APMP.T-K4.1 Comparison report of the ITS-90 realization at the freezing point of silver 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-K4 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 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-K4.1 for the freezing point of silver.

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 sealed silver freezing point cell as the transfer artifact is supplied by CMS, and the Ag cell details are as follows,

Serial number: 08070

Model: 5908

Manufacturer: FLUKE

Nominal purity: 99.9999 %

Size: OD=48 mm; ID=8 mm; H=285 mm

The measurement sequence of the transfer artifact is as follows:

1) The comparison between the transfer sealed cell and CMS's reference cell was made prior to sending it to NIM.

2) After the completion of the measurements at CMS, the transfer cell was sent to NIM. An HTSPRT was also taken to NIM, for the comparisons, although this was not used as a transfer standard between CMS and NIM.

3) The comparison between the sealed cell and NIM's reference cell was made.

4) After the completion of the measurements at NIM, the cell 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 the cell to NIM	On 10 Dec 2013
3	NIM completed the third step	from 10 Dec to 20 Dec 2013
4	CMS collected the cell 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 criteria value of the sealed silver freezing point cell chosen by CMS was assessed by the repeatability of the realization. The stability values obtained from the standard deviation of W at the freezing point of silver must be better than 3 mK (the data from the early realization may be used). The stability data of the sealed cell was supported by CMS, and listed in **Appendix B**.

2) A HTSPRT was used to compare the sealed cell with the CMS's reference cell, and the measurements were carried out more than twice. All results were reported with self-heating correction, hydrostatic correction and gas pressure correction.

3) On completion of the first set of measurements, CMS carried the artifact to NIM. Measurement results were listed in **Appendix C**.

NIM measurements

1) After the artifact was brought to NIM, NIM inspected the artifacts 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 sealed cell was assembled into the NIM's high temperature fixed point furnace, and a HTSPRT was used to compare the sealed cell with the NIM's reference cell. The measurements have been carried out more than two times. All results were reported with self-heating correction, hydrostatic correction and gas pressure correction.

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 will inspect 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 sealed cell was assembled into the CMS's high temperature fixed point furnace, and a HTSPRT was used to compare the sealed cell with the CMS's reference cell. The measurements have been carried out more than two times. All results were reported with self-heating correction, Hydrostatic correction and gas pressure correction.

3) The measurement loop was closed. Measurement results were listed in **Appendix C.**

5. Summary of Data Submission

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

$$R_{\text{corrected}} = R_{\text{measured}} + R_{\text{self}} + R_{\text{hydr}} + R_{\text{pres}} \tag{1}$$

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.

In this comparison, the bridge reading of HTSPRT at the Ag fixed point, which was adopted rather than using resistance was to exclude the calibration uncertainty on the standard resistor as well as to follow the usual practice in CMS while doing the cell comparisons.

Here, the $X_{\text{corrected}}$ is expressed as,

$$X_{\text{corrected}} = X_{\text{measured}} + X_{\text{self}} + X_{\text{hydr}} + X_{\text{pres}} \tag{2}$$

where X_{measured} is the measured bridge reading of SPRT at the fixed points. X_{self}, X_{hydr} and X_{pres} are the bridge reading changes due to the self-heating of the SPRT, hydrostatic and gas pressure in the cell of fixed point respectively.

For the comparison at the freezing point of silver, another one HTSPRT (No.RS90X-2) in addition to the transfer HTSPRT (No.RS10X-01) was also employed at CMS to reduce the risk as well as to get an objective result, the results coming from both HTSPRTs were included hereinafter, and the information and practical use of the HTSPRTs is shown in **Table 3**. The measurement results of the transfer Ag cell with the No.RS90X-2 HTSPRT are shown in **Table 4**. The correction due to the effect of the pressure in the transfer Ag cell has not been made. The results show the stability of Ag cell is equivalent to about +/- 2.1mK. So, the stabilities of the artifacts meet the requirements of the comparison protocol.

Table 3 Information and measurement data of two HTSPRTs calibrated at the transfer Ag cell, CMS's reference Ag cell and NIM's reference Ag cell

HTSPRT manufacturer	HTSPRT Type .	HTSPRT No.	Nominal resistance	Lab	Fixed point cells
CHINO	R800-3	RS90X-2	2.5Ω	NIM	Transfer Ag cell NIM's reference Ag cell
		RS10X-01	2.5Ω	CMS	Transfer Ag cell CMS's reference Ag cell
		RS10X-01	2.5Ω	CMS	Transfer Ag cell CMS's reference Ag cell

Table 4 Repeatability of the measurements at CMS prior to the comparison.

Fixed Point	X_{measured}	X_{self} $\times 10^{-6}$	X_{hydr} $\times 10^{-7}$	$X_{\text{corrected}}$	$R_{\text{corrected}}$ /Ω	W
$Ag_{\text{tra-cell}}$	1.09694560	-2.23	-6.3	1.09694274	10.9692792	4.2869156
TPW	0.25588517	-3.76	1.7	0.25588158	2.5587812	
$Ag_{\text{tra-cell}}$	1.09694499	-1.91	-6.3	1.09694245	10.9692763	4.2869237
TPW	0.25588460	-3.74	1.7	0.25588103	2.5587757	
$Ag_{\text{tra-cell}}$	1.09694610	-1.89	-6.3	1.09694358	10.9692876	4.2869271
TPW	0.25588466	-3.74	1.7	0.25588109	2.5587763	

Note: $Ag_{\text{tra-cell}}$ is the transfer Ag cell.

