Final Report on APMP.T-K7

Key Comparison of water triple point cells

Shu-Fei Tsai[1], Rod White[2], Jun Tamba[3], Kazuaki Yamazawa[3], Mong-Kim Ho[4], C M Tsui[5], Ghufron Zaid[6], Aditya Achmadi[6], Kee Sool Gam[7], Hafidzah Othman[8], Nurulaini Md Ali[8], Kho Hao Yuan[9] (Before Sep 2011), Ye Shaochun[9] (Since Nov 2011), Hans Liedberg[10], Charuayrat Yaokulbodee[11]

[1]Center for Measurement Standards, ITRI (CMS/ITRI), Taiwan
[2]Measurement Standards Laboratory(MSL), New Zealand
[3]National Metrology Institute of Japan, AIST (NMIJ/AIST), Japan
[4]National Measurement Institute of Australia (NMIA), Australia
[5]Standards and Calibration Laboratory (SCL), Hong Kong
[6]Puslitbang KIM-LIPI, Indonesia
[7]Korea Research Institute of Standards and Science (KRISS), Korea
[8]National Metrology Laboratory, SIRIM Berhad (SIRIM), Malaysia
[9]National Metrology Center (NMC), A*STAR, Singapore
[10]National Metrology Institute of South Africa (NMISA), South Africa
[11]National Institute of Metrology Thailand (NIMT), Thailand

Pilot Laboratory:
CMS, [1]Center for Measurement Standards, ITRI (CMS/ITRI), Taiwan

Co-Pilot Laboratories:
MSL, [2]Measurement Standards Laboratory of New Zealand, New Zealand
NMIJ, [3]National Metrology Institute of Japan, AIST (NMIJ/AIST), Japan

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1. Introduction

This is the report of APMP.T-K7 key comparison of water-triple-point cells. The decision to organize this comparison was made at the APMP-TCT meeting in November 2000, but was postponed until the final report of CCT-K7 was published in 2006. CMS (Taiwan) organized the comparison, with the support from co-pilot institutes MSL (New Zealand) and NMIJ (Japan).

The final version of the protocol was submitted to CCT WG7 in May 2007 and obtained approval in October 2007. The comparison measurements were commenced in February 2008 and finalized in September 2009, and the report submission was closed on 23 Nov. 2010, however the closure measurement results, after cells were back to each laboratory, from some participants were not collected in full until January 2011.

2. Organization of the comparison

2.1 Participants

A total of 11 NMIs took part in this comparison as shown in the following table:

Table 1: Participants of APMP.T-K7

Country	NMI	Contact Person	Email
Australia	National Measurement Institute, Australia (NMIA)	Ms. Kim Nguyen	Kim.Nguyen@measurement.gov.au
Hong Kong	Standards and Calibration Laboratory(SCL)	Mr. C M Tsui Ms. Julian Cheung	cmtsui@itc.gov.hk cpcheung@itc.gov.hk
Indonesia	Puslitbang KIM-LIPI	Mr. Aditya Achmadi Dr. Ghufron Zaid	aditya_achmadi@yahoo.com gzaid01@yahoo.com
Japan+	National Metrology Institute of Japan(NMIJ/AIST)	Dr. Jun Tamba	j-tamba@aist.go.jp
Korea	Korea Research Institute of Standards and Science(KRISS)	Dr. Kee Sool Gam	ksgam@kriss.re.kr
Malaysia	Standards & Industrial Research Institute of Malaysia(SIRIM)Berhad	Ms. Hafidzah Othman Ms. Nurulaini Md Ali	hafidzah_othman@sirim.my aini@sirim.my
New Zealand+	Measurement Standards Laboratory(MSL)	Dr. Rod White	r.white@irl.cri.nz
Singapore	National Metrology Centre(NMC)	Mr. Kho Hao Yuan Dr. Wang Li since Sept.	kho_hao_yuan@nmc.a-star.edu.sg wang_li@nmc.a-star.edu.sg
South Africa	National Metrology Institute of South Africa (NMISA)	Mr Hans Liedberg	hliedber@csir.co.za
Taiwan*	Center for Measurement Standards(CMS)/ITRI	Ms. Shu-Fei Tsai	Shu-Fei_Tsai@itri.org.tw
Thailand	National Institute of Metrology Thailand(NIMT)	Ms.Charuayrat Yaokulbodee	charuayrat@nimt.or.th

*: Pilot Laboratory
+: Co-Pilot Laboratories

2.2 Method of the comparison

The comparison was organized as a collapsed star comparison and consisted of four phases:

1) CMS completes the comparison of its national reference against the two common reference cells and sends the report to two co-pilots before the inter-cell comparison begins;
2) each participating laboratory selects one of its cells for use as a transfer cell and directly compares it against its national reference;
3) the selected transfer cell is sent together with the measurement results to CMS where all transfer cells are compared against two common reference cells;
4) the transfer cells are sent back to the laboratories to directly re-compare with the same reference cell(s), as before, to check the transfer cell stability.

The participants were asked to compare the selected transfer cell against their national reference on two separately prepared ice mantles. Measurements should not start until at least one week after the preparation of the ice mantle, and then be carried out in about two weeks, resulting in a minimum of ten results per mantle. The protocol recommended that the ice mantle of the transfer cell be prepared by using the BIPM technique, and the measurement procedure should be that normally applied by the laboratory. The participants were also asked to measure an immersion profile.

At CMS, all cells were compared with two common reference cells provided by CMS. The mean of the temperature difference between the transfer cell and these two reference cells measured on the same day served the comparison result for all participants' cells.
For each cell, measurements were made at least for two different mantles. Immersion profiles were also measured at CMS.

2.3 Transfer cells and two CMS reference cells

The transfer cells selected by each participant and the two CMS reference cells are presented in Table 2. The designations used in this report differ in many cases from those used by the laboratories because a uniform labeling system was adopted here for convenience. Each cell is designated here by the acronym of the laboratory owning the cell, followed by a serial number. The sixth column of the table lists special accessories which were sent with some of the cells and which were also used for the measurements at CMS.

2.4 Laboratory equipment and uncertainty

The equipment, measuring conditions, and ice mantle preparation technique are summarized in Table 3. The detailed uncertainty budget and immersion profile of cell submitted by each participating laboratory are reported in Table 3 and Appendix 2-4.

3. Comparison of the transfer cells at CMS

3.1 Experimental setup

The water triple point cells were kept in one TPW maintenance bath, which can maintain up to four cells. The set-point of the bath was 1 mK below the triple point. All measurements were made with the same 25.5 Ω SPRT. An ASL F900 bridge measured the resistance of the thermometer against a 100 Ω standard resistor, which was kept in an oil bath regulated at 20 °C. The oil bath was equipped with a resistance thermometer to monitor the temperature. The ASL Bridge was connected to a computer via an IEEE interface to remotely control the instrument settings and data acquisition. The bridge settings for the bandwidth, gain, and carrier frequency were 0.1 Hz, 10^5, and 30 Hz respectively. Twelve measurements, taken every 33 seconds at currents of both 1 mA and $\sqrt{2}$ mA, were used to extrapolate and determine the zero-current resistance. The laboratory temperature was controlled to be within (23±2) °C.

Table 2: Transfer cells selected by the participating laboratory and reference cells of CMS

Country	Laboratory	Cell designation used in this report	Manufacturer or type	Model of cell	Year of fabrication or purchase	Accessories or comments on special use	Inner diameter of well /mm	Cell diameter /mm	Depth of well below water surface / mm
Taiwan	CMS	CMS5029 CMS5030	Hart Scientific	5901A-Q	2008	—	12	50	265
Australia	NMIA	NMIA AC6	NMIA		1971	—		50	227
Hong Kong	SCL	SCL5045	Hart Scientific	5901A-G	2007	—	12	50	291
Indonesia	KIM-LIPI	KIM-LIPI224	PTB	5 PTB 89	1989	—	12	50	215
Japan	NMIJ	NMIJT93-3	TOA KEIKI	SY-12	1993	Centering adjuster / Height adjuster / Clip	12	65	238
Korea	KRISS	KRISS2000-24	KRISS		2002	Aluminum bushing used	11	50	246
Malaysia	SIRIM	SIRIM2000-22	KRISS	CRM 51-01-001	2007	—	11	50	246
New Zealand	MSL	MSL01-02	MSL		2001	—	9	60	248
Singapore	NMC	NMC2087	Jarrett	B11	2003	—	11	64	285
South Africa	NMISA	NMISA1181	Hart Scientific	5901A-G	2004	Foam pad at bottom of well	12	50	265
Thailand	NIMT	NIMT1480	Hart Scientific	5901	2005	—	13.6	60	265

Table 3: Overview of the equipment and measuring conditions used in each participating laboratory

Laboratory	Resistance bridge	Measurement current (frequency)	Bandwidth and gain	Repeated number and sampling frequency	Reference resistor	Temp. control of reference resistor	SPRT(length of sensor)	Storage container for WTP cells	Technique ice mantle preparation
NMIA	ASL F18 (AC) ASL F900 (AC)	1 mA and √2 mA (75 Hz)	0.1 Hz, 10^4	10, 8 sec	100 Ω Guildline 9330	20 °C± 5 mK	NML-CSIRO B119(40 mm) Hart 0275(45 mm) Chino RS072-04 (60 mm) Chino RS076-06 (60 mm)	NMI-made water bath	solid CO_2 & ethanol
SCL	ASL F18 (AC)	1 mA and √2 mA (75 Hz)	0.02 Hz, 10^4	12, 60 sec	25 Ω Tinsley 5685A	23 °C± 20 mK	Tinsley 5187SA(40 mm)	Isotech 18233	solid CO_2 & alcohol
KIM-LIPI	MI 6010C (DC)	1 mA and √2 mA	–	100, 6 sec	100 Ω Tinsley 5685A	23 °C±0.1 °C	Kunming 92212(30 mm)	liquid bath	solid CO_2
NMIJ	Isotech TTI-3 (DC)	1 mA and √2 mA	–	10, 20 sec	10 Ω Tinsley 5685A	36 °C±0.1 °C	Chino R800-2 (40 mm)	Isotech 18233	R-134a heat-pipe cooled with liquid nitrogen, and ethanol for heat transfer
KRISS	ASL F900 (AC)	1 mA and √2 mA (30 Hz)	0.1 Hz, 10^4	10, 40 sec	100 Ω Tinsley 5685A	25.00 °C±0.01 °C	Leeds&Northrup 8163Q 1854020 (25 mm)	crushed ice container	solid CO_2
SIRIM	ASL F18 (AC)	1 mA and √2 mA (75 Hz)	0.1 Hz, 10^4	40, 10 sec	100 Ω Tinsley 5685A	23 °C± 2 mK	YSI 8163-QC (43 mm)	ice bath	solid CO_2
MSL	ASL F18 (AC)	1 mA and √2 mA (75 Hz)	0.02 Hz	10, 50 sec	25 Ω Tinsley 5685A	29.45 °C± 2 mK	Leeds&Northrup 8167 (35 mm)	self-draining vacuum dewar containing crushed ice	dry ice to initiate freezing, and then an Immersion cooler to build mantle
NMC	MI6010A (DC)	1 mA and √2 mA	–	50, 16 sec	10 Ω Tinsley 5685A	25 °C±0.05 °C	Tinsley 5187SA 253126(40 mm)	Hart 7012	solid CO_2 & alcohol
NMISA	ASL F18 (AC)	1 mA and√2 mA (25 Hz)	0.1 Hz, 10^5	5, 11 sec	100 Ω Tinsley 5685A	Temperature measured and resistance corrected using measured temperature coefficient.	Rosemount 162CE 4203 (50 mm) Isotech l 670 163 (32 mm to 41 mm)	Isotech 18233	Methanol heat pipe with solid CO_2 ,and ethanol for heat transfer
CMS	ASL F900 (AC)	1 mA and√2 mA (30 Hz)	0.1 Hz, 10^5	12, 33 sec	100 Ω Tinsley 5685A	20 °C± 5 mK	YSI 8167-25 1235 (33.3 mm)	Isotech 18233	solid CO_2 & alcohol
NIMT	ASL F18 (AC)	1 mA and √2 mA (75 Hz)	0.1 Hz, 10^4	30, 20 sec	25 Ω Tinsley 5685A	23 °C±0.1 °C	Tinsley 5187SA(40mm)	Hart WTP bath	solid CO_2 & alcohol

3.2 Measurement procedure

During one day, we could measure up to four cells including two reference cells (R_1 & R_2) and two transfer cells (T_1 & T_2) from two participants. The measurement sequence and data labeling is described in Table 4. For the same cell, the letters A, B, C, D denote the first, the second,…, and the fourth in the sequence of measurements on one cell;

Table 4: The measurement sequence and data labels for the daily analysis

Sequence	Reference1	Reference2	Transfer1	Transfer2
1	R_{1A}			
2		R_{2A}		
3			T_{1A}	
4			T_{1B}	
5		R_{2B}		
6				T_{2A}
7				T_{2B}
8		R_{2C}		
9	R_{1B}			
10			T_{1C}	
11			T_{1D}	
12	R_{1C}			
13				T_{2C}
14				T_{2D}
15	R_{1D}			
16		R_{2D}		

Cell R_1 is CMS5030
Cell R_2 is CMS5029

3.3 Data analysis

The 16 measurements taken on any one day were reduced to 3 values: the difference between the two reference cells, ΔR, and the difference between each of the transfer cells and the mean reference, ΔT_1, and ΔT_2, according to the following formulae:

$$\Delta R = ⅓(R_{2A} – R_{1A} + R_{2C} – R_{1B} + R_{2D} – R_{1D})$$

$$\Delta T_1 = ¼(T_{1A} + T_{1B} + T_{1C} + T_{1D} – R_{2A} – R_{2B} –R_{1B} – R_{1C})$$

$$\Delta T_2 = ¼(T_{2A} + T_{2B} + T_{2C} + T_{2D} – R_{2B} – R_{2C} –R_{1C} – R_{1D})$$

Note that measurements of the transfer cells are compared only with reference measurements taken immediately before or immediately after the transfer-cell measurements.

The measurements were executed for at least ten days over the whole period of the comparison, hereafter
ΔR_{AVG} denotes the average of ΔR over the whole period of the comparison; ΔT_{jAVG} denotes the average of ΔT_j on the same ice mantle over the whole period of the comparison.

The above are only for demonstrating the measurement procedure and the corresponding data analysis method, the follow-up hydrostatic effect correction is applied to all cells according to the depth of well below water surface. Any isotopic or impurity corrections are also applied if required.

4. Measurements of TPW cells at CMS

4.1 Stability of two common reference cells

As mentioned above, up to four cells were compared during one day; the cells were measured in separate groups arranged as in Table 5, which was always including two common reference cells. The average of temperature difference in terms of ΔR_{AVG} within different groups is shown in Fig. 1, and it shows that both reference cells were fairly stable over a long period of about 1.5 years according to the consistent results even within a limited 1σ interval.

Table 5: Groups of cells for APMP.T-K7 comparison

Measurement period	Groups of cells			
2 May~16 May 2008	CMS National reference cell groups		CMS5029	CMS5030
30 May~13 June 2008	CMS National reference cell groups		CMS5029	CMS5030
3 Sept.~ 16 Sept. 2008	NMIA AC6	SCL5045	CMS5029	CMS5030
12 Oct.~ 23 Oct. 2008	NMIA AC6	MSL01-06*	CMS5029	CMS5030
26 Nov.~ 9 Dec. 2008	NMISA1181	SCL5045	CMS5029	CMS5030
19 Dec.~ 19 Dec.2008	NMISA1181	MSL01-02	CMS5029	CMS5030
9 April~21 April 2009	KIM-LIPI224	MSL01-02	CMS5029	CMS5030
5 May~ 19 May 2009	KIM-LIPI224	NIMT1480	CMS5029	CMS5030
1 June~12 June 2009	KRISS2000-24	NIMT1480	CMS5029	CMS5030
22 June~3 July 2009	KRISS2000-24	NMIJT93-3	CMS5029	CMS5030
20 July~31 July 2009	SIRIM2000-22	NMIJT93-3	CMS5029	CMS5030
28 Aug.~8 Sept. 2009	SIRIM2000-22	NMC2087	CMS5029	CMS5030
21 Sept.~30 Sept. 2009	CMS National reference cell	NMC2087	CMS5029	CMS5030

* MSL01-06 is shown here only to illustrate what cells were compared during the measurement period from 12 Oct.2008 to 23 Oct. 2008; however the relevant measurement data of this cell is not included in this report because only one mantle measurement was made on this cell before the Carnet was expired.

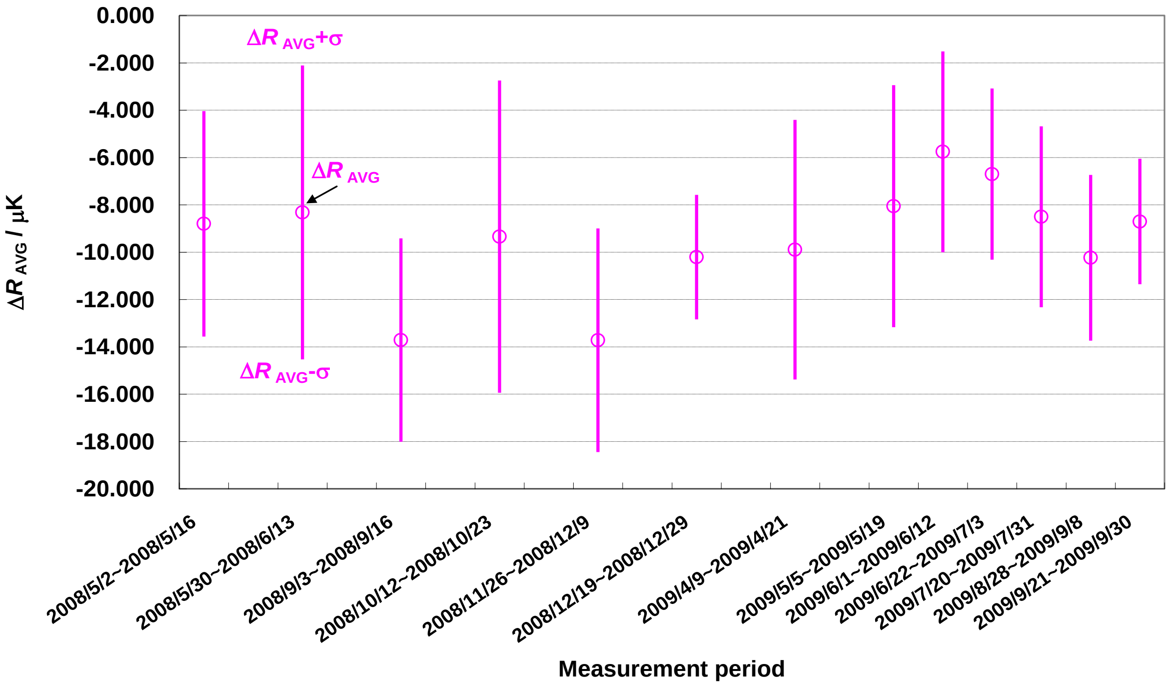

Fig 1: Stability of two reference cells used for APMP.T-K7

4.2 Temperature differences between transfer cells and reference cells

The temperature differences of all transfer cells from both APMP reference cells, which have been corrected by self-heating effect and hydrostatic-head effect are summarized in the following Figures 2-6 and Table 6. In Table 6, two columns in bold type indicate ΔT_{jAVG} measured on each of two ice mantles, and because some cells were drifting during the measurements, the standard deviation of the temperature difference rather than the standard deviation in the mean of the difference is represented on the third and the fifth columns, and is adopted in the following uncertainty analysis.

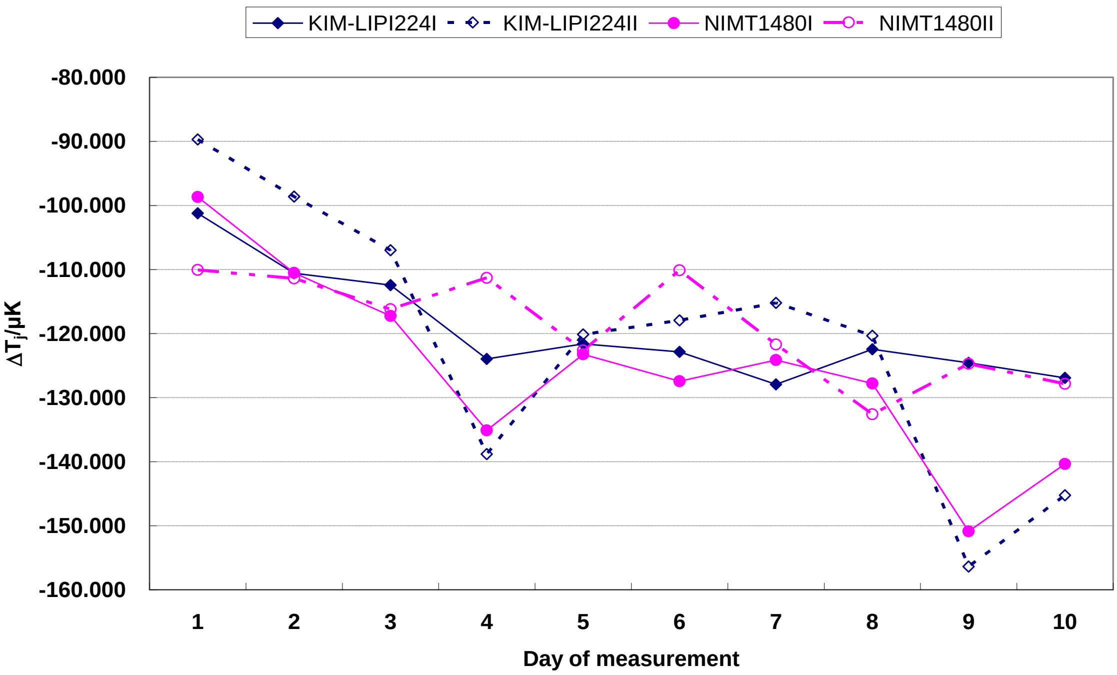

Figure 2: Temperature difference between the transfer cells and the mean of the two reference cells over the whole period of the comparison. The results have been corrected by self-heating effect and hydrostatic-head effect.

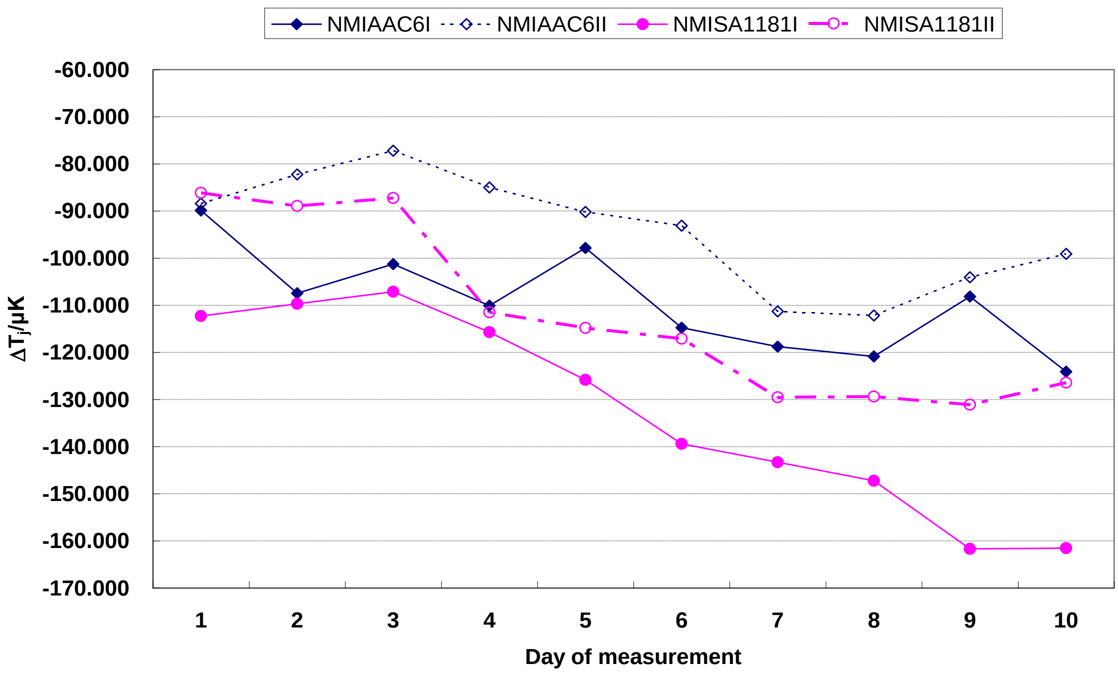

Figure 3: Temperature difference between the transfer cells and the mean of the two reference cells over the whole period of the comparison. The results have been corrected by self-heating effect and hydrostatic-head effect.

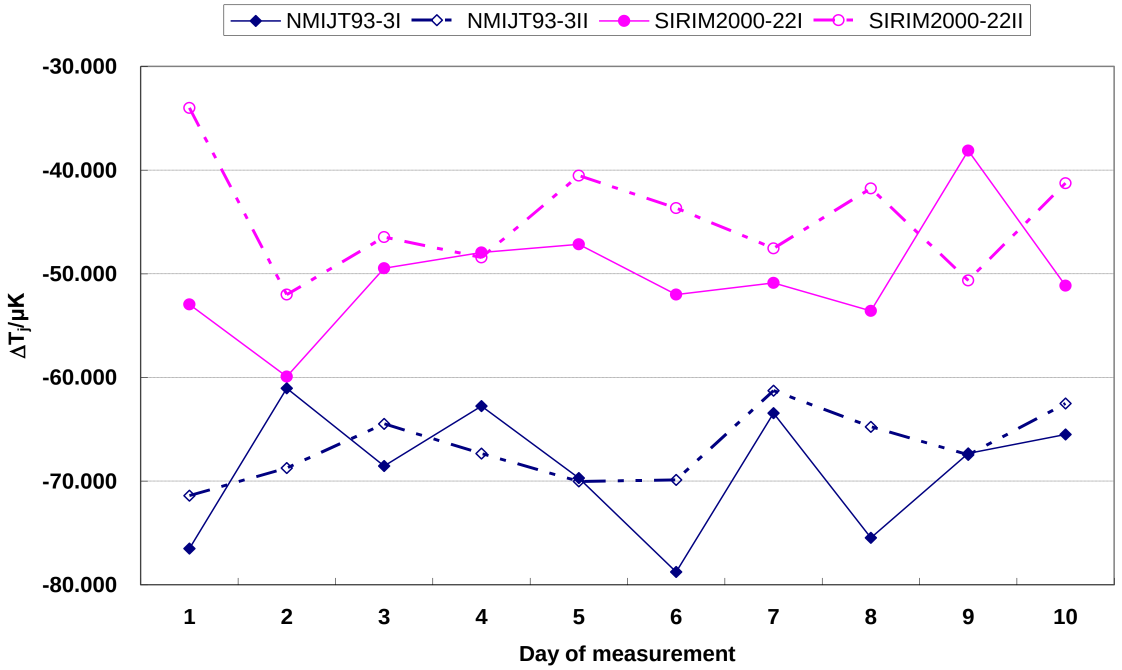

Fig 4: Temperature difference between the transfer cells and the mean of the two reference cells over the whole period of the comparison. The results have been corrected by self-heating effect and hydrostatic-head effect.

