

APMP.T-K3.6 comparison report of the ITS-90 realization at the triple point of argon between NIM and CMS

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1 Introduction

Several key comparisons organized by the Consultative Committee for Thermometry (CCT) were carried out to compare the ITS-90 realization in different national metrology institutes [1, 2]. Generally, the number of participants in a CCT Key Comparison (CCT KC) is limited to a few laboratories in each major economic region due to time period and workload. A series of bilateral comparisons and multilateral comparisons were organized to link more laboratories to the CCT-KC. National Institute of Metrology, China (NIM) participated in the CCT-K3 in early days. In early 2012, Center for measurement Standards, Taiwan (CMS) had made an initiation to establish a bilateral comparison with NIM at the argon triple point and the freezing point of silver. The objectives of this comparison are to link the CMS to the CCT KC and facilitate the CMS CMC submission. In October 2012, NIM as the pilot agreed to provide the link to CCT KC. The comparisons were registered in BIPM key comparison database (KCDB) in 2013 as APMP.T-K3.6 for the triple point of Argon.

2 Participants

The information of the participant Labs is shown in **Table 1**.

Table 1 Participating Labs

Pilot Lab	NIM	National Institute of Metrology,	Beijing, China	Jianping Sun sunjp@nim.ac.cn
Participating Lab	CMS	Center for Measurement Standards	Taiwan	Shu-Fei Tsai Shu-Fei_Tsai@itri.org.tw

3. Information on Transfer Artifact & Sequence of events

A SPRT as the transfer artifact is supplied by CMS, and the SPRT details are as follows,

Serial number: RS095-04

Model: R800-2

Manufacturer: CHINO

Nominal resistance: 25.5 Ω

Size: (ϕ 7.0 \pm 0.5) mm x 600 mm

The measurement sequence of the SPRTs is as follows:

- 1) The SPRT was calibrated at CMS’s triple point of argon before sending it to NIM.
- 2) After the completion of the measurements at CMS, The SPRT was sent to NIM.
- 3) The SPRT was calibrated at NIM’s triple point of argon.
- 4) After the completion of the measurements at NIM, the SPRT was returned to CMS.
- 5) The first step was carried out again, and the measurement work was completed.
- 6) All results were sent to the independent party.

The measurement period is shown in **Table 2**. The chairman of APMP TCT at the time when submitting measurement results served as the independent party in this comparison.

Table 2 Measurement period of this comparison between NIM and CMS

Measurement Sequence	Description	Time Period
1	CMS completed the first step	Before Nov 2013
2	CMS delivered SPRT to NIM	On 10 Dec 2013
3	NIM completed the third step	from 10 Dec to 20 Dec 2013
4	CMS collected SPRT from NIM	On 20 Dec 2013
5	CMS completed the fifth step	Mar 2014
6	NIM and CMS sent all of the data to the independent party	Nov 2018

4. Technical Instructions

CMS measurements (Pre-submission of artifacts to NIM):

- 1) Before the comparison began, the stability of the artifact under thermal cycling was assessed by CMS. The SPRT chosen by CMS must meet the ITS-90 purity requirements and then was stabilized by annealing at a temperature of 480 °C. The stability criteria value for an SPRT is calculated from the difference between the $R(273.16\text{ K})$ Ω before and after annealing. The triple point of water (TPW) should be measured after every annealing cycle and documented in the Excel data file listed in **Appendix B**. The stability values obtained was required to be better than 0.4 mK to qualify the SPRTs for the CMS measurements.
- 2) After annealing and stabilizing the SPRT, the measurement sequence to be followed was as followed: TPW, Ar, TPW.
- 3) On completion of the first set of measurements, CMS sent the artifact to NIM. Measurement results were listed in **Appendix C**.

NIM measurements

- 1) After the artifact was brought to NIM, NIM inspected the artifact for damage. If there was damage, NIM and CMS would discuss and agree on how to proceed. If no damage happened, the measurements would go on.
- 2) The SPRT was firstly be measured at the TPW. If the difference between the TPW value and the last measurement value in CMS was less than 0.4 mK, the measurement sequence to be followed was as follows: TPW, Ar, TPW. If the SPRT was found to be unstable, the SPRT had to be stabilized by annealing at a temperature of 480 °C and be checked again. Measurement results were listed in **Appendix B**.
- 3) On completion of the measurements, CMS collected the artifacts from NIM. Measurement results were listed in **Appendix C**.

CMS measurements (Post-carrying the artifacts back from NIM)

- 1) After the artifact was returned to CMS. CMS inspected the artifacts for damage. If there was damage, NIM and CMS would discuss and agree on how to proceed. If no damage happens, the measurements would go on.
- 2) The SPRT was firstly be measured at the TPW. If the difference between the TPW value and the last measurement value in NIM was less than 0.4 mK, the measurement sequence to be followed was as followed: TPW, Ar, TPW. If the SPRT was found to be unstable, the SPRT would be stabilized by annealing at a temperature of 480 °C and be checked again.
- 3) The measurement loop was closed. Measurement results were listed in **Appendix C**.

5. Summary of Data Submission

Here, the $R_{corrected}$ is expressed as,

$$R_{corrected} = R_{measured} + R_{self} + R_{hydr} + R_{pres} \quad (1)$$

Where $R_{measured}$ is the resistance value of SPRT at the fixed points, R_{self} , R_{hydr} and R_{pres} are the resistance changes due to the self-heating of the SPRT, hydrostatic and gas pressure in the cell of fixed point respectively. For the triple point of Argon, R_{pres} is equal to zero.

The measurement results of SPRT (No.RS095-04) stability for the triple point of argon are shown at the triple point of water in Table 3. The results show the maximum change of the resistances at the triple point of water during the period in CMS before transportation, or in NIM, or back to CMS, the artifact met the requirements of the stability in the comparison protocol. They are equivalent to 0.14 mK, 0.39 mK, and 0.20 mK respectively.

