40	∞
Resistance readout	0.05	ppm	Normal	0.05	0.52	mK	0.03	∞
Standard resistor	3.7E-05	ohm	Normal	3.7E-05	5227.10	mK/ohm	0.19	∞
Hydrostatic head correction	0.02	m	Rectangular	0.01	2.20	mK/m	0.03	∞
Gas pressure correction	1500	Pa	Rectangular	866	3.3E-05	mK/Pa	0.03	∞
Heat flux	0.01	mK	Normal	0.01	1.00	-	0.01	∞
Self-heating correction	4.7E-06	ohm	Normal	4.7E-06	10772.00	mK/ohm	0.05	∞
TPW measurement	0.23	mK	Normal	0.23	2.03	-	0.46	5.17E+08
W stability	-1.1E-06	adm.	Rectangular	-6.1E-07	269300.00	mK	-0.17	∞

Combined uncertainty =	0.67
Effective degrees of freedom =	1.20E+06
k =	2.0
Expanded uncertainty =	1.34

Fixed Point :	Ga							
Description	**Uncertainty Estimate** *xi*	**Unit**	**Probability distribution**	**Standard uncertainty** *uxi*	**Sensitivity coefficient** *ci*	**Unit**	**Contribution to uncertainty, mK** *ci · uxi*	**Degrees of freedom** *νι*
Repeatability of test thermometer readings	3.0E-06	ohm	Normal	3.0E-06	10088.00	mK/ohm	0.03	45
Fixed point cell temperature uncertainty	0.11	mK	Normal	0.11	1.00	-	0.11	∞
Resistance readout	0.054	ppm	Normal	0.05	0.29	mK	0.02	∞
Standard resistor	3.7E-05	ohm	Normal	3.7E-05	2892.11	mK/ohm	0.11	∞
Hydrostatic head correction	0.0275	m	Rectangular	0.02	-1.20	mK/m	-0.02	∞
Gas pressure correction	5000	Pa	Rectangular	2887	-2.0E-05	mK/Pa	-5.8E-02	∞
Heat flux	0.03	mK	Normal	0.03	1.00	-	0.03	∞
Self-heating correction	3.0E-06	ohms	Normal	3.0E-06	10088.00	mK/ohm	0.04	∞
TPW measurement	0.32	mK	Normal	0.32	1.13	-	0.36	4.18E+07

Combined uncertainty =	0.40
Effective degrees of freedom =	1.31E+06
k =	2.0
Expanded uncertainty =	0.80

Fixed Point :	Hg							
Description	**Uncertainty Estimate** *xi*	**Unit**	**Probability distribution**	**Standard uncertainty** *uxi*	**Sensitivity coefficient** *ci*	**Unit**	**Contribution to uncertainty, mK** *ci · uxi*	**Degrees of freedom** *νι*
Repeatability of test thermometer readings	1.8E-06	ohm	Normal	1.8E-06	9908.00	mK/ohm	0.02	45
Fixed point cell temperature uncertainty	0.38	mK	Normal	0.38	1.00	-	0.38	∞
Resistance readout	0.054	ppm	Normal	0.05	0.21	mK	0.01	∞
Standard resistor	3.7E-05	ohm	Normal	3.7E-05	2144.64	mK/ohm	0.08	∞
Hydrostatic head correction	0.0275	m	Rectangular	0.02	7.10	mK/m	0.11	∞
Gas pressure correction	0	Pa	Rectangular	0	5.4E-05	mK/Pa	0.0E+00	∞
Heat flux	0.02	mK	Normal	0.02	1.00	-	0.02	∞
Self-heating correction	1.8E-06	ohms	Normal	1.8E-06	9908.00	mK/ohm	0.03	∞
TPW measurement	0.11	mK	Normal	0.11	0.83	-	0.09	3.61E+06

Combined uncertainty =	0.42
Effective degrees of freedom =	1.17E+07
k =	2.0
Expanded uncertainty =	0.83

APPENDIX C – TECHNICAL PROTOCOL

BILATERAL COMPARISON OF TEMPERATURE STANDARDS

SIM.T-K9.3

Instituto Nacional de Metrologia, Qualidade e Tecnologia (Inmetro), Brazil
Trinidad and Tobago Bureau of Standards (TTBS), Trinidad and Tobago

Standard Platinum Resistance Thermometers from the Hg Triple Point to the Zn Freezing Point

TECHNICAL PROTOCOL

January/2020, revised November/2020

Contents

10. INTRODUCTION

10.1. Under the Mutual Recognition Arrangement (MRA)[1] the metrological equivalence of national measurement standards will be determined by a set of key comparisons chosen and organized by the Consultative Committees of the CIPM working closely with the Regional Metrology Organizations (RMOs).