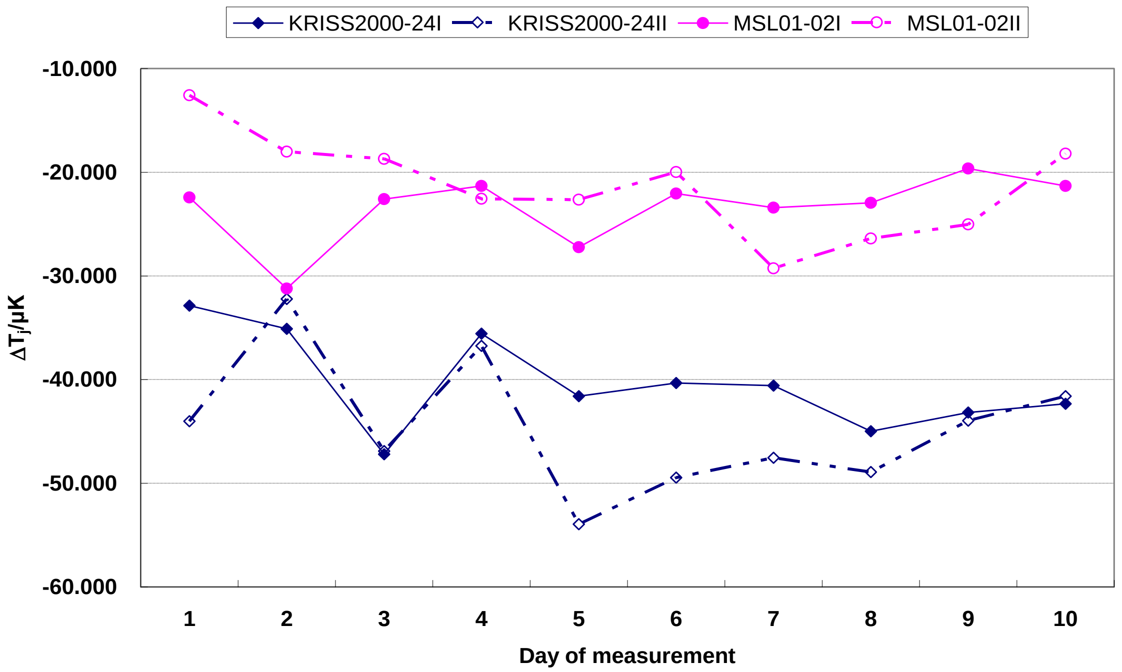

Fig 5: Temperature difference between the transfer cells and the mean of the two reference cells over the whole period of the comparison. The results have been corrected by self-heating effect and hydrostatic-head effect.

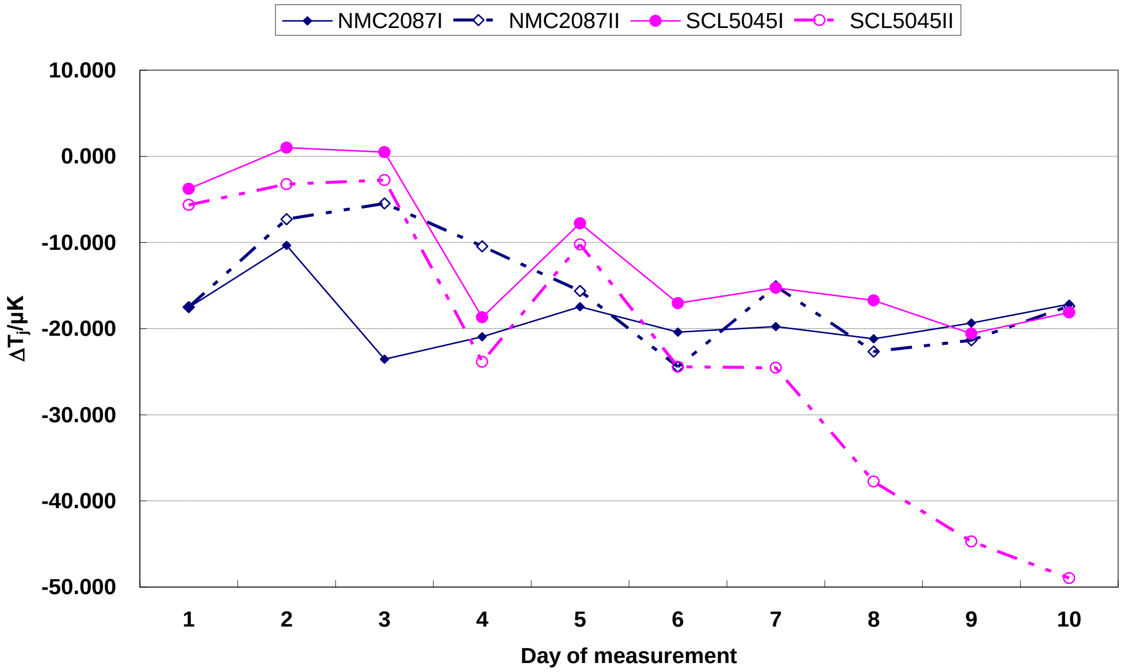

Fig 6: Temperature difference between the transfer cells and the mean of the two reference cells over the whole period of the comparison. The results have been corrected by self-heating effect and hydrostatic-head effect.

Table 6: Arithmetic mean value and the standard deviation of ΔT_j on two ice mantles for all transfer cells

Cell	ΔT_{jAVG} /μK	Std. dev. of ΔT_{jAVG} /μK	ΔT_{jAVG} /μK	Std. dev. of ΔT_{jAVG} /μK
NMIA AC6	**-109.31**	10.81	**-94.28**	12.04
SCL5045	**-11.65**	8.33	**-22.61**	17.11
KIM-LIPI224	**-119.46**	8.57	**-120.94**	20.76
NMIJT93-3	**-68.91**	6.17	**-66.79**	3.40
KRISS2000-24	**-40.38**	4.58	**-44.53**	6.40
SIRIM2000-22	**-50.32**	5.57	**-44.64**	5.45
MSL01-02	**-23.42**	3.38	**-21.34**	4.86
NMC2087	**-18.77**	3.57	**-15.73**	6.38
NMISA1181	**-132.38**	21.02	**-112.21**	18.34
NIMT1480	**-125.54**	14.86	**-118.87**	8.17

4.3 Uncertainty budget

The uncertainty was evaluated according to the influence on the measured temperature differences between cells. What follows is the evaluation demonstration of individual uncertainty component, which was rounded up to contain one digit after the decimal point.

For an uncertainty component obtained from a Type B evaluation, if the uncertainty for a single cell is u_B, the combined uncertainty of the temperature difference $\Delta T_{j\,(j=1)} = ¼(T_{1A} + T_{1B} + T_{1C} + T_{1D} - R_{2A} - R_{2B} - R_{1B} - R_{1C})$ or $\Delta T_{j\,(j=2)} = ¼(T_{2A} + T_{2B} + T_{2C} + T_{2D} - R_{2B} - R_{2C} - R_{1C} - R_{1D})$ is $u_B(\Delta T_j)$. $u_B^2(\Delta T_j) = \frac{1}{16}\left\{[4u_B(T_j)]^2 + [2u_B(R_{j+1})]^2 + [2u_B(R_j)]^2\right\}$ is derived accordingly by taking j=1, or $u_B^2(\Delta T_j) = \frac{1}{16}\left\{[4u_B(T_j)]^2 + [2u_B(R_j)]^2 + [2u_B(R_{j-1})]^2\right\}$ if j=2.

For type B evaluation, $u_\mathrm{B} \equiv u_\mathrm{B}(T_\mathrm{j}) \approx u_\mathrm{B}(R_{\mathrm{j}-1}) \approx u_\mathrm{B}(R_\mathrm{j}) \approx u_\mathrm{B}(R_{\mathrm{j}+1})$, so $u_\mathrm{B}(\Delta T_\mathrm{j}) = \sqrt{24/16}\,u_\mathrm{B} = \sqrt{3/2}\,u_\mathrm{B}$ is obtained therefore.

Long-term stability of the temperature reference

Cell CMS5029 and CMS5030, as the reference cells, were compared with transfer cells or national cells from participating laboratories over the duration of about one and a half year. The second column of Table 7 is the average of ΔR (refer to 3.2-3.3) over the whole period of the comparison, and the third column is the standard deviation of the mean.

Taking into account the small values of the standard deviation of the mean shown in the third column of Table 7, the temperature realized on both reference cells can be considered as stable during the same measurement period. Nevertheless, the uncertainty component associated with the long term stability during the entire comparison was estimated by the spread of ΔR_AVG ($\Delta R_\mathrm{AVG,MAX}$ - $\Delta R_\mathrm{AVG,MIN}$) divided by $2\sqrt{3}$, and the result is listed on Table 8.

Table 7: Mean value of the temperature difference of Cell CMS5029 against Cell CMS5030 over the whole duration of APMP.T-K7 comparison

Measurement period	ΔR_AVG/μK	Std. dev. of the mean/μK
2 May~16 May 2008	-8.8	1.6
30 May~13 June 2008	-8.3	1.9
3 Sept.~ 16 Sept. 2008	-13.7	1.4
12 Oct.~ 23 Oct. 2008	-9.3	2.1
26 Nov.~ 9 Dec. 2008	-13.7	1.5
19 Dec.~ 19 Dec.2008	-10.2	0.9
9 April~21 April 2009	-9.9	1.8
5 May~ 19 May 2009	-8.1	1.7
1 June~12 June 2009	-5.8	1.4
22 June~3 July 2009	-6.7	1.2
20 July~31 July 2009	-8.5	1.3
28 Aug.~8 Sept. 2009	-10.2	1.2
21 Sept.~30 Sept. 2009	-8.7	0.9

Reproducibility

We used the arithmetic mean to combine the results for the two ice mantles into a single number for each cell and applied a Birge ratio test which is mathematically similar to the *t*-test. We calculated the experimental standard deviation *s* (external consistency) and compared it with the propagated standard uncertainty *u* (internal consistency) as

$$u = \frac{\sqrt{\sum_{i=1}^{N} u_i^2}}{N}$$

Where u_i is the experimental standard deviation of ΔT_jAVG for 10 measurements of the same mantle, inclusive of the drift effect, ranging from 3.4 μK to 21.1 μK as presented in Table 6. If $s > 2u$ we conclude that both results corresponding to each ice mantle are statistically different.

There is no statistically significant dependence on different ice mantles for all TPW cells, the standard uncertainty of reproducibility covering the cell drifting effect was determined by the propagated standard uncertainty *u* and the uncertainty caused by different ice mantles is neglected.

Bridge non-linearity

The uncertainty due to the resistance bridge non-linearity was estimated by applying a resistance bridge calibrator (RBC 100) to the bridge. The RBC 100 uses four base resistors to give 35 different four-wire resistances under various series and parallel combinations of the four base resistors. For each resistance, the average value is obtained by repeatedly measuring by the bridge, after that, 35 average values are fitted using the method of least squares, and the standard deviation of residuals of 2×10^{-8} is used for the uncertainty due to the combined effect of the bridge non-linearity and noise. The corresponding uncertainty at the water triple point for a single cell is 5.1 µK and the combined uncertainty for the temperature difference from the reference is thus 6.3 µK.

Self-heating correction

If the thermal resistances have approximately the same magnitude in transfer and reference cells, the difference between the self-heating corrections should be very small. In addition the uncertainties on self-heating corrections in transfer cells and APMP.T-K7 reference cells are strongly correlated. In this case the uncertainty in self-heating corrections only contributes to the Type A uncertainty of the comparison of the cells. The contribution to the uncertainty at the water triple point is 3.7 µK for a single cell. The combined uncertainty for the temperature difference from the reference is thus 4.6 µK.

Hydrostatic pressure correction

Assuming a normal distribution, the standard uncertainty of the depth of water over the thermometer sensing element estimated to be ±5 mm, corresponding to 3.7 µK. As the depth difference from the reference cell was used to make hydrostatic pressure correction, the combined uncertainty for the difference from the reference is still 3.7 µK

Stray thermal exchange

Referring to the final report on CCT-K7[1], the uncertainty due to stray thermal exchanged was estimated by changing the room temperature of 3.5 °C, and found to be 2.5 µK. The effect due to the room lighting effect is 5 µK, and that caused by the bath temperature when varied within 1 mK-2 mK is 2 µK. Assuming a rectangular distribution for each term, the combined uncertainty for the temperature difference from the reference is thus 4.9 µK.

The full uncertainty budget is shown in Table 8. It applies to the comparison of a transfer cell with the APMP.T-K7 reference including the long term stability of this reference over the period of the comparison.

Table 8: Uncertainty budget for the temperature difference between a transfer cell and the APMP.T-K7 reference

Sources of uncertainty	Standard uncertainty / µK
Reproducibility (containing the drift effect)	10.7-17.3
Long term stability of the temperature reference	2.3
Bridge non-linearity	6.3
Self-heating correction	4.6
Hydrostatic pressure correction	3.7
Stray thermal exchanges	4.9

The results obtained on the two ice mantles (Table 6) are averaged and signified as ($T_{\mathrm{transfer,i}} - T_{\mathrm{ref,APMP}}$) in the second column of Table 9, where the mean value of CMS5029 and CMS5030 for two ice mantles during the whole period of the comparison; represented as $T_{\mathrm{ref,APMP;}}$ which has been corrected by the isotopic effect of -0.65 µK (refer to chapter 5).

Standard uncertainty of reproducibility in column 3 of Table 9 is calculated as the propagated standard uncertainty u. The last column is the combined standard uncertainty inclusive of reproducibility standard uncertainty, isotope correction uncertainty of 0.68 µK (refer to chapter 5), and type B uncertainty components listed in the 3^{rd}-7^{th} rows of Table 8.

Table 9: Temperature difference between the transfer cells and the APMP reference

Cell	$(T_{\text{transfer,i}} - T_{\text{ref,APMP}})$ /µK	Std. uncertainty of reproducibility	Combined std. uncertainty/µK
NMIA AC6	**-101.2**	8.1	**13.1**
SCL5045	**-16.5**	9.5	**14.0**
KIM-LIPI224	**-119.6**	11.2	**15.2**
NMIJT93-3	**-67.2**	3.5	**10.9**
KRISS2000-24	**-41.8**	3.9	**11.0**
SIRIM2000-22	**-46.8**	3.9	**11.0**
MSL01-02	**-21.7**	3.0	**10.7**
NMC2087	**-16.6**	3.7	**10.9**
NMISA1181	**-121.7**	13.9	**17.3**
NIMT1480	**-121.6**	8.5	**13.3**

5. Temperature difference between the national reference and the APMP.T-K7 reference cells in pilot laboratory

CMS as a pilot has to consider the temperature difference between its national reference and the APMP.T-K7 reference with the related combined standard uncertainty.

The national reference is assumed to represent the ideal water triple point temperature, within a related realization uncertainty which includes the effects of impurities and isotopes. For CMS, the national reference is represented by an ensemble of three cells CMS5023, CMS5029, and CMS5030, all with known isotopic composition, and two of which, cells CMS5029 and CMS5030, are also used as the APMP.T-K7 reference cells.

Regarding the temperature difference between the national reference and the APMP.T-K7 reference $(T_{\text{national ref,i}} - T_{\text{ref,APMP}})$, both of $T_{\text{national ref,i}}$ and $T_{\text{ref,APMP}}$ are already corrected by the isotopes effect in addition to the effects of hydrostatic head and self-heating, and however the impurity effect of $(T_{\text{no impurity}} - T_{\text{national ref,i}})$ is not applied. The effect of the isotopes on the TPW is given by [3], that is $(T_{\text{national ref,i}} - T_{\text{VSMOW,n}})$ or $(T_{\text{ref,APMP}} - T_{\text{VSMOW,r}}) = A(\text{D})\delta\text{D} + A(^{17}\text{O})\delta^{17}\text{O} + A(^{18}\text{O})\delta^{18}\text{O}$

According to the isotope correction and related uncertainty for cells CMS 5029 and CMS 5030 stated in Appendix A2.2, it is determined that $(T_{\text{VSMOW,r}} - T_{\text{ref,APMP}})$= -0.65 µK with uncertainty of 0.68 µK (k =1), which should apply to all of the data calculations concerning about $T_{\text{ref,APMP}}$.

6. Temperature difference between the transfer cells and the national reference

Each participant, excluding the pilot, determined the temperature difference between its transfer cell and its national reference associated with the corresponding combined standard uncertainty.

The national reference is assumed to represent the ideal water triple point temperature, within a related realization uncertainty which includes the effects of impurities and isotopes.

In this chapter, national reference means one or an ensemble of TPW cells used in this comparison. The national reference so defined may differ from the corresponding CCT-K7 national reference because the laboratories may have changed the definition of their national reference in the time interval between the end of CCT-K7 and the beginning of this comparison, as considered in CCT WG8 report to the 23rd CCT Meeting.

In addition to the original report provided by each of the 10 participating laboratories, further communications were made between pilot and each participant to avoid ambiguous wording. Consequentially, most of the original report from each of the 10 participating laboratories is kept in Appendix 3, but an amendment in a form of mathematic equation as follows is placed on the temperature difference and its uncertainty to make the results more definitely.

$(T_{\mathrm{transfer,i}} - T_{\mathrm{national\ ref,i}})'$: corrections of isotopic and impurity effects have not applied on the temperature of national reference at participating lab. i

$(T_{\mathrm{transfer,i}} - T_{\mathrm{national\ ref,i}})$: corrections of isotopic and impurity effects have applied on the temperature of national reference at participating lab. i

$u(T_{\mathrm{transfer,i}} - T_{\mathrm{national\ ref,i}})$: uncertainty budget

The effect of the isotopes on the TPW is specified by $(T_{\mathrm{national\ ref,i}} - T_{\mathrm{VSMOW}}) = A(\mathrm{D})\delta\mathrm{D} + A(^{17}\mathrm{O})\delta^{17}\mathrm{O} + A(^{18}\mathrm{O})\delta^{18}\mathrm{O}$, and the correction of impurity effect $(T_{\mathrm{national\ ref,i}} - T_{\mathrm{no\ impurity}})$ was made only in MSL and NMC.

The measurement results and the information about national references reported by participants are referred to Appendix 3 and are summarized in Tables 10 and Table 11. Note that as subtracting $(T_{\mathrm{transfer,i}} - T_{\mathrm{national\ ref,i}})$ of Table 10 from $(T_{\mathrm{transfer,i}} - T_{\mathrm{ref,APMP}})$ of Table 9 will eliminate $T_{\mathrm{transfer,i}}$ to give $(T_{\mathrm{national\ ref,i}} - T_{\mathrm{ref,APMP}})$ on the 2nd column of Table 12, the corrections of isotope and impurity for Table 9 and Table 10 are applied to temperatures of national cells and reference cells but aren't necessary to transfer cells $(T_{\mathrm{transfer,i}})$.

Table 10: Temperature difference between the transfer cell and the national reference for each participant, and associated standard uncertainty

Transfer Cell	$(T_{\text{transfer,i}} - T_{\text{national ref,i}})$' /µK	Isotopic correction applied to national reference? (Y / corrected value if not yet)	Impurity correction applied to national reference? (Y / N /corrected value if not yet)	$(T_{\text{transfer,i}} - T_{\text{national ref,i}})$ /µK	Standard uncertainty (k = 1) /µK
NMIA AC6	–	Y	N	**-120.0**	**23.1**
SCL5045	–	Y	N	**+11.0**	**59.0**
KIM-LIPI224	-187	+2.7	N	**-184.3**	**110.0**
NMIJT93-3	–	Y	N	**-71.0**	**40.0**
KRISS2000-24	+15	-45.1	N	**-30.1**	**66.0**
SIRIM2000-22	-670	-25.5	N	**-695.5**	**100.0**
MSL01-02	–	Y	Y	**-45.5**	**10.3**
NMC2087	-84	-1.5	-40	**-125.5**	**90.0**
NMISA1181	-110	0	N	**-110.0**	**68.0**
NIMT1480	-114.25	-1.3	N	**-115.6**	**75.0**

Note : For MSL, the corrections of isotope and impurity have been applied to both of $T_{\text{MSL01-02}}$ and $T_{\text{national ref}}$ to give $(T_{\text{MSL01-02}} - T_{\text{national ref.}})$ = +2.4 µK in Appendix A3.8, here -45.5 µK is derived by subtracting the corrections from $T_{\text{MSL01-02}}$.

Table 11: Information from the participants on the definition of national reference

Country	Laboratory	Definition of national reference	Reference cells	Isotope correction	Impurity correction
Australia	NMIA	Group of 2 cells	Isotech B11-50-420 MSL01/3	($T_{VSMOW} - T_{national\ ref}$)= +6.8 µK ($T_{VSMOW} - T_{national\ ref}$)= +62.6 µK	was not applied
Hong Kong	SCL	One cell	Jarrett A13 1297 (1986)	($T_{VSMOW} - T_{national\ ref}$)= 0 µK	was not applied
Indonesia	KIM-LIPI	One cell	Hart Scientific (2007)	($T_{VSMOW} - T_{national\ ref}$)= -2.7 µK	was not applied
Japan	NMIJ	Group of 7 cells	TOA KEIKI 15146 (2003) TOA KEIKI 16161 (2004) TOA KEIKI&NMIJ 17165 (2005) Hart Scientific Q1008 (2005) TOA KEIKI&NMIJ T2006-1 (2006) TOA KEIKI&NMIJ T2006-2 (2006) TOA KEIKI&NMIJ T2006-3 (2006)	($T_{VSMOW} - T_{national\ ref}$)= +35.9 µK ($T_{VSMOW} - T_{national\ ref}$)= +34.9 µK ($T_{VSMOW} - T_{national\ ref}$)= +50.6 µK ($T_{VSMOW} - T_{national\ ref}$)= -1.0 µK ($T_{VSMOW} - T_{national\ ref}$)= +50.2 µK ($T_{VSMOW} - T_{national\ ref}$)= -15.4 µK ($T_{VSMOW} - T_{national\ ref}$)= +1.4 µK	was not applied
Korea	KRISS	Group of 2 cells	KRISS 2002-07 (2002) KRISS 2000-5 (2002)	($T_{VSMOW} - T_{national\ ref}$)= +45.1 µK ($T_{VSMOW} - T_{national\ ref}$)= +45.1 µK	was not applied
Malaysia	SIRIM	One cell	KRISS 9801-6 (1998)	($T_{VSMOW} - T_{national\ ref}$)= +25.5 µK	was not applied
New Zealand	MSL	Group of 5 cells	MSL 01-02 (2001) MSL 01-04 (2001) MSL 04-01 (2004) MSL 06-01 (2006) MSL 06-02 (2006)	($T_{VSMOW} - T_{national\ ref}$)= +39.6 µK ($T_{VSMOW} - T_{national\ ref}$)= +49.1 µK ($T_{VSMOW} - T_{national\ ref}$)= +78.3 µK ($T_{VSMOW} - T_{national\ ref}$)= +68.0 µK ($T_{VSMOW} - T_{national\ ref}$)= +70.2 µK	($T_{no\ impurity} - T_{national\ ref}$)= +8.3 µK ($T_{no\ impurity} - T_{national\ ref}$)= +11.4 µK ($T_{no\ impurity} - T_{national\ ref}$)= +15.5 µK ($T_{no\ impurity} - T_{national\ ref}$)= +15.7 µK ($T_{no\ impurity} - T_{national\ ref}$)= +15.3 µK
Singapore	NMC	One cell	Hart Scientific 5901D-Q 1027 (2006)	($T_{VSMOW} - T_{national\ ref}$)= +1.5 µK	($T_{no\ impurity} - T_{national\ ref}$)= +40.0 µK
South Africa	NMISA	Group of 2 cells	Jarrett model A11 2035 (1998) Jarrett model A11 2048 (1998)	($T_{VSMOW} - T_{national\ ref}$)= 0 µK	was not applied
Taiwan	CMS	Group of 3 cells	Hart Scientific 5901A-Q 5023 (2007) Hart Scientific 5901A-Q 5029 (2008) Hart Scientific 5901A-Q 5030 (2008)	($T_{VSMOW} - T_{national\ ref}$)= +0.3 µK ($T_{VSMOW} - T_{national\ ref}$)= +0.7 µK ($T_{VSMOW} - T_{national\ ref}$)= -2.0 µK	was not applied
Thailand	NIMT	One cell	Hart Scientific_5901-Q 1012 (2008)	($T_{VSMOW} - T_{national\ ref}$)= +1.3 µK	was not applied

7. Comparison of the national reference

7.1 Temperature difference between the national reference and the APMP reference

The deviations of the national reference cells from the APMP reference and their associated uncertainties are obtained by combining the results of the comparison of the transfer cells in CMS (Table 9), and the calibration results provided by the laboratories (chapter 5-6 and Table 10):

$$T_{\text{national ref,i}} - T_{\text{ref,APMP}} = (T_{\text{transfer,i}} - T_{\text{ref,APMP}}) - (T_{\text{transfer,i}} - T_{\text{national ref,i}})$$

$$u(T_{\text{national ref,i}} - T_{\text{ref,APMP}}) = [\,u^2(T_{\text{transfer,i}} - T_{\text{ref,APMP}}) + u^2(T_{\text{transfer,i}} - T_{\text{national ref,i}})]^{1/2}$$

The results have been corrected by isotopic and impurity effects as well as self-heating and hydrostatic-head effects are presented both in Table 12 and Fig. 7, which reveal that ($T_{\text{national ref,SIRIM}} - T_{\text{ref,APMP}}$) and ($T_{\text{national ref,NMC}} - T_{\text{ref,APMP}}$) are significantly higher than the others.

