CCT-K4.1 NMIA-NMIJ Bilateral Comparison at the Ag FP

Final report

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1. Introduction

The CCT-K4.1 was initiated by NMI of Australia (NMIA) to link their improved realisation of the Ag point to the CCT-K4 Ag results. At the time of the CCT-K4, NMIA (formerly CSIRO-NML) had only one silver cell and this cell was contaminated shortly after the CCT-K4. Subsequently, more silver cells were fabricated at different times to form an ensemble of five cells before the start of the K4.1. Every cell in the ensemble was periodically assessed by a cell-to-reference cell comparison using two identical heat pipe furnaces. Thus at a given time, the value of reference cell was tightly linked to the other four cells in the ensemble.

For the CCT-K4.1 bi-lateral comparison, NMIA was the pilot and the NMI of Japan (NMIJ) was the participant. A silver cell provided by NMIA and used as the artefact was circulated in accordance with the pilot-participant-pilot scheme. It is standard practice for NMIJ to use argon at 6N purity and NMIA argon 5N to regulate the pressure in the silver cell. To mitigate this, the effect of different argon purity was assessed in the post-circulation measurements. First the comparison was made (i) under argon 6N atmosphere to preserve the cell ambience after it left NMIJ then (ii) the measurement was repeated under 5N argon atmosphere. The lab-to-lab measurement circle was started in 2011 and completed in 2017.

To ensure blindness, results from each laboratories were protected by a password and submitted to the Chair of the APMP who, in turn, synchronised the release of the data submission.

Participants

Lab	Contact	Timeframe
National Measurement Institute of Australia (NMIA)	Mong-Kim Ho	2011
National Measurement Institute of Japan (NMIJ)	Dr Januarius V. Widiatmo	2012
National Measurement Institute of Australia (NMIA)	Mong-Kim Ho	2017

2. Artefact

The artefact used for this bilateral was an open silver cell Serial Number Ag2009/2 6N purity fabricated by NMIA.

Schedule	Particulars
Pre-circulation at NMIA	Under argon 5N atmosphere
Artefact at NMIJ	Under argon 6N
Post-circulation at NMIA	(i) Used at argon 6N, then
	(ii) Under argon 5N atmosphere

3. Measurement procedure

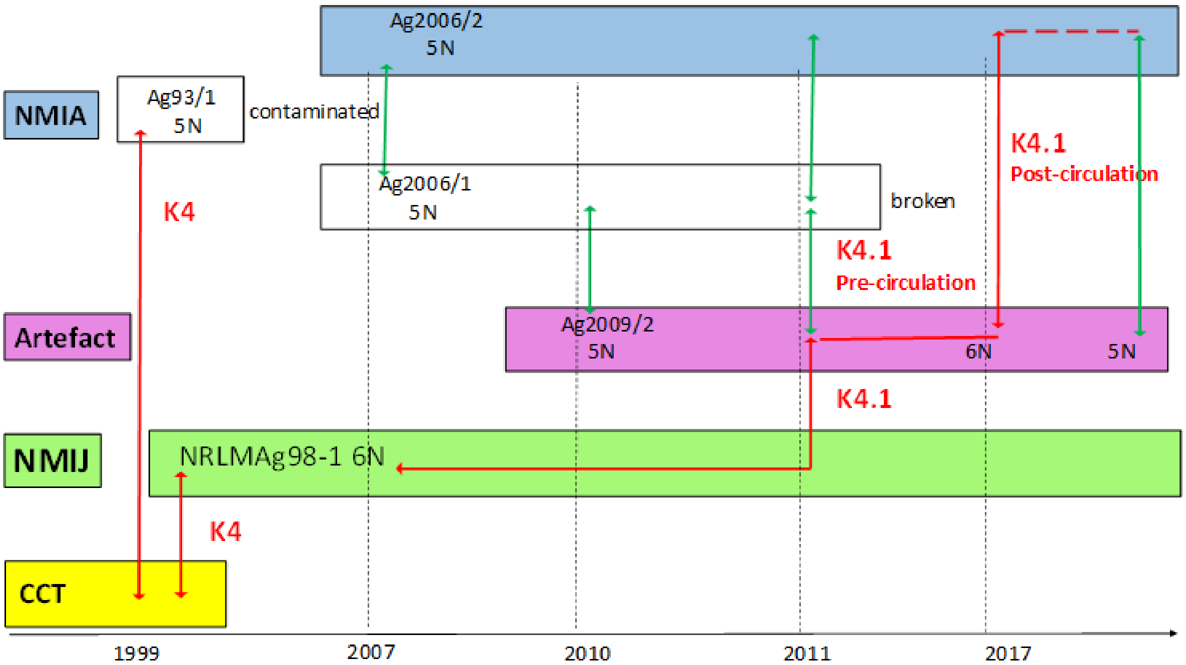
The artefact was calibrated by comparison with the NMIA reference Ag cell, both filled with Ar 5N, using at least two High Temperature SPRTs (HTSPRT) before being sent to NMIJ. After calibration by a similar fashion by NMIJ using Ar 6N, the artefact was again calibrated by NMIA with Ar 6N then with Ar 5N.

The status of the NMIA reference silver cell in the K4.1 and the 5N, 6N filling gas of the artefact are quite complex thus the whole process is best illustrated by using a schematic diagram as per Fig 1.

A little bit of history

For the CCT-K4, NMIJ used cell NRLMAg98-1 Argon 6N and NMIA cell Ag93/1 argon 5N. Shortly afterwards, NMIA embarked on a multiple-cell system for each fixed point, thus more silver cells were gradually produced and added to the ensemble. The ensemble is periodically assessed by comparing every cell in the ensemble with a reference cell in a cell-to-cell method, each cell was held in an identical heat pipe furnace. All measurements were done using an AC bridge. The first inter-comparison of the silver cell ensemble was conducted in 2007, using reference Ag2006/1. More silver cells were added for the second comparison in 2010 using the same reference cell. The third comparison was done in 2011, just before the start of the K4.1. The green lines in Fig.1 represent the cells involved in each of the NMIA silver cell inter-comparison that was performed at different times. Time scale is marked with the dashed black vertical lines.

Figure. 1: Summary of measurements performed by the NMIA and NMIJ for the K4.1. The red line illustrates the linking mechanism from K4.1 to CCT-K4 through the K4.1 artefact Ag2009/2. The stability of the artefact depicted by the green line is determined by measurements done in 2010, 2011 and 2017 with respect to the NMIA silver ensemble. The horizontal time axis is not to scale.



K4.1 circulation

The red lines in Fig. 1 demonstrate the linking mechanism from the CCT-K4 to the CCT-K4.1 via the artefact circulation.

3.1 Pre-circulation:

- At NMIJ: cell NRLMAg98-1 was used as the artefact for the CCT-K4 thus served as the link from CCT-K4 to the CCT-K4.1.
- At NMIA: Cell Ag2006/**2** and cell Ag2009/2 was compared with the reference cell Ag2006/**1** respectively in 2007 and 2010. Cell Ag2009/2 was later used as the artefact for the CCT-K4.1.

Note: NMIJ used argon 6N and NMIA used argon 5N for the pre-circulation measurements.

3.2 Artefact circulation:

- At NMIJ: Ag2009/2 was compared with NMIJ cell NRLMAg98-1.
- **3.3 Post circulation at NMIA**:From here on, the purity of the argon used to regulate the gas pressure inside a particular cell is given in bracket next to the cell S/No.
- As the artefact Ag2009/2 was slightly pressurised with argon 6N at ambient by NMIJ, its pressure *as-received* was checked by NMIA prior to measurements as stipulated by the protocol.
- The pressure of the artefact Ag2009/2 (Ar 6N) at ambient was (97.38 ± 0.02) kPa.
- Artefact Ag2009/2 (Ar 6N) was pumped to about 9 × 10^{-6} mbar at 300 °C and back-filled with argon 6N prior to the realisation of the Ag FP as per NMIA standard procedure.
- Reference cell Ag2006/**1** (Ar 5N) broke and the replacement cell Ag2006/**2** (Ar 5N) was assigned as the NMIA reference silver cell. The relationship between Ag2006/**1** (Ar 5N) and Ag2006/**2** (Ar 5N) had already been established by the 2007 ensemble measurement.
- The newly appointed reference cell Ag2006/2 (Ar 5N) was used to compare with Ag2009/2 (Ar 6N) as per protocol.
- Ag2009/2 (Ar 6N) was purged to about 2 × 10^{-6} mbar then re-filled with argon 5N and the comparison of Ag2009/2 (Ar 5N) with Ag2006/2 (Ar 5N) was conducted.

4. Data submission

Table 1 gives the average temperature difference Δ*T*(Transfer−Reference)/mK adjusted for self-heating and hydrostatic pressure applicable at each laboratory. Complete raw data submitted can be found in Appendix 2.

Table 1: Temperature difference Δ*T*(Transfer−Reference)/mK calculated from raw data submitted by NMIJ and NMIA, corrected for the effect of self-heating and hydrostatic pressure.