10.2. This document describes the technical protocol of a bilateral comparison of temperature standards between Instituto Nacional de Metrologia, Qualidade e Tecnologia (INMETRO), Brazil, and Trinidad and Tobago Bureau of Standards (TTBS), Trinidad and Tobago.

10.3. This technical protocol has been prepared and approved by the two participants indicated above.

10.4. The procedures outlined in this document cover the technical procedure to be followed during measurement of two transfer standards. The procedure, which follows the guidelines established by the BIPM[2], is based on current best practices in the use of standard platinum resistance thermometers and takes account of the experience gained from the research and calibration activities of the participants over the years.

10.5. This comparison is aimed at checking the degree of equivalence between fixed point calibration results of standard platinum resistance thermometers (SPRT) in the range between the triple point of mercury (-38.8344 °C) and the freezing point of zinc (419.527 °C), as performed by both institutes. As consequence, the results of this comparison will subside TTBS to stablish its calibration and measurement capabilities (CMCs) on the BIPM KCDB, by means of a direct link to CCT-K9 key comparison through the results obtained by Inmetro.

11. ORGANIZATION

11.1. **Participants**

11.1.1. Details of mailing and electronic addresses are given in Appendix 1. The participating institutes are:

- Instituto Nacional de Metrologia, Qualidade e Tecnologia (Inmetro) – Brazil
- Trinidad and Tobago Bureau of Standards (TTBS) – Trinidad and Tobago

11.1.2. Inmetro is the pilot of this bilateral comparison, taking main responsibility for running comparison.

11.1.3. By their declared intention to participate in this bilateral comparison, the laboratories accept the general instructions and the technical protocol written down in this document and commit themselves to follow strictly the procedures of this protocol as well as the version of the "Guidelines for Key Comparisons" in effect at the time of the initiation of the Bilateral Comparison.

11.1.4. Once the protocol and list of participants have been approved, no change to the protocol or list of participants may be made without prior agreement of all participants.

[1] MRA, Mutual Recognition Arrangement, BIPM, 1999.
[2] Measurement comparisons in the CIPM MRA, CIPM MRA-D-05 version 1.6, BIPM, Paris.

11.1.5. The participants must be able to submit an uncertainty budget of their temperature measurements according to section 3.4.

11.2. **Transfer Standards**

11.2.1. Each laboratory will provide a SPRT as transfer standards, as described below:

Laboratory	INMETRO	TTBS
SPRT ID	SPRT #1	SPRT #2
Manufacturer	Rosemount	Isotech
Model	162CE	670Q
Serial number	3713	234
Nominal resistance at 0 °C	25 Ω	25 Ω
Number of wires	4	4

11.3. **Handling of the Artefact**

11.3.1. The artefact should only be handled by authorized persons and stored in such a way as to prevent damage.

11.3.2. During measurements, if there is any unusual occurrence, the pilot laboratory should be notified immediately before proceeding.

11.4. **Transport of Artefact**

11.4.1. Both Inmetro and TTBS will be in charge to transport the standards to the other laboratory.

11.5. **Timetable**

Activity	**Start Month**	**Provisional date**
Submission of a technical protocol to participants for unanimous approval	January 2020	
Submission of revised technical protocol to SIM/ WG3 (thermometry WG) for approval.	January 2020	
Travelling of SPRT #1 to TTBS	January 2020	
Completion of the measurements of both standards at TTBS	January 2020	
Travelling of both standards to Inmetro	January 2020	
Completion of the measurements of both standards at Inmetro		March 2020
Draft A ready to both participants		July 2020
Deadline for comments on Draft A		August 2020
Draft B ready and submitted to SIM/WG3		December 2020
Paper submission		February 2021

3. MEASUREMENT INSTRUCTIONS

3.1. Measurand

3.1.1. The measurand of this comparison are the $W(t_{90})$ measured values, where

$$W(t_{90}) = \frac{R(t_{90})}{R(TPW)} \quad (1)$$

where $R(t_{90})$ and $R(TPW)$ are, respectively, the values of electrical resistance of the SPRT measured at the fixed points, and the resistance at the triple point of water (TPW).