Table 12: Temperature difference between the national reference and APMP reference

Laboratory	($T_{\text{national ref,i}} - T_{\text{ref,APMP}}$) /µK	$u(T_{\text{national ref,i}} - T_{\text{ref,APMP}})$ (k = 1) / µK
NMIA	**+18.8**	**26.7**
SCL	**-27.5**	**60.7**
KIM-LIPI	**+64.7**	**147.8**
NMIJ	**+3.8**	**41.5**
KRISS	**-11.7**	**67.0**
SIRIM	**+648.7**	**100.6**
MSL	**+23.8**	**14.9**
NMC	**+108.9**	**90.7**
NMISA	**-11.7**	**70.2**
CMS	**-0.1**	**31.0**
NIMT	**-6.0**	**76.2**

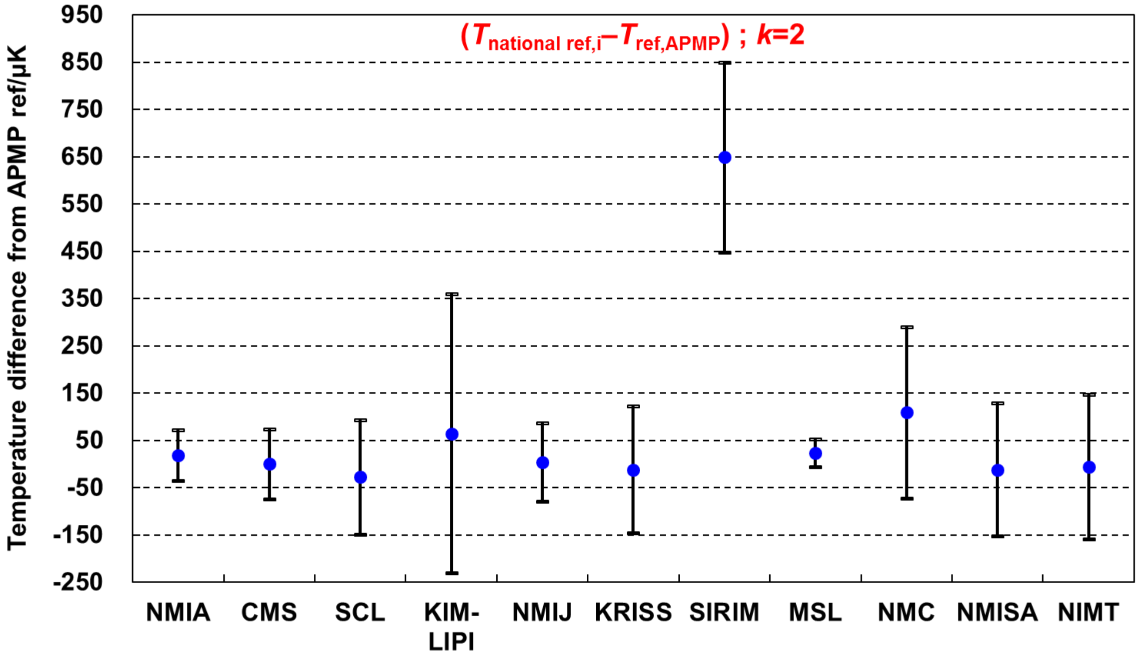

Fig. 7: Temperature difference of the national reference from the APMP reference. The uncertainty bars shows the expanded uncertainty with coverage factor k =2

7.2 APMP.T-K7 reference value

After excluding the obvious outlier value of ($T_{\text{national ref,SIRIM}} - T_{\text{ref,APMP}}$) in view of Fig. 7, the second largest ($T_{\text{national ref,NMC}} - T_{\text{ref,APMP}}$) was removed next, which based on the statistical interquartile range method [8]. This statistical technique was developed to identify outliers when the distribution is normal. It uses the median Q2, lower quartile Q1 and upper quartiles Q3 (defined as the 25th and 75th percentiles). Except for ($T_{\text{national ref,SIRIM}} - T_{\text{ref,APMP}}$), the other ten data on column 2 of Table 12 are calculated and then obtain that the lower quartile Q1 is -10.2 and the upper quartile Q3 is 22.5. The difference (Q3 - Q1) called the interquartile range or IQR shows how the data is spread about the median. The data that falls below Q1 - 1.5 × (IQR) or above higher Q3 + 1.5 × (IQR) are extreme values in the tails of the distribution, and it happens that ($T_{\text{national ref,NMC}} - T_{\text{ref,APMP}}$) =108.9 is an outlier because it's higher than Q3 + 1.5 × (IQR)=71.7.

The APMP.T-K7 reference value (T_{APRV} in the following) is defined as the arithmetic mean of the individual result for the national reference (n =11–2 = 9 laboratories):

$$(T_{\text{APRV}} - T_{\text{ref, APMP}}) = \frac{\sum_{\text{i=1}}^{\text{n}} (T_{\text{nationalref,i}} - T_{\text{ref, APMP}})}{n}$$

The uncertainty of the arithmetic mean T_{APRV} is calculated as the standard deviation of the mean:

$$u(T_{\text{APRV}} - T_{\text{ref, APMP}}) = \sqrt{\frac{\sum_{\text{i=1}}^{\text{n}} (T_{\text{nationalref,i}} - T_{\text{ref, APMP}} - (T_{\text{APRV}} - T_{\text{ref, APMP}}))^2}{n(n-1)}}$$

Table 13 shows the results for the two estimators, and the Birge ratio is defined to compare the standard deviation of the mean/the weighted mean to the uncertainties calculated as propagated uncertainties from the individual result. It is estimated to be s/u for arithmetic mean (refer to 4.3) and $\sqrt{\sum (x_i - x_w)^2 u_i^{-2} / n-1}$ for weighted mean [9], where x_w *is* the weighted mean of x_i (i.e. ($T_{\text{national ref,i}} - T_{\text{ref,APMP}}$)), and individual uncertainties u_i are taken from the 3rd column of Table 12.

Table 13: The results of T_{APRV} relative to $T_{\text{ref,APMP}}$ by using two statistical estimators

Estimator	(T_{APRV} – $T_{\text{ref,APMP}}$) /µK	std. uncertainty /µK	Birge ratio
arithmetic mean	**6.0**	**9.0**	**0.38**
weighted mean	15.4	4.8	0.45

The Birge ratio for the estimator of arithmetic mean is slightly smaller than the other, and the arithmetic mean is adopted instead of the weighted mean because seven laboratories' ($T_{\text{national ref,i}}$ – $T_{\text{ref,APMP}}$) are within the ($T_{\text{APRV}} - T_{\text{ref,APMP}}$) ± 2$u$($T_{\text{APRV}} - T_{\text{ref,APMP}}$) = 6.0 µK ± 18.0 µK interval as depicted in Fig. 8 rather than only three laboratories inside the interval of weighted mean and related uncertainty (15.4 µK± 9.6 µK), that is, the arithmetic mean is the most representative value of ($T_{\text{APRV}} - T_{\text{ref,APMP}}$).

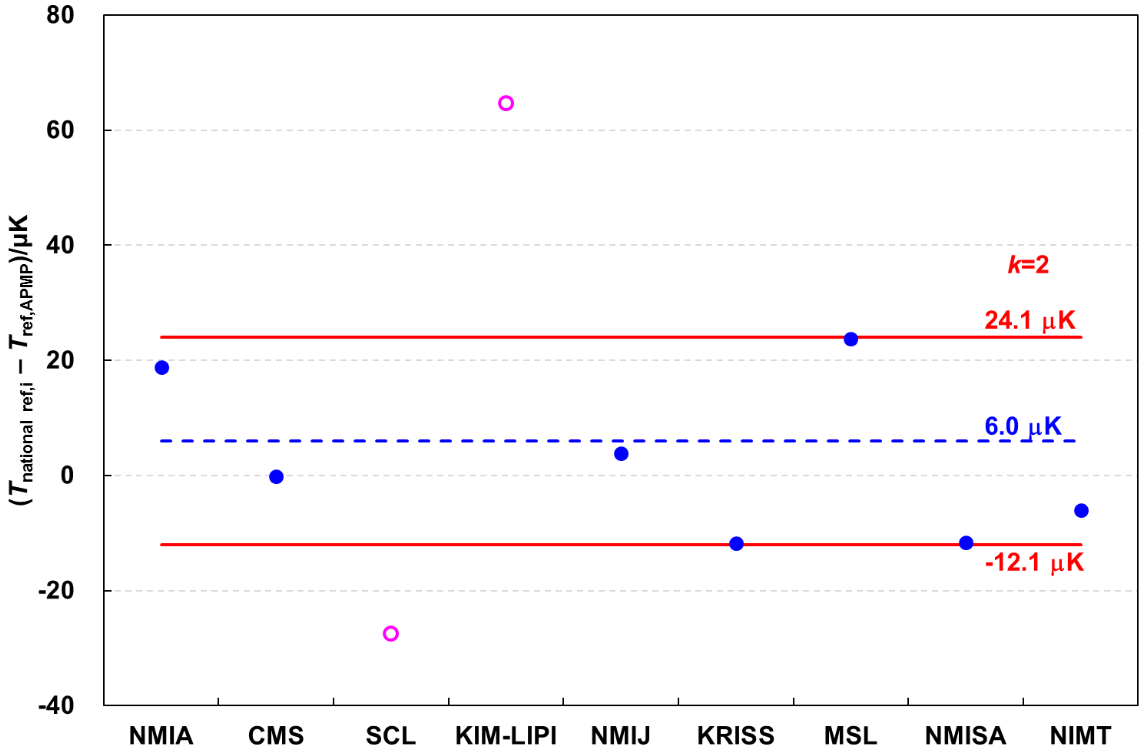

Fig. 8: The $(T_{\text{national ref,i}} - T_{\text{ref,APMP}})$ for seven participating laboratories are within the expanded uncertainty interval with coverage factor k =2 and centered at $(T_{\text{APRV}} - T_{\text{ref,APMP}})$.

The results of APMP.T-K7 can be expressed in terms of temperature difference of national reference of each participant with respect to the T_{APRV} as indicated in Table 14 and Fig. 9.

Table 14: Temperature difference between the national reference and APMP.T-K7 Reference Value

Laboratory	$(T_{\text{national ref,i}} - T_{\text{APRV}})$ /µK	$u(T_{\text{national ref,i}} - T_{\text{APRV}})$ (k=2) /µK
NMIA	**+12.8**	**56.3**
SCL	**-33.5**	**122.7**
KIM-LIPI	**+58.7**	**296.2**
NMIJ	**-2.2**	**84.9**
KRISS	**-17.7**	**135.1**
SIRIM	**+642.6**	**202.1**
MSL	**+17.7**	**34.8**
NMC	**+102.9**	**182.3**
NMISA	**-17.7**	**141.5**
CMS	**-6.1**	**64.6**
NIMT	**-12.0**	**153.5**

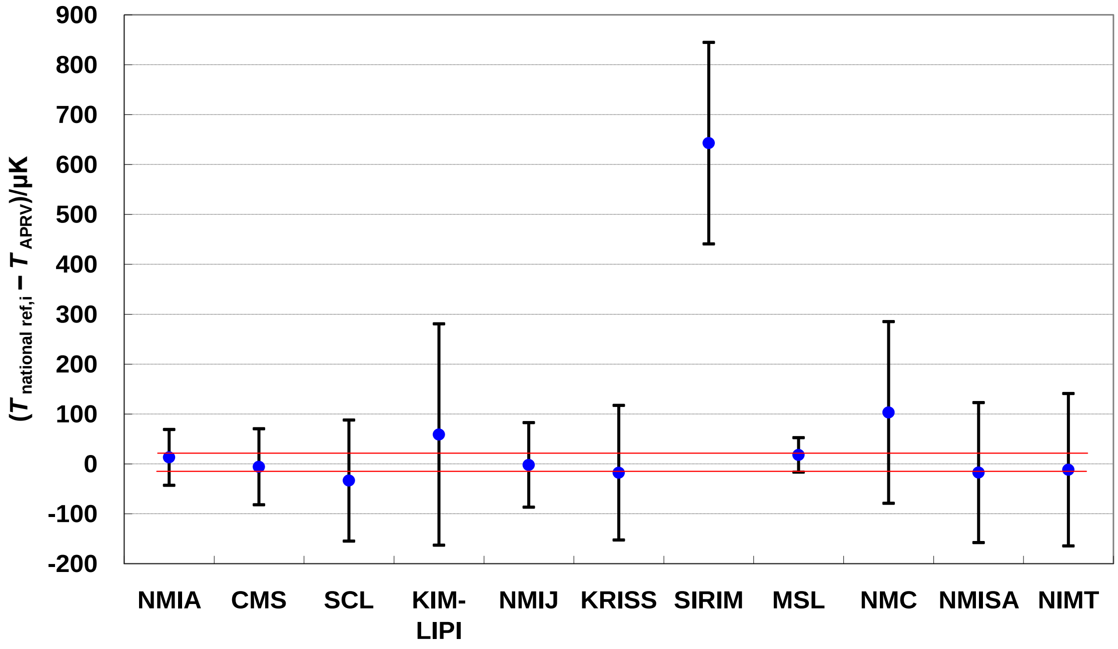

Fig. 9: Temperature difference of the national reference from the T_{APRV}. The uncertainty bars shows the expanded uncertainty with coverage factor k =2

7.3 Linking APMP.T-K7 to CCT-K7

The results obtained by the laboratories that participated in both CCT-K7 and APMP.T-K7 were utilized to link between APMP.T-K7 comparison and CCT-K7 comparison. Potential linking laboratories are NMIA, NMIJ, KRISS, MSL, NMC, and NMISA, and two of them, including NMIJ and MSL, used the same transfer cell in both comparisons.

However, in light of some transfer cells used in CCT-K7 might be severely affected by impurity effects in 9 years, and some labs redefine their national reference after CCT-K7, not all above laboratories but only some are appropriate to be used as the representative linking laboratories based on the same criteria. As the mean temperature of the reference cells realized by CMS ($T_{\mathrm{ref,APMP}}$) against the mean temperature of the reference cells realized by BIPM ($T_{\mathrm{ref,BIPM}}$) should be an **"invariant quantity"** among linking cells, the invariant quantity in terms of ($T_{\mathrm{ref,APMP}}$–$T_{\mathrm{ref,BIPM}}$) should be consistent each other within the combined uncertainty. It can be derived by the following terms:

$$(T_{\mathrm{ref,APMP}}-T_{\mathrm{ref,BIPM}}) = (T_{\mathrm{transfer\text{-}CCT,j}}-T_{\mathrm{ref,BIPM}}) - (T_{\mathrm{transfer\text{-}APMP,j}}-T_{\mathrm{ref,APMP}}) + (T_{\mathrm{transfer\text{-}APMP,j}}-T_{\mathrm{transfer\text{-}CCT,j}})$$

Where, ($T_{\mathrm{transfer\text{-}CCT,j}}$–$T_{\mathrm{ref,BIPM}}$) is referred to Table 16 on Final report of CCT-K7 [1]; ($T_{\mathrm{transfer\text{-}APMP,j}}$–$T_{\mathrm{ref,APMP}}$) is shown on Table 9; and ($T_{\mathrm{transfer\text{-}APMP,j}}$–$T_{\mathrm{transfer\text{-}CCT,j}}$) is provided by the potential linking laboratories.

Table 15 Comparison on the invariant quantity of ($T_{ref,APMP}$–$T_{ref,BIPM}$) among six potential linking laboratories unit: μK

Laboratory	NMIA		NMIJ		KRISS[#]		MSL		NMC[#]		NMISA	
Item	value	u	value	u	value	u	value	u	value	u	value	u
($T_{transfer\text{-}CCT,j}$– $T_{ref,BIPM}$)	-62.0	12.0	33.3	12.0	44.8	12.0	76.0	12.0	13.5	12.0	82.3	13.0
($T_{transfer\text{-}APMP,j}$– $T_{ref,APMP}$)	-101.2	13.1	-67.2	10.9	-41.8	11.0	-21.7	10.7	-16.6	10.9	-121.7	17.3
($T_{transfer\text{-}APMP,j}$– $T_{transfer\text{-}CCT,j}$)	18.6	19.8	0.0	0.0	39.0	60.7	0.0	0.0	136	80.6	-87.0	68.0
($T_{ref,APMP}$- $T_{ref,BIPM}$)	**57.8**	*26.6*	**100.5**	*16.3*	**125.6**	*62.9*	**97.7**	*16.1*	**166.1**	*82.3*	**117.0**	*71.4*

[#] Additional explanation is expressed in Appendix 6

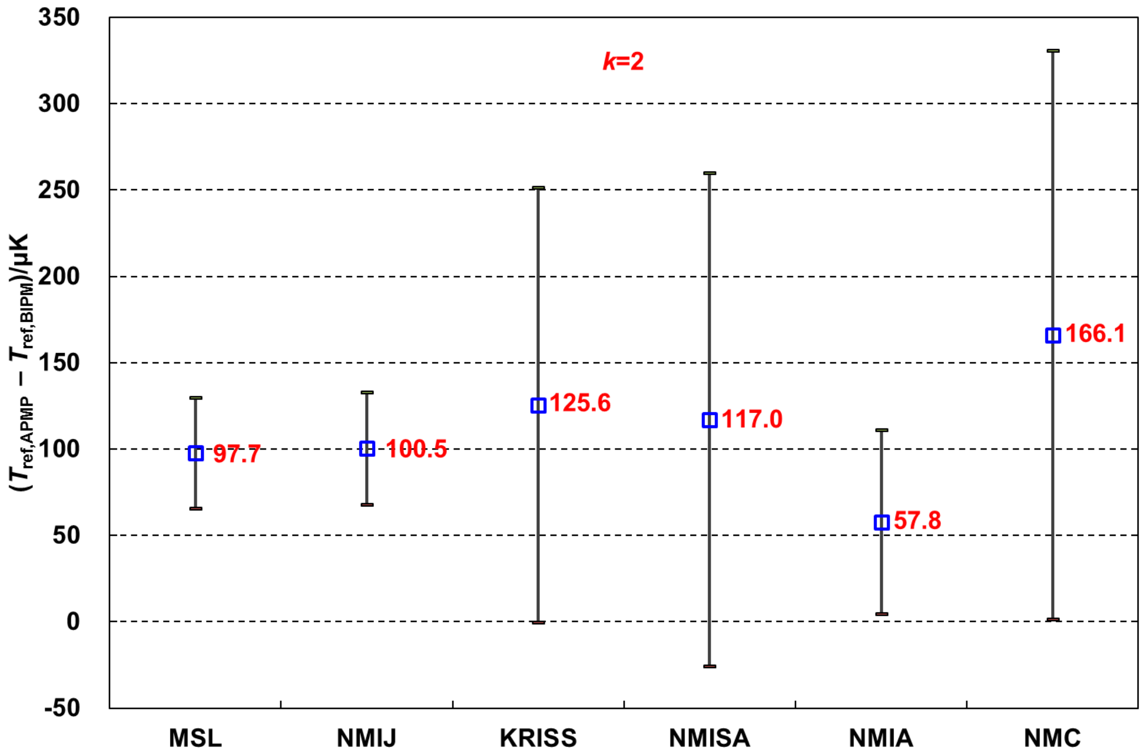

Fig. 10 Comparison on the ($T_{ref,APMP}$–$T_{ref,BIPM}$) among six potential linking laboratories. The uncertainty bars shows the expanded uncertainty with coverage factor k = 2

Although it seems that ($T_{ref,APMP}$–$T_{ref,BIPM}$) among all potential linking laboratories are consistent within expanded uncertainties (k = 2), in fact, some data is significantly higher or lower than the others, and besides the wildly varied uncertainties are hard to lead off a representative result. Consequently, in stead of covering all six potential linking labs as the linking labs, MSL and NMIJ are taken as the final linking labs because they used the same transfer cell in both comparisons and the invariant quantity ($T_{ref,APMP}$–$T_{ref,BIPM}$) are very close between these two labs, and the temperature difference between two transfer cells measured in CMS ($T_{transfer\text{-}APMP,MSL}$–$T_{transfer\text{-}APMP,NMIJ}$ = 45.5 μK) also approximates to that measured in BIPM ($T_{transfer\text{-}CCT,MSL}$–$T_{transfer\text{-}CCT,NMIJ}$ = 42.7 μK).

The mean of the linking cells used with respect to the CCT-K7 KCRV measured during CCT-K7 is obtained via Table 16 and Table 20 on CCT-K7 report:

$\frac{1}{2}\sum_{j=1}^{2}(T_j^{linking}-T_{KCRV})\big|_{CCT-K7}=32.7$ μK with uncertainty of $u(\frac{1}{2}\sum_{j=1}^{2}(T_j^{linking}-T_{KCRV}))=11.6$ μK.

According to Table 9 and Table 13 on this report, $\frac{1}{2}\sum_{j=1}^{2}(T_{j}^{\mathrm{linking}}-T_{\mathrm{APRV}})\big|_{\mathrm{APMPT.T\text{-}K7}}=$ -50.5 μK, and the associated uncertainty is $u(\frac{1}{2}\sum_{j=1}^{2}(T_{j}^{\mathrm{linking}}-T_{\mathrm{APRV}}))=9.9$ μK.

Where T_{j}^{linking} represents the temperature of transfer cell used in CCT-K7 or in APMP. T-K7 for two linking labs.

Hence, $(T_{\mathrm{APRV}}-T_{\mathrm{KCRV}})\big|_{\mathrm{APMP.T\text{-}K7}}$ = 83.1 μK is obtained after some algebra, this difference shows the impact of the redefinition of the water triple point temperature in terms of VSMOW that took place in between these two comparison. Furthermore, 83.1 μK is 10.1 μK higher than the value of 73 μK computed in CCT-K7 [1], which is the results for cells using the ocean water definition (95 μK above the BIPM reference in Table 22 [1]) deviated from the T_{KCRV} (22 μK above the BIPM reference in Table 20 [1]).

The uncertainty of the difference $(T_{\mathrm{APRV}}-T_{\mathrm{KCRV}})\big|_{\mathrm{APMP.T\text{-}K7}}$ is calculated as

$$u(T_{\mathrm{APRV}}-T_{\mathrm{KCRV}})\big|_{\mathrm{APMP.T\text{-}K7}}=\sqrt{u^{2}(\frac{1}{2}\sum_{j=1}^{2}(T_{j}^{\mathrm{linking}}-T_{\mathrm{KCRV}}))+u^{2}(\frac{1}{2}\sum_{j=1}^{2}(T_{j}^{\mathrm{linking}}-T_{\mathrm{APRV}}))}=15.2\ \mu\mathrm{K}.$$

8. Bilateral equivalence

The bilateral degree of equivalence between any pair of APMP.T-K7 participants (participant *i* and participant *j*) is expressed by the temperature difference between the national references of the two participants:

$D_{ij}=T_i-T_j=(T_{\text{national ref},i}-T_{\text{national ref},j})=(T_{\text{national ref},i}-T_{\text{APRV}})-(T_{\text{national ref},j}-T_{\text{APRV}})$

and the related uncertainty

$U_{ij}=\sqrt{U_i^2+U_j^2}=U(T_{\text{national ref},i}-T_{\text{national ref},j})=\sqrt{U^2(T_{\text{nationalref},i}-T_{\text{APRV}})+U^2(T_{\text{nationalref},j}-T_{\text{APRV}})}$

The data $T_{i(j)}$ and $U_{i(j)}$ are taken from Table 14, and $U_{i(j)}$ is the expanded uncertainty (k=2) of the participating laboratory. In Table 16, the bilateral temperature difference between the participants and the corresponding uncertainties are given above the diagonal, below the diagonal the quantified demonstrated equivalence, $QDE_{0.95}$, is shown. This is a one-parameter description of equivalence. It describes the interval +/- $QDE_{0.95}$ within which two laboratories' results can be expected to agree with 95 % confidence. It is calculated as

$$QDE_{0.95}(i,j)=\left|D_{ij}\right|+\left\{1.645+0.3295\times\exp\left[-4.05\left|D_{ij}\right|/u_{ij}\right]\right\}u_{ij}$$

Table 16 The bilateral temperature difference between the participants, the related uncertainty (above the diagonal), and the *QDE* between the participants (below the diagonal) unit: μK

j → *i* ↓	NMIA	SCL	KIM-LIPI	NMIJ	KRISS	SIRIM	MSL	NMC	NMISA	CMS	NIMT	
NMIA		**46.3**	**-45.9**	**15.0**	**30.5**	**-629.8**	**-4.9**	**-90.1**	**30.5**	**18.9**	**24.8**	D_{ij}
		135.0	301.5	101.9	146.4	209.8	66.2	190.8	152.3	85.7	163.5	U_{ij}
SCL	**279.5**		**-92.2**	**-31.3**	**-15.8**	**-676.1**	**-51.2**	**-136.4**	**-15.8**	**-27.4**	**-21.5**	D_{ij}
			320.6	149.2	182.5	236.4	127.5	219.7	187.3	138.7	196.5	U_{ij}
KIM-LIPI	**595.5**	**652.6**		**60.9**	**76.4**	**-583.9**	**41.0**	**-44.2**	**76.4**	**64.8**	**70.7**	D_{ij}
				308.1	325.6	358.6	298.2	347.8	328.3	303.2	333.6	U_{ij}
NMIJ	**201.1**	**297.8**	**613.4**		**15.5**	**-644.8**	**-19.9**	**-105.1**	**15.5**	**3.9**	**9.8**	D_{ij}
					159.6	219.2	91.8	201.1	165.0	106.7	175.4	U_{ij}
KRISS	**292.0**	**358.4**	**653.4**	**313.5**		**-660.3**	**-35.4**	**-120.6**	**0.0**	**-11.6**	**-5.7**	D_{ij}
						243.1	139.5	226.9	195.6	149.8	204.5	U_{ij}
SIRIM	**974.9**	**1065.0**	**1173.9**	**1005.4**	**1060.2**		**624.9**	**539.7**	**660.3**	**648.7**	**654.6**	D_{ij}
							205.1	272.2	246.7	212.2	253.8	U_{ij}
MSL	**129.9**	**269.3**	**587.9**	**183.4**	**281.3**	**962.2**		**-85.2**	**35.4**	**23.8**	**29.7**	D_{ij}
								185.6	145.7	73.4	157.4	U_{ij}
NMC	**413.2**	**503.7**	**684.8**	**443.9**	**502.5**	**987.5**	**400.0**		**120.6**	**109.0**	**114.9**	D_{ij}
									230.8	193.4	238.3	U_{ij}
NMISA	**303.3**	**367.7**	**658.5**	**324.1**	**386.3**	**1066.1**	**293.1**	**509.4**		**-11.6**	**-5.7**	D_{ij}
										155.5	208.8	U_{ij}
CMS	**171.4**	**276.0**	**605.5**	**209.7**	**294.0**	**997.7**	**151.0**	**433.7**	**305.4**		**5.9**	D_{ij}
											166.5	U_{ij}
NIMT	**322.9**	**386.3**	**666.1**	**344.5**	**402.3**	**1072.1**	**312.8**	**518.1**	**410.7**	**327.4**		

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Appendix 1

Measurement report form for APMP.T-K7

General information of transfer cell

Laboratory:…………………………………………………………………………………………………

Contact person:……………………………………………………………………………………...

Contact address, email :………………………………………..……………………………………….

………

Transfer cell: manufacturer and type:…………………………………………………………………

Purchase or manufacture date:…………………………………………………………………………

Accessories or comments on special use:……………………………………………………………

Inner diameter of well/mm:……………………………………………………………………………

Cell diameter /mm:……………………………………………………………………………………

Depth of well below water surface /mm:………………………………………………………………

Measurement results on first ice mantle

Date of preparation of ice mantle of transfer cell:…………………...…………………………………...

Technique for preparation :…………………………………………………………………. ………...

……………………………………………………………………………………………………

Date of preparation of the mantle of the reference cell(s):……………………………………………….

Date of measurement	Temperature difference from national reference	Experimental standard deviation of temperature difference from national reference	Distance from sensor midpoint to surface level of water in tr. cell	Hydrostatic-head correction for transfer cell	Self-heating correction for transfer cell
mean					
std. dev. of the mean					

The temperature differences should already be corrected for hydrostatic-head and self-heating effects. To allow comparison with our measurements, the corrections should also be given separately.

Measurement results on second ice mantle

Date of preparation of ice mantle :………………...…………………………………………………..

Technique for preparation :……………………………………………………………………………….

…………………………………………………………………………………………………...

Date of preparation of the mantle of the reference cell(s):……………………………………………….

Date of measurement	Temperature difference from national reference	Experimental standard deviation of temperature difference from national reference	Distance from sensor midpoint to surface level of water in tr. cell	Hydrostatic-head correction for transfer cell	Self-heating correction for transfer cell
mean					
std. dev. of the mean					

The temperature differences should already be corrected for hydrostatic-head and self-heating effects. To allow comparison with our measurements, the corrections should also be given separately.

Resulting temp. difference between transfer cell and national reference: …………………

Correction

Is the isotopic composition of the national reference analyzed? ☐Yes / ☐No

Isotopic correction:………………...…………………with uncertainty………………... ………………

Impurity correction:………………...…………………with uncertainty………………... ……………

Measurement results on first ice mantle (only for CCT-K7 participant who changes its transfer cell)

Date of preparation of ice mantle of transfer cell:…………………...…………………………………...

Technique for preparation :……………………………………………………………………. ………...