The measurement data of two HTSPRTs from CMS calibrated at the transfer Ag cell, CMS's reference Ag cell and NIM's reference Ag cell is shown in **Table 5** and **6.** In **Table 5**, X is this bridge reading of HTSPRT at the Ag fixed point. And $\boldsymbol{X}_{\mathbf{measured}}$ is the measured bridge reading. $\boldsymbol{X}_{\mathbf{corrected}}$ which corrected by self-heating effect, hydrostatic effect is applied for reference Ag cell as well as transfer Ag cell, however the pressure effect is only for reference Ag cell. The difference in temperature between the CMS reference Ag cell and the transfer Ag cell, $\Delta T_{\mathrm{Ag,CMS,ref-tra}}$ is expressed as,

$$\Delta T_{\mathrm{Ag,CMS,ref-tra}} = (X_{\mathrm{cor,CMS,ref}} - X_{\mathrm{cor,CMS,tra}})/(dX/dT) \quad (3)$$

where $X_{\mathrm{cor,CMS,ref}}$ is the bridge reading of HTSPRT at the CMS reference Ag fixed point corrected by self-heating effect, hydrostatic effect and pressure effect, and $X_{\mathrm{cor,CMS,tra}}$ is the bridge reading of HTSPRT at the transfer Ag fixed point corrected by self-heating effect and hydrostatic effect. dX/dT can be obtained approximately by calculating $X \cdot 1/W_{\mathrm{r}}(\mathrm{Ag}) \cdot dW_{\mathrm{r}}(\mathrm{Ag})/dT$ according to quation (4), and is around 0.00072701/K by using CHINO RS90X-2, and is 0.00070638 /K by using CHINO RS10X-01. Fig.1 illustrated the measurement results of $\Delta T_{\mathrm{Ag,CMS,ref-tra}}$.

$$\frac{1}{X}\frac{dX}{dT} = \frac{1}{X \cdot R_0}\frac{d(X \cdot R_0)}{dT} = \frac{1}{\frac{R}{R_{\mathrm{TPW}}}}\frac{d\left(\frac{R}{R_{\mathrm{TPW}}}\right)}{dT} = \frac{1}{W(\mathrm{Ag})}\frac{dW(\mathrm{Ag})}{dT} \approx \frac{1}{W_r(\mathrm{Ag})}\frac{dW_r(\mathrm{Ag})}{dT} \quad (4)$$

Where R_0 is the resistance value of standard resistor connected to electrical bridge, and R_{TPW} is the resistance at the triple point of water. The ratio $W(\mathrm{Ag})$ and reference ratio $W_r(\mathrm{Ag})$ at Ag fixed point, are defined according to ITS-90.

Table 5 Measurement data at the transfer Ag cell and CMS's reference Ag cell before and after the measurements at NIM by using CHINO RS90X-2 and CHINO RS10X-01 respectively.

Fixed Point	$\boldsymbol{X}_{\mathbf{measured}}$	$\boldsymbol{X}_{\mathbf{self}}$ **×10^{-6}**	$\boldsymbol{X}_{\mathbf{hydr}}$ **×10^{-7}**	$\boldsymbol{X}_{\mathbf{pres}}$ **×10^{-7}**	$\boldsymbol{X}_{\mathbf{corrected}}$	$\boldsymbol{\Delta T}_{\mathbf{Ag,CMS,ref-tra}}$ **/mK**
$\mathrm{Ag}_{\mathrm{tra\text{-}cell}}$	1.09694560	-2.23	-6.3	/	1.09694274	0.41
$\mathrm{Ag}_{\mathrm{ref\text{-}cell}}$	1.09694587	-2.20	-6.3	-0.0	1.09694304	
$\mathrm{Ag}_{\mathrm{tra\text{-}cell}}$	1.09694499	-1.91	-6.3	/	1.09694245	-0.19
$\mathrm{Ag}_{\mathrm{ref\text{-}cell}}$	1.09694522	-2.28	-6.3	-0.0	1.09694231	
$\mathrm{Ag}_{\mathrm{tra\text{-}cell}}$	1.09694610	-1.89	-6.3	/	1.09694358	1.06
$\mathrm{Ag}_{\mathrm{ref\text{-}cell}}$	1.09694723	-2.25	-6.3	-0.0	1.09694435	
$\mathrm{Ag}_{\mathrm{tra\text{-}cell}}$	1.06581910	-2.65	-6.4	/	1.06581582	1.66
$\mathrm{Ag}_{\mathrm{ref\text{-}cell}}$	1.06581956	-1.94	-6.4	-0.0	1.06581698	

Ag$_{\text{tra-cell}}$	1.06581666	-1.68	-6.4	/	1.06581434	-1.08
Ag$_{\text{ref-cell}}$	1.06581621	-1.95	-6.4	-0.4	1.06581358	
Ag$_{\text{tra-cell}}$	1.06581834	-1.51	-6.4	/	1.06581619	0.11
Ag$_{\text{ref-cell}}$	1.06581878	-1.80	-6.4	-0.7	1.06581627	

Note: Ag$_{\text{ref-cell}}$ is the reference Ag cell.

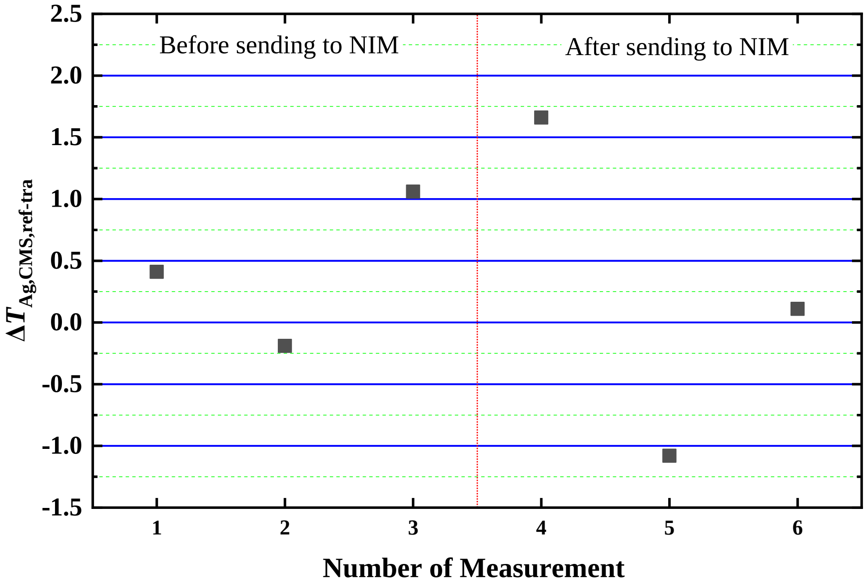

Fig.1 Measurement results of $\Delta T_{\text{Ag,CMS,ref-tra}}$.