3.1.2. With the measured values of $W(t_{90})$, the difference between both laboratories, for each SPRT *i*, at each fixed point, is given as follows:

$$\Delta t_{90,SPRT\ i} = \frac{W_{TTBS}(t_{90,SPRT\ i}) - W_{Inmetro}\ (t_{90,SPRT\ i})}{dW(t_{90})/dt_{90}} \quad (2)$$

where $dW(t_{90})/dt_{90}$ is the first derivative of W with relation to the temperature.

3.1.3. The average temperature difference in then given by:

$$\overline{\Delta t_{90}} = \frac{\Delta t_{90\_SPRT\ \#1} + \Delta t_{90\_SPRT\ \#2}}{2} \quad (3)$$

3.2. Preliminary checks

3.2.1. The artefact should be examined when received by the participant laboratory, before the start of measurements, to check if the PRT has any kind of damage. If the artefact has no damage, the laboratory will proceed with the measurements.

3.3. Measurement process

3.3.1. Each participant will measure the electrical resistances of the SPRT using four wires connection.

3.3.2. All the measured electrical resistances must be corrected to null current (0 mA).

3.3.3. Each participant will follow its own procedure while calibrating the SPRTs. This includes the procedures for annealing and stabilizing the thermometers at the TPW prior to the calibration.

3.3.4. The first point to be measured is the TPW, immediately after receiving the SPRTs. This value will be reported, in order to identify any drift due to transportation.

3.3.5. The calibration then will proceed from higher to lower temperatures. The SPRTs shall be calibrated at the zinc freezing point (Zn FP, 419.527 °C), tin freezing point (Sn FP, 231.928 °C), gallium melting point (Ga MP, 29.7646 °C) and mercury triple point (Hg TP, -38.8344 °C). Before and after each calibration point, the R_{TPW} value of the SPRTs must be measured.

3.3.6. The transfer standards used in this comparison must not be modified, adjusted or used for any purpose other than described in this document, nor given to any party other than the participants of this comparison.

3.3.7. If unacceptable performance or failure of the transfer standard is detected, the participants will discuss the situation and agree a course of action.

3.4. Measurement uncertainties

3.4.1. Each participant will calculate, for each calibration point, the measurement uncertainties, according to Appendix 3, which must include at least, but not excluding other components:

a) Repeatability of the test thermometer's readings;
b) Fixed point cell temperature;
c) Resistance readout system uncertainty;
d) Self-heating correction's uncertainty;
e) Hydrostatic head correction's uncertainty;
f) Gas pressure correction's uncertainty, if applicable;
g) Heat flux uncertainty;
h) Propagated uncertainty of the TPW measurement.

3.5. Reporting measurement results

3.5.1. Participants will report their measurement results in a period of time not exceeding three weeks after completion of measurements. The measurement report is given in Appendix 2, and must include at least the following information:

a) Initial and final *R(TPW)* measured values;
b) For each calibration point, $W(t_{90})$ and expanded uncertainty;
c) Measurement system (fixed point cells, isothermal medias and electrical resistance readouts);
d) Uncertainty analysis.

3.5.2. Measurement uncertainties will be reported in terms of temperature, by converting the W(t90) uncertainties values with the appropriate value of dW(t90)/dt90.

3.5.3. The participants should not disclose their measurement results to a third party. The participants will exchange their measurement results after all the measurements are completed.

4. RESULTS OF THE COMPARISON

4.1. The pilot laboratory will analyze the results of participant laboratories. The results of the comparison are:

4.1.1. The bilateral differences, as described in eq. 3;

4.1.2. The uncertainties of the bilateral differences, given by:

$$u^2(\overline{\Delta t_{90}}) = \frac{u^2\left(\Delta t_{90\_SPRT\ \#1}\right) + u^2\left(\Delta t_{90\_SPRT\ \#2}\right)}{2^2} \quad (4)$$

where:

$$u^2(\Delta t_{90\_SPRT\ i}) = \frac{u^2\left(W_{TTBS}(t_{90\_SPRT\ i})\right) + u^2\left(W_{Inmetro}\ (t_{90\_SPRT\ i})\right) + \left(\frac{\Delta W_{TPW,SPRT\ i}}{\sqrt{3}}\right)^2}{\left(\frac{dW(t_{90})}{dt_{90}}\right)^2} \quad (5)$$

where *SPRT i* refers to each SPRT (#1 and #2), and $\Delta W_{TPW,SPRT\ i}$ accounts for the observed change in the TPW value of the *SPRT i* after traveling from TTBS to Inmetro.