………

Date of preparation of the mantle of the reference cell(s):……………………………………………….

Date of measurement	Temperature difference from the transfer cell used in CCT.K-7	Experimental standard deviation of temperature difference from the old tr. cell	Distance from sensor midpoint to surface level of water in tr. cell	Hydrostatic-head correction for transfer cell	Self-heating correction for transfer cell
mean					
std. dev. of the mean					

The temperature differences should already be corrected for hydrostatic-head and self-heating effects. To allow comparison with our measurements, the corrections should also be given separately.

Measurement results on second ice mantle (only for CCT-K7 participant who changes its transfer cell)

Date of preparation of ice mantle :………………...…………………………………………………..

Technique for preparation :……………………………………………………………………………….

……...

Date of preparation of the mantle of the reference cell(s):……………………………………………….

Date of measurement	Temperature difference from the transfer cell used in CCT.K-7	Experimental standard deviation of temperature difference from the old tr. cell	Distance from sensor midpoint to surface level of water in tr. cell	Hydrostatic-head correction for transfer cell	Self-heating correction for transfer cell
mean					
std. dev. of the mean					

The temperature differences should already be corrected for hydrostatic head and self-heating effects. To allow comparison with our measurements, the corrections should also be given separately.

Resulting temp. difference between transfer cell used in APMP.T-K7 and CCT.T-K7: ………

Comments on the stability/drift of the CCT-K7 transfer cell after CCT-K7:
(Note: There is a possibility that the values of the transfer cells used in CCT-K7 drift for five years because of dissolution from glass. Linking laboratories should be aware of these drifts.)

Equipment used for the calibration

Description of national reference (1 or several cells, purchase or manufacture date)……………………

………

………

Manufacturer/Type of resistance bridge, AC or DC:………………………………………………..

Measurement current:…………………………………………………………………………………….

Number and sampling frequency of repeated measurements: …………………………………………

Manufacturer/Type of reference resistor:………………………………………….………………

Is reference resistor temperature controlled, if yes, stability:…………………………………………….

Manufacturer/Type of thermometer, length of sensor:…………………………………………………

Storage container for TPW cells:……………………………………………………………………..

Freezing method:…………………………………………………………………..…..…..…..…..

Immersion profile

Distance from sensor midpoint to free surface level of the liquid water	Temperature variation

The above table is for reporting measurement of the hydrostatic head effect. Measurements should be taken at a step width of 1 to 2 cm. Thermometer readings should be corrected for self-heating, measured at each position.

Uncertainty Budget

The uncertainty budget should include the following components, to which others can be added if necessary. The budget shown here can only be a model. Some additional guidance can however be obtained from the draft documents [4]. Please explain, how the contributions of chemical impurities and isotope variation were evaluated.

The repeatability for a single ice mantle is understood as the experimental standard deviation of the daily obtained temperature differences between the transfer cell and the national reference, divided by the square root of the number of daily results (here typically 10). The reproducibility for different ice mantles represents the additionally variability introduced by measuring on several different ice mantles.

The participants are required to provide a few sentences describing how they obtained the value used for each term in their uncertainty analysis. All contributions should be stated at the level of one standard uncertainty.

Origin	Contribution (*k*=1)
National reference	
(Uncertainties related only to properties of the reference cell)	
Chemical impurities (please explain how estimated)	
Isotopic variation (please explain how estimated)	
Residual gas pressure in cell	
Reproducibility [1]	
Comparison of transfer cell to national reference	
(Uncertainties related to the comparison of the two cells)	
Repeatability for a single ice mantel (incl. bridge noise) [2]	
Reproducibility for different ice mantles [3]	
Reproducibility for different types of SPRTs [4]	
Hydrostatic head of transfer cell	
Hydrostatic head of reference cell	
SPRT self-heating in the transfer cell and reference cell [5]	
Perturbing heat exchanges [6]	
others	
Non linearity and precision of bridge	
Temperature variation of standard resistor	
Reproducibility of transfer cell	
Influence of the technician	
Total uncertainty	

[1] Estimate of the reproducibility of the temperature reference due to changes in the following quantities:
crystal size, the age of the mantles, different mantles, the handling of the cells before preparation of the mantle.

[2] The repeatability for a single ice mantle is understood as the experimental standard deviation of the daily obtained temperature differences between the transfer cell and the national reference, divided by the square root

of the number of daily results (here typically 10). This component takes also in account the stability of reference resistor (temperature effect).

[3] The reproducibility for different ice mantles represents the additional variability introduced by measuring on several different ice mantles on transfer cell (probably the laboratory uses the same ice mantle of the reference cell during the time of measurements).

[4] The observed temperature differences between the transfer and the reference cells could depend on the type of SPRT's. This component takes into account possible SPRT internal insulation leakage.

[5] These uncertainties could be strongly positively correlated. All the measurements are corrected for self-heating effect. If the thermal resistances have approximately the same magnitude in transfer and reference cells the difference between the self-heating corrections is very small. In addition the uncertainties on self-heating corrections in transfer and reference cells are strongly correlated. In this case the uncertainty in self-heating corrections only contributes to the Type A uncertainty of the comparison of the cells.

[6] This component could be estimated

- by comparing the deviations from expected hydrostatic pressure correction obtained in transfer and reference cells (by changing immersion depth over the length of the sensor $\approx$ 5 cm)
- by modifying the thermal exchange between thermometer and its environment during the measurements on transfer and reference cells.

Appendix 2 Comparison of the national reference against APMP.T-K7 reference by the pilot

A2.1 Introduction

CMS as a pilot has to consider the temperature difference between its national reference and the APMP.T-K7 reference with the related combined standard uncertainty.

The national reference is assumed to represent the ideal water triple point temperature, within a related realization uncertainty which includes the effects of impurities and isotopes. For CMS, the national reference is represented by an ensemble of three cells CMS5023, CMS5029, and CMS5030, all with known isotopic composition, and two of which, cells CMS5029 and CMS5030, are also used as the APMP.T-K7 reference cells.

In this chapter, we keep most of the original report from CMS, but an amendment, in a form of mathematic equation as follows, is placed on the temperature difference and its uncertainty to make the results more definitely.

$(T_{\text{national ref,i}} - T_{\text{ref,APMP}})'$: corrections of isotopic and impurity effects have not applied on the temperature difference between national reference and APMP reference
$(T_{\text{national ref,i}} - T_{\text{ref,APMP}})$: corrections of isotopic and impurity effects have applied on the temperature difference between national reference and APMP reference
$u(T_{\text{national ref,i}} - T_{\text{ref,APMP}})$: uncertainty

In the above equations, the effect of the isotopes on the TPW is given by [3]

$$(T_{\text{national ref,i}} - T_{\text{VSMOW}}) = A(\text{D})\delta\text{D} + A(^{17}\text{O})\delta^{17}\text{O} + A(^{18}\text{O})\delta^{18}\text{O}\,,$$

and the impurity effect $(T_{\text{national ref,i}} - T_{\text{no impurity}})$ is treated as an uncertainty component only; no correction is applied.

A2.2 CMS (Taiwan)

Measurement results on first ice mantle

Date of preparation of ice mantle of national reference cells: April 24, 2008

Technique for preparation: Follow standard BIPM technique

Date of preparation of the mantle of the APMP.T-K7 reference cell(s): April 24, 2008

Date of measurement	Temperature difference from APMP.T-K7 references μK	Experimental standard deviation of temperature difference from APMP.T-K7 references μK	Distance from sensor midpoint to surface level of water in tr. Cell mm	Hydrostatic-head correction for national reference cells μK	Self-heating correction for national reference cells μK
2008/5/2	-0.577	4.369	236	172.28	-823.895
2008/5/5	-0.005	4.767	236	172.28	-817.016
2008/5/6	-0.814	2.789	236	172.28	-821.568
2008/5/7	-0.205	3.666	236	172.28	-831.732
2008/5/8	-0.627	4.982	236	172.28	-839.295
2008/5/9	-0.245	3.384	236	172.28	-848.732
2008/5/12	-1.969	5.542	236	172.28	-848.546
2008/5/13	-0.109	4.866	236	172.28	-849.032
2008/5/14	-0.179	4.496	236	172.28	-857.112
2008/5/15	-0.655	4.649	236	172.28	-851.950
2008/5/16	-0.491	4.418	236	172.28	-864.168
mean	**-0.534**				
std. dev. of the mean	**0.164**				

p.s. The differences from the APMP.T-K7 references are so low is because the two APMP.T-K7 references represent two-thirds of the value attributed to the CMS national reference.

Measurement results on second ice mantle

Date of preparation of ice mantle of national reference cells: May 21, 2008

Technique for preparation: Follow standard BIPM technique

Date of preparation of the mantle of the T-K7 reference cell(s): May 21, 2008

Date of measurement	Temperature difference from APMP.T-K7 references μK	Experimental standard deviation of temperature difference from APMP.T-K7 references μK	Distance from sensor midpoint to surface level of water in tr. Cell mm	Hydrostatic-head correction for national reference cells μK	Self-heating correction for national reference cells μK
2008/5/30	-3.259	3.447	236	172.28	-799.068
2008/6/2	-2.836	2.891	236	172.28	-810.468
2008/6/3	-0.750	3.471	236	172.28	-817.831
2008/6/4	-2.345	3.860	236	172.28	-822.631
2008/6/6	-3.573	2.818	236	172.28	-823.613
2008/6/7	-3.218	3.232	236	172.28	-826.750
2008/6/9	-2.645	2.416	236	172.28	-829.000
2008/6/10	-2.973	2.031	236	172.28	-832.586
2008/6/11	-2.305	2.829	236	172.28	-832.313
2008/6/12	-2.291	3.038	236	172.28	-837.004
2008/6/13	-1.364	3.240	236	172.28	-838.750
mean	**-2.505**				
std. dev. of the mean	**0.253**				

The temperature differences should already be corrected for hydrostatic head and self-heating effects. To allow comparison with our measurements, the corrections should also be given separately.

$(T_{\text{national ref,CMS}} - T_{\text{ref,APMP}})'$ = <u>**-0.00152 mK**</u>
$(T_{\text{national ref,CMS}} - T_{\text{ref,APMP}})$ = <u>**-0.001503 mK**</u>
$u(T_{\text{national ref,CMS}} - T_{\text{ref,APMP}})$ = <u>**0.037 mK (*k*=1)**</u>

Correction

Is the isotopic composition of the national reference analyzed? ■Yes / □No

$T_{\text{VSMOW}} - T_{\text{CMS5023}}$ = **+0.0003 mK** with uncertainty = **0.0014 mK(*k* =1)**
$T_{\text{VSMOW}} - T_{\text{CMS5029}}$ = **+0.0007 mK** with uncertainty = **0.0008 mK(*k* =1)**
$T_{\text{VSMOW}} - T_{\text{CMS5030}}$ = **-0.002 mK** with uncertainty = **0.0011 mK(*k* =1)**

Impurity correction is not applied. The uncertainty of the effect is estimated to be <u>**0.011 mK(*k* =1).**</u>

Uncertainty Budget

Origin	Contribution (k=1)
National reference	
(Uncertainties related only to properties of the reference cell)	
1.Chemical impurities (please explain how estimated)	11
2.Isotopic variation (please explain how estimated)	2
3.Residual gas pressure in cell	5
4.Reproducibility [1]	10
Comparison of transfer cell to national reference	
(Uncertainties related to the comparison of the two cells)	
5.Repeatability for a single ice mantel (incl. bridge noise) [2]	1
6.Reproducibility for different ice mantles [3]	2
7.Reproducibility for different types of SPRTs [4] (neglected, only one SPRT was used)	
8.Hydrostatic head of national reference cell	4
9.Hydrostatic head of APMP.T-K7 reference cell	4
10.SPRT self-heating in the national reference cell and APMP.T-K7 reference cell [5]	6
11.Perturbing heat exchanges [6]	13
others	
12.Non linearity and precision of bridge	20
13.Temperature variation of standard resistor	6
14.Reproducibility of transfer cell (included in 4, 5, 6)	
15.Influence of the technician (neglected, only one person)	
Total uncertainty	31

1. Chemical impurities: The uncertainty of chemical impurities is evaluated according to the chemical analysis report issued by ITRI (Industrial Technology Research Institute) for cell A-Q 5029 and cell A-Q 5030, however referred to the sample report of chemical analysis done by NIST for A-Q 5023 cell. By assuming that all impurities are not soluble in the solid phase of the fixed-point substance, the estimate is resulted from the overall impurities content and the first cryoscopic constant according to Raoult’s law. In addition, the impurities leaching from the fused-quartz envelope is estimated to be -2 µK/yr.

2. Isotopic variation: The uncertainty of isotopic variation is referred to the uncertainty cited in the isotopic analysis report issued by the University of UTAH, USA.

3. Residual gas pressure in cell: The uncertainty of residual gas pressure is referred to the following report and paper: B. Fellmuth, J. Fisher, E. Tegler, “Uncertainty budgets for characteristics of SPRTs calibrated according to the ITS-90,” CCT/01-02, 2001 Table 2. White D.R., "Measuring the residual air pressure in triple-point-of-water cells", *Meas. Sci Technol.* **15**, 2004, N15-N16

4. [1] Estimate of the reproducibility of the temperature reference due to changes in the following quantities: crystal size, the age of the mantles, different mantles, the handling of the cells before preparation of the mantle. The uncertainty of reproducibility is taken from the 22 average values of measured resistances for three national reference cells under two different mantles and different dates.

5. [2] The repeatability for a single ice mantle is understood as the experimental standard deviation of the daily obtained temperature differences between the national reference cells and the APMP.T-K7 reference cells, divided by the square root of the number of daily results (here typically 10). This component takes also in account the stability of reference resistor (temperature effect). The uncertainty of repeatability is taken from the standard deviation of the mean of the temperature differences on the second ice mantle, and the value of 1 μK is obtained by rounding up 0.253 μK to the next integer and used as the uncertainty of the repeatability.

6. [3] The reproducibility for different ice mantles represents the additional variability introduced by measuring on several different ice mantles on cell (probably the laboratory uses the same ice mantle of the reference cell during the time of measurements). The reproducibility for two ice mantles is determined by the standard deviation of the two average values concerning each ice mantle.

7. [4] The observed temperature differences between the national reference cells and APMP.T-K7 reference cells could depend on the type of SPRT's. This component takes into account possible SPRT internal insulation leakage. Two cells were compared by two different SPRTs for three runs on the same day, and the uncertainty is determined via the ANOVA analysis. However can be neglected if only one thermometer is used.

8. Hydrostatic head of national reference cell and hydrostatic head of APMP.T-K7 reference cell: Assuming a normal distribution, the standard uncertainty of the position is 5 mm, corresponding to 4 μK (0.73×10^{-3} K/m×0.005 m=3.65 μK≈ 4 μK).

9. Refer to 8.

10. [5] These uncertainties could be strongly positively correlated. All the measurements are corrected for self-heating effect. If the thermal resistances have approximately the same magnitude in transfer and reference cells the difference between the self-heating corrections is very small. In addition the uncertainties on self-heating corrections in national reference cells and APMP.T-K7 reference cells are strongly correlated. In this case the uncertainty in self-heating corrections only contributes to the Type A uncertainty of the comparison of the cells. The standard deviation of the mean for 22 self heating corrections for national reference cells is 3.4 μK, and SPRT self-heating in the national reference cell and APMP.T-K7 reference cell are combined as the uncertainty of the self-heating effect.

$$(4^2+4^2)^{1/2} \approx 6\ (\mu\mathrm{K})$$

11. [6] This component could be estimated
    - by comparing the deviations from expected hydrostatic pressure correction obtained in transfer and reference cells (by changing immersion depth over the length of the sensor ≈ 5 cm)
    - by modifying the thermal exchange between thermometer and its environment during the measurements on transfer and reference cells.

    The deviations from expected hydrostatic pressure correction obtained in national reference cells and APMP.T-K7 reference cells by changing immersion depth over the length of the sensor ≈ 5 cm is around 6 μK (42.415 μK -36.5 μK≈ 6 μK), and the uncertainty of this measurement is estimated as 6 μK/square root 3≈ 4 μK.

    Referring to the final report on CCT-K7, the uncertainty by changing the room temperature of 3.5 °C is 2.5 μK, the uncertainty from room lighting effect is 5 μK, and the uncertainty from the bath temperature variation of 1-2 mK is 2 μK. The combination of the three effects leads to 7 μK.

    The measurement of the immersion profile has been performed two times. The maximum temperature deviation, compared to the bottom position, between two runs is 14 μK, the uncertainty of data scattering is revealed to 9 μK.

12. The uncertainty is estimated by applying Resistance bridge calibrated RBC 100 to the bridge. RBC 100 uses four base resistors to give 35 different four-wire resistances under various series and parallel combinations of the four base resistors. For each resistance, the average value is obtained by repeatedly measuring by the bridge, after that, 35

average values are fitted using the method of least squares, and the standard deviation of residuals of 2×10^{-8} is used to determine the non-linearity uncertainty.

$$2\times10^{-8}/0.0010185133\ °C^{-1} = 20\ \mu K$$

13. The uncertainty resulted from the temperature variation of standard resistor is calculated by using 0.01 °C, which was the stability of liquid bath for maintaining the standard resistors.

$$0.01\ °C \times 2\ ppm\ /\ °C/0.0010185133\ °C^{-1}\ /2\sqrt{3} = 6\ \mu K$$

15. The deviation caused by the influence of the technician is estimated to about ±10 μK, the uncertainty is therefore 6 μK by assuming a symmetric rectangular probability distribution. However can be neglected if only one person do the measurements.

10 μK / square root 3 = 6 μK

Appendix 3 Calibration of the transfer cell against national reference by the participant

A3.1 Introduction

Each participant, excluding the pilot, determined the temperature difference between its transfer cell and its national reference associated with the corresponding combined standard uncertainty.

The national reference is assumed to represent the ideal water triple point temperature, within a related realization uncertainty which includes the effects of impurities and isotopes.

In this chapter, national reference means one or an ensemble of TPW cells used in this comparison. The national reference so defined may differ from the corresponding CCT-K7 national reference because the laboratories may have changed the definition of their national reference in the time interval between the end of CCT-K7 and the beginning of this comparison, as considered in CCT WG8 report to the 23rd CCT Meeting.

In addition to the original report provided by each of the 10 participating laboratories, further communications were made between pilot and each participant to avoid ambiguous wording. Consequentially, most of the original report from each of the 10 participating laboratories is kept in Appendix 3, but an amendment in a form of mathematic equation as follows is placed on the temperature difference and its uncertainty to make the results more definitely.

$(T_{\mathrm{transfer,i}} - T_{\mathrm{national\ ref,i}})'$: corrections of isotopic and impurity effects have not applied on the temperature difference between transfer cell and national reference at participating lab. i

$(T_{\mathrm{transfer,i}} - T_{\mathrm{national\ ref,i}})$: corrections of isotopic and impurity effects have applied on the temperature difference between transfer cell and national reference at participating lab. i

$u(T_{\mathrm{transfer,i}} - T_{\mathrm{national\ ref,i}})$

The effect of the isotopes on the TPW is specified by $(T_{\mathrm{national\ ref,i}} - T_{\mathrm{VSMOW}}) = A(\mathrm{D})\delta\mathrm{D} + A(^{17}\mathrm{O})\delta^{17}\mathrm{O} + A(^{18}\mathrm{O})\delta^{18}\mathrm{O}$, and the correction of impurity effect $(T_{\mathrm{national\ ref,i}} - T_{\mathrm{no\ impurity}})$ was made only in MSL and NMC.

A3.2 NMIA (Australia)

Mantle 1 /Date	Temp diff from mean of national references / mK	Exp. SD of diff from mean / mK	Sensor mid-point to water level / mm	Hydrostatic correction / mK	Self-heat correction / mK
31/01/2008	-0.07356	0.02990	197	0.14381	1.78819
	-0.16021	0.00579	197	0.14381	1.87553
	-0.13177	0.09591	197	0.14381	1.85068
	-0.11802	0.00559	197	0.14381	1.85275
	-0.16440	0.01276	197	0.14381	1.87888
mean /mK	-0.12959				
SD / mK	0.03683				
Mantle 2 /Date	**Temp diff from mean of national references / mK**	**Exp. SD of diff from mean / mK**	**Sensor mid-point to water level / mm**	**Hydrostatic correction / mK**	**Self-heat correction / mK**
15/02/2008	-0.14476	0.01519	196	0.14308	2.12472
	-0.07681	0.00650	196	0.14308	2.14108
	-0.07734	0.09350	196	0.14308	1.90929
	-0.10745	0.00599	196	0.14308	2.10396
	-0.09042	0.00724	196	0.14308	1.95218
mean /mK	-0.09936				
SD / mK	0.02829				
Mantle 3 /Date	**Temp diff from mean of national references / mK**	**Exp. SD of diff from mean / mK**	**Sensor mid-point to water level / mm**	**Hydrostatic correction / mK**	**Self-heat correction / mK**
7/03/2008	-0.15229	0.00511	208	0.15184	0.72586
	-0.11324	0.00792	198	0.14454	2.18328
	-0.14869	0.00689	198	0.14454	2.09819
	-0.13381	0.00572	198	0.14454	2.14989
	-0.10707	0.00651	198	0.14454	2.17515
mean /mK	-0.13102				
SD / mK	0.02038				

$(T_{\mathrm{NMIAAC6}} - T_{\mathrm{national\ ref.}}) =$ **−0.11999 mK**

$u(T_{\mathrm{NMIAAC6}} - T_{\mathrm{national\ ref.}}) =$ **0.04751 mK (*k*=2.06)**

Corrections to reference cells:

Is the isotopic composition of the national reference analyzed? **Yes.**

Reference	Isotopic correction /mK	Uncertainty /mK
B11-50-420	+ 0.0068	± 0.0057 (k=1)
MSL01/3	+ 0.0626	± 0.0057 (k=1)

nb. this correction has already been applied to the data in the table above!

Uncertainty analysis of results of measurements on cell AC6 pre-CMS

Uncertainty of AC6-NMI2006 as per APMP K7 protocol	**ui**	**ν i**
National References		
1.NMI reference: SD of 5 cell NMI ensemble	0.0057	4
2. SEOM of 5 mantles for specific cell	0.0039	4
3. Sensor position +/-10mm	0.0030	50
4. Stray heat fluxes (max 20uK dev. from hydro.)	0.0081	20
5. Chemical impurity included in the SD of the ensemble		
6. Isotopic variation included in the SD of the ensemble		
7. Residual gas pressure included in the SD of the ensemble		
8. Mantle reproducibility included in the SD of the ensemble		
Comparison		

9. Repeatability for single mantle. included in item 10		
10. Reproducibility for 3 mantles (SEOM of 3 mantles, SD=17.885uK)	0.0103	2
11. Reproducibility for diff SPRT (included in item 10)		
12. Hydrostatic head, Ref (+/-10mm or 7.3uK)	0.0042	4
13. Hydrostatic head, DUT (+/-10mm or 7.3uK)	0.0042	4
14. Self-heat, Ref (+/- 0.05% current ratio, typ 2mK SH)	0.0012	8
15. Self-heat, DUT (+/- 0.05% current ratio, typ 2mK SH)	0.0012	8
16. Perturbing heat exchange, Ref (max 20uK dev. from hydro)	0.0115	8
17. Perturbing heat exchange, DUT (max 20uK dev. from hydro)	0.0115	8
Others		
18. Bridge differential linearity Included in 9,10		
19. Std Resistor stability Included in 9,10		
20. Reproducibility of DUT Included in 9,10		
	Uc (k=1)/mK	**0.02311**
	ν_{eff}	**26.4**
	k	**2.06**
	U95	**0.04751**

A3.3 SCL (Hong Kong)

Date of preparation of ice mantle of transfer cell:…4 February 2008
Technique for preparation :…Filling the thermometer well with mixture of dry ice and alcohol
Date of preparation of the mantle of the reference cell(s):…5 February 2008

Date of measurement	Temperature difference from national reference	Experimental standard deviation of temperature difference from national reference	Distance from sensor midpoint to surface level of water in tr. cell	Hydrostatic-head correction for transfer cell	Self-heating correction for transfer cell
11-Feb-2008	-0.005 mK	0.006 mK	261 mm	-0.191 mK	1.250 mK
12-Feb-2008	0.006 mK	0.005 mK	261 mm	-0.191 mK	1.260 mK
13-Feb-2008	0.016 mK	0.006 mK	261 mm	-0.191 mK	1.279 mK
14-Feb-2008	-0.007 mK	0.006 mK	261 mm	-0.191 mK	1.289 mK
15-Feb-2008	0.029 mK	0.008 mK	261 mm	-0.191 mK	1.303 mK
18-Feb-2008	-0.018 mK	0.007 mK	261 mm	-0.191 mK	1.270 mK
19-Feb-2008	0.020 mK	0.009 mK	261 mm	-0.191 mK	1.261 mK
20-Feb-2008	-0.002 mK	0.009 mK	261 mm	-0.191 mK	1.278 mK
21-Feb-2008	0.018 mK	0.009 mK	261 mm	-0.191 mK	1.284 mK
22-Feb-2008	-0.014 mK	0.008 mK	261 mm	-0.191 mK	1.288 mK
mean	0.005 mK				
std. dev. of the mean	0.016 mK				

Date of preparation of ice mantle : 25 February 2008
Technique for preparation : Filling the thermometer well with mixture of dry ice and alcohol
Date of preparation of the mantle of the reference cell(s): 25 February 2008

Date of measurement	Temperature difference from national reference	Experimental standard deviation of temperature difference from national reference	Distance from sensor midpoint to surface level of water in tr. cell	Hydrostatic-head correction for transfer cell	Self-heating correction for transfer cell
03-Mar-2008	0.016 mK	0.006 mK	261 mm	-0.191 mK	1.275 mK
04-Mar-2008	0.035 mK	0.006 mK	261 mm	-0.191 mK	1.265 mK
05-Mar-2008	0.021 mK	0.006 mK	261 mm	-0.191 mK	1.260 mK
06-Mar-2008	0.027 mK	0.007 mK	261 mm	-0.191 mK	1.268 mK
07-Mar-2008	0.016 mK	0.008 mK	261 mm	-0.191 mK	1.282 mK
10-Mar-2008	0.029 mK	0.008 mK	261 mm	-0.191 mK	1.269 mK
11-Mar-2008	0.005 mK	0.007 mK	261 mm	-0.191 mK	1.328 mK
12-Mar-2008	0.016 mK	0.008 mK	261 mm	-0.191 mK	1.287 mK
13-Mar-2008	-0.003 mK	0.008 mK	261 mm	-0.191 mK	1.294 mK
14-Mar-2008	0.010 mK	0.009 mK	261 mm	-0.191 mK	1.326 mK
mean	0.017 mK				
std. dev. of the mean	0.011 mK				

$(T_{\mathrm{SCL5045}} - T_{\mathrm{national\ ref.}})$ = **+0.011 mK**
$u(T_{\mathrm{SCL5045}} - T_{\mathrm{national\ ref.}})$= **0.059 mK (*k*=1)**

Correction

We did not apply correction for isotope effect for our reference cell, the uncertainties due to impurities and isotopic composition of our reference cell was treated as random with mean value of zero.

