APMP-K3: KEY COMPARISON OF REALIZATIONS OF THE ITS-90 OVER THE RANGE –38.8344°C TO 419.527°C

Final Report

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- Approved by APMP-KC3 participants
- Approved by APMP-TCT-WG for comparisons
- Approved by CCT-WG7 7 June 2006

1 INTRODUCTION

The Comite Consulatif de Thermometrie has organised several key comparisons to provide a comparison of temperature measurements performed by different laboratories practising different techniques and instrumentation in realising the ITS-90. To keep the organising, time scale and data processing of such a comparison manageable, the number of participants in a Key Comparison (KC) is limited to a few laboratories in each major economic region. Subsequent regional key comparisons anchored by those taking part in a KC link laboratories in a particular region to the rest of the international community.

For the temperature range from 83.8058 K (triple point of Ar) to 933.473 K (freezing point of Al), a key comparison, CCT-KC3, was carried out from 1997 to 2001 by representative laboratories in North America, Europe and Asia. Following CCT-KC3, the Asia-Pacific Metrology Program Key Comparison 3 (APMP-KC3) was organised for national laboratories in the Asia/Pacific region. The participation of NMIA (Australia) and KRISS (South Korea) provide the link between CCT-KC3 and APMP-KC3.

APMP-KC3, taking place from February 2000 to June 2003, covers a temperature range from –38.8344^{o}C (triple point of Hg) to 419.527^{o}C (freezing point of zinc), using a Standard Platinum Resistance Thermometer (SPRT) as the artefact. The SPRT was tested and characterised by NMIA, the coordinating laboratory, before circulation. The SPRT was then in turn hand-delivered to 7 national laboratories, returned to NMIA for a check then to the remaining 4 laboratories in the scheme. The APMP-KC3 protocol (Appendix 1) provides guidance for main features of the APMP-KC3 such as annealing criteria and measurement sequence to be performed. The actual realisations of the fixed points within the nominated temperature range were carried out in accordance with local practice. Participants were asked to made necessary corrections to the data used to calculate the fixed point resistance ratios and to submit their results using the provided templates. Information about instrumentation used in the comparison was tabulated by the NMI of Australia.

The initial and final water triple point resistance measured by each laboratory were plotted to detect any change in the SPRT. Based on this graph, it was noted that the SPRT experienced several changes. Because of these change, the pilot laboratory has suggested several different methods for determining reference values published in the APMP-KC3 Draft A version 1.

After the circulation of Draft A, it was agreed that there should be three NMIA reference values based on the change of the artefact water triple point values and participants measurements were grouped accordingly. Draft B details how the link between the CCT-KC3 and the APMP-KC3 is established via the results obtained by KRISS and NMIA, the two laboratories participated in both comparisons. It also includes bilateral differences between participants of the APMP-KC3 and also between participants of APMP-KC3 to those of CCT-KC3 and their associated uncertainties.

Some minor numerical errors in Draft B version 3 (below) have also been corrected.

- (i) Table 3: W(In) for ITDI was listed as W(Sn)
- (ii) 4th line of last of Page 16: Table 11 was referred to as Table 10
- (iii) Table 14: U(Zn), U(Sn), U(In), U(Ga) and U(Hg) for groups 2 and 3 were wrongly calculated using the U_{loop} (formerly $U_{SPRTinstability}$) for group 1.

2 PARTICIPANTS

NMIA (Australia),formerly CSIRO-NML	Mong Kim Nguyen, Dr Mark Ballico
PSB (Singapore)	Hao Yuan Kho
CSIR (South Africa)	Hans Liedberg
NIMT (Thailand)	Paisal Asawawimol
NPL (India)	Dr Satya P. Varma
MUSSD (Sri Lanka)	K. A. Gunasoma
SIRIM (Malaysia)	Hafidzah Othman
KRISS (Korea)	Dr Kee Sool Gam
KIM-LIPI (Indonesia)	Hidayat Wiriadinata
SCL (Hong Kong)	C M Tsui
CMS (Taiwan)	Shu-Fei Tsai
ITDI (Philippines)	Rosalinda Principe

Note: NMIA is denoted as NML at some places in the report.

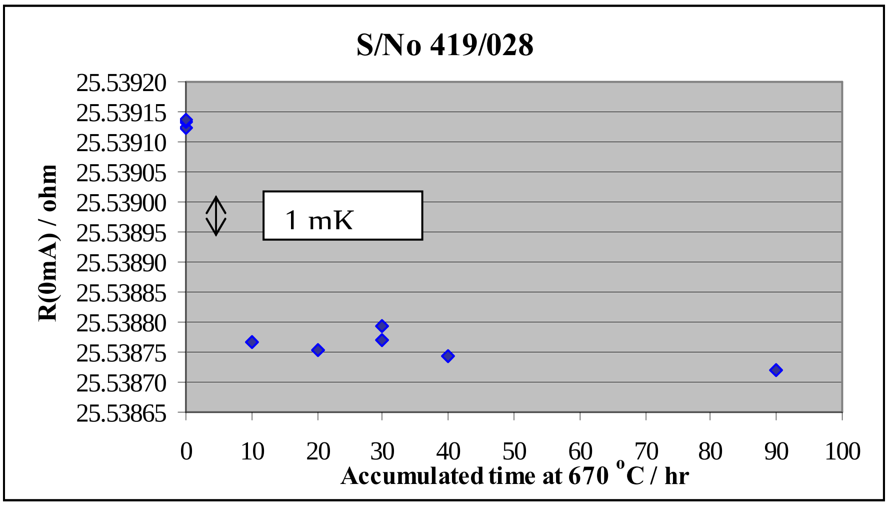
3 ARTIFACT

The artefact used for this program was an SPRT with an encapsulated ceramic sensor

S/No 419/028
Model 419
Manufacturer: Isotech
Sensor length: 7 cm

3.1 Preliminary work stabilising the SPRT

Before any measurements for the KC3 started, the stability with thermal cycling of the artifact (Graph 1) was assessed by determining the change in its RWTP values after being heated to 670 ^{o}C (with a cooling rate of 60 ^{o}C/hr). Graph 1 shows the artefact experiences initial defect annealing, but is subsequently stable.