Table 3 Measurement results of SPRT(No.RS095-04) stability at the triple point of water

SPRT. No	Date	Lab	R_{measured} / Ω	R_{self} $\times 10^{-4}$ / Ω	R_{hydr} $\times 10^{-5}$ / Ω	$R_{\text{corrected}}$ / Ω
RS095-04	01/11/2013	CMS	24.997039	-1.89	1.7	24.996866
	02/11/2013	CMS	24.997044	-2.03	1.7	24.996857
	04/11/2013	CMS	24.997041	-2.00	1.7	24.996858
	04/12/2013	CMS	24.997047	-1.93	1.7	24.996871
	10/12/2013	NIM	24.997057	-2.05	1.7	24.996869
	20/12/2013	NIM	24.997107	-2.16	1.7	24.996908
	14/03/2014	CMS	24.997094	-1.93	1.7	24.996918
	25/03/2014	CMS	24.997066	-1.86	1.7	24.996897

The calibration data of SPRT (No.RS095-04) at the triple point of argon are presented in **Table 4**.

Table 4 Calibration data of SPRT (No. RS095-04) at the triple point of Ar

Lab	Fixed Point	R_{measured} / Ω	R_{self} $\times 10^{-4}$ / Ω	R_{hydr} $\times 10^{-5}$ / Ω	$R_{\text{corrected}}$ / Ω	W
CMS	TPW	24.997041	-2.00	1.7	24.996858	0.21587496
	Ar	5.396395	-1.52	-4.6	5.396197	
	TPW	24.997047	-1.93	1.7	24.996871	
NIM	TPW	24.997095	-2.14	1.7	24.996898	0.21587421
	Ar	5.396361	-1.47	-2.7	5.396187	
	TPW	24.997100	-2.05	1.7	24.996912	
	Ar	5.39636	-1.52	-2.7	5.396181	
	TPW	24.997107	-2.16	1.7	24.996908	
CMS	TPW	24.997094	-1.93	1.7	24.996918	0.21587758
	Ar	5.396464	-1.46	-4.6	5.396272	
	TPW	24.997066	-1.86	1.7	24.996897	

6 Uncertainties of Measurements

The uncertainty budgets submitted by the participants are presented in **Tables 5** and **6**. Uncertainty budget and information of instruments submitted by NIM and CMs are shown in **Appendix D and E**. In NIM's uncertainty budget, the effect of the impurities on the fixed points was estimated on the basis of the OME method or temperature difference between the freezing point and melting point, the reproducibility was calculated from the multiple realizations of fixed points at NIM. For linking to the CCT-K3, the reference water triple point cell without the isotopic analysis in this comparison was used, and it has the negligible difference from the other cells including the cell used to participate in the CCT-K7, the cell with the isotopic analysis in NIM. At the present definition for the water triple point, the maximum temperature difference among the four NIM cells drops from 0.10mK to 0.02mK after application of the isotope correction [3].

Tables 5 Uncertainty budget submitted by NIM

Source of uncertainty	Standard uncertainty/mK	
	Ar	TPW
Type A		
Reproducibility	0.17	0.02
Chemical Impurities (SIE or OME method)	0.08	0.02
Hydrostatic-head error	0.02	0.04
effects of change in reference resistors	0.01	0.01
Non-linearity of bridge	0.01	0.04
Repeatability of bridge	0.01	0.01
Uncertainty propagated from the TPW	0.05	/
SPRT self-heating error	0.02	0.03
Heat flux-immersion error	0.05	0.03
Gas pressure in fixed-point cell	/	/
Choice of fixed-point value	0.01	/
Combined	0.20	0.08
Expanded Uncertainty($k=2$)	0.40	0.16

Tables 6 Uncertainty budget submitted by CMS

Source of uncertainty	Standard uncertainty/mK	
	Ar	TPW
Type A		
Reproducibility	0.202	0.011
Chemical Impurities	0.284	0.011
Isotopic variation	/	0.002
Hydrostatic-head error	0.010	0.004
effects of change in reference resistors	/	0.006
Non-linearity of bridge	0.016	0.020
Repeatability of bridge	0.006	0.029
Uncertainty propagated from the TPW	0.010	
SPRT self-heating error	0.020	0.006
Heat flux-immersion error	0.095	0.013
Gas pressure in fixed-point cell	/	0.005
Choice of fixed-point value	0.173	/
Combined Standard Uncertainty	0.40	0.0421
Expanded Uncertainty($k=2$)	0.80	0.085

7 Results

The differences in temperature between NIM and CMS at the triple point of argon were calculated with the W values provided by the participants as follows,

$$\Delta T_{Ar,CMS-NIM} = T_{Ar,CMS} - T_{Ar,NIM} = (W_{Ar,CMS} - W_{Ar,NIM}) / (dW_r / dT) \quad (2)$$

where $\Delta T_{Ar,CMS-NIM}$ is the difference in temperature between CMS and NIM at the the triple point of argon, $T_{Ar,CMS}$ is the temperature of realization at the reference Ar fixed point in CMS, $T_{Ar,NIM}$ is the temperature of realization at the reference Ar fixed point in NIM, $W_{Ar,CMS}$ is the arithmetic mean value of the resistance ratio measured at the reference Ar fixed point in CMS before and after NIM, $W_{Ar,NIM}$ is the arithmetic mean value of the resistance ratio measured at the reference Ar fixed point in NIM, and W_r is the reference resistance ratio. The values of dW_r/dT is 0.00434159. The uncertainty of

$\Delta T_{Ar,CMS-NIM}$ is estimated using the expanded uncertainties provided by the participants in this comparison, and is expressed by,

$$U^2(\Delta T_{Ar,CMS-NIM}) = (U^2(W_{Ar,CMS}) + U^2(W_{Ar,NIM})) / (dW_r/dT)^2 + U^2(T_{drift}) \quad (3)$$

where $u(T_{drift})$ is the uncertainty caused by the drift of the transfer SPRT during the comparison.

Figure 1 shows the resistance value R_{TPW} of the SPRT (NO.RS095-04) at the triple point of water throughout the comparison. **Figure 2** shows the resistance ratio value of the SPRT (NO.RS095-04) at the triple point of argon W_{Ar} throughout the comparison. The maximum change of the resistance value of the SPRTs at the triple point of water is 0.60 mK. The relative change of the SPRT resistance (in mK) at the water triple point and the relative change of the W_{Ar} of the SPRT (in mK) of all measurements during the entire period are shown in **Figure 3** and **Figure 4**, respectively.