Uncertainty Budget

Origin	Contribution (k=1)
National reference	
(Uncertainties related only to properties of the reference cell)	
Chemical impurities (note 1)	0.045 mK
Isotopic variation (note 1)	
Residual gas pressure in reference cell (note 2)	0.000 mK
Reproducibility of reference cell. (note 3)	0.021 mK
Comparison of transfer cell to national reference	
(Uncertainties related to the comparison of the two cells)	
Repeatability for a single ice mantel (note 4)	0.005 mK
Reproducibility for different ice mantles (note 5)	0.008 mK
Hydrostatic head of transfer cell (note 6)	0.004 mK
Hydrostatic head of reference cell (note 6)	0.004 mK
SPRT self-heating in the transfer cell and reference cell (note 7)	0.003 mK
others	
precision of bridge (note 8)	0.029 mK
Total uncertainty	0.059 mK

Note 1. The reference cell had been compared regularly with 3 other cells in SCL. These cells were purchased at different times and from different suppliers. The uncertainties due to impurities and isotopic composition can be treated as random. The standard uncertainty of the reference cell due to chemical impurities and isotopic variation was estimated by the maximum difference between the reference cell and that of the other cells = 0.077 mK / $\sqrt{3}$ = 0.045 mK

Note 2. No bubble could be observed when the reference cell was inverted.

Note 3. The reproducibility of reference cell was estimated from past calibration history over a period of 7 years when compared to a set of other triple-point-of-water cells.

Note 4. Estimated from the experimental standard deviation of the daily obtained temperature differences between the transfer cell and the reference cell, divided by square root of 10.

Note 5. Estimated from the temperature difference between the transfer cell and the mean of other 3 cells in two runs.

Note 6. The hydrostatic head is estimated to an accuracy of +/-10 mm.

Note 7. The self-heating of SPRT is estimated from the inaccuracy of the ratio between 1 mA and 1.414 mA of the resistance bridge.

Note 8. From the specification of the ASL F18 resistance bridge.

A3.4 KIM-LIPI (Indonesia)

Date of preparation of ice mantle of transfer cell : 18 March 2008
Technique for preparation : Dry ice method
Date of preparation of the mantle of the reference cell(s) : 18 March 2008

Date of measurement	**Temperature difference from national reference** (mK)	**Experimental standard deviation of temperature difference from national reference** (mK)	**Distance from sensor midpoint to surface level of water in tr. cell**	**Hydrostatic-head correction for transfer cell** (mK)	**Self-heating correction for transfer cell** (mK)
27-maret-08	0.042	0.0634	215 mm	0.157	-1.1
28-maret-08	0.109	0.0589	215 mm	0.157	-1.1
14-Apr-08	0.386	0.0465	215 mm	0.157	-1.1
15-Apr-08	0.305	0.0503	215 mm	0.157	-1.1
16-Apr-08	0.262	0.0582	215 mm	0.157	-1.1
17-Apr-08	0.268	0.0547	215 mm	0.157	-1.1
18-Apr-08	0.223	0.0528	215 mm	0.157	-1.1
19-Apr-08	0.217	0.0514	215 mm	0.157	-1.1
20-Apr-08	0.279	0.0518	215 mm	0.157	-1.1
21-Apr-08	0.184	0.0570	215 mm	0.157	-1.1
24-Apr-08	0.213	0.0598	215 mm	0.157	-1.1
mean	0.226				
std. dev. of the mean	0.094				

Date of preparation of ice mantle : 25 April 2008
Technique for preparation : Dry ice method
Date of preparation of the mantle of the reference cell(s) : 18 march 2008

Date of measurement	**Temperature difference from national reference** (mK)	**Experimental standard deviation of temperature difference from national reference** (mK)	**Distance from sensor midpoint to surface level of water in tr. cell**	**Hydrostatic-head correction for transfer cell** (mK)	**Self-heating correction for transfer cell** (mK)
29-Apr-08	0.021	0.0725	215 mm	0.157	-1.1
30-Apr-08	0.074	0.0664	215 mm	0.157	-1.1
2-May-08	0.078	0.0674	215 mm	0.157	-1.1
3-May-08	0.162	0.0615	215 mm	0.157	-1.1
5-May-08	0.192	0.0619	215 mm	0.157	-1.1
6-May-08	0.177	0.0614	215 mm	0.157	-1.1
7-May-08	0.149	0.0533	215 mm	0.157	-1.1
8-May-08	0.236	0.0665	215 mm	0.157	-1.1
9-May-08	0.166	0.0690	215 mm	0.157	-1.1
10-May-08	0.228	0.0546	215 mm	0.157	-1.1
mean	0.148				
std. dev. of the mean	0.070				

$(T_{\text{KIM-LIPI224}} - T_{\text{national ref.}})'$ = **-0.187 mK**
$(T_{\text{KIM-LIPI224}} - T_{\text{national ref.}})$ = **-0.1843 mK**

$u(T_{\text{KIM-LIPI224}} - T_{\text{national ref.}})$ = **0.110 mK (*k*=1)**

Correction

$(T_{\text{VSMOW}} - T_{\text{national ref.}})$ = **-0.0027 mK** with uncertainty = **0.007 mK (*k*=1)**

Impurity correction is not applied. The uncertainty of the effect is estimated to be **0.1 mK(*k*=1)**

Uncertainty Budget

Origin	**Contribution (k=1) mK**
National reference	
(Uncertainties related only to properties of the reference cell)	
Chemical impurities (please explain how estimated)	0.100
Isotopic variation (please explain how estimated)[a]	0.007
Residual gas pressure in cell	0.020
Reproducibility [1]	0.020
Comparison of transfer cell to national reference	
(Uncertainties related to the comparison of the two cells)	
Repeatability for a single ice mantel (incl. bridge noise) [2]	0.030
Reproducibility for different ice mantles [3]	0.040
Reproducibility for different types of SPRTs [4]	0.050
Hydrostatic head of transfer cell	0.003
Hydrostatic head of reference cell	0.003
SPRT self-heating in the transfer cell and reference cell [5]	0.060
Perturbing heat exchanges [6]	0.040
others	
Non linearity and precision of bridge	0.0074
Temperature variation of standard resistor	0.005
Reproducibility of transfer cell	0.020
Influence of the technician	
Total uncertainty	0.147

[1] Estimate of the reproducibility of the temperature reference due to changes in the following quantities:
crystal size, the age of the mantles, different mantles, the handling of the cells before preparation of the mantle.

[2] The repeatability for a single ice mantle is understood as the experimental standard deviation of the daily obtained temperature differences between the transfer cell and the national reference, divided by the square root of the number of daily results (here typically 10). This component takes also in account the stability of reference resistor (temperature effect).

[3] The reproducibility for different ice mantles represents the additional variability introduced by measuring on several different ice mantles on transfer cell (probably the laboratory uses the same ice mantle of the reference cell during the time of measurements).

[4] The observed temperature differences between the transfer and the reference cells could depend on the type of SPRT's. This component takes into account possible SPRT internal insulation leakage.

[5] These uncertainties could be strongly positively correlated. All the measurements are corrected for self-heating effect. If the thermal resistances have approximately the same magnitude in transfer and reference cells the difference between the self-heating corrections is very small. In addition the uncertainties on self-heating corrections in transfer and reference cells are strongly correlated. In this case the uncertainty in self-heating corrections only contributes to the Type A uncertainty of the comparison of the cells.

[6] This component could be estimated

- by comparing the deviations from expected hydrostatic pressure correction obtained in transfer and reference cells (by changing immersion depth over the length of the sensor $\approx$ 5 cm)
- by modifying the thermal exchange between thermometer and its environment during the measurements on transfer and reference cells.

[a] Estimated by uncertainty of TPW cell certificate.

A3.5 NMIJ (Japan)

Date of preparation of ice mantle of transfer cell:…………………...12/Jul/2007
Technique for preparation: The ice mantle is formed by using an R-134a heat-pipe cooled with liquefied nitrogen, and ethanol as transferring medium.
Date of preparation of the mantle of the reference cell(s):…………12/Jul/2007

Date of measurement	Temperature difference from national reference /mK	Experimental standard deviation of temperature difference from national reference /mK	Distance from sensor midpoint to surface level of water in tr. Cell / cm	Hydrostatic-head correction for transfer cell /mK	Self-heating correction for transfer cell /mK
27.Jul.07	-0.078	0.012	20.6	-0.15	1.974
30.Jul.07	-0.057	0.013	20.6	-0.15	1.942
31.Jul.07	-0.090	0.009	20.6	-0.15	1.960
1.Aug.07	-0.076	0.012	20.6	-0.15	1.960
2.Aug.07	-0.072	0.009	20.6	-0.15	1.940
3.Aug.07	-0.056	0.008	20.6	-0.15	1.980
6.Aug.07	-0.051	0.007	20.6	-0.15	1.997
7.Aug.07	-0.078	0.011	20.6	-0.15	1.962
9.Aug.07	-0.073	0.008	20.6	-0.15	1.975
10.Aug.07	-0.067	0.010	20.6	-0.15	1.980
mean	-0.070				
std. dev. of the mean	0.004				

Date of preparation of ice mantle: ………………...…………………..22/Aug/2007
Technique for preparation: The ice mantle is formed by using an R-134a heat-pipe cooled with liquefied nitrogen, and ethanol as transferring medium.
Date of preparation of the mantle of the reference cell(s):……………22/Aug/2007

Date of measurement	Temperature difference from national reference /mK	Experimental standard deviation of temperature difference from national reference /mK	Distance from sensor midpoint to surface level of water in tr. Cell / cm	Hydrostatic-head correction for transfer cell /mK	Self-heating correction for transfer cell /mK
30.Aug.07	-0.065	0.011	20.5	-0.15	1.950
31.Aug.07	-0.089	0.016	20.5	-0.15	1.939
3.Sep.07	-0.068	0.004	20.5	-0.15	1.989
4.Sep.07	-0.092	0.008	20.5	-0.15	1.915
5.Sep.07	-0.070	0.016	20.5	-0.15	1.939
10.Sep.07	-0.056	0.013	20.5	-0.15	1.966
11.Sep.07	-0.072	0.007	20.5	-0.15	2.001
12.Sep.07	-0.075	0.015	20.5	-0.15	1.972
13.Sep.07	-0.076	0.009	20.5	-0.15	1.971
14.Sep.07	-0.055	0.011	20.5	-0.15	2.011
mean	-0.072				
std. dev. of	0.004				

the mean	

($T_{\mathrm{NMIJT93\text{-}3}} - T_{\mathrm{national\ ref.}}$) = **-0.071 mK**
u($T_{\mathrm{NMIJT93\text{-}3}} - T_{\mathrm{national\ ref.}}$) = **0.040 mK (*k*=1)**

Correction

($T_{\mathrm{VSMOW}} - T_{\mathrm{national\ ref.}}$) = **-0.015 mK to +0.051 mK** for each of seven cells (ref to: International Journal of Thermophysics Volume 29, Number 5, 1749-1760)
u($T_{\mathrm{VSMOW}} - T_{\mathrm{national\ ref.}}$) = **0.0019 mK (*k*=1)**

Impurity correction is not applied. The uncertainty of the effect is estimated to be **0.020 mK (*k*=1)**.

Uncertainty Budget

Origin	Contribution (k=1)
National reference	
(Uncertainties related only to properties of the reference cell)	
Chemical impurities (please explain how estimated)	0.020 mK
Isotopic variation (please explain how estimated)	0.002 mK
Residual gas pressure in cell	0.001 mK
Reproducibility [1]	0.013 mK
Comparison of transfer cell to national reference	
(Uncertainties related to the comparison of the two cells)	
Repeatability for a single ice mantel (incl. bridge noise) [2]	0.011 mK
Reproducibility for different ice mantles [3]	0.006 mK
Reproducibility for different types of SPRTs [4]	0.002 mK
Hydrostatic head of transfer cell	0.008 mK
Hydrostatic head of reference cell	0.008 mK
SPRT self-heating in the transfer cell and reference cell [5]	neglected (because of no significant differences between seven cells)
Perturbing heat exchanges [6]	0.023 mK
others	
Non linearity and precision of bridge	0.014 mK
Temperature variation of standard resistor	neglected (because of short period for comparison measurements)
Reproducibility of transfer cell	included in repeatability for a single ice mantel and reproducibility for different ice mantles
Influence of the technician	neglected (only one person)
Ambiguity of the definition of the triple point of water	0.004 mK

Total uncertainty (Combined uncertainty)	0.040 mK

Explanation

[Chemical impurity]

After the temperature comparison measurements for defining the national reference, the water of one of seven cells was collected just after the cell was broken, and then analyzed to estimate the effect of the chemical impurities dissolved in the water of the cells. Quantitative analyses or qualitative analyses for 65 elements were undertaken using the actual water from the cell with an inductively coupled plasma mass spectrometer (ICPMS). The depression of the triple point of water by an impurity is estimated thermodynamically, and the standard uncertainty of the chemical impurities is evaluated as less than 0.020 mK.

[Isotopic variation]

Five cells of seven cells were manufactured with small ampoules. After removing the ampoules, the isotopic compositions of the water in the ampoules were analyzed. Two cells of seven cells were broken after the thermal measurements to analyze the water. The uncertainty of isotopic correction includes repeatability of isotopic measurements, reproducibility among measuring laboratories of the isotopic composition analyses, systematic error of measurements and correcting equation.

Details of the above chemical impurity effect and isotopic variation effect could be found in the paper, Isotopic Correction of Water Triple Point Cells at NMIJ, J. Tamba, M. Sakai, I. Kishimoto, M. Arai, Int J Thermophys, DOI 10.1007/s10765-008-0456-3.

[1] Estimate of the reproducibility of the temperature reference due to changes in the following quantities:
crystal size, the age of the mantles, different mantles, the handling of the cells before preparation of the mantle.

[2] The repeatability for a single ice mantle is understood as the experimental standard deviation of the daily obtained temperature differences between the transfer cell and the national reference, divided by the square root of the number of daily results (here typically 10). This component takes also in account the stability of reference resistor (temperature effect).

[3] The reproducibility for different ice mantles represents the additional variability introduced by measuring on several different ice mantles on transfer cell (probably the laboratory uses the same ice mantle of the reference cell during the time of measurements).

[4] The observed temperature differences between the transfer and the reference cells could depend on the type of SPRT's. This component takes into account possible SPRT internal insulation leakage.

[5] These uncertainties could be strongly positively correlated. All the measurements are corrected for self-heating effect. If the thermal resistances have approximately the same magnitude in transfer and reference cells the difference between the self-heating corrections is very small. In addition the uncertainties on self-heating corrections in transfer and reference cells are strongly correlated. In this case the uncertainty in self-heating corrections only contributes to the Type A uncertainty of the comparison of the cells.

[6] This component could be estimated

- by comparing the deviations from expected hydrostatic pressure correction obtained in transfer and reference cells (by changing immersion depth over the length of the sensor ≈ 5 cm)
- by modifying the thermal exchange between thermometer and its environment during the measurements on transfer and reference cells.

A3.6 KRISS (Korea)

Date of preparation of ice mantle of transfer cell: January 23, 2009
Technique for preparation : Similar to standard BIPM technique. We did not use alcohol in the step 2 of BIPM technique.
Date of preparation of the mantle of the reference cell(s): January 23, 2009

Date of measurement	Temperature difference from national reference	Experimental standard deviation of temperature difference from national reference	Distance from sensor midpoint to surface level of water in tr. cell	Hydrostatic-head correction for transfer cell	Self-heating correction for transfer cell
February 2, 2009	-0.013 mK	0.022 mK	220 mm	0.161 mK	1.543 mK
February 3, 2009	-0.017	0.022	220	0.161	1.537
February 4, 2009	+0.014	0.022	220	0.161	1.567
February 5, 2009	+0.019	0.022	220	0.161	1.561
February 6, 2009	+0.013	0.022	220	0.161	1.553
February 9, 2009	+0.033	0.022	220	0.161	1.510
February 10, 2009	+0.026	0.022	220	0.161	1.548
February 11, 2009	+0.041	0.022	220	0.161	1.558
February 12, 2009	+0.028	0.022	220	0.161	1.571
February 13, 2009	+0.002	0.022	220	0.161	1.555
February 16, 2009	-0.014	0.022	220	0.161	1.551
mean	+0.012	0.022	220	0.161	1.550
std. dev. of the mean	0.020				0.017

Date of preparation of ice mantle of transfer cell: February 20, 2009
Technique for preparation : Similar to standard BIPM technique. We did not use alcohol in the step 2 of BIPM technique.
Date of preparation of the mantle of the reference cell(s): February 20, 2009

Date of measurement	Temperature difference from national reference	Experimental standard deviation of temperature difference from national reference	Distance from sensor midpoint to surface level of water in tr. cell	Hydrostatic-head correction for transfer cell	Self-heating correction for transfer cell
February 27,2009	+0.037 mK	0.022 mK	220 mm	0.161 mK	1.566 mK
March 2, 2009	+0.029	0.022	220	0.161	1.570
March 3, 2009	-0.001	0.022	220	0.161	1.561
March 4, 2009	+0.004	0.022	220	0.161	1.522
March 5, 2009	+0.024	0.022	220	0.161	1.502
March 6, 2009	+0.037	0.022	220	0.161	1.497
March 9, 2009	+0.006	0.022	220	0.161	1.504
March 10, 2009	+0.029	0.022	220	0.161	1.512
March 11, 2009	+0.022	0.022	220	0.161	1.543
March 12, 2009	+0.007	0.022	220	0.161	1.563
March 13, 2009	+0.007	0.022	220	0.161	1.544
mean	+0.018				1.535
std. dev. of the mean	0.014				0.028

$(T_{KRISS2000\text{-}24} - T_{national\ ref.})$ = **<u>+0.015 mK</u>**
$u(T_{KRISS2000\text{-}24} - T_{national\ ref.})$ = **<u>0.066 mK (*k*=1)</u>**

Correction

$(T_{VSMOW} - T_{national\ ref.})$ = **<u>+0.045 mK</u>** with uncertainty = **<u>0.001 mK (*k*=1)</u>** (KRISS national reference cell and transfer cell manufactured at the same batch, ref to International Journal of Thermophysics Volume 29, Number 3, 808-814)

Impurity correction = **<u>0 mK</u>** with uncertainty = **<u>0.03 mK(*k*=1)</u>**

Uncertainty Budget

Origin	Contribution (k=1)
National reference	
(Uncertainties related only to properties of the reference cell)	
Chemical impurities (please explain how estimated)	0.03 mK
Isotopic variation (please explain how estimated)	0.001 mK
Residual gas pressure in cell	0.005 mK
Reproducibility [1]	0.009 mK
Comparison of transfer cell to national reference	
(Uncertainties related to the comparison of the two cells)	
Repeatability for a single ice mantel (incl. bridge noise) [2]	0.010 mK
Reproducibility for different ice mantles [3]	0.004 mK
Reproducibility for different types of SPRTs [4]	0.004 mK
Hydrostatic head of transfer cell	0.004 mK
Hydrostatic head of reference cell	0.004 mK
SPRT self-heating in the transfer cell and reference cell [5]	0.033 mK
Perturbing heat exchanges [6]	0.045 mK
others	
Non linearity and precision of bridge	0.005 mK
Temperature variation of standard resistor	0.003 mK
Reproducibility of transfer cell	0.007 mK
Influence of the technician	0.006 mK
Total uncertainty	0.066 mK

1. Chemical impurities: The uncertainty of chemical impurities has been referred to the following report.
D.I. head, R.L. Rusby and J.E. Martin, “Cryogenic Triple Point Cells at NPL,” NPL Report QM116, October 1995. Table 3. Uncertainty Budget for Platinum Resistance Thermometer No. 1728839. (9 page)

2. Isotopic variation: The uncertainty of isotopic variation has been referred to the following report.
K.S.Gam,K.H.Kang,Y.G.Kim,I.Yang, “Isotopic composition of water used in triple-point cells.” International Journal of Thermophysics, 2008, Table 2. Corrections to the realized temperatures based on the isotopic compositions of KRISS TPW cells.

3. Residual gas pressure in cell: The uncertainty of residual gas pressure has been referred to the following report.
B. Fellmuth, J. Fisher, E. Tegler, “Uncertainty budgets for characteristics of SPRTs calibrated according to the ITS-90,” CCT/01-02, 2001. Table 2. PTB Uncertainty budgets, corresponding to the ISO guidelines, for the calibration of SPRTs at the defining fixed points.

4. [1] Estimate of the reproducibility of the temperature reference due to changes in the following quantities: crystal size, the age of the mantles, different mantles, the handling of the cells before preparation of the mantle.
The uncertainty of reproducibility has been taken from the raw data of 25 times measured resistance through 2 reference cells.

5. [2] The repeatability for a single ice mantle is understood as the experimental standard deviation of the daily obtained temperature differences between the transfer cell and the national reference, divided by the square root of the number of daily results (here typically 10). This component takes also in account the stability of reference resistor (temperature effect).
The uncertainty of repeatability has been taken from the standard deviation of the mean of the measured resistance in each day. The averaged value of 0.010 mK of the uncertainty in each day is used as the uncertainty of the repeatability.

6. [3] The reproducibility for different ice mantles represents the additional variability introduced by measuring on several different ice mantles on transfer cell (probably the laboratory uses the same ice mantle of the reference cell during the time of measurements).
Temperature difference dT(ice mantle) between ice mantle of transfer cell has been taken the temperature difference between averaged temperature difference of first run comparison dT(run 1) and second run comparison dT(run 2).

$$dT(\text{ice mantle}) = dT(\text{run 1}) - dT(\text{run 2}) = 0.018\ \text{mK} - 0.012\ \text{mK} = 0.007\ \text{mK}$$

The uncertainty of the reproducibility for different ice mantles has been calculated like following equation.

$$u(\text{ice mantle}) = dT(\text{ice mantle}) / \text{square root } 3 = 0.004\ \text{mK}$$

7. [4] The observed temperature differences between the transfer and the reference cells could depend on the type of SPRT's. This component takes into account possible SPRT internal insulation leakage.
The uncertainty of a SPRT internal insulation leakage u(leakage) has been taken from the variation of the observed temperature differences between the transfer and the reference cells. The standard deviation of the mean of the all observed temperature differences between the transfer and the reference cells is used for the u(leakage).

$$u(\text{leakage}) = 0.004\ \text{mK}$$

8. Hydrostatic head of transfer cell and hydrostatic head of reference cell: The uncertainty of hydrostatic head correction has been referred to the following report.
B. Fellmuth, J. Fisher, E. Tegler, “Uncertainty budgets for characteristics of SPRTs calibrated according to the ITS-90,” CCT/01-02, 2001. Table 2. PTB Uncertainty budgets, corresponding to the ISO guidelines, for the calibration of SPRTs at the defining fixed points.

9. [5] These uncertainties could be strongly positively correlated. All the measurements are corrected for self-heating effect. If the thermal resistances have approximately the same magnitude in transfer and reference cells the difference between the self-heating corrections is very small. In addition the uncertainties on self-heating corrections in transfer and reference cells are strongly correlated. In this case the uncertainty in self-heating corrections only contributes to the Type A uncertainty of the comparison of the cells.
The variation of the self-heating effect has been taken for the uncertainty of the self-heating effect. The standard deviation of the mean for the self-heating effect of the 2 reference cell and the transfer cell are combined together the uncertainty of the self-heating effect u(self-heating).

$$u(\text{self-heating}) = (0.017^2 + 0.028^2)^{1/2} = 0.033\ \text{mK}$$

10. [6] This component could be estimated

- by comparing the deviations from expected hydrostatic pressure correction obtained in transfer and reference cells (by changing immersion depth over the length of the sensor ≈ 5 cm)
- by modifying the thermal exchange between thermometer and its environment during the measurements on transfer and reference cells.

The uncertainty of perturbing heat exchanges has been taken from the immersion depth temperature profile. The temperature difference between bottom and 5 cm height is 0.034 mK which shows at the table of immersion profile. The value of 0.034 mK is divided by square root 3 for using a uncertainty. The measurement of the immersion profile has been performed 4 times. From the 4 times measurements, the uncertainty of data scattering is revealed to 0.040 mK. These 2 uncertainties are combined together for the uncertainty of perturbing heat exchanges.

$$u(\text{perturbing}) = (0.020^2 + 0.040^2)^{1/2} = 0.045\ \text{mK}$$

11. Non linearity and precision of bridge error calculated using 0.01 ppm error of the specification of ASL F900 bridge.

$$u(\text{n-l}) = [dR(F900)/(dR/dT)] / \text{square root } 3$$
$$= [0.000001\ \Omega/0.1087\ \Omega\bullet K^{-1}] / \text{square root } 3 = 0.005\ \text{mK}$$

Temperature variation of standard resistor error calculated using 10 mK, which was the stability of liquid bathe for maintaining the standard resistors.

12. The averaged value of 0.010 mK for the uncertainty is used as the uncertainty of the of influence of the technician . The uncertainty of the influence of the technician has been calculated like following equation.

$$u(\text{influence technician}) = 0.010\ \text{mK} / \text{square root } 3 = 0.006\ \text{mK}$$

A3.7 SIRIM (Malaysia)

Date of preparation of ice mantle of transfer cell : **11/4/2008**
Technique for preparation : **Dry ice**
Date of preparation of ice mantle of the reference cell(s) : **11/4/2008**

	Date of measurement	Temperature difference from national reference, (mK)	Experimental standard deviation of temperature difference from national reference, (mK)	Distance from sensor midpoint to surface level of water in transfer cell, (m)	Self-heating correction for transfer cell
1	22 April 2008	-0.431	0.195	0.248	1.54225E-06
2	23 April 2008	-0.523			1.53575E-06
3	24 April 2008	-0.482			1.66500E-06
4	25 April 2008	-0.938			1.65050E-06
5	28 April 2008	-0.705			1.55875E-06
6	28 April 2008	-0.967			1.56675E-06
7	29 April 2008	-0.519			1.61800E-06
8	30 April 2008	-0.535			1.61575E-06
9	30 April 2008	-0.832			1.72150E-06
10	30 April 2008	-0.697			1.64075E-06
	Average	-0.663			

Date of preparation of ice mantle of transfer cell : **9/5/2008**
Technique for preparation : **Dry ice**
Date of preparation of ice mantle of the reference cell(s) : **9/5/2008**

	Date of measurement	Temperature difference from national reference, (mK)	Experimental standard deviation of temperature difference from national reference,(mK)	Distance from sensor midpoint to surface level of water in transfer cell, (m)	Self-heating correction for transfer cell
1	21 May 2008	-1.031	0.168	0.248	1.62625E-06
2	21 May 2008	-0.747			1.62725E-06
3	22 May 2008	-0.621			1.72925E-06
4	22 May 2008	-0.759			1.66350E-06
5	23 May 2008	-0.712			1.54350E-06
6	26 May 2008	-0.468			1.54125E-06
7	26 May 2008	-0.537			1.52350E-06
8	27 May 2008	-0.529			1.65750E-06
9	27 May 2008	-0.687			1.64450E-06
10	-	-			-
	Average	-0.677			

$(T_{\mathrm{SIRIM2000\text{-}22}} - T_{\mathrm{national\ ref.}})'$ = **-0.670 mK**
$(T_{\mathrm{SIRIM2000\text{-}22}} - T_{\mathrm{national\ ref.}})$ = **-0.6504 mK**

$u(T_{\mathrm{SIRIM2000\text{-}22}} - T_{\mathrm{national\ ref.}})$ = **0.10 mK (*k*=1)**

Correction

$(T_{\mathrm{VSMOW}} - T_{\mathrm{national\ ref.}})$ = **+0.0255 mK**

$(T_{VSMOW} - T_{SIRIM2000\text{-}22})$ = **+0.0451 mK**

Impurity correction is not applied.