Graph 1 : Variation of water triple point values with times after being heated to 670^{o}C

4 MEASUREMENT PROCEDURE

Following the annealing process to stabilise the artefact, the SPRT was calibrated three times (ie. Zn, Cd, Sn, In, Ga, Hg) by NMIA, the coordinating laboratory, before being sent to participatant laboratories. After the SPRT was received by each participant and prior to any annealing, the initial RTPW measured was reported to NMIA. The SPRT was then annealed at 440 ^{o}C until the change in RTPW was below about 0.2 mK. NMIA plotted the initial and final RTPW reported by each participant to keep track of any change in the artifact due to transportation and thermal cycling (Graph 2). The initial RTPW was the value before annealing and the final was the value obtained at the completion of the calibration. The water triple point resistance R(WTP) plotted were the corrected R(WTP), adjusted for the effect of self heating, the hydrostatic head in the WTP cell and the difference in the reference resistor of the resistance bridge.

Measurements at fixed points were taken in order of decreasing temperatures alternating with a measurement at the triple point of water. Most participating laboratories have the capability to perform the comparison over the entire temperature range from Zn to Hg. The exception were KIM-LIPI with measurements from Zn to Sn and ITDI with measurement at In only. In this program NMIA was the only laboratory that included the Cd point in each calibration. Table 1 lists the circulation order of the artifact and the fixed point measurements carried out at each laboratory.

Table 1: List of circulation.

Lab	Fixed point measurements
NMIA	Zn, Cd, Sn, In, Ga, Hg
PSB	Zn, Sn, Ga, Hg
CSIR	Zn, Sn, Ga, Hg
NIMT	Zn, Sn, Ga, Hg
NPL	Zn, Sn, Ga, Hg
MSS	Zn, Sn, In, Ga, Hg
SIRIM	Zn, Sn, In, Ga, Hg
KRISS	Zn, Sn, In, Ga, Hg
NMIA	Zn, Cd, Sn, In, Ga, Hg
KIM-LIPI	Zn, Sn
SCL	Zn, Sn, In, Ga, Hg
CMS	Zn, Sn, In, Ga, Hg
ITDI	In
NMIA	Zn, Cd, Sn, In, Ga, Hg

5 SUMMARY OF RAW DATA SUBMISSIONS

The raw submissions from each laboratory are given in Appendix 2, however, for convenience, these are summarised in Table 2 below. Data received from participants may or may not be the averaged values. As no other participants were equipped with the fixed point of cadmium, the Cd resistance ratios measured by NMIA are omitted from Table 2.

Table 2: Summary of measurement data received from participants in APMP-KC3

Lab	**W(Hg)**	**W(Ga)**	**W(In)**	**W(Sn)**	**W(Zn)**
NMIA1a	0.8441547	1.1181233	1.6097246	1.8926848	2.5687122
NMIA1b	0.8441561	1.1181230	1.6097233	1.8926848	2.5687119
NMIA1c	0.8441553	1.1181245	1.6097247	1.8926843	2.5687123
PSB	0.8441559	1.1181271	-	1.8926817	2.568706
CSIR	0.8441561	1.1181249	-	1.8926851	2.5687124
NIMT	0.844158	1.1181226	-	1.8926823	2.5687091
NPL	0.8441638	1.1181259	-	1.8926941	2.5687254
MUSSD	0.8441581	1.1181247	1.609721	1.8926862	2.5687081
SIRIM	0.8441574	1.11812138	1.60972393	1.89268657	2.5686998
KRISS	0.8441561	1.11812412	1.60971663	1.89268372	2.5687085
NMIA2a	0.8441553	1.1181245	1.6097217	1.8926803	2.5687074
NMIA2b	0.8441558	1.1181243	1.6097226	1.8926827	2.5687078
KIM-LIPI	-	-	-	1.892694	2.568719
SCL	0.8441557	1.1181233	1.6097271	1.8926833	2.5687086
CMS	0.8441575	1.1181237	1.6097273	1.8926823	2.5686936
ITDI	-	-	1.609826	-	-
NMIA3a	0.8441574	1.1181240	1.6097191	1.8926790	2.5686990
NMIA3b	0.8441565	1.1181241	1.6097206	1.8926786	2.5686977
NMIA3c	0.8441566	1.1181238	1.6097192	1.8926787	2.5686984

Each participant provided an uncertainty analysis, which is reproduced in Appendix 3. For the purposes of further analysis, we have calculated the 95% confidence level from these submissions, using the ISO-GUM methodology. These uncertainties have, where necessary, been converted into equivalent temperature uncertainties, expressed in mK. Where participants have assigned an infinite degree of freedom, for calculation purposes, we have used a value of 1×10^8 instead of 100 that was used in Draft A. The equivalent temperature uncertainties at the 95% confidence level of the WTP and each of the fixed point ratios are listed in Table 3.

Table 3: Uncertainty of WTP and fixed point ratio W in mK at 95% confidence level

	W(Hg)		W(WTP)		W(Ga)		W(In)		W(Sn)		W(Zn)	
	U95	k	U95	k	U95	k	U95	k	U95	k	U95	k
NMIA1a	0.30	2.00	0.12	2.00	0.39	0.39	0.56	2.00	0.41	2.00	0.60	2.00
NMIA1b	0.31	2.00	0.12	2.00	0.25	2	0.84	2.00	0.34	2.00	0.44	2.00
NMIA1c	0.25	2.00	0.25	2.00	0.25	2	0.84	2.00	0.65	2.00	0.42	2.00
PSB	2.48	1.96	0.82	1.96	1.35	1.96	-	-	2.68	1.96	3.11	1.96
CSIR	0.41	2.13	0.25	2.11	0.48	2.13	-	-	0.96	2.13	1.05	2.05
NIMT	0.47	1.96	0.15	1.96	0.55	1.96	-	-	2.66	1.96	2.49	1.96
NPL	0.47	1.96	0.49	1.96	0.46	1.96	-	-	0.65	1.96	0.90	1.96
MUSSD	1.86	1.99	0.77	1.98	0.94	1.99	2.37	1.99	1.64	1.99	2.31	2.00
SIRIM	0.69	2.01	0.34	1.96	0.73	2.09	1.07	1.96	1.30	2.00	1.31	1.96
KRISS	0.16	2	0.062	2	0.14	2	0.66	2	0.54	2	0.84	2
NMIA2a	0.28	2.00	0.12	2.00	0.25	2.00	0.77	2.00	1.05	2.00	1.56	2.00
NMIA2b	0.28	2.00	0.12	2.00	0.27	2.00	0.84	2.00	0.79	2.00	0.38	2.00
KIMLIPI	-	-	0.26	2.26	-	-	-	-	1.11	1.96	1.79	1.96
SCL	0.63	1.98	0.31	2.00	0.53	2.00	1.17	1.99	1.17	1.99	1.24	1.98
CMS	0.52	1.96	0.21	1.96	0.46	1.96	0.94	1.96	1.07	1.96	1.35	1.96
ITDI (*)	-	-	0.75	-	-	-	2.29	2	-	-	-	-
NMIA3a	0.25	2.00	0.12	2.00	0.27	2.00	0.98	2.00	0.38	2.00	0.77	2.00
NMIA3b	0.26	2.00	0.12	2.00	0.25	2.00	0.67	2.00	0.98	2.00	1.96	2.00
NMIA3c	0.36	2.00	0.12	2.00	0.27	2.00	1.32	2.00	0.56	2.00	0.56	2.00

(*) ITDI did not provide a coverage factor to convert from a standard uncertainty to a 95% confidence interval. We have assumed a k=2 coverage factor in this case.