Lab	Reference	**Δ*T*(Transfer−Reference) /mK**	**U_{95} / mK**
NMIA-pre circulation	Ag2006/**1** argon 5N	1.83	4.92
NMIJ	Argon 6N	–2.01	2.79
NMIA-post circulation	Ag2006/**2** argon **6**N	–3.98	4.26
	Ag2006/**2** argon **5**N	–2.87	3.73

5. K4.1 data analysis

Glossary:

$NMIA_1$:	NMIA reference cell Ag2006/1 filled with argon 5N, broken in 2017
$NMIA_2$:	NMIA reference cell Ag2006/2 filled with argon 5N
NMIJ:	NMIJ reference cell NRLMAg98-1, undisturbed after being used as the reference for CCT-K4, realised under argon 6N.
R(xx):	Resistance obtained from Ag cell S/No xx
R_{TPW}:	Nominal resistance at the Triple Point of Water
$Arft_{6N}$:	K4.1 artefact S/No Ag2009/2 under argon 6N
$Arft_{5N}$:	Artefact pumped to remove argon 6N then filled with 5N argon for NMIA post-circulation
ΔT(NMIJ):	mK difference between NMIJ Ag temperature and artefact under argon 6N
ΔT(NMIA):	mK difference between NMIA Ag temperature and artefact under argon 6N
$\Delta T(NMIA_{5N})$:	mK difference between NMIJ Ag temperature and artefact under argon 5N

$\Delta T(\text{NMIA-NMIJ})_{K4.1}$: mK difference between NMIJ and NMIA Ag temperatures for the CCT-K4.1

dW/dT: Taken as 2.84×10^{-6} mK^{-1} at Ag FP temperature

5.1 K4.1 results using the post- circulation measurement

At NMIJ, the artefact was compared with NMIJ reference Ag cell, both under an atmosphere of argon 6N. The difference between the artefact/transfer cell to the NMIJ reference Ag cell is:

$$\Delta T(\mathrm{NMIJ}) = \frac{R(\mathrm{Arft_{6N}}) - R(\mathrm{NMIJ})}{R_{\mathrm{TPW}} \times \mathrm{d}W/\mathrm{d}T} \quad (1)$$

Immediately

$$\Delta T(\mathrm{NMIA}) = \frac{R(\mathrm{Arft_{6N}}) - R(\mathrm{NMIA_2})}{R_{\mathrm{TPW}} \times \mathrm{d}W/\mathrm{d}T} \quad (2)$$

Therefore: $\Delta T(\mathrm{NMIA} - \mathrm{NMIJ})_{\mathrm{K4.1}} = \frac{R(\mathrm{NMIA_2}) - R(\mathrm{NMIJ})}{R_{\mathrm{TPW}} \times \mathrm{d}W/\mathrm{d}T} = \Delta T(\mathrm{NMIJ}) -$

$$\Delta T(\mathrm{NMIA} - \mathrm{NMIJ})_{\mathrm{K4.1}} = \frac{R(\mathrm{NMIA_2}) - R(\mathrm{NMIJ})}{R_{\mathrm{TPW}} \times \mathrm{d}W/\mathrm{d}T} = \Delta T(\mathrm{NMIJ}) - \Delta T(\mathrm{NMIA}) \quad (3)$$

Table 2: The average Ag temperature difference between NMIA and NMIJ, and its corresponding expanded uncertainty (95% level of confidence and k = 2).

Quantity	Value / mK	U_{95}(k=2) / mK
ΔT(NMIJ)	–2.01	2.79
ΔT(NMIA)	–3.98	4.26
ΔT(NMIA-NMIJ)$_{\mathrm{K4.1}}$	**1.97**	**5.09**

Note: the uncertainty of ΔT(K4.1) includes the uncertainty of the purity of the cells.

5.2 Artefact stability

It is NMIA standard practice to periodically conduct an inter-comparison of every cell in the ensemble of a particular fixed point. Before the circulation of the K4.1 in 2011, cells NMIA$_2$ and Arft$_{5N}$ were compared against NMIA$_1$. After the circulation in 2017, the artefact Arft$_{5N}$ was compared against cell NMIA$_2$. Results from these two inter-comparisons were used to determine the stability of the artefact after circulation to NMIJ. The stability of NMIA$_1$ and NMIA$_2$ were determined from the inter-comparisons performed in 2007 and 2011.

Table 3: Artefact stability determination based on the NMIA 2011 and 2017 inter-comparison of the Ag ensemble. All cells were under argon 5N atmosphere.

Temperature difference ΔT / mK	**Value / mK**	**U_{95} (k=2) / mK**	**Reference cell S/No.**	**File Reference**
(NMIA$_2$ – NMIA$_1$)$_{2011}$	4.48	1.89	Ag2006/1	RN112072
(Arft$_{5N}$ – NMIA$_1$)$_{2011}$	1.83	3.57	Ag2006/1	RN112072
(Arft$_{5N}$ – NMIA$_2$)$_{2017}$	–2.87	1.40	Ag2006/2	RN170314
(Arft$_{5N2011}$– Arft$_{5N2017}$)	**0.22**	4.28	Ag2006/2	RN170314

The artefact has been kept intact since 2011, so we assumed that the artefact did not change throughout the lab circulation and we assigned the difference ΔT (Arft$_{5N2011}$ – Arft$_{5N2017}$) as the uncertainty U(ArtfStability) of our assumption.

Argon 5N versus argon 6N

The artefact was filled with argon 6N purity at NMIJ. Thus the first post-circulation NMIA measurement was performed with the artefact under argon 6N purity. Next, the artefact was evacuated to about 5×10^{-6} mbar then back-filled with argon 5N purity for the second post-circulation measurement. The NMIA reference silver cell for both measurements was under argon 5N.

Table 4: Effect of using argon 5N versus 6N

Temperature difference ΔT / mK	**Value / mK**	$U_{95}(k=2)$ **/ mK**	**Artefact status**	**Reference**
$(\mathrm{Arft}_{6N} - \mathrm{NMIA}_2)_{2017}$	–3.98	2.54	With 6N argon after returned from NMIJ	RN170314
$(\mathrm{Arft}_{5N} - \mathrm{NMIA}_2)_{2017}$	–2.87	1.40	argon 6N replaced by argon 5N	RN170314
$(\mathbf{Arft}_{6N} - \mathbf{Arft}_{5N})_{2017}$	**–1.11**	2.9	n/a	RN170314

As we are only interested in the difference, the uncertainties given in the 3rd column of Table 7 exclude the component due to the chemical impurity of the reference cell.

The difference between using argon 5N and 6N to regulate the pressure in the artefact was well within the uncertainty of the measurement. This difference is also very well in agreement with the 2 mK effect reported by G. Bongiovanni, L. Crovini and P. Marcarino, Metrologia **11,** 125-132 (1975).
We assigned the difference $(\mathrm{Arft}_{6N} - \mathrm{Arft}_{5N})_{2017}$ of –1.11 mK as the uncertainty for any inconsistency caused by using different argon purity.

5.3 Uncertainty of the K4.1 temperature difference between NMIA and NMIJ

$$U^2\{\Delta T(\mathrm{NMIA}-\mathrm{NMIJ})_{\mathrm{K4.1}}\} = [U^2\{\Delta T(\mathrm{NMIJ})\} + U^2\{\Delta T(\mathrm{NMIA})\} + U^2(\mathrm{ArftStability})] + U^2\{\Delta T(\mathrm{Ar6N}-5\mathrm{N})\} \quad (4)$$

Using the $U\{\Delta T(\mathrm{NMIA})\}$ and $U\{\Delta T(\mathrm{NMIJ})\}$values as submitted; the differences given in step 5.2 (artefact stability) and 5.3 (different argon purity) were treated as type-B rectangular distribution, namely 0.22 mK and 1.11 mK respectively. Furthermore, to be consistent with CCT-K4 (CCT-K4 report page 22), we excluded the standard uncertainty of the bridge readings at NMIJ in the calculation of $U^2\{\Delta T(\mathrm{NMIA}-\mathrm{NMIJ})_{\mathrm{K4.1}}\}$. Thus $U\{\Delta T(\mathrm{NMIA}-\mathrm{NMIJ})_{\mathrm{K4.1}}\} =$ 5.09 mK

6. NMIA CCT-K4.1 to the KCRV of the CCT-K4

The linkage from K4.1 to K.4 is via the participation of NMIJ in both comparisons. In general, the linkage mechanism from K4.1 NMIA Ag realisation to the CCT-K4 via the comparison with NMIJ is as follows:

$$\Delta T(\mathrm{NMIA}_{\mathrm{K4.1}} - \mathrm{KCRV}_{\mathrm{CCT-K4}}) = \Delta T(\mathrm{NMIA}_{\mathrm{K4.1}} - \mathrm{NMIJ}_{\mathrm{K4.1}}) + \Delta T(\mathrm{NMIJ}_{\mathrm{K4.1}} - \mathrm{NMIJ}_{\mathrm{CCT-K4}}) + \Delta T(\mathrm{NMIJ}_{\mathrm{CCT-K4}} - \mathrm{KCRV}_{\mathrm{CCT-K4}}) \quad (5)$$

where

$\Delta T(\mathrm{NMIA}_{\mathrm{K4.1}} - \mathrm{KCRV}_{\mathrm{CCT-K4}})$: mK difference between NMIA Ag temperature in the CCT-K4.1 to that of the KCRV of the CCT-K4

$\Delta T(\mathrm{NMIA}_{\mathrm{K41}} - \mathrm{NMIJ}_{\mathrm{K4.1}})$: mK difference between NMIA and NMIJ Ag temperature in the CCT-K4.1

$\Delta T(\mathrm{NMIJ}_{\mathrm{K4.1}} - \mathrm{NMIJ}_{\mathrm{CCT-K4}})$: ≡ 0 mK difference between NMIJ Ag temperature in the CCT-K4.1 to that of the CCT-K4. Since the same Ag cell S/No. NRLMAg98-1 was used for the CCT-K4 and the CCT-K4.1, we assumed that the cell remains unchanged and assigned an uncertainty for this assumption.