Table 6 Measurement data at the transfer Ag cell and NIM's reference Ag cell

Fixed Point	R_{measured} /Ω	R_{self} ×10^{-5} /Ω	R_{hydr} ×10^{-5} /Ω	R_{pres} ×10^{-6} / Ω	$R_{\text{corrected}}$ /Ω	$\Delta T_{\text{Ag,NIM,ref-tra}}$ /mK
Ag$_{\text{tra-cell}}$	10.6581028	-0.21	-0.93	/	10.6580914	0.97
Ag$_{\text{ref-cell}}$	10.6581068	-0.18	-0.65	-0.3	10.6580982	
Ag$_{\text{tra-cell}}$	10.6580958	-0.21	-0.93	/	10.6580844	0.72
Ag$_{\text{ref-cell}}$	10.6580988	-0.18	-0.65	-1.0	10.6580895	
Ag$_{\text{tra-cell}}$	10.6580918	-0.21	-0.93	/	10.6580804	0.54
Ag$_{\text{ref-cell}}$	10.6580928	-0.17	-0.65	-0.4	10.6580842	

In **Table 6**, R is this resistance of HTSPRT at Ag fixed point, $\boldsymbol{R}_{\text{measured}}$ is the measured resistance. $\boldsymbol{R}_{\text{corrected}}$ which corrected by self-heating effect, hydrostatic effect is applied for reference Ag fixed point as well as transfer Ag fixed point, however the pressure effect correction is only for reference cell. The difference in temperature between the NIM reference Ag cell and the transfer Ag cell, $\Delta T_{\text{Ag,NIM,ref-tra}}$ is expressed as,

$$\Delta T_{\text{Ag,NIM,ref-tra}} = (R_{\text{cor,NIM,ref}} - R_{\text{cor,NIM,tra}})/(dR/dT) \qquad (5)$$

Where, $R_{\text{cor,NIM,ref}}$ is the resistance of HTSPRT at the NIM reference Ag fixed point corrected by self-heating effect, hydrostatic effect and pressure effect, and $R_{\text{cor,NIM,tra}}$ is the resistance of HTSPRT at the transfer Ag fixed point corrected by self-heating effect and hydrostatic effect. dR/dT is 0.0070400 Ohm/K for the measurements at NIM measurements. Fig.2 illustrated the measurement results of $\Delta T_{\text{Ag,NIM,ref-tra}}$.

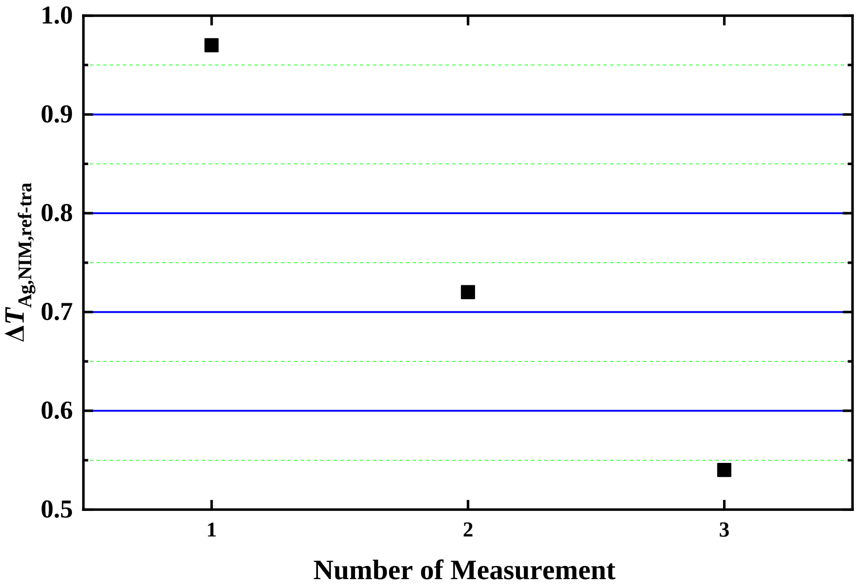

Fig.2 Measurement results of $\Delta T_{\text{Ag,NIM,ref-tra}}$.

6 Uncertainties of Measurements

The uncertainty budgets submitted by the participants are presented in **Tables 7** and **8**. 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, the reproducibility was calculated from the multiple realizations of fixed points at NIM. 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]. For CMS's uncertainty budget, the reproducibility of silver point was derived from the standard deviation of *W* values among different plateaus, and OME method was performed to estimate the measurement uncertainty caused by impurities in Ag cells [4]. The reference water triple point cell at CMS with the isotopic and impurity analysis was used in this comparison, and the evaluation of each uncertainty component can be referred to the final report of APMP. T-K7 [5].