6 DIFFERENCES TO PILOT LABORATORY

6.1 Conversion of ΔW to ΔT

Uncertainties and resistance ratio differences are converted to equivalent temperature differences and uncertainties using the formula

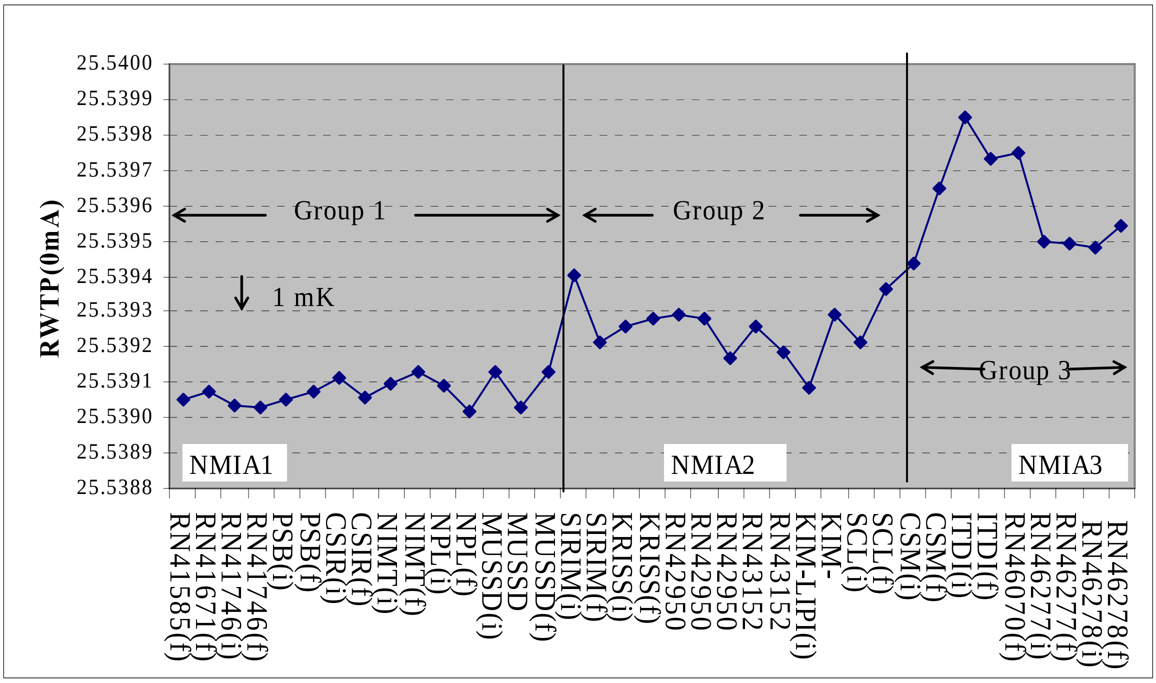
$$\Delta T / \mathrm{mK} = \frac{\Delta W}{dW_r / dT}$$

where the values of dW_r/dT are taken as:

T	dW_r/dT
T(Zn)	3.50×10^{-6}
T(Sn)	3.71×10^{-6}
T(In)	3.80×10^{-6}
T(Ga)	3.95×10^{-6}
T(Hg)	4.04×10^{-6}

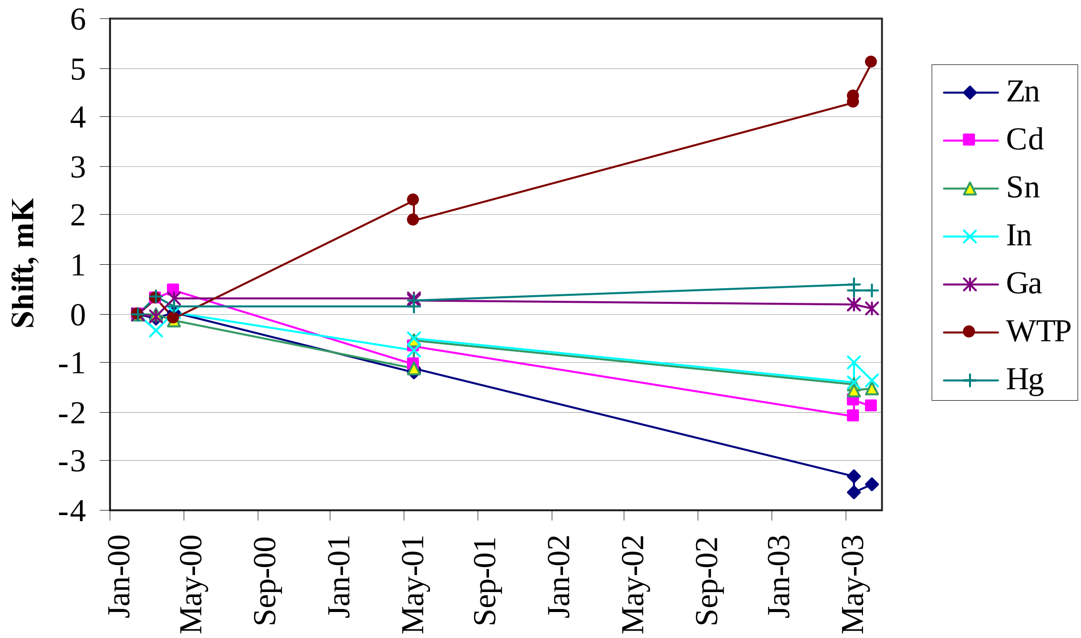
6.2 Change in the characteristic of the artefact

For each participant, the water triple point value R_{WTP} measured after receiving the SPRT, and the value after the last fixed point measurement are plotted in Graph 2. This graph shows the change in the artefact through the course of the comparison.



Graph 2: Before-and-after calibration R(WTP) values from each laboratory.

The stability of the SPRT can also be assessed by examining the measured change in the SPRT calibration between the calibrations made at NMIA over the course of the inter-comparison. Graph 3 gives the temperature equivalent of the change in calibration from the first NMIA calibration.