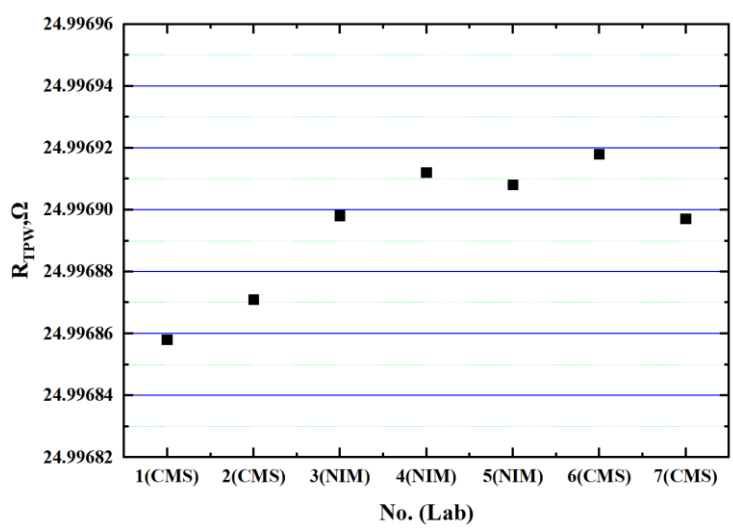


Figure 1 Resistance value of the SPRT (NO.RS095-04) at the triple point of water throughout the comparison

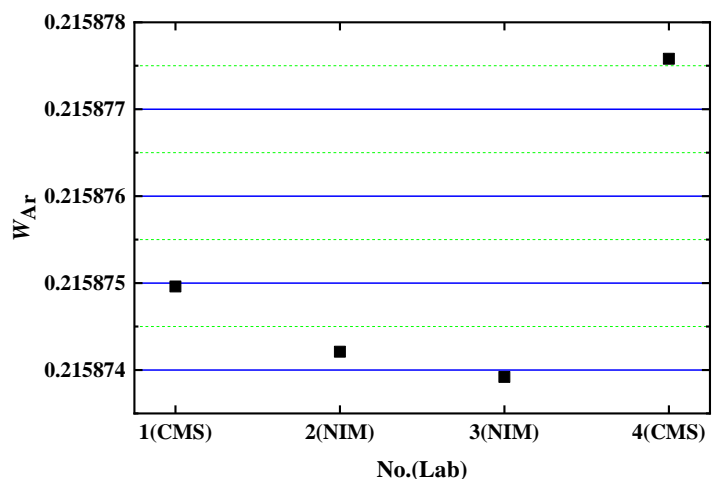


Figure 2 Resistance ratio value of the SPRT (NO.RS095-04) at the triple point of argon throughout the comparison.

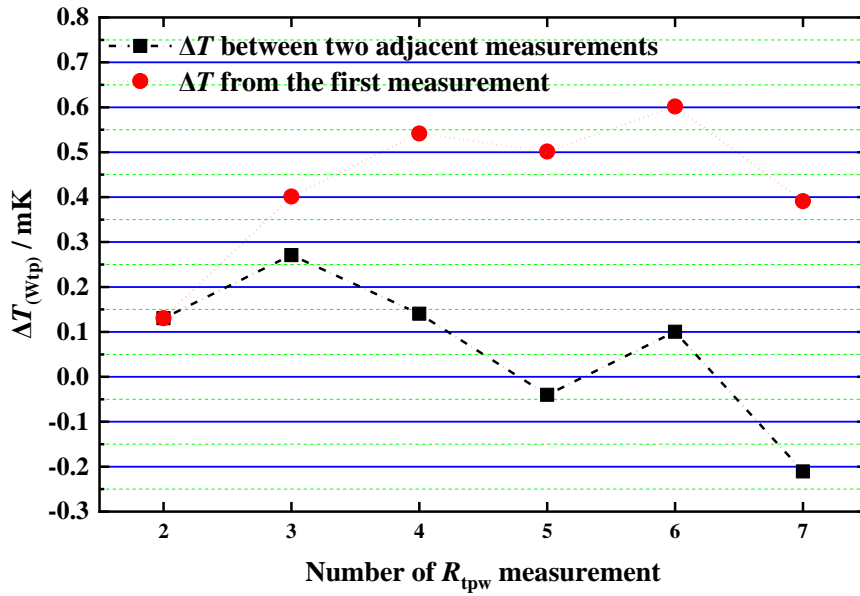


Figure 3 Relative change of the SPRT resistance (in mK) at the water triple point of all measurements during the entire period.

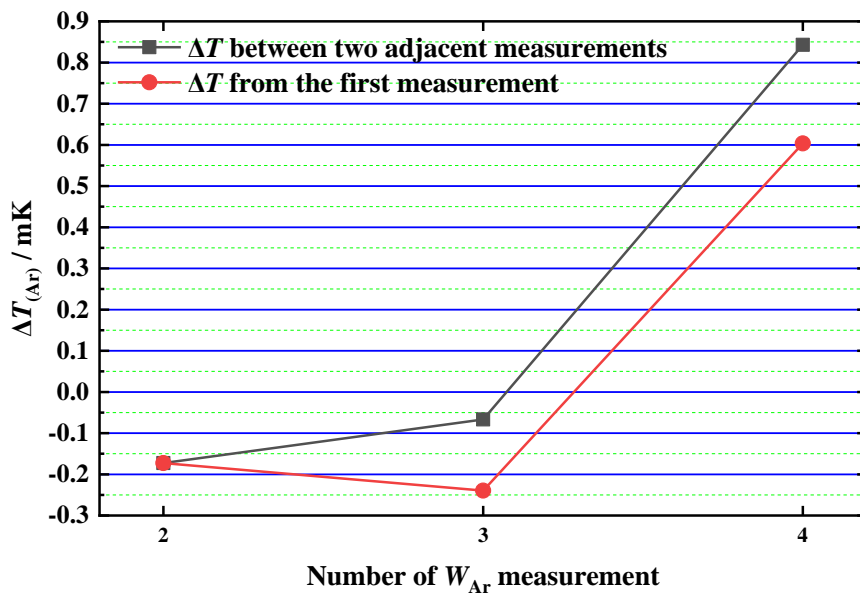


Figure 4 Relative change of the resistance ratio value of the SPRT (NO.RS095-04) at the triple point of argon W_{Ar} (in mK) throughout the comparison.