Tables 7 Uncertainty budget submitted by NIM

Source of uncertainty	**Standard uncertainty/mK**	
	TPW	**Ag**
Type A		
Reproducibility	0.02	1.20
Chemical Impurities (OME method)	0.02	0.50
Hydrostatic-head error	0.04	0.03
effects of change in reference resistors	0.01	0.01
Non-linearity of bridge	0.04	0.10
Repeatability of bridge	0.01	0.10
Uncertainty propagated from the TPW	/	/
SPRT self-heating error	0.03	0.09
Heat flux-immersion error	0.03	0.30
Gas pressure in fixed–point cell	/	0.01
Choice of fixed-point value	/	0.12
Combined	0.08	1.40
Expanded Uncertainty(*k*=2)	0.16	2.8

Tables 8 Uncertainty budget submitted by CMS

Source of uncertainty	**Standard uncertainty/mK**	
	TPW	**Ag**
Type A		
Reproducibility	0.011	2.170
Chemical Impurities	0.011	0.330
Isotopic variation	0.002	/
Hydrostatic-head error	0.004	0.016
effects of change in reference resistors	0.006	0.016
Non-linearity of bridge	0.020	0.096
Repeatability of bridge	0.029	1.781
Uncertainty propagated from the TPW		/
SPRT self-heating error	0.006	0.129
Heat flux-immersion error	0.013	0.081
Gas pressure in fixed–point cell	0.005	0.003
Choice of fixed-point value	/	0.439
Combined Standard Uncertainty	0.0421	2.87
Expanded Uncertainty(*k*=2)	0.085	5.8

7 Results

The differences between NIM and CMS at the freezing point of silver, $\Delta T_{\mathrm{Ag,CMS-NIM}}$ were calculated as follows,

$$\Delta T_{\mathrm{Ag,CMS-NIM}} = \overline{\Delta T_{\mathrm{Ag,CMS,ref-tra}}} - \overline{\Delta T_{\mathrm{Ag,NIM,ref-tra}}}$$

$$= T_{\mathrm{Ag,CMS,ref}} - T_{\mathrm{Ag,CMS,tra}} - \left(T_{\mathrm{Ag,NIM,ref}} - T_{\mathrm{Ag,NIM,tra}}\right) \quad (6)$$

$$= \left(X_{\mathrm{Ag,CMS,ref}} - X_{\mathrm{Ag,CMS,tra}}\right) / \frac{dX}{dT} - \left(R_{\mathrm{Ag,NIM,ref}} - R_{\mathrm{Ag,NIM,tra}}\right) / \frac{dR}{dT}$$

Where, $\overline{\Delta T_{\mathrm{Ag,CMS,ref-tra}}}$ is the arithmetic mean value of the temperature difference between the CMS reference Ag cell and the transfer Ag cell before and after NIM;

$\overline{\Delta T_{\mathrm{Ag,NIM,ref-tra}}}$ is the arithmetic mean value of the temperature difference between the NIM reference Ag cell and the transfer Ag cell;

$T_{\mathrm{Ag,CMS,ref}}$ is the average temperature at CMS reference Ag fixed point;

$T_{\mathrm{Ag,CMS,tra}}$ is the average temperature at the transfer Ag fixed point realized at CMS;

$T_{\mathrm{Ag,NIM,ref}}$ is the average temperature at NIM reference Ag fixed point;

$T_{\mathrm{Ag,NIM,tra}}$ is the average temperature at the transfer Ag fixed point realized at NIM;

$X_{\mathrm{Ag,CMS,ref}}$ is the average bridge reading of HTSPRT at CMS reference Ag fixed point;

$X_{\mathrm{Ag,CMS,tra}}$ is the average bridge reading of HTSPRT at transfer Ag fixed point realized at CMS;

$R_{\mathrm{Ag,NIM,ref}}$ is the average resistance of HTSPRT at NIM reference Ag fixed point;

$R_{\mathrm{Ag,NIM,tra}}$ is the average resistance of HTSPRT at transfer Ag fixed point realized at NIM;

$\frac{dX}{dT}$ and $\frac{dR}{dT}$ are approximately taken as constants.

The standard uncertainty of $\Delta T_{\mathrm{Ag,CMS-NIM}}$ is estimated as is expressed by the participants in this comparison:

$$u^2\left(\Delta T_{\mathrm{Ag,CMS-NIM}}\right) = u^2\left(\overline{\Delta T_{\mathrm{Ag,CMS,ref-tra}}}\right) + u^2\left(\overline{\Delta T_{\mathrm{Ag,NIM,ref-tra}}}\right) + u^2\left(T_{\mathrm{drift}}\right)$$

$$= u^2\left(T_{\mathrm{Ag,NIM,ref}}\right) + u^2\left(\mathrm{T}_{\mathrm{Ag,CMS,ref}}\right) + u^2\left(T_{\mathrm{Ag,NIM,tra}} - T_{\mathrm{Ag,CMS,tra}}\right) + u^2\left(T_{\mathrm{drift}}\right) \quad (7)$$

The standard uncertainty source of $T_{\mathrm{Ag,NIM,tra}} - T_{\mathrm{Ag,CMS,tra}}$ is defined according to the reference as follows [2].

$$u^2\left(T_{\mathrm{Ag,NIM,tra}} - T_{\mathrm{Ag,CMS,tra}}\right) = u_{\mathrm{A}}^2 + u_{\mathrm{C}}^2 \quad (8)$$

Here, u_A is calculated by the standard deviation of $\Delta T_{\mathrm{Ag,CMS,ref-tra}}$ and $\Delta T_{\mathrm{Ag,NIM,ref-tra}}$, and is 0.80 mK. u_C is the stability of the transfer Ag cell, and is 2.08 mK. $u(T_{\mathrm{drift}})$ is the standard uncertainty caused by the drift of the transfer HTSPRT during the comparison, and is 0.54 mK.

By calculation, $\Delta T_{\mathrm{Ag,CMS-NIM}}$ and the expanded uncertainty(k=2) of $\Delta T_{\mathrm{Ag,CMS-NIM}}$ are shown in **Table 9** and **Figure 3**.