Graph 3: Change in fixed point ratios compared to the initial values as measured by NMIA

6.3 Determination of NMIA reference values

From Graph 2, it was noted that the RTPW shifted three times, effectively equivalent to having four different SPRTs:

- between MUSSD and SIRIM , increased by 3.7 mK in transit, then decreased by 2 mK by the end of SIRIM calibration, then
- between CMS and ITDI, increased by 4.2 mK, and
- between ITDI and NMIA, decreased by 2.5 mK, to a value similar to that of obtained by CMS.

In APMP-KC3 draft-A report we proposed several methods for dealing with this shift. At the Nov 2003 APMP-TCT meeting, participants agreed with the proposal to divide the data into three groups (Table 4):

- **Group 1:** data provided by PSB, CSIR, NIMT, NPL and MUSSD were compared to reference value NMIA1, the average of the first set of NMIA data consisting of NMIA1a, b and c
- **Group 2**: data provided by SIRIM, KRISS, KIM-LIPI and SCL were compared to NMIA2, the average of the second set of NMIA data consisting of NMIA2a and b.
- **Group 3**: data provided by CMS and ITDI were compared to NMIA3, the average of the third set of NMIA data consisting of NMIA3a, b and c.

Table 4: The NMIA reference value and participant laboratories in each group.

Value	Calculated from	Reference for
NMIA1	NMIA1a, b and c	PSB, CSIR, NIMT, NPL, MUSSD
NMIA2	NMIA2a and b	SIRIM, KRISS, KIM-LIPI, SCL
NMIA3	NMIA3a, b and c	CMS, ITDI

As seen in Table 2, there are up to 3 separate calibrations of the artefact at NMIA within each group and that the uncertainty of each NMIA calibration is different (depending upon the measurement noise and measured repeatability of the TPW before and after each fixed point etc.). We have chosen to use the variance weighted average of the NMIA calibrations in each group as the NMIA reference value for that group, given by:

$$W(NMIA_{ave}) = \frac{\sum_{1}^{n} W_i / U_i^2}{\sum_{1}^{n} 1 / U_i^2}$$

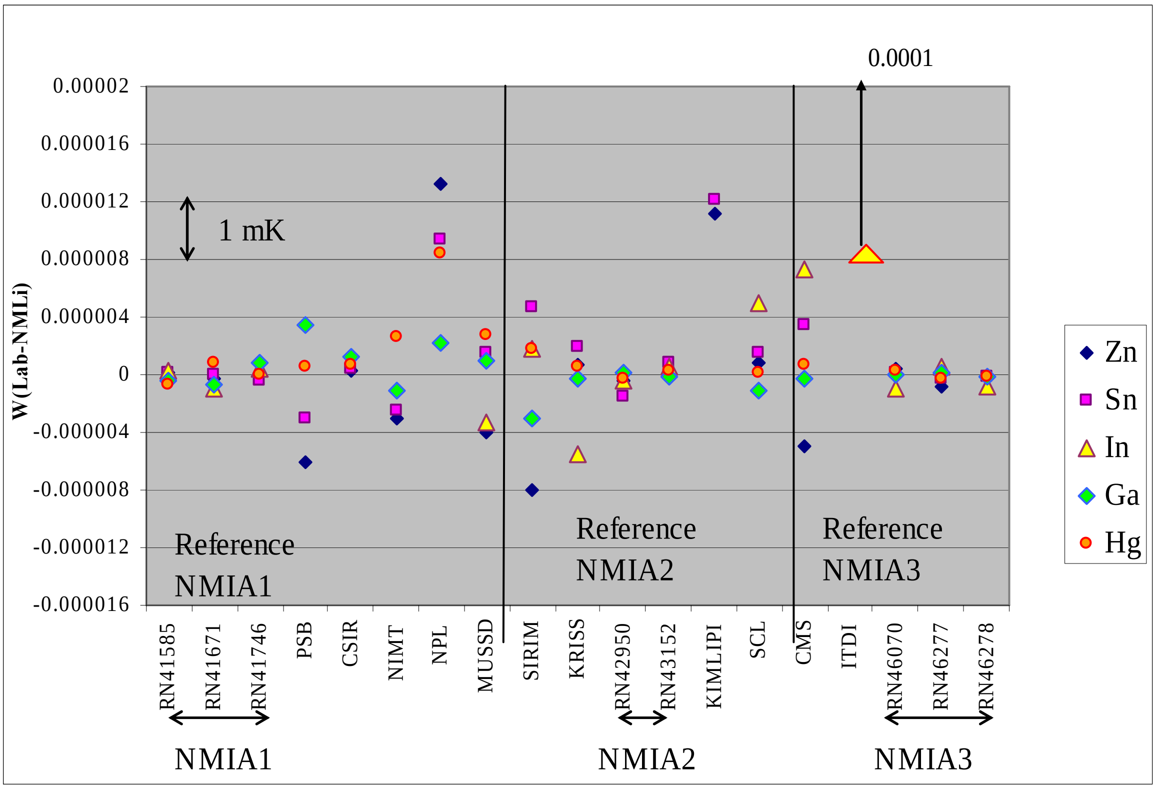
The NMIA reference value for each of the 3 groups are given in Table 5. Uncertainties for W(NMIA2) used in the link is considered in section 7.2 and 7.3.

Table 5: W($NMIA_{ave}$)

	W(NMIA1)	W(NMIA2)	W(NMIA3)
Zn	2.5687121	2.5687078	2.5686986
Sn	1.8926847	1.8926818	1.8926789
In	1.6097243	1.6097221	1.6097200
Ga	1.1181236	1.1181244	1.1181240
Hg	0.8441553	0.8441556	0.8441568

6.4 Differences ΔW(Lab-NMIA)

The difference of each participant from NMIA was calculated as ΔW(Lab-$NMIA_i$) using the appropriate $NMIA_i$ for each group from Table 5, and these differences are plotted in Graph 4.



Graph 4: ΔW(Lab-$NMIA_i$) using NMIA reference value 1, 2 and 3. Those with prefix RN are NMIA data.

7 LINK FROM APMP-KC3 to CCT-KC3

KRISS and NMIA are the two laboratories that participated in the CCT-KC3 as well as the APMP-KC3, linking both comparisons. There was no KCRV for the CCT-KC3, however, at the December 2003 CCT meeting, a proposal to use a reference value, suggested by CCT-WG8 and called the ARV "average reference value" for the purposes of CMC review was adopted. We propose to use this ARV as the reference value to which we will link the APMP-KC3.

The link from APMP-KC3 to CCT-KC3 can be established via KRISS, or via NMIA. Of course the final result should be independent of the choice of link. In the following 3 sections we present the links via each lab, and show that, within their estimated uncertainties, the two links are consistent. As we have no reason to prefer one link over the other, we present the final results referenced to the simple average of the two links, and present the results for each laboratory relative to the CCT-KC3-ARV.