$\Delta T(\mathrm{NMIJ}_{\mathrm{CCT-K4}} - \mathrm{KCRV}_{\mathrm{CCT-4}})$ –2.74 mK ± 3.2 mK (k=2) difference between NMIJ Ag realisation in the CCT-K4 to that of the KCRV CCT-K4, as given in Table 8 Page 29 of [1].

Table 5: Temperature difference between the silver of NMIA K4.1 and the CCT-K4 KCRV.

Temperature difference	Value / mK	U_{95}(k=2) / mK
$\Delta T(\mathrm{NMIA}_{\mathrm{K4.1}} - \mathrm{KCRV}_{\mathrm{CCT\text{-}K4}})$	–0.78	6.22

7. Uncertainty of the K4.1 to K4 linkage

The uncertainty in the temperature difference $\Delta \mathrm{T}(\mathrm{NMIA}_{\mathrm{K4.1}} - \mathrm{KCRV}_{\mathrm{CCT-K4}})$ is as follows:

$$U^2\{\Delta T(\mathrm{NMIA}_{\mathrm{K4.1}} - \mathrm{KCRV}_{\mathrm{CCT-K4}})\}$$
$$= U^2\{\Delta T(\mathrm{NMIA}_{\mathrm{K4.1}} - \mathrm{NMIJ}_{\mathrm{K4.1}})\} + U^2\{\Delta T(\mathrm{NMIJ}_{\mathrm{K4.1}} - \mathrm{NMIJ}_{\mathrm{CCT-K4}})\}$$
$$+ U^2\{\Delta T(\mathrm{NMIJ}_{\mathrm{CCT-K4}} - \mathrm{KCRV}_{\mathrm{CCT-K4}})\} \quad (6)$$

where

$U\{\Delta T(\mathrm{NMIA}_{\mathrm{K4.1}} - \mathrm{KCRV}_{\mathrm{CCT-K4}})\}$ mK uncertainty of the difference between NMIA Ag temperature in the K4.1 to that of the KCRV K4.

$U\{\Delta T(\mathrm{NMIA}_{\mathrm{K4.1}} - \mathrm{NMIJ}_{\mathrm{K4.1}})\}$ mK uncertainty of the difference between NMIA Ag temperature in the K4.1 to that of the NMIJ K4.1.

$U\{\Delta T(\mathrm{NMIJ}_{\mathrm{K4.1}} - \mathrm{NMIJ}_{\mathrm{CCT-K4}})\}$ mK uncertainty in the assumption that cell NRLMAg98-1 has not changed from the CCT-K.4 to the K4.1

$U\{\Delta T(\mathrm{NMIJ}_{\mathrm{CCT-K4}} - \mathrm{KCRV}_{\mathrm{CCT-K4}})\}$ mK uncertainty of the difference between NMIJ Ag temperature to the KCRV value of the CCT-K4.

Correlation: Since NMIJ used the same silver cell in both the K4.1 and CCT-K4, any systematic errors that is expected to be constant between the K4.1 and K4 would be cancelled thus we only have to consider those that are expected to be different between the K4.1 and K4. Table 6 shows the correlated and uncorrelated uncertainty components where the correlated are excluded from the uncertainty of the linkage.

Table 6: Uncertainty components for NMIJ in the CCT-K4.1 and CCT-K4. **Correlated** components between the CCT-K4.1 and CCT-K4 in **bold** face are excluded from the uncertainty of the linkage from CCT-K4.1 to CCT-K4.

Uncertainty component / mK	***NMIJ K4**	**NMIJ K4.1**
Type A		
repeatability of bridge readings	0.70	-
degree of freedom	8	-
repeatability of temperature differences	-	0.32
degree of freedom	-	3
Type B		
hydro static head	0.02	-
SPRT self-heating	0.06	0.18
immersion	**0.25**	**0.27**
gas pressure in cell	0.01	0.03
chemical impurities	**0.79**	**0.79**
Plateau reproducibility	-	0.44
bridge measurement error	0.081	0.17
choice of freezing pt value		0.58
SPRT leakage effect/drift	1.15	0.48
temperature drift propagation from TPW		
Total Type B uncertainty u_B	1.42	1.15
Expanded uncertainty *U*(*k*=2)	**2.92**	**2.49**
Expanded $U_{\text{correlated}}$ (k=2)	1.66	1.67
Expanded $U_{\text{uncorrelated}}$ (k=2)	1.18	0.81

* From Table 6 Page 21 of [1]

Uncorrelated uncertainty of the K4.1 to CCT-K4 linkage is the quadrature sum of the two values:

$$\boldsymbol{U(\mathrm{NMIJ_{K4.1}} - \mathrm{NMIJ_{CCT-K4}})_{\mathrm{uncorrelated}} = 1.43\ \mathrm{mK}\,,\ k = 2}$$

8. Bilateral differences

The bilateral difference $\Delta T(\mathrm{NMIA_{K4.1}}–\mathrm{Lab_{CCT\text{-}K4}})$ is calculated as follows:

$$\Delta T(\mathrm{NMIA_{K4.1}} - \mathrm{Lab_{CCT-K4}}) = \Delta T(\mathrm{NMIA_{K4.1}} - \mathrm{NMIJ_{K4.1}}) + \Delta T(\mathrm{NMIJ_{K4.1}} - \mathrm{NMIJ_{CCT-K4}}) + \Delta T(\mathrm{NMIJ_{CCT-K4}} - \mathrm{Lab_{CCT-K4}}) \quad (7)$$

with an uncertainty of

$$U^2\{\Delta T(\mathrm{NMIA_{K4.1}} - \mathrm{Lab_{CCT-K4}})\} \\ = U^2\{\Delta T(\mathrm{NMIA_{K4.1}} - \mathrm{NMIJ_{K4.1}})\} + U^2\{\Delta T(\mathrm{NMIJ_{K4.1}} - \mathrm{NMIJ_{CCT-K4}})\} \\ + U^2\{\Delta T(\mathrm{NMIJ_{CCT-K4}} - \mathrm{Lab_{CCT-K4}})\} \quad (8)$$

where

$\Delta T(\mathrm{NMIA_{K4.1}} - \mathrm{Lab_{CCT-K4}})$ mK temperature difference between NMIA K4.1 and a particular participant in the CCT-K4.

$\Delta T(\mathrm{NMIJ_{CCT-K4}} - \mathrm{Lab_{CCT-K4}})$ mK temperature difference between NMIJ K4 and a particular participant in the CCT-K4.

$U\{\Delta T(\mathrm{NMIA_{K4.1}} - \mathrm{Lab_{CCT-K4}})\}$ mK expanded uncertainty of the silver temperature difference between NMIA K4.1 and a particular participant in the CCT-K4

$U\{\Delta T(\mathrm{NMIJ_{CCT-K4}} - \mathrm{Lab_{CCT-K4}})\}$ mK expanded uncertainty of the silver temperature difference between NMIJ K4.1 and a particular participant in the CCT-K4

The bilateral differences between NMIJ and participants of the CCT-K4 and their associated expanded uncertainties given in Table 10 Page 31 of [1] are reproduced here in Table 7. Subsequently, the bilateral differences between NMIA (in the K4.1) and participants of the CCT-K4 and their corresponding expanded uncertainties are computed and presented in Table 8.

Table 7: Bilateral differences between NMIJ and participants of the CCT-K4 and their corresponding expanded uncertainties U_{95} at k=2.

Participant	$\boldsymbol{\Delta T(\mathrm{NMIJ_{CCT-K4}} - \mathrm{Lab_{CCT-K4}})}$ **/ mK**	$\boldsymbol{U\{\Delta T(\mathrm{NMIJ_{CCT-K4}} - \mathrm{Lab_{CCT-K4}})\}}$ **/mK**
BNM/INM	–0.05	4.65
IMGC	–3.59	4.35
KRISS	–3.49	4.07
NIM	0.29	7.01
NIST	–3.90	3.52
NMi/VSL	4.38	5.39
NML/NMIA*	10.30	13.3
NPL	1.15	4.03
NRC	–3.97	6.06
PTB	–4.01	3.62
VNIIM	–0.58	4.19

*Name changed to NMIA in 2004

Table 8: Bilateral differences between NMIA in the CCT-K4.1 and participants of the CCT-K4 and their corresponding expanded uncertainties U_{95} at k=2.

Participant	$\Delta T(\mathbf{NMIA_{K4.1}} - \mathbf{Lab_{CCT-K4}})$ / mK	$U\{\Delta T(\mathbf{NMIA_{K4.1}} - \mathbf{Lab_{CCT-K4}})\}$ / mK
BNM/INM	1.91	7.04
IMGC	–1.63	6.85
KRISS	–1.53	6.68
NIM	2.25	8.78
NIST	–1.94	6.36
NMi/VSL	6.34	7.55
NPL	3.11	6.65
NRC	–2.01	8.05
PTB	–2.05	6.41
VNIIM	1.38	6.75