Table 9 $\Delta T_{\mathrm{Ag,CMS-NIM}}$ and uncertainty of $\Delta T_{\mathrm{Ag,CMS-NIM}}$

Fixed point	$\boldsymbol{\Delta T_{\mathrm{Ag,CMS-NIM}}}$ **/mK**	$\boldsymbol{U(\Delta T_{\mathrm{Ag,CMS-NIM}})}$ **/mK, (*k*=2)**
Ag	-0.42	7.9

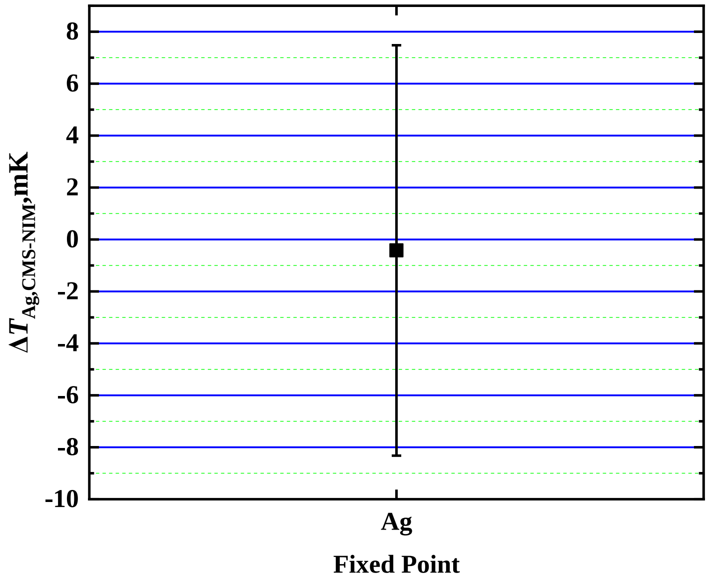

Figure 3 $\Delta T_{\mathrm{Ag,CMS-NIM}}$ and expanded uncertainty of $\Delta T_{\mathrm{Ag,CMS-NIM}}$

8 Link from APMP.T-K4.1 to CCT-K4

The link from APMP.T-K4.1 to CCT-K4 via NIM is given by,

$$\Delta T_{\mathrm{Ag,CMS-KCRV}} = \Delta T_{\mathrm{Ag,CMS-NIM}} - \Delta T_{\mathrm{Ag,KCRV-NIM\_Old}} + \Delta T_{\mathrm{Ag,NIM-NIM\_Old}} \quad (9)$$

where $\Delta T_{\mathrm{Ag,CMS-KCRV}}$ is the difference in temperature between CMS reference Ag fixed point and the key comparison reference value (KCRV) of CCT-K4 at the Ag fixed point,

$\Delta T_{\mathrm{Ag,CMS-NIM}}$ is the difference in temperature between CMS and NIM new reference Ag fixed points, as shown in Eq. (6) and Table 9 as well;

$\Delta T_{\mathrm{Ag,KCRV-NIM\_Old}}$ is the difference in temperature between KCRV and old NIM reference Ag fixed point, as seen in Table 10;

$\Delta T_{\mathrm{Ag,NIM-NIM\_Old}}$ is the difference in temperature between NIM reference Ag fixed point and NIM old reference Ag fixed point, and is 0.98 mK (U=1.0mK, k=2), see the reference [6].

The standard uncertainty of $\Delta T_{\mathrm{Ag,CMS-KCRV}}$ is expressed by,

$$u^2(\Delta T_{\mathrm{Ag,CMS-KCRV}}) = u^2(\Delta T_{\mathrm{Ag,CMS-NIM}}) + u^2(\Delta T_{\mathrm{Ag,KCRV-NIM\_Old}}) + u^2(\Delta T_{\mathrm{Ag,NIM-NIM\_Old}}) \tag{10}$$

$\Delta T_{\mathrm{Ag,CMS-KCRV}}$ and the expanded uncertainty(k=2) of $\Delta T_{\mathrm{Ag,CMS-KCRV}}$ are shown in **Table 10** and **Figure 2**.

Table 10 $\Delta T_{\mathrm{Ag,CMS-KCRV}}$ and the expanded uncertainty of $\Delta T_{\mathrm{Ag,CMS-KCRV}}$

Fixed point	$\Delta T_{\mathrm{Ag,KCRV-NIM\_Old}}$ **/mK**	$u(\Delta T_{\mathrm{Ag,KCRV-NIM\_Old}})$ **/mK, (k=1)**	$\Delta T_{\mathrm{Ag,CMS-KCRV}}$ **/mK**	$U(\Delta T_{\mathrm{Ag,CMS-KCRV}})$ **/mK, (k=2)**
Ag	3.03	1.57	-2.47	8.5

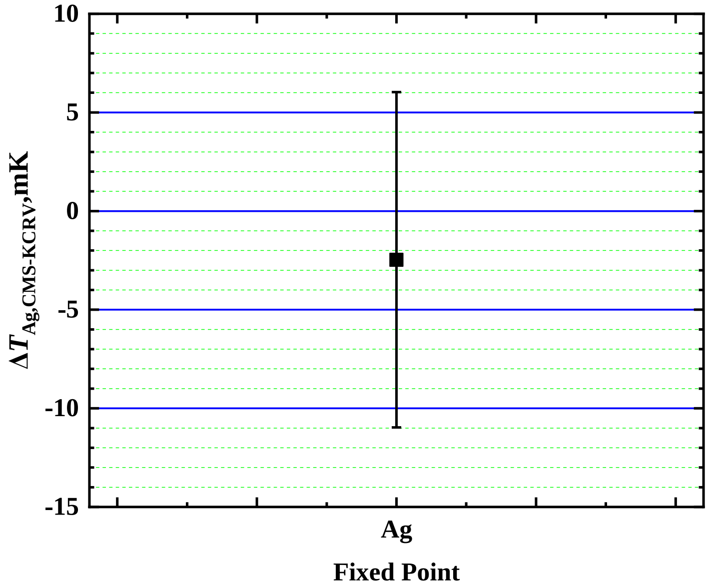

Figure 4. $\Delta T_{\mathrm{Ag,CMS-KCRV}}$ and the uncertainty of $\Delta T_{\mathrm{Ag,CMS-KCRV}}$