Simply, we need to know the offset between the NMIA scales and the CCT-KC3-ARV.

Note 1: As many participants have chosen to quote uncertainties at k=2, and because of difficulties in dealing appropriately with "degrees of freedom" in this data analysis, we have chosen to provide data analysed at the k=2 level, rather than the 95% confidence level. As all the k's values from participants are within a few % of k=2, the departure from the 95% confidence level is not significant.

Note 2: The uncertainty of the pilot lab comparison does not need to be included, since it is only a constant which is subtracted from all the participants data in order to rescale the y-axis. We could just as easily have calculated and plotted ($W-W_{ref}$) where W_{ref} is the ITS-90 value. It just moves the y-axis's scale to a more convenient position.

7.1 Change of fixed point cells since CCT-KC3

Since the completion of the CCT-KC3, there has been a change of In cells. Both KRISS and NMIA used one In cell in the CCT-KC3 and another in the APMP-KC3. Therefore, we have to apply corrections to the In results obtained from the CCT-KC3. Details of old and new In cells as well and their differences and uncertainties as listed in Table 6.

i) **KRISS**: A correction of –3.46 mK is added to the difference (KRISS–ARV) for the In point.

ii) **NMIA**: A correction of +0.34 mK is added to the difference (NMIA-ARV) for the In point.

Table 6: Details of In cells used in CCT-KC3 and APMP-KC3 and their differences

	KRISS		**NMIA**	
In cell	**Old**	**New**	**Old**	**New**
S/No	In91-6	In99-1	In96/1	In00/1
Used in	CCT-KC3	APMP-KC3	CCT-KC3	APMP-KC3
Type	Sealed	Open	Open	Open
Purity	6N	6N	6N	6N
ΔT(old-new)	+3.46 mK		–0.34 mK	
Uncertainty k=2	±0.09 mK		±0.10 mK	

7.2 APMP-KC3 linked to CCT-KC3 via KRISS

The link via KRISS is given by:

$$\mathbf{\Delta T(ARV–NMIA)_{KRISS} = \Delta T(KRISS–NMIA)_{APMP} - \Delta T(KRISS\text{-}ARV)_{CCT} - \Delta T(old–new)_{KRISS}}$$

Where

NMIA ≡ NMIA2	is the pilot lab reference value for the KRISS-NMIA loop
$\Delta T(ARV\text{-}NMIA)_{KRISS}$	is the difference between NMIA and the ARV via the KRISS link (calculated here)
$\Delta T(KRISS\text{-}NMIA)_{APMP}$	is the difference between KRISS and NMIA in APMP-KC3
$\Delta T(KRISS\text{-}ARV)_{CCT}$	is the difference between KRISS and the ARV in CCT-KC3 (obtained from WG8 Dec2003 meeting minutes)
$\Delta T(old\text{-}new)_{KRISS}$	is the difference between old and new cells given in Table 6 (zero for cells other than indium)

As the link is established via KRISS, the uncertainty of the difference between the results of $KRISS_{CCT}$ and $KRISS_{APMP}$ is due to the uncertainty

i) U(ARV) of the ARV, provided in the minutes of the December 2003 WG8 report

ii) $U(KRISS)_{CCT}$ of KRISS results in CCT-KC3 (given in NIST technical report)

iii) $U(KRISS)_{APMP}$ of KRISS results in the APMP-KC3 (given in APMP-KC3)

Correlations: As we are subtracting the KRISS results in the two comparisons, any correlated systematic errors are not important. All systematic errors in the KRISS results, which are expected to be constant between CCT-KC3 and APMP-KC3 rounds will cancel. In the final uncertainty, we only need to include uncertainty terms for which the effect may be different between the CCT-KC3 and APMP-KC3 comparisons. For example, KRISS claims 0.54mK uncertainty at Zn point due to impurities: This offset will be the same between CCT-KC3 and APMP-KC3 comparisons, so it does not contribute to the uncertainty of the link from CCT-KC3 to APMP-KC3. However, for the In data, two cells were used instead of one. The uncertainty due to the difference caused by using one In cell in the CCT-KC3 and another cell in the APMP-KC 3 is considered un-correlated and hence is included. Table 7 gives the KRISS uncertainty analysis (taken from the NIST report on CCT-KC3), where we have separated the uncorrelated and correlated components. We noticed that the published uncertainties of CCT-KC3 participating laboratories given in various publications are not consistent, hence for reference purposes, the sources of uncertainties used in this analysis are mentioned where necessary. Note that KRISS has given the type-A at k=1 and the other components as rectangular distributions ($k=\sqrt{3}$).

Accordingly, the total uncertainty, $U(ARV\text{-}NMIA)_{KRISS}$ is given by:

$$\mathbf{U^2(ARV–NMIA)_{KRISS} = U^2(ARV) + \left(U^2(KRISS)_{CCT} + U^2(KRISS)_{APMP} \right)_{uncorrelated}}$$

Note that the uncertainty budget submitted by KRISS for APMP-KC3 was identical to that they had submitted to CCT-KC3, so we take:

$$\mathbf{\left(U(KRISS)_{CCT} \right)_{uncorrelated} = \left(U(KRISS)_{APMP} \right)_{uncorrelated}}$$

Table 8 lists the differences and the uncertainty of individual inputs to obtain $\Delta T(ARV\text{-}NMIA)_{KRISS}$ using KRISS data.

Table 7: Uncertainty components for KRISS in APMP-KC3 (k=1), and the quadrature sums (at k=2). Components correlated between CCT-KC3 and APMP-KC3 are in boldface.

mK	k	Hg	Ga	In	Sn	Zn
Type A	1	0.06	0.06	0.06	0.15	0.19
Metal purity	**√3**	**0.002**	**0.014**	**0.47**	**0.3**	**0.54**
Hydrostatic	√3	0.054	0.012	0.033	0.022	0.027
Ref.resistor	√3	0.03	0.003	0.005	0.006	0.009
Bridge at WTP	√3	0.03	0.03	0.03	0.03	0.03
BridgeLinearity	**√3**	**0.01**	**0.025**	**0.03**	**0.01**	**0.007**
WTPpropagation	**√3**	**0.02**	**0.02**	**0.18**	**0.21**	**0.29**
SelfHeat	√3	0.02	0.02	0.07	0.09	0.09
Immersion	√3	0.03	0.002	0.045	0.04	0.04
GasPressure	√3	0.04	0.01	0.03	0.02	0.03
FPrealisation	**√3**	**0.05**	**0.05**	**0.2**	**0.1**	**0.2**
CellChange	√3			0.045		
At k=2						
uncorr.	2	0.16	0.13	0.17	0.32	0.40
corr.	2	0.06	0.07	0.63	0.44	0.74
total	2	0.17	0.15	0.65	0.55	0.85

Table 8: Difference of APMP-KC3 to CCT-KC3 via KRISS result and their uncertainties at k=2.