The standard uncertainty of the drift of SPRT is calculated on the basis of a rectangular probability distribution. The uncertainty caused by the reference Ar fixed point in CMS is 0.8 mK ($k = 2$), and the uncertainty caused by the reference Ar fixed point in NIM is 0.4 mK ($k = 2$). (The uncertainty of $\Delta T_{Ar,CMS-NIM}$ is calculated as 1.26 mK ($k=2$) by using the results from the Draft A (non-final version) of the CCT-K9). $\Delta T_{Ar,CMS-NIM}$ and the uncertainty of $\Delta T_{Ar,CMS-NIM}$ are shown in **Table 7** and **Figure**

5.

Table 7 $\Delta T_{\text{Ar,CMS-NIM}}$ and uncertainty of $\Delta T_{\text{Ar,CMS-NIM}}$

Fixed point	$\Delta T_{\text{Ar,CMS-NIM}}$ /mK	$U(\Delta T_{\text{Ar,CMS-NIM}})$ /mK, ($k=2$)
Ar	0.51	1.14

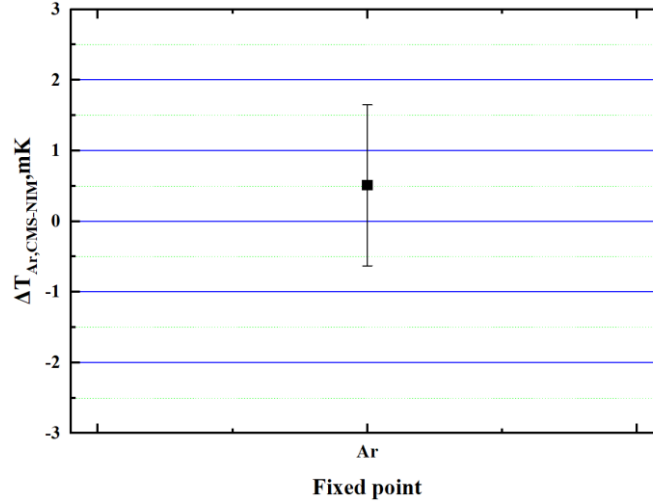


Figure 5 $\Delta T_{\text{Ar,CMS-NIM}}$ and uncertainty of $\Delta T_{\text{Ar,CMS-NIM}}$

8 Link from APMP.T-K3.6 to CCT-K3

The link from APMP.T-K3.6 to CCT-K3 via NIM is given by,

$$\Delta T_{\text{Ar,CMS-ARV}} = \Delta T_{\text{Ar,CMS-NIM}} - \Delta T_{\text{Ar,ARV-NIM_Old}} + \Delta T_{\text{Ar,NIM-NIM_Old}} \quad (4)$$

where $\Delta T_{\text{Ar,CMS-ARV}}$ is the difference in temperature between CMS reference Ar fixed point and the average (ARV) of CCT-K3 at the Ar fixed point, $\Delta T_{\text{Ar,CMS-NIM}}$ is the difference in temperature between CMS and NIM reference Ar fixed points. $\Delta T_{\text{Ar,ARV-NIM_Old}}$ is the difference in temperature between ARV and old NIM reference Ar fixed point, $\Delta T_{\text{Ar,NIM-NIM_Old}}$ is the difference in temperature between NIM reference Ar fixed point and NIM old reference Ar fixed point, see the reference [4], and is 0.17mK ($U=0.09$ mK, $k=2$). The uncertainty of $\Delta T_{\text{Ar,CMS-ARV}}$ is expressed by,

$$U^2(\Delta T_{\text{Ar,CMS-ARV}}) = U^2(\Delta T_{\text{Ar,CMS-NIM}}) + U^2(\Delta T_{\text{Ar,ARV-NIM_Old}}) + U^2(\Delta T_{\text{Ar,NIM-NIM_Old}}) \quad (5)$$

By calculation, the uncertainty of $\Delta T_{\text{Ar,CMS-ARV}}$ is 1.26 mK($k=2$) (The uncertainty of $\Delta T_{\text{Ar,CMS-ARV}}$ is calculated as 1.37 mK($k=2$) by using the results from the Draft A (non-final version) of the CCT-K9.) $\Delta T_{\text{Ar,CMS-ARV}}$ and the uncertainty of $\Delta T_{\text{Ar,CMS-ARV}}$ are shown in **Table 8** and **Figure 6**.

Table 8 $\Delta T_{\text{Ar,CMS-ARV}}$ and the uncertainty of $\Delta T_{\text{Ar,CMS-ARV}}$

Fixed point	$\Delta T_{\text{Ar,ARV-NIM_Old}}$ /mK	$U(\Delta T_{\text{Ar,ARV-NIM_Old}})$ /mK, ($k=2$)	$\Delta T_{\text{Ar,CMS-ARV}}$ /mK	$U(\Delta T_{\text{Ar,CMS-ARV}})$ /mK, ($k=2$)
Ar	0.03	0.52	0.65	1.26