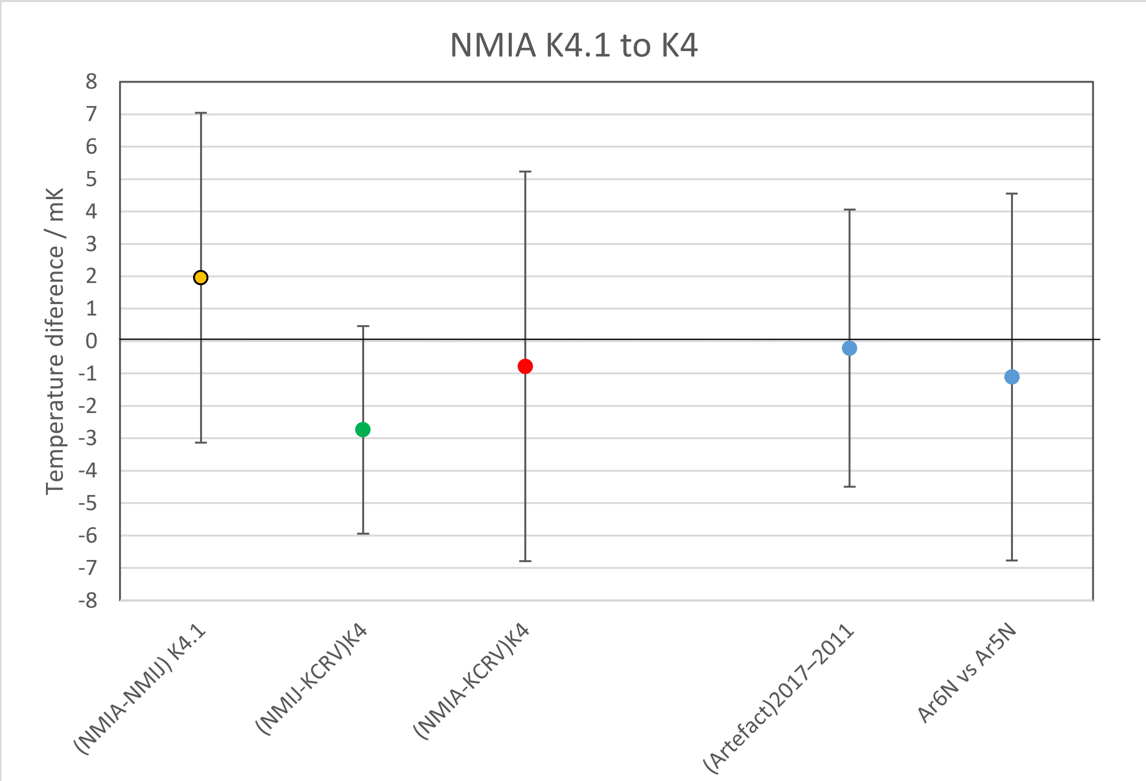


Figure 2: K4.1 relatively to the CCT-K4 results where the errors bars are the expanded uncertainties (k=2). For illustration purposes, the stability of the artefact and the effect of using argon 5N versus are also plotted on the same graph.

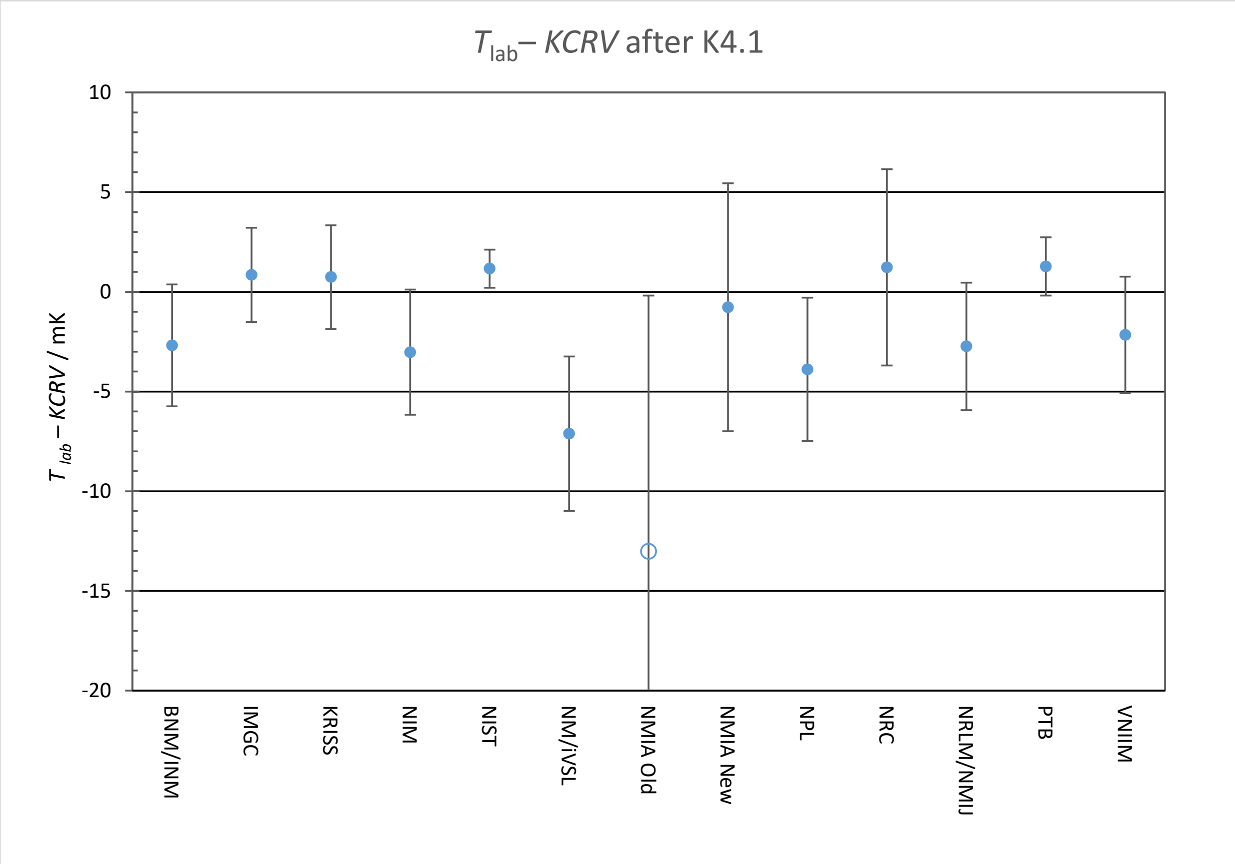


Figure 3: Differences T_{lab} – KCRV at the silver fixed point. The error bars are the expanded uncertainties (k=2) of the differences. This graph is reproduced from the Fig. 10 Page 27 of [1], with the new value for the difference T_{NMIA}–KCRV added.

REFERENCE

1. H .G Nubbemeyer and J. Fisher: Report to the CCT on Key Comparison 4 – Comparison of Local Realisation of Aluminium and Silver Freezing-Point Temperature – CCT-K4 01/29/2002

Appendix 1: Protocol of the CCT-K4.1

INTRODUCTION

In 1998-2000, a key comparison for the Al and Ag realisation, CCT-K4, coordinated by the Physikalisch-Technische Bundesanstalt (PTB) with 11 other participants was carried out. The silver cell used by NMIA for this CCT-K4 was broken before direct comparison with other Ag cells at NMIA commenced. The uncertainty of an indirect link to NMIA's new Ag cells, via 0.25-ohm HTSPRT measurements, was limited by the stability of the HTSPRTs used. NMIA has now made and directly compared five silver cells, with known purity, that form the NMIA Ag cell ensemble. NMIA wishes to reduce the uncertainty of the linkage from this ensemble to the CCT-K4 KCRV by a direct bilateral comparison with NMIJ where information for a direct linkage from the present NMIJ Ag realisation to the CCT-K4 is available. The NMIJ result in CCT-K4 was TNMIJ-TKCRV= **–2.74 ± 3.29** mK, which should be suitable for NMIA's linkage purposes for supporting NMIA's a reduction of NMIA CMCs, currently at 14 mK, to a desired **4** mK.

NMIA has constructed an Ag point cell to be used as the transfer cell. Each participant will use at least two SPRTs to measure the temperature difference between the transfer cell and the local reference Ag point cell. Two identical furnaces will be used to allow for direct cell comparisons without cooling the SPRT to ambient. The major uncertainty terms associated with the transfer will be estimated based on experimental data from:

- The use of at least two SPRTs (to assess possible leakage effects)
- Measurement of 3 mantles (to assess mantle repeatability)
- Several measurements on each mantle (to assess type-A component and repeatability)
- Immersion profiles (to assess conduction errors).
- Measurements of the transfer after being returned from NMIJ (confirm cell stability)

As NMIA intends to use the comparison to improve its results in the CCT-K4, the initial and final NMIA measurement results will be sent to NMIJ prior to NMIJ sending their results to NMIA. This will ensure that the comparison satisfies the MRA guidelines for the comparison being "blind".

Upon receiving the NMIJ results, NMIA will analyse and report the comparison results**. NMIJ will review the raw data used in the report and analysis, to confirm that they are the same as the data submitted to NMIJ prior to NMIA seeing the NMIA data.**

2. TRANSFER CELL

The transfer cell details are as follows:
S/No: Ag2009/2
Type: Open cell
Manufacturer: NMIA
Cell dimension: 620 mm high × 50 mm outer diameter
Thermometer well: **7.5 mm** ID, 610 mm deep
Graphite crucible: 300 mm high
Immersion: 249 mm
Description: A 300 mm high graphite crucible with approximately 1.9 kg silver metal is placed in a protecting quartz tube of approximately 620 mm in length and 50 mm in diameter. The protecting quartz tube is closed off with a stainless steel cap containing an exhaust-port for gas exchange. The gas port is fitted with a Swagelok valve.
The cell is packed in a custom-made carrying case to be hand-carried between participating labs, dimension 193 × 163 × 747 mm. The cell/carrying case total weight is 9 kg. An ATA Carnet is

provided for the import/export of the transfer cell. The transfer cell is also referred to as the **artefact**

3. SCHEDULE

Participants are expected to perform their measurements over a 4-week period plus 2 weeks for transport of the artefact to the next laboratory. In order to ensure that the comparison proceeds as quickly as possible, it is **essential** that the laboratories have already identified at least two stable HTSPRTs to be used in this comparison prior to receiving the silver cell artefact. Following is the proposed schedule:

Table 1: Circulation schedule.