/mK	**Data Source**	**Zn**	**Sn**	**In** *	**Ga**	**Hg**
ΔT(KRISS-NMIA)$_{APMP}$	-	0.2	0.51	–1.44	–0.07	0.14
ΔT(KRISS-ARV)$_{CCT}$	Dec03WG8	–0.41	–0.07	1.79 –3.46 = –1.67	0.04	0.45
ΔT(ARV-NMIA)$_{KRISS}$	-	0.61	0.58	0.23	–0.11	–0.31
U(ARV)	Dec03WG8	0.38	0.3	0.32	0.08	0.12
U(KRISS)$_{CCT}$ uncorrelated	Table 7	0.4	0.32	0.17	0.13	0.16
U(KRISS)$_{APMP}$ uncorrelated	Table 7	0.4	0.32	0.17	0.13	0.16
U(ARV-NMIA)$_{KRISS}$	Quadrature sum	0.68	0.55	0.4	0.2	0.25

(*) Different KRISS In cell was used, see Table 6. We make the following calculation:

$T_{In91-6} - T_{In99-1} = +3.46$ mK (KRISS's new In cell is 3.46mK colder)

$T_{In91-6} - ARV = -1.79$ (From CCT-KC3 report), so

$ARV - T_{In99-1} = 1.79 - 3.46 = -1.67$ (simply combining the two equations above)

7.3 APMP-KC3 linked to CCT-KC3 via NMIA

For the NMIA link, the value of T(ARV-NMIA) is just the negative of the value determined in CCT-KC3 and the uncertainty in this difference is due to the uncertainty of:

i) the ARV, provided in the minutes of the December 2003 WG8 report,
ii) NMIA result in the CCT-KC3,
iii) NMIA result in the APMP-KC3

$$\mathbf{\Delta T(ARV–NMIA)_{NMIA} = – \Delta T(NMIA–ARV)_{CCT} – \Delta T(old–new)_{NMIA}}$$

Where

$\Delta T(\text{ARV-NMIA})_{NMIA}$	is the difference between NMIA and the ARV via the NMIA link (calculated here)
$\Delta T(\text{NMIA-ARV})_{CCT}$	is the difference between NMIA and the ARV in CCT-KC3 (obtained from WG8 Dec2003 meeting minutes)
$\Delta T(\text{old-new})_{NMIA}$	is the difference between old and new cells given in Table 6 (zero for cells other than indium)

As the link is established via NMIA, the uncertainty of the difference between the results of $NMIA_{CCT}$ and $NMIA_{APMP}$ is due to the uncertainty

iv) U(ARV) of the ARV, provided in the minutes of the December 2003 WG8 report
v) $U(NMIA)_{CCT}$ of NMIA results in CCT-KC3 (given in NIST technical report)
vi) $U(NMIA)_{APMP}$ of NMIA results in the APMP-KC3 (given in APMP-KC3)

As with the case of KRISS data, only those components uncorrelated between the NMIA data in the CCT-KC3 and APMP-KC3 comparisons as well as the uncertainty due to changing the In cell are included. Again, we assume that any systematic errors are constant between the two comparisons, and do not contribute to the uncertainty of the link between them.

$$\mathbf{U^2(ARV–NMIA)_{NMIA} = U^2(ARV) + (U^2(NMIA)_{CCT} + U^2(NMIA)_{APMP})_{uncorrelated}}$$

Table 9 gives the NMIA uncertainty analysis, separated into correlated and uncorrelated components, and Table 10 gives data for the link and its uncertainty.

Note that those uncertainty components which are correlated between APMP and CCT comparisons were either identical or very similar, so we have used the uncertainty budget used by NMIA in the APMP-KC3, and assumed that:

$$\mathbf{(U(NMIA)_{CCT})_{uncorrelated} \approx (U(NMIA)_{APMP})_{uncorrelated}}$$

Table 9: Uncertainty components for NMIA in APMP-KC3 (values from report RN43512 at k=2), and the quadrature sums (also k=2). Components correlated between CCT-KC3 and APMP-KC3 comparisons are in boldface.

µK at k=2	Hg	Ga	In	Sn	Zn
Measurement sca	100	26	27	28	30
Chemical Impur	**200**	**200**	**500**	**200**	**200**
FP realization	**100**	**100**	**100**	**100**	**150**
Reference Resist	10				0
Self heating	10	10	10	10	20
Quadrature effec	20	20	21	22	23
Hydrostatic head	71	12	33	22	27
Conduction	10	10	10	10	10
Insulation degradation		10	10	10	10
Gas Pressure		40	98	66	86
Propagation of S	81	90	645	730	99
Propagation of	**69**	**93**	**140**	**168**	**242**
Bridge nonlinea	**40**	**40**	**42**	**43**	**46**
AC/DC	20	20	30	40	50
CellChange			50		
uncorr(µK)	150.67	107.80	656.95	735.46	149.85
corr	237.40	245.46	530.44	282.97	350.97
total	281.18	268.08	844.36	788.02	381.62

Table 10: Difference of APMP-KC3 to CCT-KC3 via NMIA result and their k=2 uncertainty.

/mK	Source	Zn	Sn	In*	Ga	Hg
$\Delta T(\mathrm{NMIA} - \mathrm{ARV})_{\mathrm{CCT}}$	Dec03WG8	0.04	–0.68	–1.19	–0.12	–0.10
$\Delta T(\mathrm{ARV}\text{-}\mathrm{NMIA})_{\mathrm{NMIA}}$	-	–0.04	0.68	1.19–0.34 = 0.85	0.12	0.10
U(ARV)	Dec03WG8	0.38	0.30	0.32	0.08	0.12
$U(\mathrm{NMIA})_{\mathrm{CCT}}$ uncorrelated	Table 9	0.15	0.74	0.66	0.11	0.15
$U(\mathrm{NMIA})_{\mathrm{APMP}}$ uncorrelated	Table 9	0.15	0.74	0.66	0.11	0.15
$U(\mathrm{ARV}\text{-}\mathrm{NMIA})_{\mathrm{NMIA}}$	Quadrature sum	0.44	1.08	0.98	0.17	0.24

(*) Different NMIA In cell was used, see Table 6. We make the following calculation:

$T_{In96/1} – T_{In00/1} = –0.34$ mK (NMIA's new In cell is 0.34mK hotter)

$T_{In96/1}$ –ARV = –1.19 (From CCT-KC3 report), so

ARV – $T_{In00/1}$ = 1.19–0.34=0.85 (simply combining the two equations above)

7.4 APMP-KC3 linked to CCT-KC3 via KRISS and NMIA

As we have no reason to prefer the use of linking via NMIA or via KRISS, we chose to use the simple average of the values. As these two links from APMP-KC3 to CCT-KC3 are independent of each other and we have no reason to assume they are correlated, we add the uncertainties in quadrature, and thereby gain the advantage of a reduction in the uncertainty of the link.

$$\Delta T(\mathrm{ARV–NMIA})_{\mathrm{KRISS\&NMIA}} = (1/2)\ (\ \Delta T(\mathrm{ARV–NMIA})_{\mathrm{KRISS}} + \Delta T(\mathrm{ARV–NMIA})_{\mathrm{NMIA}}\ )$$

$$U^2(\mathrm{ARV–NMIA})_{\mathrm{KRISS\&NMIA}} = (1/2)^2\ (\ U^2(\mathrm{ARV–NMIA})_{\mathrm{KRISS}} + U^2(\mathrm{ARV–NMIA})_{\mathrm{NMIA}}\ )$$

Table 11 summarises the results of each of these 3 linking mechanisms.

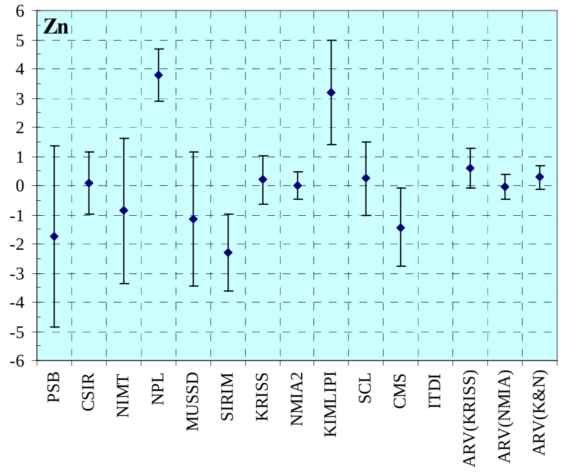
Table 11: Summary of link mechanisms between APMP-KC3 and CCT-KC3.

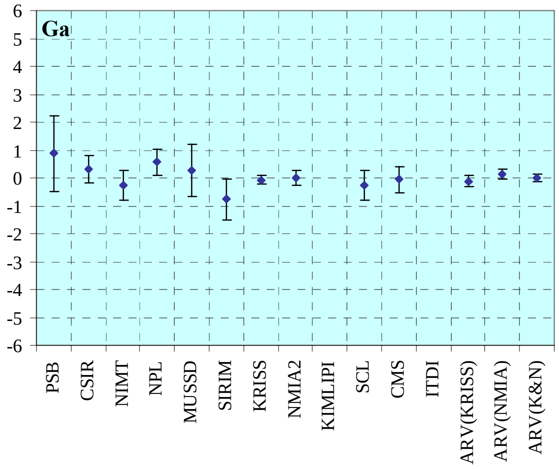
	Via KRISS $\Delta T(\mathrm{ARV\text{-}NMIA})_{\mathrm{KRISS}}$		**Via NMIA $\Delta T(\mathrm{ARV\text{-}NMIA})_{\mathrm{NMIA}}$**		**Via KRISS&NMIA $\Delta T(\mathrm{ARV\text{-}NMIA})_{\mathrm{KRISS\&NMIA}}$**	
/mK	ΔT	U(k=2)	ΔT	U(k=2)	ΔT	U(k=2)
Zn	0.61	0.68	–0.04	0.44	0.28	0.40
Sn	0.58	0.55	0.68	1.08	0.63	0.61
In	0.23	0.40	0.85	0.98	0.54	0.53
Ga	–0.11	0.20	0.12	0.17	0.00	0.13
Hg	–0.31	0.25	0.10	0.24	-0.10	0.18

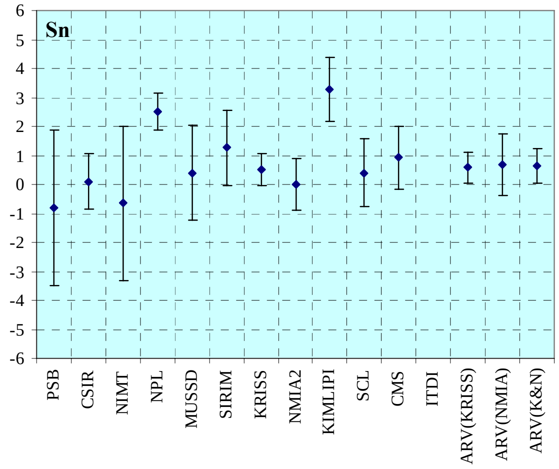
7.5 APMP-KC3 participants compared to NMIA and ARV CCT-KC3 links

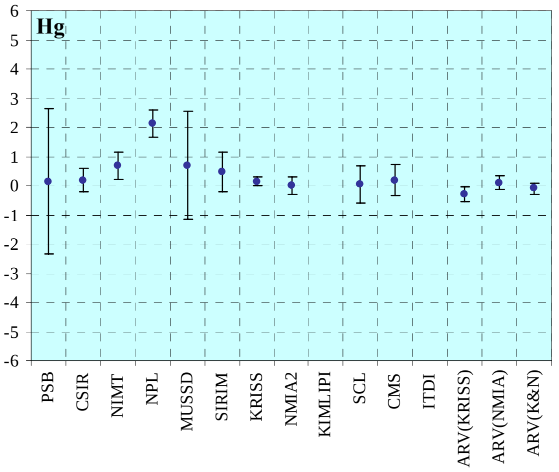
In the following graphs, each of the participants, as well as the 3 linkage values of the CCT-KC3-ARV are plotted, relative to the NMIA reference.