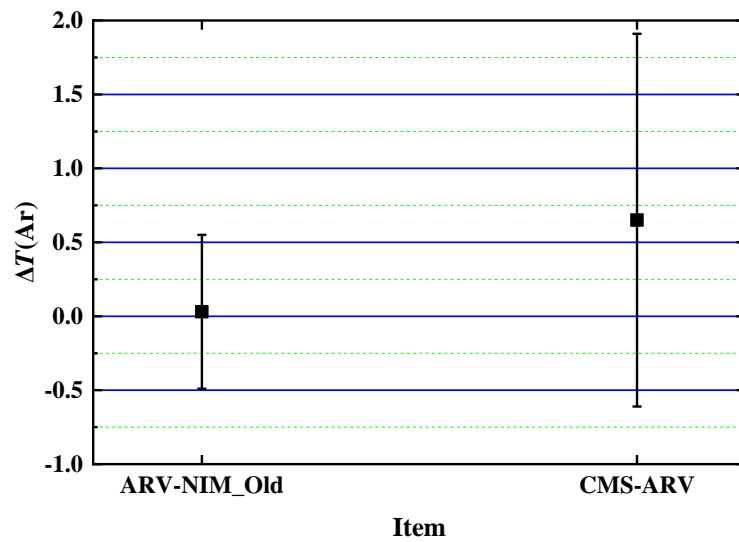


Figure 6 The value and the corresponding uncertainty of $\Delta T_{\text{Ar,ARV-NIM_Old}}$ and $\Delta T_{\text{Ar,CMS-ARV}}$

APPENDIX A: APMP.T-K3.6 Protocol

APPENDIX B: Stability of the Transfer SPRT

APPENDIX C: Measurement Results

APPENDIX D: Measurement Uncertainty

APPENDIX E: Instrumentation Information

Reference

- [1] Mangum B.W., Strouse G.F., Guthrie W.F., Pello R., Stock M., Renaot E., Hermier Y., Bonnier G., Marcarino P., Gam K.S., Kang K.H., Kim Y.-G., Nicholas J.V., White D.R., Dransfield T.D., Duan Y., Qu Y., Connolly J., Rusby R.L., Gray J., Sutton G.J.M, Head D.I., Hill K.D., Steele A., Nara K., Tegeler E., Noatsch U., Heyer D., Fellmuth B., Thiele-Krivoj B., Duris S., Pokhodun A.I., Moiseeva N.P., Ivanova A.G., de Groot M.J., Dubbeldam J.F., *Metrologia* 39:179(2002).
- [2] Nubbemeyer H.G., Fischer J., *Metrologia* 39, Tech.Suppl., 03001 (2002).
- [3] X. K. Yan, J. T. Zhang, Y. L. Wang, C. F. Ma, Y. N. Duan, *Int. J. Thermophys.* 29:104(2008).
- [4] Jianping Sun, Shaochun Ye, Haoyuan Kho, Jintao Zhang, Li Wang, *Int. J. Thermophys.* 36:1935(2015).

APPENDIX A: APMP.T-K3.6 Protocol

APMP.T-K3.6: Realizations of the ITS-90 at the Triple Point of Argon Bilateral Comparison between NIM (China) and CMS (Taiwan)

Protocol

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Dec, 2013

1. Introduction

Several key comparisons organized by the Comité Consultatif de Thermometrie (CCT) were carried out to compare the ITS-90 realization in different national metrology institutes. Always, the number of participants in a CCT Key Comparison (CCT KC) is limited to a few laboratories in each major economic region during time period and workload. A series of bilateral comparisons and multilateral comparisons were organized to link more laboratories to the CCT KC.

NIM participated in the CCT-K3 in early days. Early in 2012, CMS had made an initiation to establish a bilateral comparison with NIM at the argon triple point. The objectives of this comparison are to insure the temperature measurement including the uncertainty assessment between the two National Metrology Institutes (NMIs), link the CMS to the CCT KC and facilitate the CMS CMC submission. In October 2012, NIM as the pilot agreed to provide the link to CCT KC.

Each participating institute is responsible for its own costs of the measurements, insurance, and any customs charges as well as any damage that may occur within its country. Transportation of the transfer SPRT is the responsibility of CMS.

The following topics describe the schedule of comparison, the information on transfer artifact, the realization technique, the measurement uncertainties and the report format.

2. Participants information

The participants in this comparison are

1. NIM (China), pilot laboratory

Jianping Sun

Division of Thermometry and Materials Evaluation

National Institute of Metrology

Tel: 86-10-64526303

E-mail:sunjp@nim.ac.cn

2. CMS (Taiwan),

Shu-Fei Tsai

Measurement Standards & Technology Division

Center for measurement Standards

Industrial Technology Research Institute

Tel: 886-3-5732125(9)

E-mail:Shu-Fei_Tsai@itri.org.tw

3. Information on Transfer Artifact & sequence of events

CMS will supply a SPRT as the transfer artifact.

The transfer SPRT details are as follows:

Serial number: RS095-04

Model: R800-2

Manufacturer: CHINO

Nominal resistance: 25.5 Ω

Size: ($\phi 7.0 \pm 0.5$) mm x 600 mm

The measurement sequence of the SPRTs is as follows:

- 1) The SPRT will be calibrated at CMS's triple point of argon prior to sending it to NIM.
- 2) After the completion of the measurements at CMS, The SPRT will be sent to NIM.
- 3) The SPRT will be calibrated at NIM's triple point of argon.
- 4) After the completion of the measurements at NIM, the SPRT will be returned to CMS.
- 5) The first step will be carried out again, and the measurement work will be completed.
- 6) All results and uncertainties will be sent to the independent party to be identified.

Table1. Schedule of the comparison

Measurement Sequence	Description	Time Period
1	CMS complete the first step	By 11 Nov 2013
2	CMS deliver SPRT to NIM	By 5 Dec 2013
3	NIM complete the third step	3 weeks
4	CMS collect SPRT from NIM	By 31 Dec 2013
5	CMS complete the fifth step	By 31 March 2014
6	NIM and CMS will sent all of the data to the independent party	By 30 May 2014

4. Technical Instructions

CMS measurements (Pre-submission of artifacts to NIM):

- 1) Before the bilateral comparison begins, CMS will assess the stability of the artifacts under thermal cycling. The SPRT chosen by CMS must meet the ITS-90 purity requirements. The SPRT will be stabilized by annealing at a temperature of 480 °C. The stability criteria value for an SPRT is calculated from the difference between the $R(273.16 \text{ K}) \Omega$ before and after annealing. The

stability values obtained must be better than 0.4 mK to qualify the SPRTs for the CMS measurements. The triple point of water (TPW) should be measured after every annealing cycle and documented in the Excel data file listed in Appendix A.