APPENDIX A: APMP.T-K4.1 Protocol

APPENDIX B: Stability of the Transfer SPRT and Sealed Ag Cell

APPENDIX C: Measurement Results

APPENDIX D: Measurement Uncertainty

APPENDIX E: Instrumentation Information

Reference

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APPENDIX A: APMP.T-K4.1 Protocol

APMP.T-K4.1: Realizations of the ITS-90 at the Freezing Point of Silver Bilateral Comparison between NIM (China) and CMS (Taiwan)

Protocol

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1. Introduction

Several key comparisons organized by the Comité Consulatif 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-K4 in early days. Early in 2012, CMS had made an initiation to establish a bilateral comparison with NIM at the freezing point of silver. 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 sealed silver freezing point cell with a transfer HTSPRT as the transfer artifacts.

The transfer sealed cell details are as follows:
Serial number: 08070
Model: 5908
Manufacturer: FLUKE
Nominal purity: 99.9999 %
Size: OD=48 mm; ID=8 mm; H=285 mm

The transfer HTSPRT details are as follows:
Serial number: RS10X-01
Model: R800-3
Manufacturer: CHINO
Resistance value (at 0 °C): 2.55 Ω±0.1 Ω
Protection tube: (Φ7.0 ± 0.5) mm × 700 mm

The measurement sequence is as follows:

1) The comparison between the sealed cell and CMS's reference cell will be made prior to sending them to NIM.
2) After the completion of the measurements at CMS, The cell will be sent to NIM.
3) The comparison between the sealed cell and NIM's reference cell will be made.
4) After the completion of the measurements at NIM, the cell 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 the cell to NIM	By 5 Dec 2013
3	NIM complete the third step	3 weeks
4	CMS collect Ag cell from NIM	By 31 Dec 2013
5	CMS complete the fifth step	By 31 May 2014
6	NIM and CMS will sent all of the data to the independent party	By 30 June 2014

4. Technical Instructions

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

1) For the sealed silver freezing point cell, the repeatability of the realization of the sealed cell takes on the stability criteria value, and the stability values obtained from the

standard deviation of W(Ag) must not more than 3 mK (the data from the early realization may be used). The stability data of the sealed cell will be supported by CMS, and is listed in Appendix A.

2) A HTSPRT will be used to compare the sealed cell with the CMS's reference cell, and the measurements will be carried out more than two times. All results will be reported with self-heating correction, Hydrostatic correction and gas pressure correction.

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 sealed cell will be assembled into the NIM's high temperature fixed point furnace, a complete freezing curve will be obtained, and the transfer HTSPRT will be used to compare the sealed cell with the NIM's reference cell, and the measurements will be carried out more than two times. All results will be reported with self-heating correction, Hydrostatic correction and gas pressure correction.

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 artifacts are 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 sealed cell will be assembled into the CMS's high temperature fixed point furnace, a complete freezing curve will be obtained, and a HTSPRT will be used to compare the sealed cell with the CMS's reference cell, and the measurements will be carried out more than two times. All results will be reported with self-heating correction, Hydrostatic correction and gas pressure correction.

3) The measurement loop will be closed. Measurement results will be listed in Appendix B.

5. Reporting of Data

The participating laboratories will submit the following:

1) HTSPRT immersion curves for each of the NMI reference cell and traveling cell used in the Ag fixed point measurements. Measurements do not need to be made with the supplied artifacts, but must be made with thermometers of similar design.
2) Freezing curves for Ag 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.
3) CMS will provide the stability data of the transfer Ag cell.
4) The file listed in Appendix B should be used to record the measurement results.
5) The file listed in Appendix C should be used to record the Measurement Uncertainty pertaining to the comparison.
6) 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.

$$\Delta T_{\text{CMS,Trans,NIM}} = T_{\text{CMS,Trans}} - T_{\text{NIM}} \approx \left[\frac{\sum_{\text{m}=1}^{3} [X(\text{Ag})_{\text{CMS,m}} - X(\text{Ag})_{\text{NIM,m}}]}{3} \right] / \frac{dX(\text{Ag})}{dT}$$

$X(\text{Ag})_{\text{CMS,m}}$: the resistance/ratio value of Ag transfer cell using the transfer HTSPRT by NIM

$X(\text{Ag})_{\text{NIM,m}}$: the resistance/ratio of NIM Ag reference cell using the transfer

HTSPRT by NIM

$T_{\mathrm{CMS,\ Trans}}$: the temperature of Ag transfer cell

T_{NIM}: the temperature of Ag reference cell of NIM

$$\Delta T_{\mathrm{CMS,NIM}} = T_{\mathrm{CMS}} - T_{\mathrm{NIM}} = (T_{\mathrm{CMS,Trans}} - T_{\mathrm{NIM}}) + (T_{\mathrm{CMS}} - T_{\mathrm{CMS,Trans}})$$

T_{CMS}: the temperature of Ag reference cell of CMS

2) NIM has maintained its traceability to the CCT-K4 KCRV. The differences between the participants and the CCT KCRV with associated uncertainties, thus providing linkage to CCT KC for the purpose of CMC acceptance.