Date	Laboratory
Mar 2011	NMIA initial measurements
Mid-Feb 2012	to NMIJ
Sept 2012	NMIJ measurements
Mid Jan 2013	Back to NMIA
Mar 2013	NMIA final measurements
May 2013	NMIA prepares report

Contact details:

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4. EQUIVALENCE AND LINKAGE TO CCT-K4

- The protocol follows the same methodology as the CCT-K4.
- NMIJ, the linking laboratory, will be asked to provide information allowing the linkage of their present Ag cell realisation to that achieved in the CCT-K4, and this information will be incorporated into the final report.

5. DETAILED INSTRUCTIONS

5.1. NMIJ and NMIA identify at least two suitable and sufficiently stable SPRTs of their choice of same or different types of SPRTs. To minimise conduction error caused by radiation, it is recommended that the SPRTs chosen should provide a close fit in the thermometer well. The SPRTs should also be thermally stable, this could be tested by cycling the SPRTs between ambient and the Ag FP temperature several times, checking (i) their electrical leakage at the Ag temperature and (ii) their Water Triple Point Resistances R(TPW) after each thermal excursion then select the most stable SPRTs to use for this bilateral comparison.

Instructions for NMIA prior to despatching the transfer cell

5.2. Balance the furnaces for the realisation of the **transfer** cell and NMIA **reference** silver cell. The furnaces should be controlled so that the cells do **not** melt from bottom that could lead to breakage.

5.3. Assess conduction errors for each SPRT in each cell (measure R at bottom, 20 mm, 40 mm and 60 mm from the bottom and return to bottom).

5.4. Measure one complete freezing and melting curve for each cell.

5.5. Freeze one cell after the other, staggering to ensure that self-heating-corrected measurements can be taken at *approximately* the maximum, 40% and 60% of the freezing curve obtained from each cell. The maximum values are to be used for comparison purposes and the remaining data are for extra information

5.6. Use argon gas to maintain the pressure of both the NMIA Ag reference and the transfer cell at ~0.5 kPa above atmospheric pressure..

Note: NMIA uses **argon 5N** purity to regulate the pressure of Ag reference and transfer cells,

5.7. Melt both cells and repeat step 5.5 two more times, **using at least one different SPRT.**

5.8. Cool the transfer cell and pressurise to approximately 5 kPa of argon above atmospheric pressure.

5.9. Advise NMIJ that the cell is ready to be collected.

Instructions for NMIJ upon receipt of the transfer

5.10. Visually inspect the artefact for damage and email NMIA to confirm the cell arrived undamaged.

5.11. Connect a pressure gauge to the cell and confirm that the cell still maintains a **slight overpressure** of argon then pump the transfer to remove argon 5N filled by NMIA

Note: NMIJ uses **argon 6N** purity.

5.12. Circulate argon through the transfer cell such that the argon gas pressure is slightly above 1 atm when the cell is melting. **Slowly** increase (~ 4 °C per minute) the cell temperature until it is 5 °C below the freeze.

5.13. Ensure that the furnace is balanced so that the cell does not melt from the bottom that could break the cell. When the furnace is balanced, melt the cell as per local practice. The cell is now ready to be used.

5.14. Follow steps 5.3 to 5.7. Send the first freezing/melting curve of the transfer cell to NMIA to confirm suitability.

5.15. When measurements are concluded, ensure that the transfer cell is completely frozen before slowly cooling the transfer cell over several hours to ambient temperature, then pressurise it with argon 6N to approximately 5 kPa above atmospheric pressure.

5.16. Advise NMIA to collect the transfer cell.

Instructions for NMIA after transfer cell is returned

5.17. Inspect the transfer for any damage.

5.18. Connect a pressure gauge to the transfer cell and confirm that it still maintains a **slight overpressure** of argon (**6N argon** to be used).

5.19. Follow step 5.5 three times to obtain data from 3 mantles (6N argon).

5.20. Pump the transfer cell to replace argon 6N filled at NMIJ by argon **5N**.

5.21. Allow cell to remain molten for several days at the new gas purity.

5.22. Follow step 5.5 three times to obtain data from 3 mantles (5N argon).

Exchange of data

5.23. Send the initial and final measurement data and uncertainty analysis to NMIJ

5.24. After receipt of the NMIA initial and final results and uncertainties, NMIJ to send their results to NMIA.

NMIJ to also provide:

- **Details of any assigned correction to the temperature of the NMIJ reference cell (eg impurity, 1/F extrapolation etc.)**
- **Additional information giving details of the relationship between their present Ag realisation and that used in CCT-K4.**

Possible effect of argon 5N and 6N on the comparison:

The standard NMIA Ag procedure is to use 5N purity Ar gas, whereas the standard NMIJ procedure is to use 6N purity. Reference [1] suggested that the effect of using argon 6N instead of 5N on the Ag temperature is less than 2mK FP depression for 0.1% (1000ppm) oxygen impurity in argon. The expected difference between 5N and 6N is thus insignificant. However, the additional measurements (steps 5.20 to 5.23) to be performed at NMIA after the return of the transfer cell will be used to determine an additional uncertainty estimate, to be added to the uncertainty of the transfer cell.

6. Data submission

Comparison	Ag Bilateral		Lab	

HTSPRT	Serial#	Type	nominal R0	sensor length
HTSPRT1				
HTSPRT2				
HTSPRT3				
	Serial #	Type	Current	
Bridge				
Resistor				
Silver cell	S/No	Purity	Source	mm immersion
Reference				
Transfer				

Data

Ar purity	

Date	HTSPRT	FP Cell	DataFile	R(0mA)/ Ω	ΔR(Lab-Ref)/	Comment
Date	# 1	Ref	Mantle1.1			Max
		Transfer	Mantle1.2			
		Ref	Mantle1.3			40%
		Transfer	Mantle1.4			
		Ref	Mantle1.5			60%
		Transfer	Mantle1.6			
Date	# 2	Ref	Mantle2.1			
		Transfer	Mantle2.2			
		Ref	Mantle2.3			
		Transfer	Mantle2.4			
		Ref	Mantle2.5			
		Transfer	Mantle2.6			
Date	#3	Ref	Mantle3.1			
		Transfer	Mantle3.2			
		Ref	Mantle3.3			
		Transfer	Mantle3.4			
		Ref	Mantle3.5			
		Transfer	Mantle3.6			

Tracking hydrostatic

	HTSPRT1		HTSPRT2		HTSPRT3	
From bottom /cm	Ref cell R(0mA)/Ω	Transfer cell R(0mA)/Ω	Ref cell R(0mA)/Ω	Transfer cell R(0mA)/Ω	Ref cell R(0mA)/Ω	Transfer cell R(0mA)/Ω
0						
1						
2						
4						
6						

Table 1: Comparison data

7 UNCERTAINTIES

Uncertainty due to the Local Reference cell:

- Cell impurity
- Conduction error: Deviation from the theoretical dT/dh
- Hydrostatic head correction
- Self-heating correction
- Gas Pressure

Uncertainty due to the Transfer cell

- Conduction error: Deviation from the theoretical dT/dh
- Hydrostatic head correction
- Self-heating correction
- Gas pressure

Uncertainty in the difference

- Differential linearity of the bridge
- Type-A: (eg electrical leakage and noise: standard deviation of the mean of n differences), choice of maximum, or as determined by local practice.
- Fixed point realisation (flatness of the freezing curves)

- Stability of the HTSPRT
- Rounding
- Others:

In the analysis of the data, the pilot laboratory will add the terms for:

- Reproducibility, if any, of the transfer cell
- Uncertainty in the realised transfer cell temperature due to purity of argon gas.
- Uncertainty of transfer cell's temperature difference to the CCT-KC4 reference value.

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8 REFERENCE

[1] G. Bongiovanni, L. Crovini and P. Marcarino, Metrologia **11,** 125-132 (1975)

Appendix 2: NMIJ data and uncertainty submission

Table 1: Comparison data

Comparison	Ag Bilateral	Lab	NMIJ

HTSPRT	Serial#	Type	nominal R0	sensor length
HTSPRT1	1120	quartz	0.25	32 mm (697 mm sheath)
HTSPRT2	BTC337	quartz	0.6	53 mm (665 mm sheath)
HTSPRT3	1112	quartz	0.25	26 mm (697 mm sheath)
	Serial #	**Type**	**Current**	
Bridge	TTI3	DC	10, 10√2 mA	
Resistor	274443, 279586	temperature controlled		
Silver cell	**S/No**	**Purity**	**Source**	**mm immersion**
Nat. Std.				
Reference	NRLM Ag 98-1	6N	NMIJ	214
Transfer	Ag2009/2	open	NMIA	249

Data

Date	HTSPRT	FP Cell	DataFile	R(0mA)/Ω	ΔR(Transfer-Ref)/Ω	Comment
2012/12/12	#1	Ref Transfer	Mantle1.1 Mantle1.2	1.07825794 1.07825695	-9.9E-07	Max
2012/12/13	#1	Ref Transfer	Mantle2.1 Mantle2.2	1.07825997 1.07825915	-8.2E-07	Max
2012/12/18	#2	Ref Transfer	Mantle3.1 Mantle3.2	2.55408400 2.55407978	-4.22E-06	Max
2012/12/19	#2	Ref Transfer	Mantle3.1 Mantle3.2	2.55408467 2.55408097	-3.7E-06	Max