Uncertainty Budget

	QUANTITY	SOURCE	TYPE	Raw Std. U xi	UNIT	SEN. COEF (c_i)	PROB. DIST	DIV	Std U contr. for each u (xi), °C	v_i (DOF)	eff DOF for each Vi
A	***Comparison of transfer cell to national reference***										
1	Repeatability of single ice mantle	1st mantle	A	0.06173	mK	1	t	1	0.06173	9	1.61391E-06
2	Repeatability of single ice mantle	2nd mantle	A	0.05613	mK	1	t	1	0.05613	9	1.10300E-06
3	Reproducibility for different ice mantles		A	0.00693	mK	1	t	1	0.00693	1	2.30985E-09
4	Hydrostatic head of transfer cell		B	0.00001	mK	1	R		0.00001	80	1.75230E-22
5	SPRT self-heating in the transfer cell and reference cell	1st mantle	B	0.05196	mK	1	R		0.03000	80	1.01251E-08
6	SPRT self-heating in the transfer cell and reference cell	2nd mantle	B	0.06220	mK	1	R		0.03591	80	2.07896E-08
B	***National Reference***										
7	Reproducibility		A	0.03043	mK	1	t		0.03043	1	8.56948E-07
8	Hydrostatic head of reference cell		B	0.00001	mK	1	R		0.00001	80	3.26286E-22

Total Effective DOF		**3.60708E-06**
Combined uncertainties(Uc)	**0.10062** mK	
Uc^4	**0.000102522**	
Overall Effective DOF (calculated)		Uc^4/sum eff 28.4225 DOF
Coverage factor (k) at 95% CL for Effective dF(calculated)	=	2.00

Expanded Uncertainty (k x Uc) = **0.201 mK**

1. Reproducibility

	Average from each mantle	Standard deviation from each mantle	Convert (Kelvin)	Convert (milikelvin)	Standard uncertainty(mK)
1st mantle	25.55073401 ohm	2.19009E-05 ohm	0.000215 K	0.214905 mK	**0.030426**
2nd mantle	25.55072611 ohm	1.56995E-05 ohm	0.000154 K	0.154054 mK	

Comparison of transfer cell to national reference

2. Repeatability of single ice mantle

	Standard deviation of temperature difference	Standard uncertainty(mK)
1st mantle	0.195223 mK	**0.0617348**
2nd mantle	0.168394 mK	**0.0561312**

3. Reproducibility for different ice mantles

	Average of temperature difference	Standard deviation from 2 mantles	Standard uncertainty(mK)
1st mantle	-0.66289 mK	0.009804 mK	**0.0069326**
2nd mantle	-0.67675 mK		

4. Hydrostatic pressure effect

	dT/dL	L	Standard uncertainty (Kelvin)	Standard uncertainty Convert (milikelvin)
Hydrostatic head of transfer cell	-0.00073 K/m	0.248 m	1.08812E-08 K	**1.09E-05**
Hydrostatic head of reference cell	-0.00073 K/m	0.268 m	1.27108E-08 K	**1.27E-05**

5. SPRT self-heating in the transfer cell and reference cell

Average of self heating	Standard deviation of self	Convert (ohm)	Convert (Kelvin)	Standard

	(transfer & reference)		heating (transfer & reference)						uncertainty(mK)
1st mantle	1.62399E-06	ratio	5.29538E-08	ratio	5.29538E-06	ohm	5.19616E-05	K	**0.051961606**
2nd mantle	1.64489E-06	ratio	6.33883E-08	ratio	6.33882E-06	ohm	6.22006E-05	K	**0.062200586**

A3.8 MSL (New Zealand)

Date of preparation of ice mantle of transfer cell: 27-28 March 2008

Technique for preparation: Dry ice is used to initiate freezing at the bottom of the thermometer well. An immersion cooler is then used to build the mantle.

Date of preparation of the mantle of the reference cells: 27-28 March 2008

Table 1: Summary of measurements

Date of measurement	Temperature difference from national reference /mK	Experimental standard deviation of temperature difference from national reference /mK	Distance from sensor midpoint to surface level of water in tr. Cell /mm	Self-heating correction for transfer cell at 1 mA /mK
1 8 April	-0.0072	0.0226	238	-0.416
2 9 April	-0.0092	0.0226	238	-0.437
3 10 April	0.0337	0.0226	237	-0.420
4 11 April	-0.0136	0.0226	238	-0.440
5 14 April	0.0060	0.0226	237	-0.433
6 14 April	-0.0090	0.0226	237	-0.449
7 15 April	-0.0359	0.0226	237	-0.437
8 15 April	0.0082	0.0226	237	-0.453
9 16 April	-0.0038	0.0226	238	-0.459
10 16 April	0.0325	0.0226	238	-0.445
11 17 April	0.0246	0.0226	238	-0.447

The temperature differences are corrected for isotopic compositions, hydrostatic-head, self-heating, and impurities.

$(T_{\mathrm{MSL01\text{-}02}} - T_{\mathrm{national\ ref.}})$ = **+0.0024 mK**
$u(T_{\mathrm{MSL01\text{-}02}} - T_{\mathrm{national\ ref.}})$ = **0.0103 mK (k=1)**

Table 2 below gives an overall summary of the results of measurements of the differences between the cells of the MSL ensemble. The reported mean is the mean difference between the measured cell temperature and the mean of all cell measurements. The reported standard deviation is the standard-deviation-of-the-mean of the measured differences for each cell.

Table 2: Summary of observed temperature differences between cells and the mean of all measurements.

Cell	MSL 01-02	MSL 01-04	MSL 04-01	MSL 06-01	MSL 06-02
Mean/μK	2.4	-2.3	6.1	-5.5	-0.7
Standard uncertainty/μK	6.4	5.6	5.7	5.1	6.8

Table 3: Summary of the cells in the MSL ensemble

Cell serial number	Seal-off date	Glass type	δD / ‰	δ^{18}O / ‰	δ^{17}O / ‰	Capacitance turnover frequency / kHz
MSL 06/02	21/11/06	Fused silica	-96.1	-14.7	-7.8	1.2
MSL 06/01	28/11/06	Fused silica	-92.9	-14.39	-7.6	1.6
MSL 04/01	27/01/04	Fused silica	-107.8	-15.8	-8.4	1.4
MSL 01/02	11/04/01	Borosilicate	-53.2	-9.2	-4.9	2.3
MSL 01/04	03/04/01	Borosilicate	-66.8	-10.7	-5.7	2.8

Table 4: Summary of uncertainties in the realisation of the triple point of water.

Uncertainty term	MSL 01-02		MSL 01-04		MSL 04-01		MSL 06-01		MSL 06-02	
	Corr.	Unc.	Corr.	Unc.	Corr.	Unc.	Corr.	Unc.	Corr.	Unc.
Res. gas	0	0	0	0	0	0	0	0	0	0
Isotopes	39.6	1.2	49.1	1.5	78.3	2.4	68	2.1	70.2	2.1
Hydrostatic	173	4	182	4	184	4	172	4	173	4
Buoyancy	0	0	0	0	0	0	0	0	0	0
Impurities	8.3	4.1	11.4	6	15.5	8	15.7	8	15.3	8
Crystal size	0	5	0	5	0	5	0	5	0	5
TOTAL	221	8	243	9	278	11	256	10	259	10

Residual gas pressure
The effect of residual gas pressure in the cells was assessed using the bubble compression test and found to be less than 1 μK for all five of the cells, and therefore negligible.

Isotopes
All cell temperatures are corrected for departures of the isotopic composition from V-SMOW using the equation recommended in the Technical Annex to the Mise en Practique for the kelvin. The standard uncertainties in the corrections are estimated as 3% of the correction.

Hydrostatic effect
The true triple-point temperature is realised at the surface of the water in the cells where ice, water and water vapour coexist. However, the location where the temperature is measured is some 250 mm below this level. Accordingly a correction of 730 μK/m must be applied to account for the hydrostatic pressure. For the MSL cells the corrections are about 185 μK. The standard uncertainty in the correction, due largely to uncertainties in the location of the thermal centre of the SPRT, is about 4 μK.

When measuring differences between cells with the same SPRT, the uncertainties in the hydrostatic corrections are almost 100% correlated so that the contribution to uncertainty in the measured temperature differences is practically zero.

Buoyancy effect
The effect of the localised cooling caused by the mantle floating against the bottom of the thermometer well is eliminated with the use of the sponge at the bottom of the well. No correction or uncertainty is applied.

Impurities
There are three distinct contributions to the uncertainties due to impurities that must be considered: dissolved gases, ionic impurities, and non-ionic impurities.

The dissolved gases arise from the incomplete degassing of the cells during manufacture. The effect of these gases dissolved in the water is typically less than one third of the effects due to the residual gas pressure (described above), and therefore negligible in the five cells of the ensemble.

The ionic impurities in the water are measured directly with the capacitance conductivity test. Any increase in turnover frequency beyond 0.93 kHz is due to ionic impurities. Chemical models of the molar conductivity indicate that the most likely impurities would also cause a temperature depression of about 1 μK/kHz in the triple-point temperature (the exact value depends on the ions). A correction is applied and a standard uncertainty equal to half the correction is applied.

By far the greatest contribution to the uncertainty is due to non-ionic impurities. These are mostly due to dissolution of the glass either during manufacture of the cell or later as the cell ages. With borosilicate cells there is a correlation between the ionic and non-ionic impurities, and if the dissolution of the glass is uniform, the total correction for ionic and non-ionic impurities is about 12 μK/kHz. For the cells manufactured by MSL we have found that the leaching dominates etching as a dissolution process so that a total correction of 6 μK/kHz should be applied to the conductivity results. An uncertainty equals to half the correction is applied.

For fused-silica cells the problem is more difficult. On one hand the dissolution rates with fused silica are very much reduced, so the cells age better. However, the dissolution products of pure silica ionise only very weakly in water, which makes the conductivity tests too insensitive to yield data on dissolution with aging. Also, fused silica cells must be sealed at a higher temperature leading to a greater initial concentration of silicic acid in the water. Comparisons between freshly manufactured borosilicate and fused-silica cells suggest that the fused-silica cells realise temperatures about 10 μK to 20 μK below the borosilicate cells. We therefore apply a 15 μK correction plus a small amount for ionic impurities according to the conductivity. Again, an uncertainty equal to half the correction is applied. The impurity corrections for the five cells range between 8.3 μK and 15.7 μK.

Strain, crystal size, and defects

During the first week or so after freezing, the ice mantle in a freshly frozen cell anneals. During this period, the measured temperature rises a few tenths of a millikelvin, and takes about a week to stabilise to within 10 μK. The effect is largely due to the re-growth of ice crystals from small highly fractured crystals to larger crystals with smooth surfaces (and lower surface energy). We include a standard uncertainty of 5 μK to account for the variations in the state of the mantle.

Total uncertainty in the realisation

Table 4 summarises the uncertainties associated with the realisation of the triple point of water at MSL. The totals of the corrections applied to the cells vary from about 220 μK to 280 μK, with the differences largely due to variations in the isotopic composition. The standard uncertainties for the temperatures realised in all cells are about 10 μK, with the most significant contribution due to impurities in the water. The uncertainties in the previous ensemble range from about 10 μK to 15 μK. The older ensemble included some cells with higher impurity concentrations.

Uncertainties in measurement of differences

The following subsections summarize the contribution to the uncertainties in the measured temperature differences between the cells.

Thermal effects

When an SPRT is immersed into the cell there are immersion and radiation effects, essentially caused by the finite thermal resistance between the SPRT and the solid-liquid interface in the cell. Experiments show that for the SPRT used in the comparison, the effects of radiation piped down the SPRT sheath are undetectable. Other forms of heat leak are apparent in the departure of the immersion characteristics from the theoretical hydrostatic correction line, which are typically below 10 μK. Since all of the cells have the same design there is likely to be strong correlations between the errors in each cell when measuring the temperature differences, so the effect on the measurements reported here will be negligible.

SPRT moisture

One of the largest sources of uncertainty in measurements is due to the migration of moisture within the SPRT sheath. The effect tends to be correlated within a set of measurements on one day but vary from day to day. The effects range from a few microkelvin to several tens of microkelvin depending on the SPRT. This effect will contribute to the observed standard deviation so is assessed as a Type A uncertainty.

Resistance Bridge differential non-linearity and noise

The standard uncertainty due to differential non-linearity and noise of the F18 resistance bridge has been measured using a resistance bridge calibrator and found to be about 3.5×10^{-8} in resistance ratio. When the bridge is operated with a 25 Ω standard resistor, the equivalent standard uncertainty in a single temperature measurement is about 7 μK. This effect will contribute to the observed standard deviation so is assessed as a Type A uncertainty.

Self heating

Self-heating corrections are routinely made during triple-point comparisons. One of the contributions to error in the corrections is error in the ratios of the 1 mA and $\sqrt{2}$ mA currents supplied by the F18 bridge. For the F18 bridge, the currents are matched to within 0.1 %. When correcting an SPRT of the Meyer's design (self heating about 0.3 mK) the resulting uncertainty is about 2 μK. In repeated measurements of differences between cells, the error will be the same for all cells, so it will not contribute to uncertainty in temperature differences.

Standard resistor stability

The standard resistor has a temperature coefficient of 2.5×10^{-6}/°C, and is maintained in a stirred oil bath with a short-term stability of 2 mK r.m.s. The resulting contribution to uncertainty in measurements of temperature differences are below 2 μK. This effect will contribute to the observed standard deviation so is assessed as a Type A uncertainty.

Uncertainties in realisation

Some of the uncertainties identified above will also contribute to variations between measurements. These include, especially, the impurity effects, but also isotopic fractionation effects, and crystal size effects.

Table 5: Uncertainty Budget

Origin	Contribution (k=1) μK
National reference	
Chemical impurities	8
Isotopic variation	2
Residual gas pressure in cell	0
Reproducibility	10
Comparison of transfer cell to national reference	
Repeatability for a single ice mantle	10
Reproducibility for different ice mantles	15
Reproducibility for different types of SPRTs	20
Hydrostatic head of transfer cell	4
Hydrostatic head of reference cell	4
SPRT self-heating in the transfer cell and reference cell	2
Perturbing heat exchanges	10
Non linearity and precision of bridge	20
Temperature variation of standard resistor	1
Reproducibility of transfer cell (included above)	0
Short term stability of SPRT (SPRT moisture)	15
Total uncertainty	41

Note particularly that chemical impurities contribute to all of the non-repeatability and non-reproducibility terms, and therefore, some contributions of uncertainty due to chemical impurities are included in the total 6 times! For calculating the total uncertainty, the repeatability and reproducibility terms should be set to zero.

The MSL transfer cell is a member of MSLs TPW-cell ensemble. Table 5 in MSLs budget gives directly the difference and uncertainty with respect to the MSL national standard.

A3.9 NMC (Singapore)

Date of preparation of ice mantle of transfer cell : 30/12/2009

Technique for preparation : Standard BIPM technique for preparation of ice mantles in WTP cells

Date of preparation of the mantle of the reference cell(s): 30/12/2009

Date of measurement	Temperature difference from national reference (mK)	Experimental standard deviation of temperature difference from national reference (ohm)	Distance from sensor midpoint to surface level of water in tr. Cell (mm)	Hydrostatic-head correction for transfer cell (mK)	Self-heating correction for transfer cell (ohm)
6/1/2009	-0.053	0.000002	258	0.188	0.000274
7/1/2009	-0.116	0.000002	258	0.188	0.000279
8/1/2009	-0.118	0.000003	258	0.188	0.000280
9/1/2009	-0.080	0.000002	258	0.188	0.000275
12/1/2009	-0.144	0.000003	258	0.188	0.000281
13/1/2009	-0.055	0.000004	258	0.188	0.000276
14/1/2009	-0.109	0.000002	258	0.188	0.000272
15/1/2009	-0.187	0.000003	258	0.188	0.000276
16/1/2009	-0.172	0.000002	258	0.188	0.000274
21/1/2009	-0.035	0.000003	258	0.188	0.000283
29/1/2009	-0.103	0.000004	258	0.188	0.000284
30/1/2009	-0.108	0.000003	258	0.188	0.000278
3/2/2009	-0.144	0.000003	258	0.188	0.000280
Mean	-0.109				
Std. Dev. Of mean	0.013				

The temperature differences should already be corrected for hydrostatic-head and self-heating effects. To allow comparison with our measurements, the corrections should also be given separately.

Measurement results on third ice mantle

Date of preparation of ice mantle of transfer cell : 23/06/2009

Technique for preparation : Standard BIPM technique for preparation of ice mantles in WTP cells

Date of preparation of the mantle of the reference cell(s): 23/06/2009

Date of measurement	Temperature difference from national reference (mK)	Experimental standard deviation of temperature difference from national reference (ohm)	Distance from sensor midpoint to surface level of water in tr. Cell (mm)	Hydrostatic-head correction for transfer cell (mK)	Self-heating correction for transfer cell (ohm)
08/07/2009	-0.084	0.000003	258	0.188	0.000277
09/07/2009	-0.112	0.000002	258	0.188	0.000279
10/07/2009	-0.136	0.000003	258	0.188	0.000282
13/07/2009	-0.033	0.000004	258	0.188	0.000280
14/07/2009	-0.071	0.000003	258	0.188	0.000279
15/07/2009	-0.119	0.000002	258	0.188	0.000273
16/07/2009	-0.130	0.000003	258	0.188	0.000278
17/07/2009	-0.065	0.000004	258	0.188	0.000274
20/07/2009	-0.059	0.000002	258	0.188	0.000277
21/07/2009	-0.047	0.000003	258	0.188	0.000281
22/07/2009	-0.063	0.000002	258	0.188	0.000272
23/07/2009	-0.019	0.000003	258	0.188	0.000280
24/07/2009	-0.096	0.000002	258	0.188	0.000279
27/07/2009	-0.068	0.000002	258	0.188	0.000273
Mean	-0.079				
Std. Dev. Of mean	0.010				

The temperature differences should already be corrected for hydrostatic-head and self-heating effects. To allow comparison with our measurements, the corrections should also be given separately.

$(T_{\mathrm{NMC2087}} - T_{\mathrm{national\ ref.}})'$ = **-0.084 mK**
$(T_{\mathrm{NMC2087}} - T_{\mathrm{national\ ref.}})$ = **-0.1255 mK**
$u(T_{\mathrm{NMC2087}} - T_{\mathrm{national\ ref.}})$ = **0.09 mK (*k*=1)**

Correction

Is the isotopic composition of the national reference analyzed? ■ Yes / □ No

$(T_{\mathrm{VSMOW}} - T_{\mathrm{national\ ref.}})$ = **+0.0015 mK** with uncertainty = **0.02 mK (*k*=1)**

$(T_{\mathrm{no\ impurity}} - T_{\mathrm{national\ ref.}})$ = **+0.04 mK** with uncertainty = **0.1 mK (*k*=1)**

Uncertainty Budget

Origin	Contribution (k=1) mK
National reference	
(Uncertainties related only to properties of the reference cell)	
Chemical impurities (please explain how estimated) Water chemical content analysis is not available and impurities is based on observation of melting curve and stability of plateau	0.020
Isotopic variation (please explain how estimated) Sample of water was sent for laboratory test by TPW cell manufacturer (Hart Scientific)	0.020
Residual gas pressure in cell Estimate from bubble size	0.010
Reproducibility [1]	0.020
Comparison of transfer cell to national reference	
(Uncertainties related to the comparison of the two cells)	
Repeatability for a single ice mantel (incl. bridge noise) [2]	0.040
Reproducibility for different ice mantles [3]	0.030
Reproducibility for different types of SPRTs [4]	0.020
Hydrostatic head of transfer cell	0.006
Hydrostatic head of reference cell	0.006
SPRT self-heating in the transfer cell and reference cell [5]	0.040
Perturbing heat exchanges [6]	0.010
others	
……………….	
Total uncertainty	0.09 mK (K=1)

[1] Estimate of the reproducibility of the temperature reference due to changes in the following quantities: crystal size, the age of the mantles, different mantles, the handling of the cells before preparation of the mantle.

[2] The repeatability for a single ice mantle is understood as the experimental standard deviation of the daily obtained temperature differences between the transfer cell and the national reference, divided by the square root of the number of daily results (here typically 10). This component takes also in account the stability of reference resistor (temperature effect).

[3] The reproducibility for different ice mantles represents the additional variability introduced by measuring on several different ice mantles on transfer cell (probably the laboratory uses the same ice mantle of the reference cell during the time of measurements).

[4] The observed temperature differences between the transfer and the reference cells could depend on the type of SPRT's. This component takes into account possible SPRT internal insulation leakage.

[5] These uncertainties could be strongly positively correlated. All the measurements are corrected for self-heating effect. If the thermal resistances have approximately the same magnitude in transfer and reference cells the difference between the self-heating corrections is very small. In addition the uncertainties on self-heating corrections in transfer and reference cells are strongly correlated. In this case the uncertainty in self-heating corrections only contributes to the Type A uncertainty of the comparison of the cells.

[6] This component could be estimated by comparing the deviations from expected hydrostatic pressure correction obtained in transfer and reference cells (by changing immersion depth over the length of the sensor $\approx$ 5 cm) by modifying the thermal exchange between thermometer and its environment during the measurements on transfer and reference cells.

A3.10 NMISA (South Africa)

Date of preparation of ice mantle of transfer cell: 4 September 2007

Technique for preparation: Absolute ethanol in well for heat transfer. Cell cooled to 0.1 °C in water bath. Methanol heat pipe (cooled using solid CO_2) in well to freeze ice mantle.

Date of preparation of the mantle of the reference cell(s): 4 September 2007

Date of measurement	Temperature difference from national reference T(transfer) – T(ref) (/mK)	Experimental std deviation of temperature difference from national reference (/mK)	Distance from sensor midpoint to surface level of water in tr. cell (/mm)	Hydrostatic-head correction for transfer cell (/mK)	Self-heating correction for transfer cell (/10^{-6} Ω)
1. 2007-09-11	-0.131		233	0.170	19.4
					138.7
2. 2007-09-12	-0.114		233	0.170	19.7
					149.0
3. 2007-09-13	-0.133		231	0.169	20.9
					147.7
4. 2007-09-14	-0.124		231	0.169	20.9
					158.7
5. 2007-09-15	-0.115		231	0.169	19.1
					156.8
6. 2007-09-17	-0.112		231	0.169	20.1
					158.7
7. 2007-09-18	-0.111		230	0.168	19.3
					165.8
8. 2007-09-19	-0.130		230	0.168	20.1
					147.6
9. 2007-09-19	-0.128		230	0.168	21.3
					147.5
10. 2007-09-20	-0.101		230	0.168	20.5
					148.7
Mean:	-0.120	0.011			
Std deviation of the mean	0.003				

(Note: Two SPRTs were used to compare the cells, a Rosemount 162CE S/N 4203 and an Isotech 670 S/N 163, therefore there are two self-heating corrections for each measurement.)

The temperature differences should already be corrected for hydrostatic-head and self-heating effects. To allow comparison with our measurements, the corrections should also be given separately.

Measurement results on second ice mantle

Date of preparation of ice mantle of transfer cell: 21 September 2007

Technique for preparation: Absolute ethanol in well for heat transfer. Cell cooled to 0.06 °C in water bath. Methanol heat pipe (cooled using solid CO_2) in well to freeze ice mantle.

Date of preparation of the mantle of the reference cell(s): 21 September 2007

Date of measurement	**Temperature difference from national reference T(transfer) – T(ref) (/mK)**	**Experimental std deviation of temperature difference from national reference (/mK)**	**Distance from sensor midpoint to surface level of water in tr. cell (/mm)**	**Hydrostatic-head correction for transfer cell (/mK)**	**Self-heating correction for transfer cell ($/10^{-6}$ Ω)**
1. 2007-10-05	-0.068		239	0.0174	16.8
					149.9
2. 2007-10-08	-0.075		239	0.0174	19.4
					140.8
3. 2007-10-09	-0.072		239	0.0174	17.0
					149.1
4. 2007-10-10	-0.069		239	0.0174	17.5
					158.6
5. 2007-10-12	-0.065		239	0.0174	19.2
					159.4
6. 2007-10-17	-0.085		217.5	0.0159	18.7
					156.7
7. 2007-10-18	-0.073		220.5	0.0161	18.1
					152.5
8. 2007-10-18	-0.094		220.5	0.0161	18.7
					153.9
9. 2007-10-19	-0.099		235.5	0.0172	20.8
					160.9
10. 2007-10-19	-0.119		235.5	0.0172	21.0
					163.2
Mean:	-0.082	0.017			
Std deviation of the mean	0.005				

Measurement results on third ice mantle

Date of preparation of ice mantle of transfer cell: 14 February 2008

Technique for preparation: Absolute ethanol in well for heat transfer. Cell cooled to 0.04°C in water bath. Methanol heat pipe (cooled using solid CO_2) in well to freeze ice mantle.

Date of preparation of the mantle of the reference cell(s): 14 February 2008

Date of measurement	**Temperature difference from national reference T(transfer) – T(ref) (/mK)**	**Experimental std deviation of temperature difference from national reference (/mK)**	**Distance from sensor midpoint to surface level of water in tr. cell (/mm)**	**Hydrostatic-head correction for transfer cell (/mK)**	**Self-heating correction for transfer cell ($/10^{-6}$ Ω)**
1. 2008-02-21	-0.126		240	0.175	19.8
					153.6
2. 2008-02-23	-0.114		240	0.175	19.5
					160.3
3. 2008-02-24	-0.128		240	0.175	18.8
					161.8
4. 2008-02-25	-0.121		239	0.174	19.7
					160.9
5. 2008-02-28	-0.124		232	0.169	20.7
					161.1
Mean:	-0.122	0.005			
Std deviation of the mean	0.002				

Measurement results on fourth ice mantle

Date of preparation of ice mantle of transfer cell: 29 February 2008

Technique for preparation: Absolute ethanol in well for heat transfer. Cell cooled to 0.04 °C in water bath. Methanol heat pipe (cooled using solid CO_2) in well to freeze ice mantle.

Date of preparation of the mantle of the reference cell(s): 29 February 2008

Date of measurement	Temperature difference from national reference T(transfer) – T(ref) (/mK)	Experimental std deviation of temperature difference from national reference (/mK)	Distance from sensor midpoint to surface level of water in tr. cell (/mm)	Hydrostatic-head correction for transfer cell (/mK)	Self-heating correction for transfer cell ($/10^{-6}$ Ω)
1. 2008-03-11	-0.154		239	0.174	19.8
					147.2
2. 2008-03-12	-0.104		239	0.174	19.0
					153.3
3. 2008-03-13	-0.151		239	0.174	17.8
					154.4
4. 2008-03-14	-0.113		238	0.174	18.4
					160.3
5. 2008-03-17	-0.136		238	0.174	19.0
					151.2
Mean:	-0.132	0.022			
Std deviation of the mean	0.010				

Grand mean = (-0.120 mK·10 – 0.082 mK·10 – 0.122 mK·5 – 0.132 mK·5) / 30 = -0.110 mK

$(T_{\mathrm{NMISA1181}} - T_{\mathrm{national\ ref.}})$ = **-0.110 mK**
$u(T_{\mathrm{NMISA1181}} - T_{\mathrm{national\ ref.}})$ = **0.068 mK (k=1)**

Correction

Isotopic correction: 0 mK with uncertainty 0.038 mK (k = 1)

Impurity correction: 0 mK with uncertainty 0.032 mK (k = 1)

Uncertainty Budget

The uncertainty budget should include the following components, to which others can be added if necessary. The budget shown here can only be a model. Some additional guidance can however be obtained from the draft documents [4]. Please explain how the contributions of chemical impurities and isotope variation were evaluated.