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

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

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 Sealed Ag Cell

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/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 Transfer Ag cell: FLUKE/5908/08070
Manufacturer/ Model / Serial No of HTSPRT: CHINO / R800-3 / RS90X-2

Result sheet: Stability of the transfer Ag cell

Date	Fixed Point	$R_{measured}$ / Ω	R_{self} ×10^{-5} / Ω	R_{hydr} ×10^{-6} / Ω	$R_{corrected}$ / Ω	W
2013/12/01	$Ag_{tra-cell}$	10.9693078	-2.24	-6.3	10.9692791	4.2869156
2013/12/02	TPW	2.5588171	-3.76	1.7	2.5587812	
2013/12/02	$Ag_{tra-cell}$	10.9693017	-1.91	-6.3	10.9692763	4.2869237
2013/12/03	TPW	2.5588114	-3.74	1.7	2.5587757	
2013/12/03	$Ag_{tra-cell}$	10.9693128	-1.89	-6.3	10.9692876	4.2869272
2013/12/04	TPW	2.5588120	-3.74	1.7	2.5587763	

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

Conclusion: the stability of the silver transfer cell __is__(is / is not) satisfactory for comparison to continue.

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 transfer Ag cell: FLUKE / 5908/ 08070
Manufacturer / Model / Serial No of reference Ag cell: FLUKE / 5928 /28059
Manufacturer / Model / Serial No of SPRT: CHINO / R800-3 / RS90X-2 & RS10X-01

Comparison results by using HTSPRT (No. RS90X-2) before NIM

Fixed Point	$X_{measured}$	X_{self} ×10^{-6}	X_{hydr} ×10^{-7}	X_{pres} ×10^{-7}	$X_{corrected}$	ΔT /mK
$Ag_{tra\text{-}cell}$	1.09694560	-2.23	-6.3	/	1.09694274	0.41
$Ag_{ref\text{-}cell}$	1.09694587	-2.20	-6.3	-0.0	1.09694304	
$Ag_{tra\text{-}cell}$	1.09694499	-1.91	-6.3	/	1.09694245	-0.21
$Ag_{ref\text{-}cell}$	1.09694521	-2.28	-6.3	-0.0	1.09694231	
$Ag_{tra\text{-}cell}$	1.09694610	-1.89	-6.3	/	1.09694358	1.06
$Ag_{ref\text{-}cell}$	1.09694723	-2.25	-6.3	-0.0	1.09694435	

$X_{corrected}$ is this bridge reading was corrected by self-heating effect and hydrostatic effect for reference cell as well as transfer cell. $\Delta T = T_{\mathrm{cms}} - T_{\mathrm{tra}}$, dX/dT =0.00072701 /K.

Comparison results by using HTSPRT (No. RS10X-01) after NIM

Fixed Point	$X_{measured}$	X_{self} ×10^{-6}	X_{hydr} ×10^{-7}	X_{pres} ×10^{-7}	$X_{corrected}$	ΔT /mK□□
$Ag_{tra\text{-}cell}$	1.06581910	-2.65	-6.4	/	1.06581582	1.66
$Ag_{ref\text{-}cell}$	1.06581956	-1.94	-6.4	-0.0	1.06581698	
$Ag_{tra\text{-}cell}$	1.06581666	-1.68	-6.4	/	1.06581434	-1.08
$Ag_{ref\text{-}}$	1.06581621	-1.95	-6.4	-0.4	1.06581358	

cell						
$Ag_{tra\text{-}cell}$	1.06581834	-1.51	-6.4	/	1.06581619	0.11
$Ag_{ref\text{-}cell}$	1.06581878	-1.80	-6.4	-0.7	1.06581627	

$\boldsymbol{X}_{\mathbf{corrected}}$ is this bridge reading was corrected by self-heating effect and hydrostatic effect for reference cell as well as transfer cell. $\Delta T = T_{\text{cms}} - T_{\text{tra}}$, dX/dT =0.00070638 /K

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
Manufacturer / Model / Serial No of transfer Ag cell: FLUKE / 5908/ 08070
Manufacturer / Model / Serial No of reference Ag cell: NIM / - /201001
Manufacturer / Model / Serial No of SPRT: CHINO / R800-3 / RS10X-01

Comparison results by using HTSPRT (No. RS10X-01)

Fixed Point	$\boldsymbol{R}_{\mathbf{measured}}$ /Ω	$\boldsymbol{R}_{\mathbf{self}}$ ×$\mathbf{10^{-5}}$ /Ω	$\boldsymbol{R}_{\mathbf{hydr}}$ ×$\mathbf{10^{-5}}$ /Ω	$\boldsymbol{R}_{\mathbf{pres}}$ ×$\mathbf{10^{-6}}$ / Ω	$\boldsymbol{R}_{\mathbf{corrected}}$ /Ω	$\Delta \boldsymbol{T}$ /mK
$Ag_{tra\text{-}cell}$	10.6581028	-0.21	-0.93		10.6580914	0.97
$Ag_{ref\text{-}cell}$	10.6581068	-0.18	-0.65	-0.3	10.6580982	
$Ag_{tra\text{-}cell}$	10.6580958	-0.21	-0.93	/	10.6580844	0.72
$Ag_{ref\text{-}cell}$	10.6580988	-0.18	-0.65	-1.0	10.6580895	
$Ag_{tra\text{-}cell}$	10.6580918	-0.21	-0.93	/	10.6580906	0.54
$Ag_{ref\text{-}cell}$	10.6580928	-0.17	-0.65	-0.4	10.6580842	

$\boldsymbol{R}_{\mathbf{corrected}}$ is this resistance was corrected by self-heating effect and hydrostatic effect for reference cell as well as transfer cell.$\Delta T = T_{\text{NIM}} - T_{\text{tra}}$, dR/dT =0.0070400 Ohm/K.