*) Values at the bottom of the re-entrant tube

Tracking hydrostatic

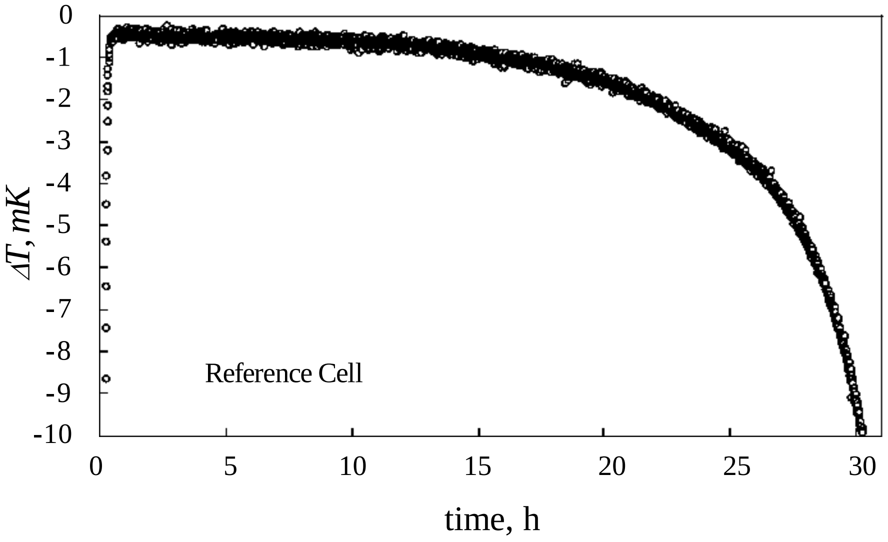
HTSPRT1 HTSPRT2 HTSPRT3

From bottom /cm	HTSPRT1 Ref cell R(0mA)/Ω	HTSPRT1 Transfer cell R(0mA)/Ω	HTSPRT2 Ref cell R(0mA)/ Ω	HTSPRT2 Transfer cell R(0mA)/ Ω	HTSPRT3 Ref cell R(0mA)/ Ω	HTSPRT3 Transfer cell R(0mA)/ Ω
0.2		1.07825631			1.09186973	
2		1.07825634			1.09186970	
4		1.07825601			1.09186970	
6		1.07825555			1.09186926	

Additional Information

1. NMIJ does not introduce any correction in this comparison to the reference cell.
2. The local realization of the silver point in this comparison was performed using cell NRLM Ag 98-1, which is the link cell to CCT-K4 (see: Nubbemeyer, H. G., Fischer, J., *Metrologia* **39**, Tech. Suppl. 03001 (2002)).
3. Two identical heat-pipe furnaces were used for realizing silver point; one for the reference and one for the transfer cells. The resistance measurements in this comparison were performed using a DC type resistance bridge around the maximum point of the freezing plateau of each cell.

Freezing Curve of the Reference Cell (NRLM Ag 98-1)



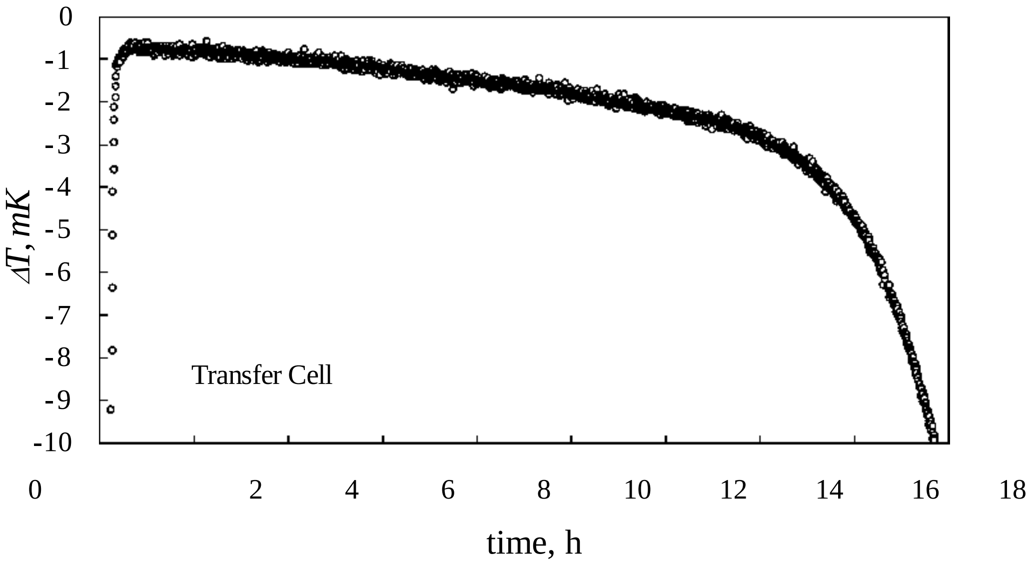
Uncertainties

Table 2: List of Uncertainties*)

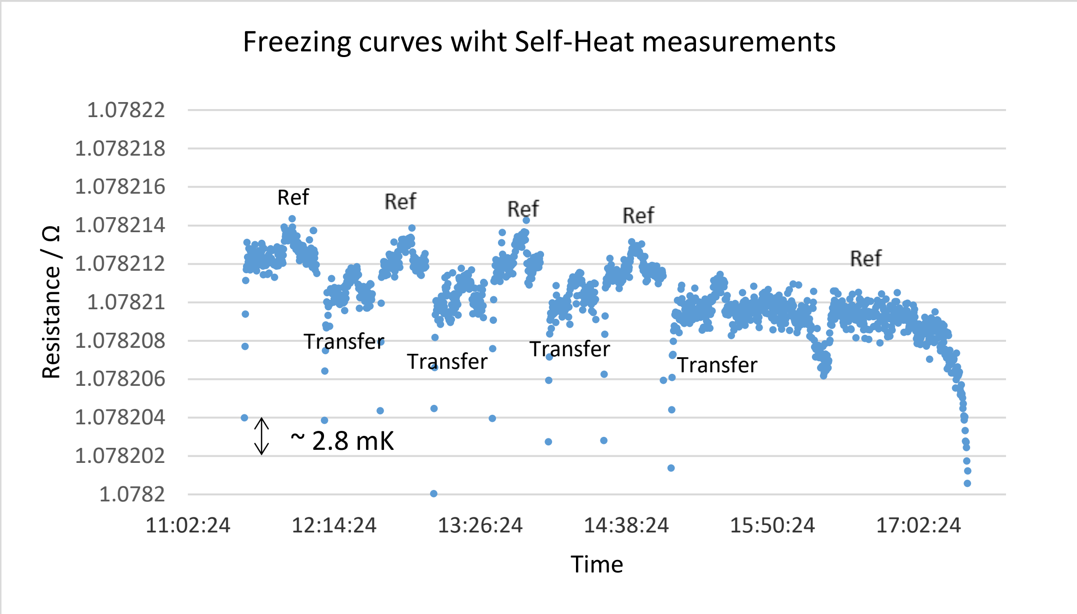
1	Uncertainty due to Local Reference Cell	
	Plateau Reproducibility	0.44
	Chemical Impurities	0.79
	Choice of Freezing-point Value	0.58
	Gas Pressure	0.03
	Thermal Immersion Uncertainty	0.27
	Self-Heating Correction Uncertainty	0.18
	Sub Total	1.12
2	Uncertainty due to Transfer Cell	
	Thermal Immersion Uncertainty	0.56
	Self-Heating Correction Uncertainty	0.09
	Sub Total	0.57
3	Uncertainty in Temperature-Difference	
	Resistance Measurement System Uncertainty	0.17
	Short-term Stability of Thermometer	0.48
	Repeatability of Temperature-Difference	0.32
	Sub Total	0.60
	Combined Uncertainty	1.40
	Expanded Uncertainty (k=2)	2.79

*) Values are in mK

Freezing Curve of the Transfer Cell (Ag2009/2)



Appendix 3: NMIA data and uncertainty submission.



Comparison CCT-K4.1		**Ag bilateral**		NMIA			
Before circulation							
HTSPRT	S/No	Type	Nominal R	Sensor/mm	From tip/mm		
1	1121	Hart 5684	0.25	35	10		
2	84012	NIM	0.25	50	5		
3	RS25A-3	Chino	2.5	45	15		
Bridge	S/No	Type	Current				
	F18/2	F18	10				
	F18/3	F900	5				
Resistor	42331	1 ohm	10				
	37095	1 ohm	10				
	62657	10 ohm	5				
Ag cell	S/No	Purity	Source	Height / mm		W	4.286
Reference	**Ag2006/1**	6	Honeywell	245.5		dT/dh	0.0054
Transfer	Ag2009/2	6	Honeywell	252.5		dW/dT 1E-6/mK	2.84
Ar purity	**5N**	**Before Circulation**					