The repeatability for a single ice mantle is understood as the experimental standard deviation of the daily obtained temperature differences between the transfer cell and the national reference, divided by the square root of the number of daily results (here typically 10). The reproducibility for different ice mantles represents the additionally variability introduced by measuring on several different ice mantles.

The participants are required to provide a few sentences describing how they obtained the value used for each term in their uncertainty analysis. All contributions should be stated at the level of one standard uncertainty.

Origin	Contribution (k=1)
National reference	
(Uncertainties related only to properties of the reference cell)	
Chemical impurities: No chemical analyses available. 114 comparisons of the 2 or 3 national ref cells were performed from 1 Feb 2000 to 17 March 2008, with mantles of various ages and conditions. The mean of the 114 std deviations is used. Reproducibility is also included in this component.	0.032 mK
Isotopic variation: No isotopic analyses available. From Nicholas et al, *Metrologia*, 1996, **33**, 265-267, it is deduced that 10% variations in ^{2}H and ^{18}O content may be expected, equivalent to 60 µK and 6 µK, respectively. These are added linearly, as distillation may reduce the amount of both heavy isotopes. Divide by √3 to get k=1.	0.038 mK
Residual gas pressure in cell: 4 mm diameter bubble in inverted type A cell.	0.0004 mK
Reproducibility [1]: included in "chemical impurities" component.	
Comparison of transfer cell to national reference	
(Uncertainties related to the comparison of the two cells)	
Repeatability for a single ice mantle (incl. bridge noise) [2]	0.010 mK
Reproducibility for different ice mantles [3]	0.022 mK
Reproducibility for different types of SPRTs [4]: 30 measurements each with Rosemount and Isotech SPRTs, means differ by 11 µK, std deviations ~ 20 µK, so difference is not significant.	
Hydrostatic head of transfer cell: 10 mm / √3	0.004 mK
Hydrostatic head of reference cell: 10 mm / √3	0.004 mK
SPRT self-heating in the transfer cell and reference cell [5]: included in repeatability & reproducibility above.	

Perturbing heat exchanges [6]: max difference between profiles measured over bottom 60 mm of ref & transfer cells, divided by $\sqrt{3}$.	0.039 mK
others	
Non linearity and precision of bridge: short-range non-linearity and resolution of bridge included in repeatability & reproducibility above.	
Temperature variation of standard resistor: included in repeatability for a single ice mantle.	
Reproducibility of transfer cell: included in "reproducibility for different ice mantles" component.	
Influence of the technician	
Total uncertainty	0.068 mK

[1] Estimate of the reproducibility of the temperature reference due to changes in the following quantities: crystal size, the age of the mantles, different mantles, the handling of the cells before preparation of the mantle.

[2] The repeatability for a single ice mantle is understood as the experimental standard deviation of the daily obtained temperature differences between the transfer cell and the national reference, divided by the square root of the number of daily results (here typically 10). This component takes also in account the stability of reference resistor (temperature effect).

[3] The reproducibility for different ice mantles represents the additional variability introduced by measuring on several different ice mantles on transfer cell (probably the laboratory uses the same ice mantle of the reference cell during the time of measurements).

[4] The observed temperature differences between the transfer and the reference cells could depend on the type of SPRT's. This component takes into account possible SPRT internal insulation leakage.

[5] These uncertainties could be strongly positively correlated. All the measurements are corrected for self-heating effect. If the thermal resistances have approximately the same magnitude in transfer and reference cells the difference between the self-heating corrections is very small. In addition the uncertainties on self-heating corrections in transfer and reference cells are strongly correlated. In this case the uncertainty in self-heating corrections only contributes to the Type A uncertainty of the comparison of the cells.

[6] This component could be estimated

- by comparing the deviations from expected hydrostatic pressure correction obtained in transfer and reference cells (by changing immersion depth over the length of the sensor ≈ 5 cm)
- by modifying the thermal exchange between thermometer and its environment during the measurements on transfer and reference cells.

A3.11 NIMT (Thailand)

Date of preparation of ice mantle of transfer cell: 27/04/08

Technique for preparation: Standard BIPM technique

Date of preparation of the mantle of the reference cell(s): 27/04/08

Date of measurement	Temperature difference from national reference **Tref. (C-Q1012)-Ttrasf. (1480)** (mK)	Experimental standard deviation of temperature difference from national reference (ohm)	Distance from sensor midpoint to surface level of water in tr. cell	Hydrostatic- head correction for transfer cell (ohm)	Self-heating correction for transfer cell (ohm)
05/05/08	0.1134	4.90 E-06	265 mm	-1.80E-05	0.000276
06/05/08	0.1001	1.66 E-06	265 mm	-1.80E-05	0.000270
07/05/08	0.1321	1.41 E-06	265 mm	-1.80E-05	0.000268
08/05/08	0.1200	4.45 E-06	265 mm	-1.80E-05	0.000266
09/05/08	0.1310	5.52 E-06	265 mm	-1.80E-05	0.000266
10/05/08	0.1343	4.47 E-06	265 mm	-1.80E-05	0.000267
12/05/08	0.1174	6.35 E-06	265 mm	-1.80E-05	0.000266
13/05/08	0.1097	4.62 E-06	265 mm	-1.80E-05	0.000263
14/05/08	0.1123	2.72 E-06	265 mm	-1.80E-05	0.000267
15/05/08	0.0893	3.32 E-06	265 mm	-1.80E-05	0.000264
mean	**0.1159**				
Std. dev. of the mean	**0.0045**				

The temperature differences should already be corrected for hydrostatic-head and self-heating effects.

To allow comparison with our measurements, the corrections should also be given separately.

Measurement results on second ice mantle

Date of preparation of ice mantle of transfer cell: 16/05/08

Technique for preparation: Standard BIPM technique

Date of preparation of the mantle of the reference cell(s): 16/05/08

Date of measurement	Temperature difference from national reference **Tref. (C-Q1012)-Ttrasf. (1480)** (mK)	Experimental standard deviation of temperature difference from national reference (ohm)	Distance from sensor midpoint to surface level of water in tr. cell	Hydrostatic- head correction for transfer cell (ohm)	Self-heating correction for transfer cell (ohm)
23/05/08	0.1051	4.02 E-06	265 mm	-1.80E-05	0.000278
24/05/08	0.0994	2.67 E-06	265 mm	-1.80E-05	0.000267
26/05/08	0.1133	2.74 E-06	265 mm	-1.80E-05	0.000276
27/05/08	0.1161	8.83 E-07	265 mm	-1.80E-05	0.000269
28/05/08	0.1025	3.53 E-06	265 mm	-1.80E-05	0.000268
29/05/08	0.1131	2.46 E-06	265 mm	-1.80E-05	0.000276
30/05/08	0.1229	1.05 E-06	265 mm	-1.80E-05	0.000278
02/06/08	0.1169	6.03 E-07	265 mm	-1.80E-05	0.000267
03/06/08	0.1082	3.01 E-06	265 mm	-1.80E-05	0.000277
04/06/08	0.1282	2.81 E-06	265 mm	-1.80E-05	0.000276
mean	**0.1126**				
Std. dev. of the mean	**0.0029**				

The temperature differences should already be corrected for hydrostatic-head and self-heating effects.

To allow comparison with our measurements, the corrections should also be given separately.

$(T_{\text{NIMT1480}} - T_{\text{national ref.}})'$ = **-0.11425 mK**
$(T_{\text{NIMT1480}} - T_{\text{national ref.}})$ = **-0.11555 mK**
$u(T_{\text{NIMT1480}} - T_{\text{national ref.}})$ = **0.075 mK (k=1)**

Correction

$(T_{\text{VSMOW}} - T_{\text{national ref.}})$ = **+0.0013 mK** with uncertainty = **0.0013 mK (k=1)**

Impurity correction is not applied. The uncertainty of the effect is estimated to be **0.03 mK(k=1)**

Uncertainty Budget

The uncertainty budget should include the following components, to which others can be added if necessary. The budget shown here can only be a model. Some additional guidance can however be obtained from the draft documents [4]. Please explain, how the contributions of chemical impurities and isotope variation were evaluated.

The repeatability for a single ice mantle is understood as the experimental standard deviation of the daily obtained temperature differences between the transfer cell and the national reference, divided by the square root of the number of daily results (here typically 10). The reproducibility for different ice mantles represents the additionally variability introduced by measuring on several different ice mantles.

The participants are required to provide a few sentences describing how they obtained the value used for each term in their uncertainty analysis. All contributions should be stated at the level of one standard uncertainty.

Origin	**Contribution (k=1)/mK**
National reference	
(Uncertainties related only to properties of the reference cell)	
Chemical impurities (please explain how estimated)	**0.030****
Isotopic variation (please explain how estimated)	**0.0013***
Residual gas pressure in cell	**0.005****
Reproducibility [1]	**0.050**
Comparison of transfer cell to national reference	
(Uncertainties related to the comparison of the two cell)	
Repeatability for a single ice mantle (incl. bridge noise) [2]	**0.006**
Reproducibility for different ice mantles [3]	**0.013**
Reproducibility for different types of SPRT [4]	**0.020**
Hydrostatic head of transfer cell	**0.004****
Hydrostatic head of reference cell	**0.004****
SPRT self-heating in the transfer cell and reference cell [5]	**0.005**
Perturbing heat exchanges[6]	**0.036**
Other	
Non linearity and precision of bridge	**-**
Temperature variation of standard resistor	**-**
Reproducibility of transfer cell	**-**
Influence of the technician	**-**
Total uncertainty	**0.075**

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[1] Estimate of the reproducibility of the temperature reference due to changes in the following quantities: crystal size, the age of the mantles, different mantles, the handling of the cells before preparation of the mantle.

[2] The repeatability for a single ice mantle is understood as the experimental standard deviation of the daily obtained temperature differences between the transfer cell and the national reference, divided by the square root of the number of daily results (here typically 10). This component takes also in account the stability of reference resistor (temperature effect).

[3] The reproducibility for different ice mantles represents the additional variability introduced by measuring on several different ice mantles on transfer cell (probably the laboratory uses the same ice mantle of the reference cell during the time of measurements).

[4] The observed temperature differences between the transfer and the reference cells could depend on type of SPRT's. This component takes into account possible SPRT internal insulation leakage.

[5] These uncertainties could be strongly positively correlated. All the measurements are corrected for self-heating effect. If the thermal resistances have approximately the same magnitude in transfer and reference cells the difference between the self-heating corrections is very small. In addition the uncertainties on self-heating corrections in transfer and reference cells are strongly correlated. In this case the uncertainty in self-heating corrections only contributes to the Type A uncertainty of the comparison of the cells.

[6] This component could be estimated

- by comparing the deviations from expected hydrostatic pressure correction obtained in transfer and reference cells (by changing immersion depth over the length of the sensor ≈ 6 cm)

- by modifying the thermal exchange between thermometer and its environment during the measurements on transfer and reference cells.

* **A sample of the water was sent for laboratory test by the TPW manufacturer. Uncertainties related to isotopic composition are obtained from the report.**

**** The uncertainty from residual gas pressure has been referred to Table 2 of the report CCT/01-02. This table also serves for estimating the contributions of hydrostatic head correction.**

Appendix 4 Immersion Profile

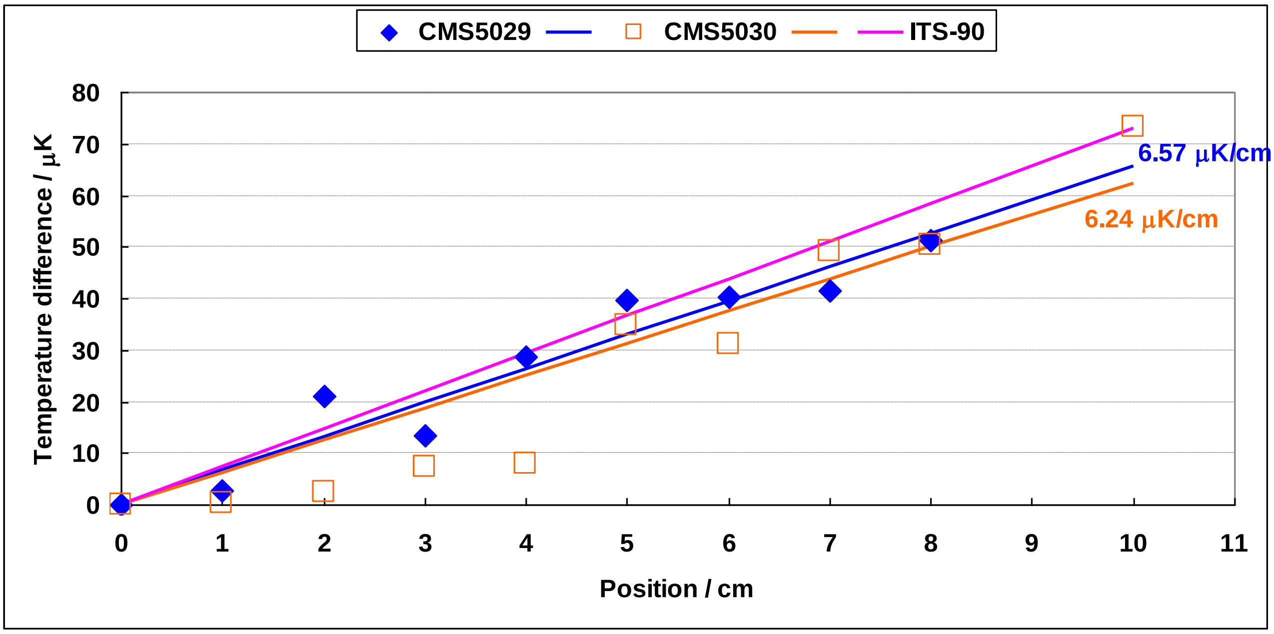
A4.1 CMS (Taiwan)

A-Q 5029 **Unit: μK**

Distance from sensor midpoint to free surface level of the liquid water	Temperature variation
23.6 cm (0 cm, bottom)	**0.000**
22.6 cm (1 cm from bottom)	**2.847**
21.6 cm (2 cm from bottom)	**21.109**
20.6 cm (3 cm from bottom)	**13.451**
19.6 cm (4 cm from bottom)	**28.571**
18.6 cm (5 cm from bottom)	**39.764**
17.6 cm (6 cm from bottom)	**40.353**
16.6 cm (7 cm from bottom)	**41.531**
15.6 cm (8 cm from bottom)	**51.153**

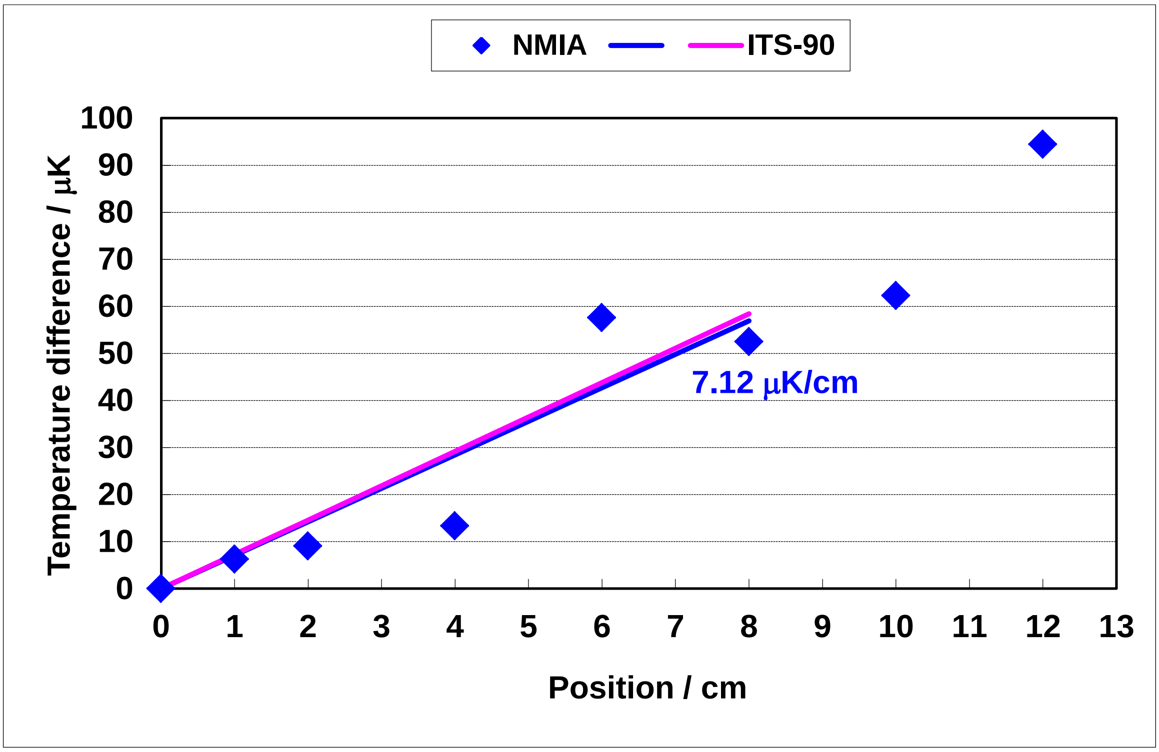
A-Q 5030 **Unit: μK**

Distance from sensor midpoint to free surface level of the liquid water	Temperature variation
23.6 cm (0 cm, bottom)	**0.000**
22.6 cm (1 cm from bottom)	**0.196**
21.6 cm (2 cm from bottom)	**2.553**
20.6 cm (3 cm from bottom)	**7.265**
19.6 cm (4 cm from bottom)	**7.855**
18.6 cm (5 cm from bottom)	**34.757**
17.6 cm (6 cm from bottom)	**31.222**
16.6 cm (7 cm from bottom)	**49.091**
15.6 cm (8 cm from bottom)	**50.269**
13.6 cm (10 cm from bottom)	**73.244**



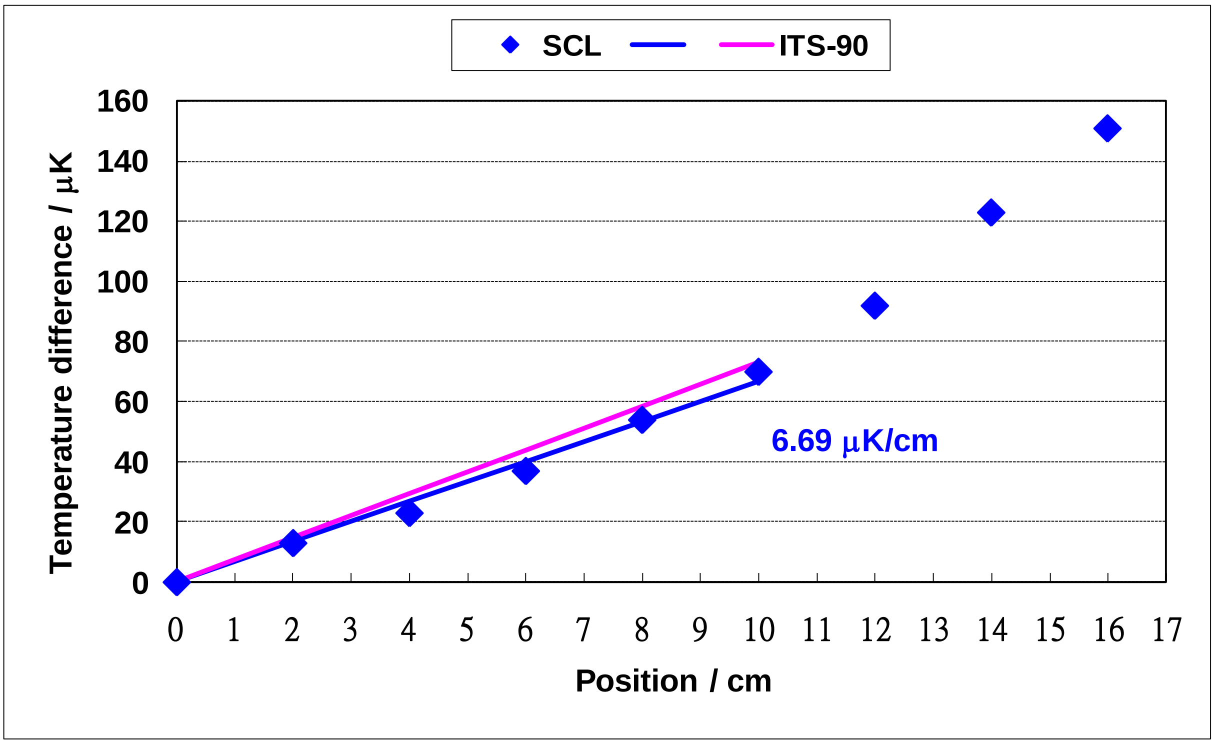
A4.2 NMIA (Australia)

Distance from sensor midpoint to free surface level of the liquid water /mm	Temperature variation /μK
197	0.00
77	94.40
97	62.28
117	52.49
137	57.58
157	13.32
177	9.01
187	6.27
197	25.46



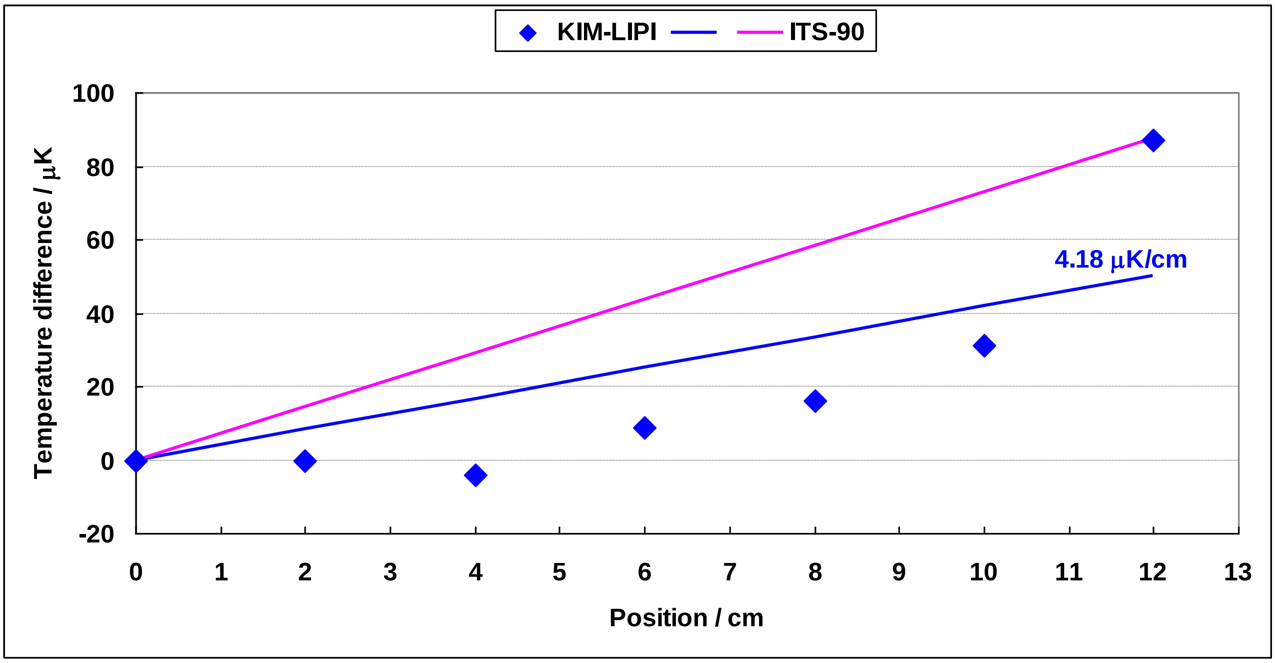
A4.3 SCL (Hong Kong)

Distance from sensor midpoint to free surface level of the liquid water	Temperature variation
261 mm	+0.000 mK
241 mm	+0.013 mK
221 mm	+0.023 mK
201 mm	+0.037 mK
181 mm	+0.054 mK
161 mm	+0.070 mK
141 mm	+0.092 mK
121 mm	+0.123 mK
101 mm	+0.151 mK



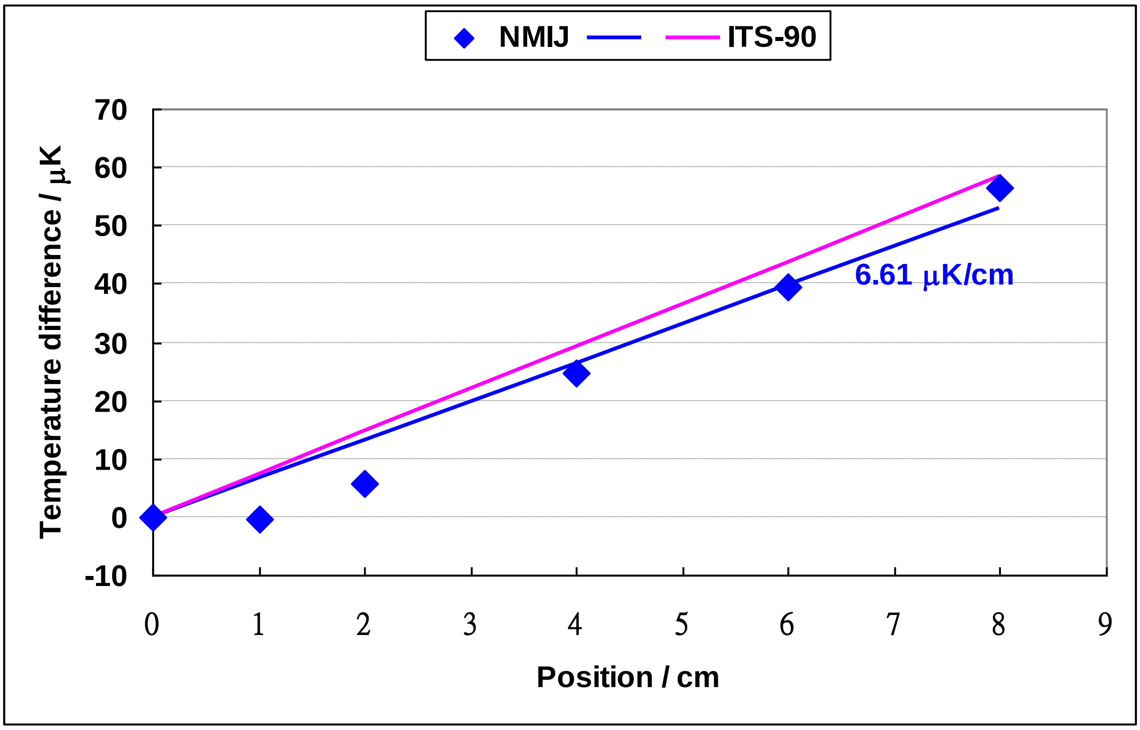
A4.4 KIM-LIPI (Indonesia)

Distance from sensor midpoint to free surface level of the liquid water	Temperature variation (difference from measurement at 200 mm) (°C)
200 mm	0.000000
180 mm	0.000000
160 mm	-0.000004
140 mm	0.000009
120 mm	0.000016
100 mm	0.000031
80 mm	0.000087