4.1.3. The degrees of equivalence, denoted by the Normalized Error (E_n), are given by:

$$E_n = \frac{|\overline{\Delta t_{90}}|}{u^2(\overline{\Delta t_{90}})} \quad (6)$$

where $\overline{\Delta t_{90}}$ is given in eq. 3, and *U* is the expanded uncertainty of *W(t90)* in terms of temperature for a confidence level of approximately 95%.

5. LINKAGE TO CCT-K9

5.1. This comparison is intended to be linked to the key comparison CCT-K9 results. The temperature differences between the TTBS ITS-90 realization and the key comparison reference value (KCRV), for each fixed point, shall be given by:

$$\mathrm{t}_{90}(\mathrm{TTBS}) - \mathrm{t}_{90}(\mathrm{K9}_{\mathrm{KCRV}}) = \overline{\Delta \mathrm{t}_{90}} + \left(\mathrm{t}_{90}(\mathrm{Inmetro}) - \mathrm{t}_{90}(\mathrm{K9}_{\mathrm{KCRV}})\right) \quad (7)$$

where t90(K9KCRV) refers to the CCT-K9 KCRV and $\overline{\Delta t_{90}}$ is the temperature difference of this comparison, for a particular fixed point. The uncertainty is then given by:

$$u^2\left(\mathrm{t}_{90}(\mathrm{TTBS}) - \mathrm{t}_{90}(\mathrm{K9}_{\mathrm{KCRV}})\right) = u^2(\overline{\Delta t_{90}}) + \mathrm{u}^2\left(\mathrm{t}_{90}(\mathrm{Inmetro}) - \mathrm{t}_{90}(\mathrm{K9}_{\mathrm{KCRV}})\right) \quad (8)$$

6. COMPARISON REPORT

6.1. The pilot laboratory will prepare the Draft A, which will be available for review in a period of time no longer than two weeks.

6.2. The pilot laboratory will then prepare the Draft B, which will be submitted to SIM/WG3 for approval.

REFERENCES

[1] Measurement comparisons in the CIPM MRA, CIPM MRA-D-05 version 1.6, BIPM, Paris.

[2] JCGM 100:2008 - *Evaluation of measurement data – Guide to the expression of uncertainty in measurement*, www.bipm.org

[3] CCT/BIPM - *Guide to the Realization of the ITS-90*, www.bipm.org

APPENDIX 1

DETAILS OF PARTICIPATING INSTITUTES

Instituto Nacional de Metrologia, Qualidade e Tecnologia – INMETRO

Address:	Laboratório de Termometria (Prédio 04) – Av. Nossa Senhora das Graças, 50 Xerém – Duque de Caxias – RJ – Brasil – CEP: 25250-020
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Trinidad and Tobago Bureau of Standards – TTBS

Address:	1-2 Century Drive, Trincity Industrial Estate, Macoya, Tunapuna Trinidad and Tobago
Contact:	Francis Hamilton
Phone:	+1 868 662-8827 ext 2311
E-mail:	Francis.Hamilton@ttbs.org.tt

APPENDIX 2

MEASUREMENT REPORT

Identification

Laboratory :	
Contact :	
e-mail :	

Transfer standard information :

SPRT ID :			
Manufacturer :			
Model :			
Serial number :			
Date of transfer standard arrival :			
Initial value of *R(TPW)* (Ω) :		±	
Final value of *R(TPW)* (Ω) :		±	

Calibration results :

Fixed point	$W(t_{90})$	Expanded uncertainty (°C)	Effective Degrees of Freedom
Zn			
Sn			
Ga			
Hg			

MEASUREMENT SYSTEM INFORMATION

Standards :

Description	Manufacturer	Model	Traceability

Electrical resistance readouts :

Description	Manufacturer	Model	Traceability

Isothermal media :

Description	Manufacturer	Model

APPENDIX 3

UNCERTAINTY ANALYSIS

Fixed Point :	

Description	Estimate x_i	Unit	Probability distribution	Standard uncertainty ux_i	Sensitivity coefficient c_i	Unit	Contribution to uncertainty $ci \cdot ux_i$	Degrees of freedom v_i
Repeatability of test thermometer readings								
Fixed point cell								
Resistance readout								
Self-heating correction								
Hydrostatic head correction								
Gas pressure correction								
Heat flux								
Propagated TPW measurement								
Propagated TPW stability								

Combined uncertainty =	
Effective degrees of freedom =	
k =	
Expanded uncertainty =	