Date	**HTSPRT**	**FP cell**	**Datafile**	**R(0mA)/Ω**	**ΔR(Transfer-Ref) /Ω**	**ΔT(Transfer-Ref) /mK**	**Comment**
10/02/2011	**84012**	**Ag2006/1**	**0211_1066**	**1.09688604**			
	84012	Ag2009/2	0211_1066	1.096887057	1.02E-06	1.399	
11/02/2011	**84012**	**Ag2006/1**	**0211_1067**	**1.096886943**			
	84012	Ag2009/2	0211_1067	1.096889032	2.09E-06	2.874	
24/02/2011	**1121**	**Ag2006/1**	**0211_1089**	**1.061865021**			
	1121	Ag2009/2	0211_1089	1.061865277	2.56E-07	0.364	
	1121	Ag2006/1	0211_1089	1.0618638			
	1121	Ag2009/2	0211_1089	1.061864399	5.99E-07	0.851	
	1121	Ag2006/1	0211_1089	1.061862857			
	1121	Ag2009/2	0211_1089	1.061863895	1.038E-06	1.475	
	1121	Ag2006/1	0211_1089	1.061863435			
	1121	Ag2009/2	0211_1089	1.061863739	3.04E-07	0.432	
25/02/2011	**1121**	**Ag2006/1**	**0211_1091**	**1.061862712**			
	1121	Ag2009/2	0211_1091	1.06186304	3.28E-07	0.466	
	1121	Ag2006/1	0211_1091	1.061862339			
	1121	Ag2009/2	0211_1091	1.061862957	6.18E-07	0.878	
	1121	Ag2006/1	0211_1091	1.061861502			
	1121	Ag2009/2	0211_1091	1.0618616	9.8E-08	0.139	
	1121	Ag2006/1	0211_1091	1.061860501			
	1121	Ag2009/2	0211_1091	1.061861138	6.37E-07	0.905	
1/03/2011	**84012**	**Ag2006/1**	**0311_1096**	**1.096889664**			
	84012	Ag2009/2	0311_1096	1.096891045	1.381E-06	1.900	
	84012	Ag2006/1	0311_1096	1.096893484			
	84012	Ag2009/2	0311_1096	1.096891548	-1.936E-06		Near end
	84012	Ag2006/1	0311_1096	1.096891798			
	84012	Ag2009/2	0311_1096	1.096889098	-2.7E-06		End of freeze
2/03/2011	**84012**	**Ag2006/1**	**0311_1102**	**1.096880849**			
	84012	Ag2009/2	0311_1102	1.096882617	1.768E-06	2.433	
	84012	Ag2006/1	0311_1103	1.096897816			
	84012	Ag2009/2	0311_1103	1.096897432	-3.84E-07	-0.528	
	84012	Ag2006/1	0311_1103	1.096896231			
	84012	Ag2009/2	0311_1103	1.096897569	1.338E-06	1.841	
3/03/2011	**RS25A-3**	**Ag2006/1**	**0311_1107**	**10.60845522**			
	RS25A-3	Ag2009/2	0311_1107	10.60847786	2.2639E-05	3.221	
	RS25A-3	Ag2006/1	0311_1107	10.60845607			
	RS25A-3	Ag2009/2	0311_1107	10.60848851	3.2445E-05	4.616	
	RS25A-3	Ag2006/1	0311_1107	10.60845346			
	RS25A-3	Ag2009/2	0311_1107	10.60848667	3.321E-05	4.724	
4/03/2011	**RS25A-3**	**Ag2006/1**	**0311_1110**	**10.60862457**			
	RS25A-3	Ag2009/2	0311_1110	10.60864017	1.5594E-05	2.218	
	RS25A-3	Ag2006/1	0311_1110	10.60862592			
	RS25A-3	Ag2009/2	0311_1110	10.60864677	2.0852E-05	2.966	
	RS25A-3	Ag2006/1	0311_1110	10.60861291			
	RS25A-3	Ag2009/2	0311_1110	10.60864263	2.9717E-05	4.227	
						1.870	
				Average	7.314000E-06	1.87	

Tracking hydro static						
From bottom	SPRT 1121	10 mA	SPRT 84012	10 mA	SPRT RS25A-3	10 mA
	Ref R/Ω	Transfer	Ref R/Ω	Transfer	Ref R/Ω	Transfer
0	1.06186577	1.06186768	1.09686492	1.09688208	10.60843323	10.60847161
10	1.06186665	1.06186846	1.09686554	1.09688269	10.60844016	10.60847546
20	1.06186695	1.06186886	1.09686499	1.09688286	10.60844533	10.608481
40	1.06186688	1.0618692	1.09686479	1.09688283	10.60844442	10.60848129
60	1.06186662	1.06186863	1.09686483	1.09688272	10.60846034	10.60849166

Uncertainty Before Circulation

Uncertainty template for cell comparisons: fill in bold red cells

RN110032				k(i)	U(i)	u(i)	ν(i)	u(i)^4/ν(i)
Lab Cell	B: Impurity	See PM-EADA 8.2.1		1.73	**3**	1.7341	50	1.81E-01
	B:Conductio	tracking (below)		1.73	**1.83**	1.0566	20	6.23E-02
	B: Hydrosta	d column height		1.73	0.027	0.0156	20	2.95E-09
	B:SelfHeat	Current multiplier:bridge		1.73	0.001	0.0006	20	5.56E-15
	B:Gas press	: Cancelled in difference						
Transfer cell	B: Conducti	Hydro tracking (below)		1.73	**2.38**	1.3741	20	1.78E-01
	B:Hydrostat	Liquid column height		1.73	0.027	0.0156	20	2.95E-09
	B:SelfHeat	Current multiplier:bridge		1.73	0.001	0.0006	20	5.56E-15
	B:Gas press	: Cancelled in difference						
Bridge	B:Different	From bridge linearity rep		1.73	0.05	0.0289	20	3.49E-08
Averaging	A: SEOM di	From n differences		1	**0.34**	0.3410	**19**	7.12E-04
	FP realisati	Included in A						
	Drift	nonflat curve: 1/2 width		1.73	**0**	0.0000	8	0.00E+00
SPRT	Instability	included in A		1.73	**0**	0.0000	8	0.00E+00
Rounding	Negligible							
					with ref cell impurity		without ref cell impurity	
					Uc	**2.48**		**1.77**
					Nu Eff	**89**		**40**
					k	**1.99**		**2.02**
					U(ext)	**4.92**		**3.57**

Comparison CCT-K4.1		**Ag bilateral**		**NMIA**			
After circulation		**5N Ar**					
HTSPRT	S/No	Type	Nominal R	Sensor /mm	from tip/mm		
1	1087	Hart	0.25	35	15		
2	RS128-03	Chino	0.25	40	15		
Bridge	S/No	Type	Current				
	F18/3	F900	10				
Resistor	48084	1 ohm	10				
Ag cell	S/No	Purity	Source	Height / mm		W	4.286
Reference	**Ag2006/2**	6	Honeywell	251.5		dT/dh	0.0054
Transfer	Ag2009/2	6	Honeywell	252.5		dW/dT 1E-6/mK	2.84
Ar purity	5N	After circulation					

Date	**HTSPRT**	**FP cell**	**Datafile**	**R(0mA)/Ω**	**ΔR(Transfer-Ref) /Ω**	**ΔT(Transfer-Ref) /mK**	**Comment**
13/07/2017	**RS128-03**	**Ag2006/2**	**0717_1926**	**1.11855661**			
13/07/2017	RS128-03	Ag2009/2	0717_1926	1.118555695	-9.15E-07	-1.23	
13/07/2017	RS128-03	Ag2006/2	0717_1926	1.118555839			
13/07/2017	RS128-03	Ag2009/2	0717_1926	1.118554105	-1.734E-06	-2.34	
14/07/2017	**RS128-03**	**Ag2006/2**	**0717_1929**	**1.118557276**			
14/07/2017	RS128-03	Ag2009/2	0717_1929	1.118555655	-1.621E-06	-2.19	
14/07/2017	RS128-03	Ag2006/2	0717_1929	1.118556389			
14/07/2017	RS128-03	Ag2009/2	0717_1929	1.118555997	-3.92E-07	-0.53	
17/07/2017	**RS128-03**	**Ag2006/2**	**0717_1934**	**1.118557546**			
17/07/2017	RS128-03	Ag2009/2	0717_1934	1.118556622	-9.24E-07	-1.25	
17/07/2017	RS128-03	Ag2006/2	0717_1934	1.118557764			
17/07/2017	RS128-03	Ag2009/2	0717_1934	1.11855722	-5.44E-07	-0.73	
17/07/2017	RS128-03	Ag2006/2	0717_1934	1.118556081			
17/07/2017	RS128-03	Ag2009/2	0717_1934	1.118555698	-3.83E-07	-0.52	
19/07/2017	**RS128-03**	**Ag2006/2**	**0717_1936**	**1.118560288**			
19/07/2017	RS128-03	Ag2009/2	0717_1936	1.118558332	-1.956E-06	-2.64	
19/07/2017	RS128-03	Ag2006/2	0717_1936	1.118559874			
19/07/2017	RS128-03	Ag2009/2	0717_1936	1.118557761	-2.113E-06	-2.85	
20/07/2017	**RS128-03**	**Ag2006/2**	**0717_1939**	**1.118560817**			
20/07/2017	RS128-03	Ag2009/2	0717_1939	1.11855881	-2.007E-06	-2.71	
20/07/2017	RS128-03	Ag2006/2	0717_1939	1.118560612			
20/07/2017	RS128-03	Ag2009/2	0717_1939	1.118559559	-1.053E-06	-1.42	
21/07/2017	**1087**	**Ag2006/2**	**0717_1944**	**1.078213459**			
21/07/2017	1087	Ag2009/2	0717_1944	1.078211559	-1.9E-06	-2.66	
21/07/2017	1087	Ag2006/2	0717_1944	1.078213913			
21/07/2017	1087	Ag2009/2	0717_1944	1.078210832	-3.081E-06	-4.31	
21/07/2017	1087	Ag2006/2	0717_1944	1.078212914			
21/07/2017	1087	Ag2009/2	0717_1944	1.078210234	-2.68E-06	-3.75	
21/07/2017	1087	Ag2006/2	0717_1944	1.078211863			
21/07/2017	1087	Ag2009/2	0717_1944	1.078210854	-1.009E-06	-1.41	
24/07/2017	**1078**	**Ag2006/2**	**0717_1950**	**1.078212261**			
24/07/2017	1078	Ag2009/2	0717_1950	1.078209915	-2.346E-06	-3.28	
24/07/2017	1078	Ag2006/2	0717_1950	1.078212094			
24/07/2017	1078	Ag2009/2	0717_1950	1.078210004	-2.09E-06	-2.93	
24/07/2017	1078	Ag2006/2	0717_1950	1.078211588			
24/07/2017	1078	Ag2009/2	0717_1950	1.078210081	-1.507E-06	-2.11	
24/07/2017	1078	Ag2006/2	0717_1950	1.078211312			
24/07/2017	1078	Ag2009/2	0717_1950	1.078209115	-2.197E-06	-3.08	
25/07/2017	**1087**	**Ag2006/2**	**0717_1953**	**1.07821134**			
25/07/2017	1087	Ag2009/2	0717_1953	1.078208899	-2.441E-06	-3.42	
25/07/2017	1087	Ag2006/2	0717_1953	1.078210913			
25/07/2017	1087	Ag2009/2	0717_1953	1.07820913	-1.783E-06	-2.50	
25/07/2017	1087	Ag2006/2	0717_1953	1.078210738			
25/07/2017	1087	Ag2009/2	0717_1953	1.078208821	-1.917E-06	-2.68	
25/07/2017	1087	Ag2006/2	0717_1953	1.078210853			
25/07/2017	1087	Ag2009/2	0717_1953	1.078207971	-2.882E-06	-4.03	
					-1.7163E-06	-2.37	