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
TPW Fixed point S/N: H5029
Ag Fixed point Cell S/N: 28059

Source of uncertainty	**Standard uncertainty/mK**	
	TPW	**Ag**
Type A		
Reproducibility	0.011	2.170
Chemical Impurities	0.011	0.330
Isotopic variation	0.002	/
Hydrostatic-head error	0.004	0.016
effects of change in reference resistors	0.006	0.016
Non-linearity of bridge	0.020	0.096
Repeatability of bridge	0.029	1.781
Uncertainty propagated from the TPW		/
SPRT self-heating error	0.006	0.129
Heat flux-immersion error	0.013	0.081
Gas pressure in fixed–point cell	0.005	0.003
Choice of fixed-point value	0.0421	0.439
Combined Standard Uncertainty	0.0421	2.87
Expanded Uncertainty(k=2)	0.085	5.8

Laboratory: National Institute of Metrology
Laboratory: Jianping Sun
Contact Address: #18, Bei San Huan Dong Lu, Beijing, China

Email：sunjp@nim.ac.cn

TPW Fixed point S/N: NIM-5
Ag Fixed point Cell S/N: NIM/201001

Source of uncertainty	**Standard uncertainty/mK**	
	TPW	**Ag**
Type A		
Reproducibility	0.02	1.20
Chemical Impurities (SIE or OME method)	0.02	0.50
Hydrostatic-head error	0.04	0.03
effects of change in reference resistors	0.01	0.01
Non-linearity of bridge	0.04	0.10
Repeatability of bridge	0.01	0.10
Uncertainty propagated from the TPW		/
SPRT self-heating error	0.03	0.09
Heat flux-immersion error	0.03	0.30
Gas pressure in fixed–point cell	/	0.01
Choice of fixed-point value	/	0.12
Combined	0.08	1.40
Expanded Uncertainty(k=2)	0.16	2.8

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

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

Transfer Ag Fixed point cell

Cell	
Cell manufacturer / Model / Serial no.	Fluke/5908/08070
Open/closed?	Closed
Pressure in cell	85.4KPa
Crucible	
Crucible material	Graphite
Crucible manufacturer	/
Crucible length	/
Metal sample	
Sample source	/
Sample purity	≥99.9999 %
Sample weight	/
Thermometer well	
Well material	Quartz glass
Well ID (mm)	8
Immersion depth of SPRT	195 mm (159.25 mm for RS90X-2/167.25 mm for RS10X-01)
Furnace/Bath	
Manufacturer	Fluke
Control type	Sodium heat-pipe furnace with a digital controller

How many zones?	Three
Furnace heater	
AC/DC?	AC
Heat pipe liner?	Yes
ITS-90 Realization Techniques	
Freeze/Melt?	Freeze
Method of forming solid/liquid interface	Induce method
Heat transferring fluid?	/
Duration of freeze/melt	Around 8hrs within 1mK
Cell used as FP/MP/TP?	FP

Ag Fixed point cell

Cell	
Cell manufacturer / Model / Serial no.	Fluke/5928/28059
Open/closed?	Open
Pressure in cell	/
Crucible	
Crucible material	Graphite
Crucible manufacturer	/
Crucible length	/
Metal sample	
Sample source	/
Sample purity	≥99.9999 %
Sample weight	/
Thermometer well	
Well material	Quartz glass
Well ID (mm)	8
Immersion depth of SPRT	195 mm (159.25 mm for RS90X-2/167.25 mm for RS10X-01)
Furnace/Bath	
Manufacturer	Fluke
Control type	Sodium heat-pipe furnace with a digital controller
How many zones?	Three
Furnace heater	
AC/DC?	AC
Heat pipe liner?	Yes
ITS-90 Realization Techniques	
Freeze/Melt?	Freeze
Method of forming solid/liquid interface	Induce method
Heat transferring fluid?	/
Duration of freeze/melt	Around 8hrs within 1mK for open cell
Cell used as FP/MP/TP?	FP

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	$1*10^4$or $1*10^5$
Read manually or off IEEE-488	IEEE-488
Normal measuring current	5mA
Self-heating current	$5*\sqrt{2}$ 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℃
Temperature coefficient of the ref resistor	Typically 2ppm/℃
Impedance at 30 Hz under (19.768±0.01) ℃	9.9998649 Ω with ± 1.5 ppm uncertainty (cited from Certificate of Calibration 2012040093-2 (EtA 570.24) issued by NPL on 31 July 2012)

Laboratory: National Institute of Metrology
Laboratory: Jianping Sun
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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

Ag Fixed point cell

Cell	
Cell manufacturer / Model / Serial no.	NIM/201001
Open/closed?	Open
Pressure in cell	/
Crucible	
Crucible material	Graphite
Crucible manufacturer	China
Crucible length	279mm
Metal sample	
Sample source	China
Sample purity	99.9999%
Sample weight	1.8kg
Thermometer well	
Well material	Quartz
Well ID (mm)	8.0 mm
Immersion depth of SPRT	170mm
Furnace/Bath	
Manufacturer	NIM
Control type	PID
How many zones?	3-zone
Furnace heater	

AC/DC?	AC
Heat pipe liner?	NO
ITS-90 Realization Techniques	
Freeze/Melt?	Freeze
Method of forming solid/liquid interface	Induced freeze
Heat transferring fluid?	No
Duration of freeze/melt	>10h
Cell used as FP/MP/TP?	FP

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	2mA
Self-heating current	$2 \times \sqrt{2}$mA
If DC, give	
Gain	
Period of reversal	
Reference resistor	
Type	AC/DC
Manufacturer / Model / Serial no.	Tinsly 5685A 13945/08
Temperature of the ref resistor	20℃
Temperature coefficient of the ref-resistor	a=0.1522×10^{-6}/℃，β=-0.0083×10^{-6}/(°C)^{2}
Impedance	9.9999885 Ω with relative uncertainty of 0.50×10^{-6} (k=3)