- 2) After annealing and stabilizing the SPRT, the measurement sequence to be followed is as followed: TPW, Ar, TPW. At this stage, at least two argon points shall be determined, and that all the measurements shall be corrected for thermometer self-heating and the hydrostatic pressure effect as shown in Appendix B.
- 3) On completion of the first set of measurements, CMS will send the artifacts to NIM. Measurement results will be listed in Appendix B.

NIM measurements:

- 1) After the artifacts are brought to NIM, NIM will inspect the artifacts for damage. If there is damage, NIM and CMS will discuss and agree on how to proceed. If no damage happens, the measurements will go on.
- 2) The SPRT will firstly be measured at the TPW. If the difference between the TPW value and the last measurement value in CMS is not less than 0.4 mK, the SPRT will be stabilized by repeatedly annealing at a temperature of 480 °C at least three times to reach the criteria and the measurement results will be listed in Appendix A. If the stability still doesn't meet the requirement, NIM will contact the CMS for a replacement. On the contrary, the measurement sequence to be followed is as follows: TPW, Ar, TPW, and at least two argon points shall be determined, and that all the measurements shall be corrected for thermometer self-heating and the hydrostatic pressure effect as shown in Appendix B.
- 3) On completion of the measurements, CMS will collect the artifacts from NIM. Measurement results will be listed in Appendix B.

CMS measurements (Post-carrying the artifacts back from NIM)

- 1) After the artifact is returned to CMS. CMS will inspect the artifacts for damage. If there is damage, NIM and CMS will discuss and agree on how to proceed. If no damage happens, the measurements will go on.
- 2) The SPRT will firstly be measured at the TPW. If the difference between the TPW value and the last measurement value in CMS is less than 0.4 mK, the measurement sequence to be followed is as followed: TPW, Ar, TPW. If the SPRT is found to be unstable, the SPRT will be stabilized by annealing at a temperature of 480 °C and be checked again. If the stability still doesn't meet the requirement, CMS and NIM will discuss and agree on how to proceed.
- 3) The measurement loop will be closed. Measurement results will be listed in Appendix B.

5. Reporting of Data

The participating laboratories must submit the following:

- 1) Melting and immersion curve for Ar fixed point cells used in the measurements. Measurements do not need to be made with the supplied artifacts, but must be made with thermometers of similar design.
- 2) The file listed in Appendix A should be used to record the Stability data of SPRT transfer artifact.
- 3) The file listed in Appendix B should be used to record the measurement results.
- 4) The file listed in Appendix C should be used to record the Measurement Uncertainty pertaining to the comparison.
- 5) The Appendix D should be used to record pertinent background information concerning the measurement equipment and fixed-point cells.

6. Reporting of Uncertainties

The individual uncertainty components should be listed along with the total combined uncertainty assigned to each of the fixed-point cells. All expanded uncertainties should be expressed as $k=2$. In an effort to harmonize the fixed-point cell uncertainty budgets used, Appendix C gives a list of each uncertainty component to be considered.

7. Determination and Reporting of Results

If the transfer artifact fails or is found to be unstable during the comparison, the participating laboratories will discuss and agree upon a course of action. If the transfer artifact is stable at NIM but unstable for the second set of data, then only the first set of CMS data will be used.

The independent party will hold the results and uncertainties until the comparisons are finalized, and the two outcome results to be reported are:

- 1) Bilateral differences with associated uncertainties between the participants.

$$\Delta T_{\text{CMS,NIM}} = T_{\text{CMS}} - T_{\text{NIM}} \approx \left[\frac{\sum_{m=1}^2 W(\text{Ar})_{\text{CMS},m}}{2} - \frac{\sum_{n=1}^2 W(\text{Ar})_{\text{NIM},n}}{2} \right] / \frac{dW_r(\text{Ar})}{dT}$$

$W(\text{Ar})_{\text{CMS},m}$: the ratio of resistance at Ar triple point and resistance at water triple point using the transfer SPRT by CMS

$W(\text{Ar})_{\text{NIM},n}$: the ratio of resistance at Ar triple point and resistance at water triple point using the transfer SPRT by NIM

T_{CMS} : the reference temperature of Ar fixed point for CMS

T_{NIM} : the reference temperature of Ar fixed point for NIM

- 2) NIM has maintained its traceability to the CCT-K3 KCRV. The differences between the participants and the CCT KC ARV or KCRV with associated uncertainties, thus providing linkage to CCT KC for the purpose of CMC acceptance.

$$T_{\text{CMS}} - T_{\text{KCRV}} = (T_{\text{CMS}} - T_{\text{NIM}}) + (T_{\text{NIM}} - T_{\text{KCRV}})$$

$$U^2(T_{\text{CMS}} - T_{\text{KCRV}}) = U^2(T_{\text{CMS}}) + U^2(T_{\text{NIM}}) + U^2(T_{\text{NIM}} - T_{\text{KCRV}})$$

The comparison report will be completed by NIM, and the results will be validated during round up meeting before a final report is issued.

APPENDIX B: Stability of the Transfer SPRT

Laboratory: CMS

Contact Person: Shu-Fei Tsai

Contact Address: Address: Bldg. 8, 321, Sec. 2, Kuang Fu Road, Hsinchu, 30011, Taiwan, R.O.C.

E-mail: Shu-Fei_Tsai@itri.org.tw

Manufacturer/Type of Resistance Bridge (AC / DC): ASL/F900AC Resistance Bridge

Manufacturer/Model/Serial No of Reference Resistor: TINSLEY/5685A

Manufacturer/Model/Serial No of TPW cell: FLUKE/5901A-Q

Manufacturer / Model / Serial No of SPRT: CHINO / R800-2 / RS095-04

Result sheet: Stability of the transfer SPRT

Date	Cell	Measured Value (Ω)			Hydrostatic $\times 10^{-5} / \Omega$	$R_{\text{corrected}}$ $/ \Omega$
		1 mA	$\sqrt{2}$ mA	0 mA		
01/11/2013	TPW	24.997039	24.997228	24.996849	1.7	24.996866
02/11/2013	TPW	24.997044	24.997247	24.996840	1.7	24.996857
14/11/2013	TPW	24.997041	24.997241	24.996841	1.7	24.996858
24/01/2014	TPW	24.997040	24.997227	24.996854	1.7	24.996871

$R_{\text{corrected}}$: The resistance has been corrected by the self-heating and hydrostatic effects

The maximum change of the resistances at the triple point of water (TPW) during the period in CMS before transportation is 0.14 mK.