Tracking hydro static								
SPRT	1087 10 mA		RS128-03 10 mA					
From bottom/mm	Ref R(10mA)/Ω	Transfer	Ref R(10mA)/Ω	Transfer				
0	1.07821151	1.07820947	1.11856101	1.11856439				
10	1.07821164			1.11856496				
20	1.07821127	1.07821005	1.11856095	1.11856453				
40	1.07821132	1.07820959	1.11856103	1.11856442				
60	1.07821079	1.07820885	1.11856127	1.11856456				
RN170314				k(i)	U(i)	u(i)	ν(i)	u(i)^4/ν(i)
Lab Cell	B: Impurity	See PM-EADA 8.2.1		1.73	3	1.7341	50	1.81E-01
	B:Conductic	Hydro tracking (below)		1.73	0.68	0.3949	20	1.22E-03
	B: Hydrostat	Liquid column height		1.73	0.027	0.0156	20	2.95E-09
	B:SelfHeat	Current multiplier:bridge		1.73	0.001	0.0006	20	5.56E-15
	B:Gas pressu	: Cancelled in difference		1.73	0.000			
Transfer cell	B: Conducti	Hydro tracking (below)		1.73	0.92	0.5312	20	3.98E-03
	B:Hydrostat	Liquid column height		1.73	0.027	0.0156	20	2.95E-09
	B:SelfHeat	Current multiplier:bridge		1.73	0.001	0.0006	20	5.56E-15
	B:Gas pressu	: Cancelled in difference		1.73	0.000			
Bridge	B:Differenti	From bridge linearity rep		1.73	0.05	0.0289	20	3.49E-08
Averaging	A: SEOM dif	From n differences		1	0.20	0.2020	15	1.11E-04
	FP realisatic	Included in A						
	Drift	nonflat curve: 1/2 width		1.73	0	0.0000	8	0.00E+00
SPRT	Instability	Included in A		1.73	0	0.0000	8	0.00E+00
Rounding	Negligible							
					with ref cell		without ref cell	
					impurity		impurity	
					Uc	**1.87**		**0.69**
					Nu Eff	**65**		**43**
					k	**2.00**		**2.02**
					U(ext)	**3.73**		**1.40**

Comparison CCT-K4.1		**Ag bilateral**		**NMIA**			
After circulation 6N Argon							

HTSPRT	S/No	Type	Nominal R	Sensor /mmm	from tip/mm
1	1087	Hart	0.25	35	15
2	RS128-03	Chino	0.25	40	15

Bridge	S/No	Type	Current
	F18/3	F900	5
Resistor	48084	1 ohm	10

Ag cell	S/No	Purity	Source	Immersion / mm			
Reference	**Ag2006/2**	6	Honeywell	251.5		W	4.286
Transfer	Ag2009/2	6	Honeywell	252.5		dT/dh	0.0054
						dW/dT 1E-6/mK	2.84

Ar purity	**6N**	RN170314					
Date	**HTSPRT**	**FP cell**	**Datafile**	**R(0mA)/Ω**	**ΔR(Transfer-Ref) /Ω**	**ΔT(Transfer-Ref) /mK**	**Comment**
27/06/2017	**1087**	**Ag2006/2**	**0617_1903**	**1.078218808**			
27/06/2017	1087	Ag2009/2	0617_1903	1.078213725	-5.083E-06	-7.115	
28/06/2017	**1087**	**Ag2006/2**	**0617_1905**	**1.078217784**			
28/06/2017	1087	Ag2009/2	0617_1905	1.078215539	-2.245E-06	-3.142	
28/06/2017	1087	Ag2006/2	0617_1905	1.078217688			
28/06/2017	1087	Ag2009/2	0617_1905	1.078214973	-2.715E-06	-3.800	
28/06/2017	1087	Ag2006/2	0617_1905	1.07821742			
28/06/2017	1087	Ag2009/2	0617_1905	1.078215507	-1.913E-06	-2.678	
29/06/2017	**1087**	**Ag2009/2**	**0617_1907**	**1.078214298**			
29/06/2017	1087	Ag2006/2	0617_1907	1.078217047	-2.749E-06	-3.848	
30/06/2017	**1087**	**Ag2006/2**	**0617_1909**	**1.078215851**			
30/06/2017	1087	Ag2009/2	0617_1909	1.078212949	-2.902E-06	-4.062	
30/06/2017	1087	Ag2006/2	0617_1909	1.078214913			
30/06/2017	1087	Ag2009/2	0617_1909	1.078212663	-2.25E-06	-3.149	
3/07/2017	**1087**	**Ag2006/2**	**0717_1912**	**1.078215089**			
3/07/2017	1087	Ag2009/2	0717_1912	1.078211555	-3.534E-06	-4.946	
3/07/2017	1087	Ag2006/2	0717_1912	1.078214314			
3/07/2017	1087	Ag2009/2	0717_1912	1.078211325	-2.989E-06	-4.184	
3/07/2017	1087	Ag2006/2	0717_1912	1.078212739			
3/07/2017	1087	Ag2009/2	0717_1912	1.078211238	-1.501E-06	-2.101	
5/07/2017	**RS128-03**	**Ag2006/2**	**0717_1915**	**1.118558085**			
5/07/2017	RS128-03	Ag2009/2	0717_1915	1.118553927	-4.158E-06	-5.610	
5/07/2017	RS128-03	Ag2006/2	0717_1915	1.11855725			
5/07/2017	RS128-03	Ag2009/2	0717_1915	1.118553947	-3.303E-06	-4.456	
5/07/2017	RS128-03	Ag2006/2	0717_1915	1.118556381			
5/07/2017	RS128-03	Ag2009/2	0717_1915	1.118554078	-2.303E-06	-3.107	
6/07/2017	**RS128-03**	**Ag2006/2**	**0717_1917**	**1.118557211**			
6/07/2017	RS128-03	Ag2009/2	0717_1917	1.118554118	-3.093E-06	-4.173	
6/07/2017	RS128-03	Ag2006/2	0717_1917	1.1185568			
6/07/2017	RS128-03	Ag2009/2	0717_1917	1.11855406	-2.74E-06	-3.697	
6/07/2017	RS128-03	Ag2006/2	0717_1917	1.11855671			
6/07/2017	RS128-03	Ag2009/2	0717_1917	1.118554154	-2.556E-06	-3.449	
					-2.87713E-06	-3.97	

Tracking hydro static				
SPRT	1087 10 mA		RS128-03 10 mA	
From botton	Ref R(10mA)/Ω	Transfer	Ref R(10mA	Transfer
0	1.07822085	1.0781368	1.11855708	1.11855555
10	1.07822069	1.0781363		
20	1.0782206	1.0781366	1.11855738	1.11855573
40	1.0782205	1.0781364	1.11855778	1.1185561
60	1.0782196	1.0781357	1.11855614	

RN170314			k(i)	U(i)	u(i)	ν(i)	u(i)^4/ν(i)
Lab Cell	B: Impurity	See PM-EADA 8.2.1	1.73	3	1.7341	50	1.81E-01
	B:Conduction	Hydro tracking (below)	1.73	1.43	0.8256	20	2.32E-02
	B: Hydrostatic	Liquid column height	1.73	0.027	0.0156	20	2.95E-09
	B:SelfHeat	Current multiplier:bridge	1.73	0.001	0.0006	20	5.56E-15
	Gas pressure	Cancelled in difference	1.73	0.000			
Transfer cell	B: Conduction	Hydro tracking (below)	1.73	1.22	0.7044	20	1.23E-02
	B:Hydrostatic	Liquid column height	1.73	0.027	0.0156	20	2.95E-09
	B:SelfHeat	Current multiplier:bridge	1.73	0.001	0.0006	20	5.56E-15
	Gas pressure	Cancelled in difference	1.73	0.000			
Bridge	B:DifferentialLine	From bridge linearity rep	1.73	0.05	0.0289	20	3.49E-08
Averaging	A: SEOM diff	From n differences	1	0.30	0.2990	15	5.33E-04
	FP realisation	Included in A					
	Drift in difference	nonflat curve: 1/2 width	1.73	1	0.5780	8	1.40E-02
SPRT	Instability	Included in A	1.73	0	0.0000	8	0.00E+00
Rounding	Negligible						

with ref cell impurity		without ref cell impurity	
Uc	**2.15**		**1.27**
Nu Eff	**92**		**51**
k	**1.99**		**2.01**
U(ext)	**4.26**		**2.54**