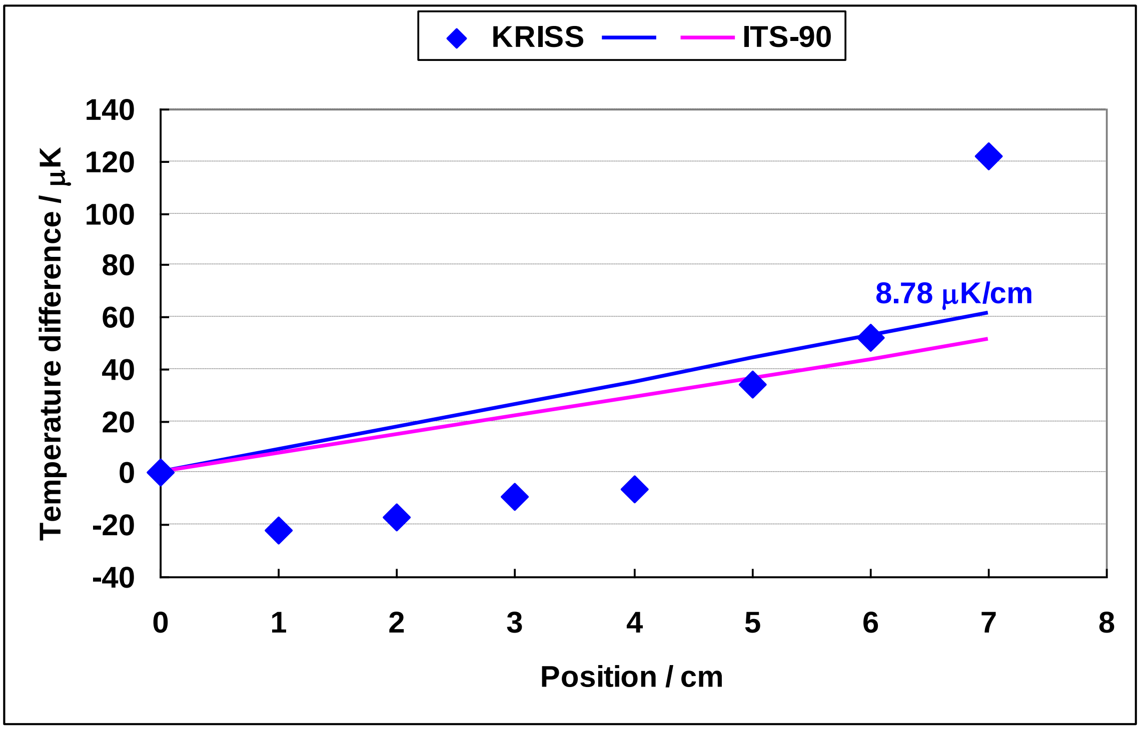
A4.5 NMIJ (Japan)

Distance from sensor midpoint to free surface level of the liquid water	Temperature variation
206 mm	0 mK
196 mm	-0.0005 mK
186 mm	0.0057 mK
166 mm	0.0248 mK
146 mm	0.0396 mK
126 mm	0.0565 mK



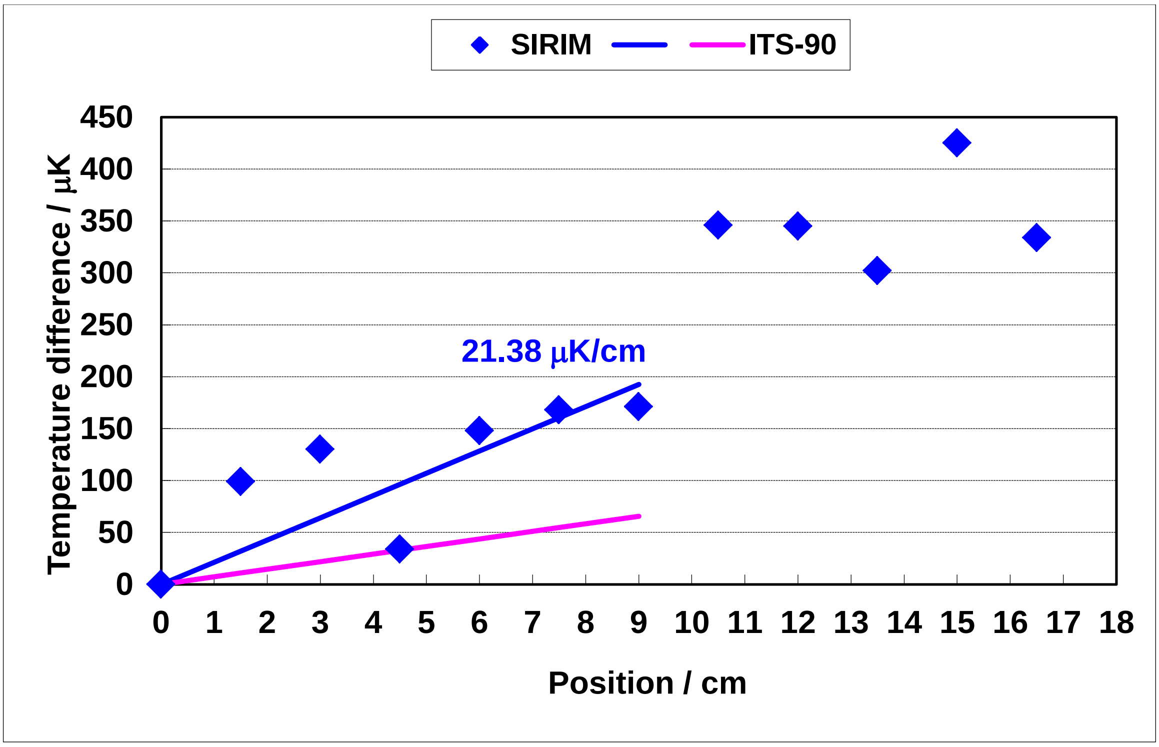
A4.6 KRISS (Korea)

Distance from sensor midpoint to free surface level of the liquid water	Temperature variation
24 cm (0 cm, bottom)	0 mK
23 cm (1 cm from bottom)	-0.022
22 cm (2 cm from bottom)	-0.017
21 cm (3 cm from bottom)	-0.009
20 cm (4 cm from bottom)	-0.006
19 cm (5 cm from bottom)	0.034
18 cm (6 cm from bottom)	0.052
17 cm (7 cm from bottom)	0.122
18 cm (8 cm from bottom)	0.157



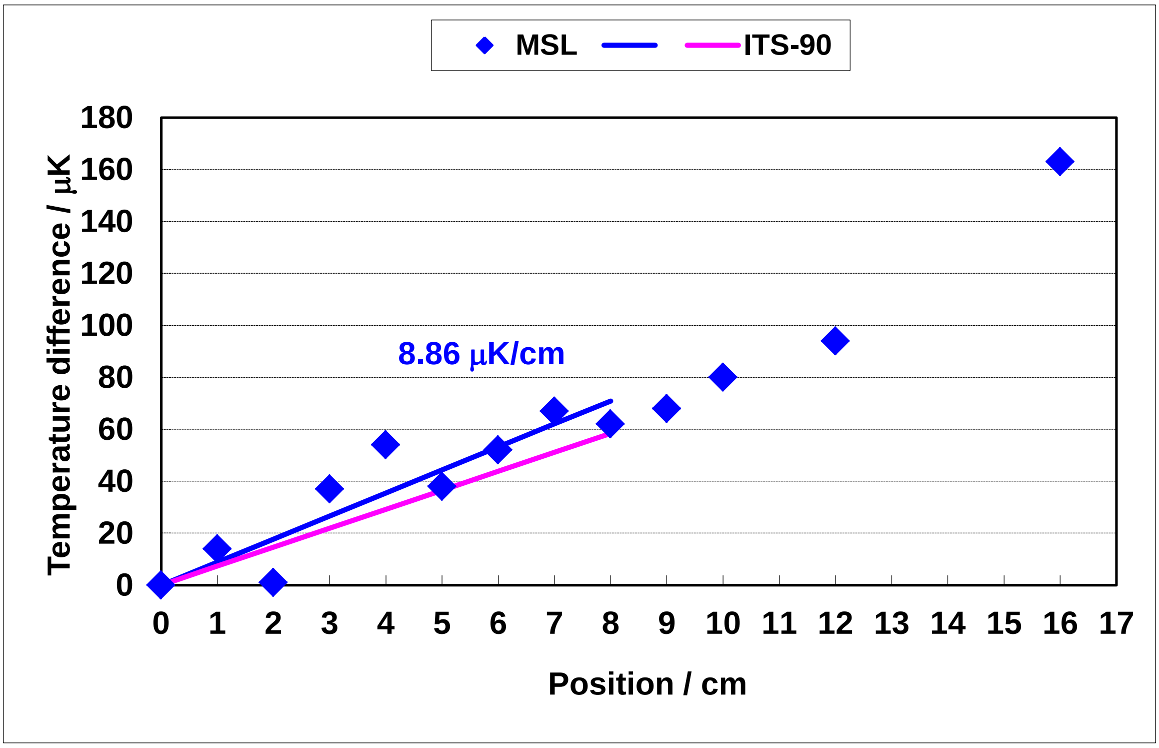
A4.7 SIRIM (Malaysia)

Distance from sensor midpoint to free surface level of the liquid water, (m)	Temperature variation, (mK)
0.000	0.000
0.015	0.099
0.030	0.130
0.045	0.034
0.060	0.148
0.075	0.168
0.090	0.171
0.105	0.346
0.120	0.345
0.135	0.302
0.150	0.425
0.165	0.334



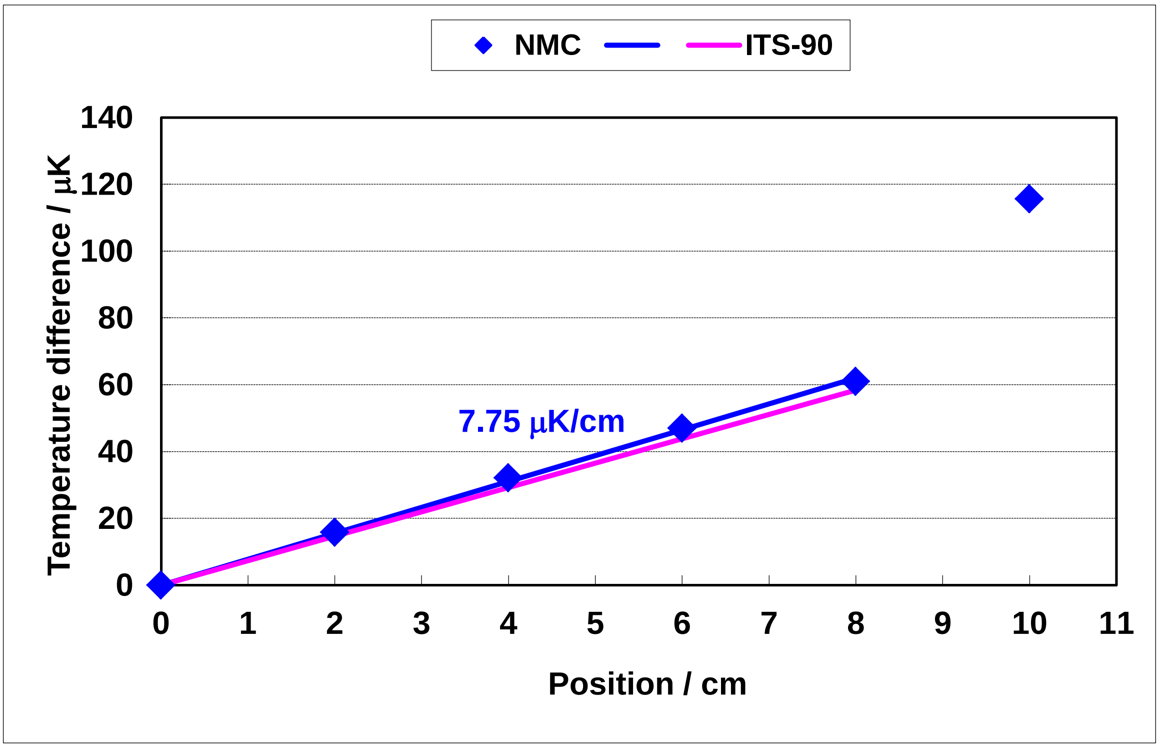
A4.8 MSL (New Zealand)

Distance from sensor midpoint to free surface level of the liquid water /mm	Temperature variation /μK
88	163
128	94
148	80
158	68
168	62
178	67
188	52
198	38
208	54
218	37
228	1
238	14
248(full immersion)	0



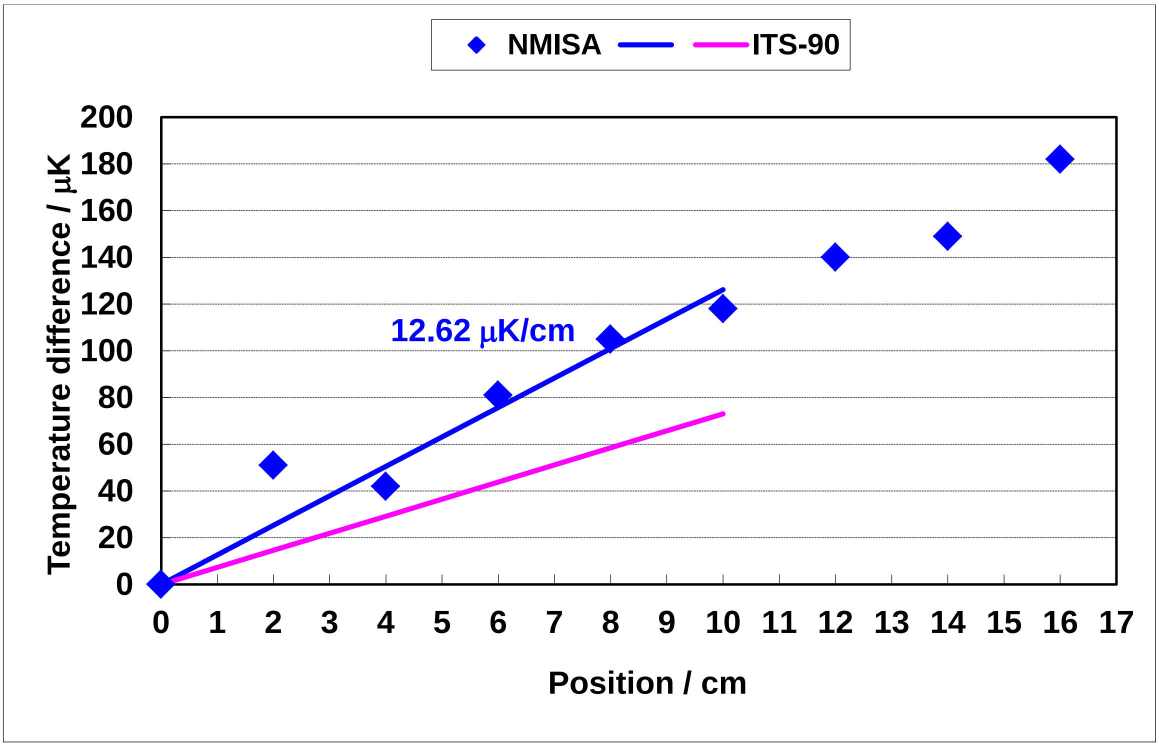
A4.9 NMC (Singapore)

Distance from sensor midpoint to free surface level of the liquid water (mm)	Temperature variation Relative to bottom data (μK)
258	0.0
238	15.8
218	32.1
198	47.0
178	61.0
158	115.7



A4.10 NMISA (South Africa)

Distance from sensor midpoint to free surface level of the liquid water (/mm)	Temperature variation ($/10^{-6}$ K)
231	0
211	51
191	42
171	81
151	105
131	118
111	140
91	149
71	182

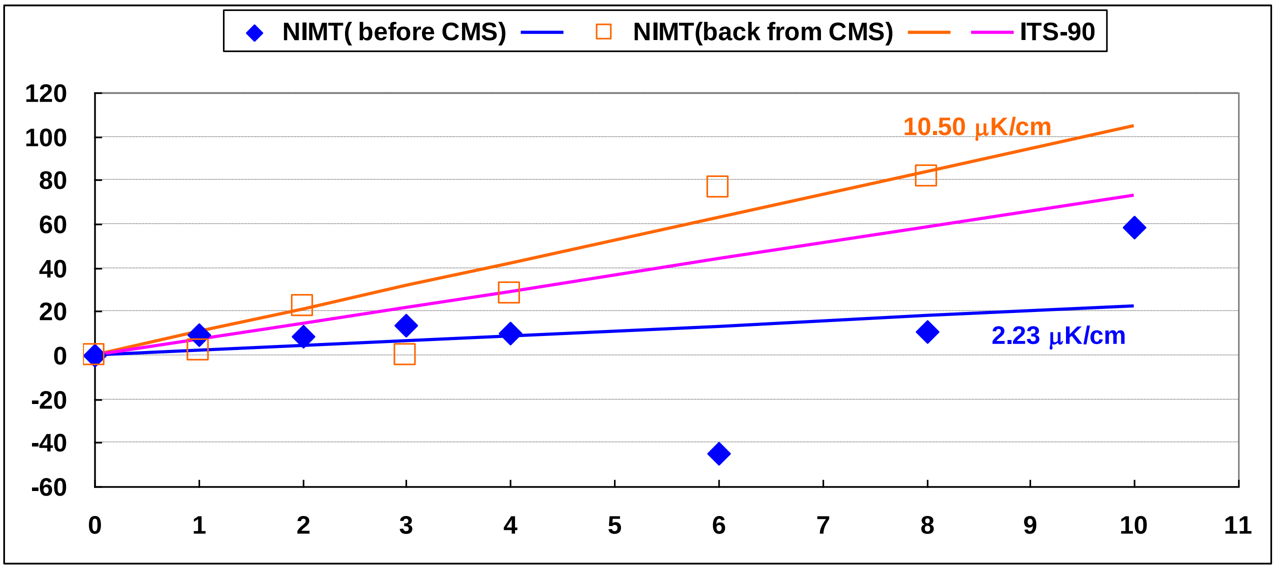


A4.11 NIMT (Thailand)

Distance from sensor midpoint to free surface level of the liquid water	Temperature variation
Bottom	0.00E+00
1 cm	9.40E-07
2 cm	9.00 E-07
3 cm	1.38 E-06
4 cm	9.80 E-07
6 cm	-4.50 E-06
8 cm	1.08 E-06
10 cm	5.88 E-06

Back from CMS

Distance from sensor midpoint to free surface level of the liquid water	Temperature variation
Bottom	0.00E+00
1 cm	1.90E-07
2 cm	2.22 E-06
3 cm	–
4 cm	2.85 E-06
6 cm	7.63 E-06
8 cm	8.15 E-06
10 cm	–



Appendix 5 Comparison of the transfer cell against national reference before sending to and back from CMS

	Before sending to CMS / • K	Back from CMS / • K	Deviation / • K
NMIA	-120.0	-104.9	+15.1
SCL	+11.0	+16.0	+5.0
KIM-LIPI	-187	in trouble with measurement system	
NMIJ	-71.0	–	≤10.0
KRISS	+15.0	+19.0	+4.0
SIRIM	-670.0	-701.0	-31.0
MSL	+2.4	did not indicate something odd	
NMC	-84.0	-90.0	-6.0
NMISA	-110.0	-115.0	-5.0
CMS	-1.5	+1.2	+2.7
NIMT	-114.25	-114.15	+0.1

Appendix 6 Additional explanation

1)KRISS cell

The original transfer cell KRISS2002-14 sent by KRISS in May 2008 was the same cell used in CCT-K7, unfortunately was broken during the normal practice on ice mantle preparation in CMS. The transfer cell KRISS2000-24 used in this comparison was fabricated at the same batch with the KRISS2002-14 cell, and was kindly delivered by KRISS in May 2009.

2)NMC data

NMC claimed to change data after Draft A, however through long discussion and checking on the evidence raised by NMC, the final decision made on Nov. 19, 2012 was not to accept NMC's request as the following:

After discussion between the pilot and copilots, it has become clear that sec. 4.7 in CIPM MRA-D-05, allows numerical changes only "on the basis of a clear failure of the traveling standard or some other phenomenon that renders the comparison or part of it invalid." This means that we cannot accept numerical corrections to data submitted prior to Report A being released to the participants, because no such failure or phenomenon has occurred.

NMC accepted this decision but requested that the file "Background information v2.docx" and the Email dated on 16 Dec 2011 shall be attached to the report as an appendix.

2)-1 **Background information v2.docx**

Background information to those who did not participate in the recent TCT meeting:

1. My ex-colleague Hao Yuan submitted the comparison report as per request. The part in question of this report is shown below:

Page: 4 of 7

Resulting temp. difference between transfer cell and national reference: -0.084
(Transfer cell measured temperature – National reference = -0.084mK)

Correction

Is the isotopic composition of the national reference analyzed? ■ Yes / □ No

Isotopic correction: -0.0015mK with uncertainty 0.02mK

Impurity, differences in filling correction: - 0.04mK with uncertainty 0.1mK

Added Description:

As a pilot, I confirmed both of the isotopic correction and impurity correction, which included the values and the calculation method, for each participant by Email.

Hao Yuan submitted a printed report as well as its e-file during the TCT meeting in Dec. 2009. At that time, I checked about the correction issue to his face, and his answer was just what I calculated as indicated in the following table (called Table 1 hereafter), and this is my first time to check the data with NMC.

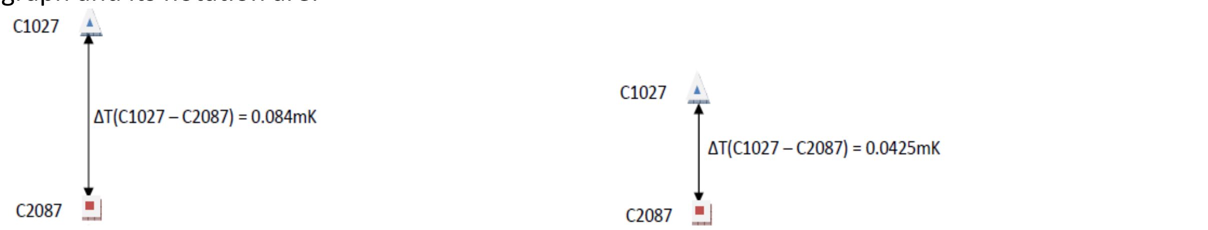
In view of the deadline was set on Nov. 23 2010, from almost the beginning to the end of Nov. 2010, I sent more than five mails to request Hao Yuan to confirm the data in Table 1, however he did not reply until 19 Jan. 2011.

2. The pilot sent an e-mail to Hao Yuan on 13 Nov 2011 for clarification of his submission and for a confirmation of the data processing she did for NMC. The part in question is as below:

Prior to CMS comparison	Measurement report form for APMP. T-K7
T(APMPTransfer2087)-T(NewNational1027)	-84 uK-1.5 μK-40 μK= **-125.5 μK** Uncertainty: **90 μK** Isotopic correction: -1.5 μK Impurity correction: -40 μK

Note that the pilot did the calculation T(APMPTransfer2087)-T(NewNational1027)= -84 uK-1.5 μK-40 μK= **-125.5 μK** and ask Hao Yuan for confirmation.

3. Hao Yuan did not reply until 19 Jan 2011 (the deadline was 23 Nov 2010). He said: “Attached is the comparison data of 3 cells (Cell1027-new national reference, Cell2087-transfer cell for APMP, Cell1300-old national reference for BIPM) before and after sending the transfer cell2087 to CMS. No significance difference between before and after, you may take the first report submitted as the final. I have put the relative difference of each cell in graphical format for easy understanding, so you will not confuse by whether to add or minus off the corrections.” The relevant part of this graph and its notation are:



Before C1027 corrected for isotopic & impurity Relative temperature difference between each cell: ΔT(C1027 – C2087) = 0.084mK (as reported)	After C1027 corrected for isotopic (-0.0015mK) & impurity (-0.04mK) (as reported) Relative temperature difference between each cell: ΔT(C1027 – C2087) = 0.0425mK

He did not show the detailed calculation, but it’s pretty clear that he calculated the difference in terms of C1027-C2087 as “0.084-0.0015-0.04=0.0425”, i.e. C2087-C1027=-0.0425. This is different with what the pilot did.

4. NMC did not receive further notice from the pilot until the draft A on 20 Nov 2011.

Added Description:

As the amended correction was received very later than the deadline, and especially was corrected in the inverse direction compared to the original one, I did not accepted this change and replied to NMC on 21 Jan 2011. Another point was that no changed was allowed after the deadline is to avoid affecting by any non-intentional disclosed information.

2)-2 the Email dated on 16 Dec 2011

Dear Ms Tsai and colleagues,

Thank you very much for your great efforts given to the K7. We thank you also for your time given to the discussion during the TCT meeting regarding the NMC issues. We have investigated the issues and here are our findings (the background information is attached for those who did not attend the TCT meeting):

1. In the NMC comparison report, a -0.04mK was reported as “impurity, differences in filling correction" with an uncertainty of 0.1 mK. We find that this is actually from a report of comparison between the Hart Scientific reference cell and our cell C1027 (the report is attached). Based on this comparison report, C1027 reads 0.04 mK higher than the ITS-90 definition. Therefore, after this correction C1027 shall read lower. From this point of view, Hao Yuan’s calculation is correct.

   Additional support to this finding is that in the NMC’s comparison report, under the uncertainty claim, it says:

Origin	Contribution (k=1) mK
National reference	
(Uncertainties related only to properties of the reference cell)	
Chemical impurities (please explain how estimated) Water chemical content analysis is not available and impurities is based on observation of melting curve and stability of plateau	0.020

   It’s clear that chemical impurity is not available.

   As a conclusion, the -0.04mK correction is not the correction due to the impurity. I think this will clear doubts of many of you.

   Now, it’s arguable if this correction should be applied. Hart agrees with us that we should not use the Hart comparison result to do the correction.

2. As for the isotopic correction of -0.0015mK, it’s from the Hart certification (the certification is attached). Confirmed with Hart, it means that the isotopic component will make our cell read lower by -0.0015mK. Therefore, after the correction, our cell shall read higher. For this correction, the pilot’s calculation is correct.

3. If we don’t apply the correction of -0.04 mK and only apply the correction of isotopic effect, the following parts of the draft A shall be amended:

   Page 61, the last row should be:

   “Impurity correction is not applied. The uncertainty of the effect is estimated to be 0.020 mK (k=1).”

   As a result, (TNMC2087 – Tnational ref.) should be -0.084mK - 0.0015mK = -0.0855 mK

   Page 16, Table 10, the third row from bottom.

   "-40" should be " - ".
   "-125.5" should be "-85.5".

   Page 18, Table 12, the fourth row from bottom.

   "+108.9" should be "+68.2".
   Because (85.5uK - 17.3uK = 68.2uK), and "-17.3uK" is indicated in table 9.

   The change will have no effect on APMP KCRV as NMC value was not counted.

4. Some information were missing in the previous NMC report (? in the draft A), they are:

   Page 6, "? (DC)" should be "MI6010A(DC)".

   Page 17, "Jarrett B11 1027 (?)" should be "Hart Scientific 5901D-Q 1027 (2006)"

5. The difference between the NMC BIPM ref and the NMC APMP ref is not relevant as the NMC BIPM ref was already drifted respected to the comparison result when the NMC APMP ref was purchased. Anyway, this has no effect at all as NMC is not used as linking laboratory. But it might be better to mention this it in the report. The value of the difference given now is misleading.

I hope I have made it clear and if you have anything needs further clarification, please let me know. We are very sorry about the mistakes we have made. Now the decision is yours.

Best regards,

Wang Li