Conclusion: the stability of the SPRT is (is / is not) satisfactory for comparison to continue.

Laboratory: National Institute of Metrology

Laboratory: Jianping Sun

Contact Address: #18, Bei San Huan Dong Lu, Beijing, China

E-mail: sunjp@nim.ac.cn

Manufacturer / Model / Serial No of SPRT: CHINO / R800-2 / RS095-04

Length of Sensor: 30mm

Stability of the transfer SPRT

Date	Cell	Measured Value (Ω)			Hydrostatic $\times 10^{-5} / \Omega$	$R_{\text{corrected}}$ $/ \Omega$
		1 mA	$\sqrt{2}$ mA	0 mA		
10/12/2013	TPW	24.9970568	24.9972622	24.9968514	1.7	24.996869
20/12/2013	TPW	24.9971071	24.9973231	24.9968911	1.7	24.996908

$R_{\text{corrected}}$: The resistance has been corrected by the self-heating and hydrostatic effects

The temperature change of the TPW value firstly measured in NIM against to the last measurement value in CMS is -0.02 mK, and is 0.39 mK if the temperature difference between the first and the last measurements in NIM is considered.

Conclusion: the stability of the SPRT is (is / is not) satisfactory for comparison to continue.

Laboratory: CMS

Contact Person: Shu-Fei Tsai

Contact Address: Address: Bldg. 8, 321, Sec. 2, Kuang Fu Road, Hsinchu, 30011, Taiwan, R.O.C.

E-mail: Shu-Fei_Tsai@itri.org.tw

Manufacturer/Type of Resistance Bridge (AC / DC): ASL/F900AC Resistance Bridge

Manufacturer/Model/Serial No of Reference Resistor: TINSLEY/5685A

Manufacturer/Model/Serial No of TPW cell: FLUKE/5901A-Q

Manufacturer / Model / Serial No of SPRT: CHINO / R800-2 / RS095-04

Result sheet: Stability of the transfer SPRT

Date	Cell	Measured Value (Ω)			Hydrostatic $\times 10^{-5} / \Omega$	$R_{\text{corrected}}$ $/ \Omega$
		1 mA	$\sqrt{2}$ mA	0 mA		
14/03/2014	TPW	24.997094	24.997287	24.996901	1.7	24.996918
25/03/2014	TPW	24.997066	24.997251	24.996881	1.7	24.996897

$R_{\text{corrected}}$: The resistance has been corrected by the self-heating and hydrostatic effects

The temperature change of the TPW value firstly measured after back to CMS against to the last measurement value in NIM is 0.10 mK, and is 0.20 mK if the temperature difference between the first and the last measurements in CMS is considered.

Conclusion: the stability of the SPRT is (is / is not) satisfactory for comparison.

APPENDIX C: Measurement Results

Laboratory: CMS (Center for measurement Standards)

Contact Person: Shu-Fei Tsai Contact Address: Address: Bldg. 8, 321, Sec. 2, Kuang Fu Road, Hsinchu, 30011, Taiwan, R.O.C.

E-mail: Shu-Fei_Tsai@itri.org.tw

Manufacturer / Model / Serial No of SPRT: CHINO / R800-2 / RS095-04

Length of Sensor: 31.57 mm (Bottom end to the middle of sensor)

SPRT Calibration results before NIM

Fixed Point	$R_{\text{measured}} / \Omega$	$R_{\text{self}} \times 10^{-4} / \Omega$	$R_{\text{hydr}} \times 10^{-5} / \Omega$	$R_{\text{corrected}} / \Omega$	W
TPW	24.997041	-2.00	1.7	24.996858	
Ar	5.396395	-1.52	-4.6	5.396197	0.21587496
TPW	24.997047	-1.93	1.7	24.996871	

$R_{\text{corrected}}$: The resistance has been corrected by the self-heating, and hydrostatic effects.

SPRT Calibration results after NIM

Fixed Point	$R_{\text{measured}} / \Omega$	$R_{\text{self}} \times 10^{-4} / \Omega$	$R_{\text{hydr}} \times 10^{-5} / \Omega$	$R_{\text{corrected}} / \Omega$	W
TPW	24.997094	-1.93	1.7	24.996918	
Ar	5.396464	-1.46	-4.6	5.396272	0.21587758
TPW	24.997066	-1.86	1.7	24.996897	

$R_{\text{corrected}}$: The resistance has been corrected by the self-heating, and hydrostatic effects.

Laboratory: National Institute of Metrology

Laboratory: Jianping Sun

Contact Address: #18, Bei San Huan Dong Lu, Beijing, China

E-mail: sunjp@nim.ac.cn

Manufacturer / Model / Serial No of SPRT: CHINO / R800-2 / RS095-04

Length of Sensor: 30mm

Result sheet:

Fixed Point	$R_{\text{measured}} / \Omega$	$R_{\text{self}} \times 10^{-4} / \Omega$	$R_{\text{hydr}} \times 10^{-5} / \Omega$	$R_{\text{corrected}} / \Omega$	W
TPW	24.997095	-2.14	1.7	24.996898	
Ar	5.396361	-1.47	-2.7	5.396187	0.21587421
TPW	24.997100	-2.05	1.7	24.996912	
Ar	5.39636	-1.52	-2.7	5.396181	0.21587392
TPW	24.997107	-2.16	1.7	24.996908	

$R_{\text{corrected}}$: The resistance has been corrected by the self-heating, and hydrostatic effects.

APPENDIX D: Measurement Uncertainty

Laboratory: CMS (Center for measurement Standards)

Contact Person: Shu-Fei Tsai Contact Address: Bldg. 8, 321, Sec. 2, Kuang Fu Road, Hsinchu, 30011, Taiwan, R.O.C.

E-mail: Shu-Fei_Tsai@itri.org.tw

Ar Fixed point S/N: AR-60003

TPW Fixed point S/N: H5029

Source of uncertainty	Standard uncertainty/mK	
	Ar	TPW
Type A		
Reproducibility	0.202	0.011
Chemical Impurities	0.284	0.011
Isotopic variation	/	0.002
Hydrostatic-head error	0.010	0.004
effects of change in reference resistors	/	0.006
Non-linearity of bridge	0.016	0.020
Repeatability of bridge	0.006	0.029
Uncertainty propagated from the TPW	0.001	
SPRT self-heating error	0.020	0.006
Heat flux-immersion error	0.095	0.013
Gas pressure in fixed-point cell	/	0.005
Choice of fixed-point value	0.173	0.0421
Combined Standard Uncertainty	0.40	0.0421
Expanded Uncertainty($k=2$)	0.80	0.085

Laboratory: National Institute of Metrology

Laboratory: Jianping Sun

Contact Address: #18, Bei San Huan Dong Lu, Beijing, China

Email: sunjp@nim.ac.cn

Ar Fixed point S/N: NIM-Ar

TPW Fixed point S/N: NIM-5

Source of uncertainty	Standard uncertainty/mK	
	Ar	TPW
Type A		
Reproducibility	0.17	0.02
Chemical Impurities (SIE or OME method)	0.08	0.02
Hydrostatic-head error	0.02	0.04
effects of change in reference resistors	0.01	0.01
Non-linearity of bridge	0.01	0.04
Repeatability of bridge	0.01	0.01
Uncertainty propagated from the TPW	0.05	
SPRT self-heating error	0.02	0.03
Heat flux-immersion error	0.06	0.03
Gas pressure in fixed-point cell	/	/
Choice of fixed-point value	0.01	/
Combined	0.20	0.08
Expanded Uncertainty($k=2$)	0.40	0.16

APPENDIX E: Instrumentation Information

Laboratory: CMS (Center for measurement Standards)

Contact Person: Shu-Fei Tsai Contact Address: Bldg. 8, 321, Sec. 2, Kuang Fu Road, Hsinchu, 30011, Taiwan, R.O.C.

E-mail: Shu-Fei_Tsai@itri.org.tw

Ar Fixed point cell

Cell	
Cell manufacturer / Model / Serial no.	Fluke/5908/Ar/Ar-60003
Thermometer well	
Well material	Stainless steel
Well ID (mm)	8.0mm
Immersion depth of SPRT	160mm
ITS-90 Realization Techniques	
Freeze/Melt?	Melt
Method of forming solid/liquid interface	Quasi-Adiabatic method
Heat transferring fluid?	Liquid nitrogen
Duration of freeze/melt	>24h
Cell used as FP/MP/TP?	TP

TPW Fixed point cell

Cell	
Cell manufacturer / Model / Serial no.	Fluke/ 5901A-Q/5029
Water source and purity	99.9999951%
Thermometer well	
Well material	quartz
Well ID (mm)	12.0mm
Immersion depth of SPRT	265mm
Heat transfer liquid	Water
Cell maintained in Ice bath/ Water bath	Water bath
Ice mantle	
Method of preparation	Solid CO ₂ & Alcohol
Annealing time before use	At least 7days

Bridge and Reference Resistor

Bridge	
Manufacturer / Model / Serial no.	ASL/F900/011220/01
AC/DC	AC

If AC, give	
Frequency	30Hz
Bandwidth	0.1 Hz
Gain	$1 \cdot 10^4$ or $1 \cdot 10^5$
Read manually or off IEEE-488	IEEE-488
Normal measuring current	1 mA
Self-heating current	$\sqrt{2}$ mA
If DC, give	
Gain	
Period of reversal	
Reference resistor	
Type	AC/DC
Manufacturer / Model / Serial no.	Tinsly 5685A
Temperature of the ref resistor	20°C
Temperature coefficient of the ref resistor	Typically 2ppm/°C

Laboratory: National Institute of Metrology

Laboratory: Jianping Sun

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Ar Fixed point cell

Cell	
Cell manufacturer / Model / Serial no.	NIM, NIM-Ar(2008)
Open/closed?	Open
Pressure in cell	/
Crucible	
Crucible material	Stainless steel
Crucible manufacturer	China
Crucible length	160 mm
Metal sample	
Sample source	American
Sample purity	99.9999%
Sample weight	300g
Thermometer well	
Well material	Stainless steel
Well ID (mm)	9.0mm
Immersion depth of SPRT	80mm
Furnace/Bath	
Manufacturer	NIM
Control type	PID
How many zones?	1
Furnace heater	
AC/DC?	AC
Heat pipe liner?	No
ITS-90 Realisation Techniques	
Freeze/Melt?	Melt
Method of forming solid/liquid interface	Quasi-Adiabatic method
Heat transferring fluid?	Liquid nitrogen
Duration of freeze/melt	>15h
Cell used as FP/MP/TP?	TP

TPW fixed point cell

Cell	
Cell manufacturer / Model / Serial no.	NIM/-/NIM-5
Water source and purity	China, 99.9999%
Well diameter	Φ10mm
Immersion depth	220mm
Heat transfer liquid: water / alcohol / others	Alcohol
Cell maintained in	
Ice bath / Water bath	Alcohol bath
Ice mantle	
Method of preparation	Cooling with liquid nitrogen
Annealing time before use	7 days

Bridge and Reference Resistor

Bridge	
Manufacturer / Model / Serial no.	ASL/F900 012923/02
AC/DC	AC
If AC, give	
Frequency	25Hz
Bandwidth	0.2
Gain	1×10^5
Read manually or off IEEE-488	IEEE-488
Normal measuring current	1 mA
Self-heating current	$\sqrt{2}$ mA
If DC, give	
Gain	
Period of reversal	
Reference resistor	
Type	AC/DC
Manufacturer / Model / Serial no.	Tinsly 5685A 11769/30
Temperature of the ref resistor	20°C
Temperature coefficient of the ref-resistor	$a=0.2276 \times 10^{-6}/^{\circ}\text{C}$, $\beta=-0.0664 \times 10^{-6}/(^{\circ}\text{C})^2$