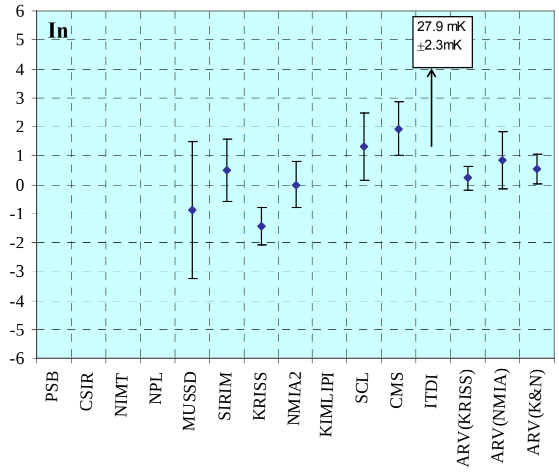
Graph 8: ΔT(Lab-NMIA) and 3 linkage mechanisms for ΔT(ARV-NMIA) are plotted for each of the fixed points. k=2 error bars are simply the uncertainties given by the lab (no allowance for SPRT instability etc)











8 LAB-ARV RESULTS

In this section the difference of each of the participant laboratories to the CCT-KC3-ARV and the uncertainty of this difference are calculated.

8.1 Instability of the artefact

In order to compare the participants to the CCT-KC3-ARV, the uncertainty in the NMIA reference value for the SPRT for each of the 3 groups (loops) must be increased to allow for the stability of the SPRT (U_{Loop} , given in Table 13) *within* each group (loop).

We will make 3 basic assumptions to calculate this additional “artefact” instability or drift.

1. We assume that changes in δR_{WTP} (from Graph 2) are proportionally related to changes in the calibration W values for the artefact.
2. We will use the measured change betweens the 3 NMIA calibrations (in 2001, 2002 and 2003) to determine the “sensitivity coefficient” between ΔR_{WTP} and ΔW_{Zn}, ΔW_{Sn}, ΔW_{In}, ΔW_{Ga}, ΔW_{Hg}. As Graph 3 shows the relationship between changes at each fixed point are all roughly proportional, we use the average slope between the first and last NMIA calibrations to determine the value of this sensitivity coefficient, which is given in Table 12. It is generally assumed that a 1mK equivalent shift in thermometer R_{WTP} suggests that the calibration at higher temperatures would shift proportionally to (W-1). The data for the shifts in the calibration of the APMP-KC3 thermometer agreed well with this, as illustrated in Graph 9. For the APMP-KC3 thermometer 1 mK shift at the WTP predicts a shift of 0.5×(W-1) mK shift in W.
3. The measured SD of R values at a fixed point is due to (a) variation of the SPRT and (b) variation between the participants cells and standards resistors, and so is an overestimate of the instability of the SPRT. If we were simply to use the SD of all the Zn ratios in the comparison, it would include all the variation amongst all the Zn cells used by all the labs. As we know that some of these cells are clearly bad, this would lead to the incorrect conclusion that the SPRT was unstable. The same is also true for the WTP cell data, but since WTP cells are generally much better (0.2mK or so) these values will provide a better estimate of the SPRT instability. We take the standard deviation of R(WTP) within each loop as the instability $\delta T(R_{WTP})$ of the SPRT for such loop.

Table 12: Sensitivity factor $\Delta T(W)$ / $\Delta T(R_{WTP})$

	$\Delta T(W)$	$\Delta T(R_{WTP})$	$\Delta T(W)$ / $\Delta T(R_{WTP})$
W(Zn)	3.40 mK		–0.75
W(Sn)	1.46 mK		–0.32
W(In)	1.08 mK		–0.24
W(Ga)	–0.07 mK		0.02
W(Hg)	–0.35 mK		0.08
WTP		–4.53 mK	0.00

Graph 9: Measured mK shift in SPRT calibration per mK shift in R_{WTP}.

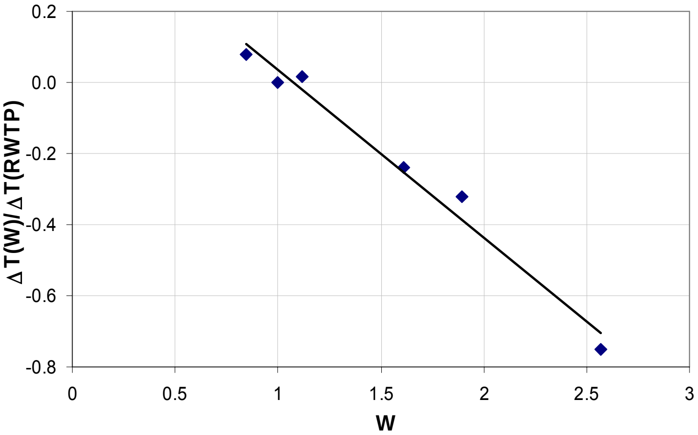


Table 13: U_{loop}: Uncertainty $\delta T(W)$ due to fluctuation δR_{WTP} within each loop

U(k=2) / mK	$U_{Loop,1}$	$U_{Loop,2}$	$U_{Loop,3}$
$\delta T(R_{WTP})$	0.39	0.81	1.43
$\delta T(W_{Zn}) = \delta T(R_{WTP}) \times \Delta T(W_{Zn}) / \Delta T(R_{WTP})$	–0.29	–0.61	–1.08
$\delta T(W_{Sn}) = \delta T(R_{WTP}) \times \Delta T(W_{Sn}) / \Delta T(R_{WTP})$	–0.12	–0.26	–0.46
$\delta T(W_{In}) = \delta T(R_{WTP}) \times \Delta T(W_{In}) / \Delta T(R_{WTP})$	–0.09	–0.19	–0.34
$\delta T(W_{Ga}) = \delta T(R_{WTP}) \times \Delta T(W_{Ga}) / \Delta T(R_{WTP})$	0.01	0.01	0.02
$\delta T(W_{Hg}) = \delta T(R_{WTP}) \times \Delta T(W_{Hg}) / \Delta T(R_{WTP})$	0.03	0.06	0.11

8.2 Total uncertainty in Lab_{APMP} –ARV difference

The difference $T(Lab_{APMP} – ARV)$ in mK of each APMP-KC3 participant to that of the CCT-KC3-ARV is calculated as:

$$\Delta T(Lab_{APMP} – ARV) = \Delta T(Lab_{APMP} – NMIA_{i \cdot APMP}) – \Delta T(ARV – NMIA)_{KRISS\&NMIA}$$

using the appropriate value of $NMIA_{i.APMP}$ for each group.

The uncertainty in this, $U(Lab_{APMP}–ARV)$, contains the following contributions:

1. The uncertainty of the participant lab measurements
2. The uncertainty in the pilot lab's SPRT W values against the ARV. This includes (section 7.2 and 7.3) (i) the ARV uncertainty (ii) the uncorrelated part of uncertainty of the link between the pilot and the ARV and (iii) the uncorrelated part of the pilot lab calibration of the SPRT.
3. The instability of the SPRT between the pilot and the participant.

$$U^2(Lab_{APMP} – ARV) = U^2(Lab_{APMP}) + U^2(ARV – NMIA)_{KRISS\&NMIA} + U^2_{Loop,i}$$

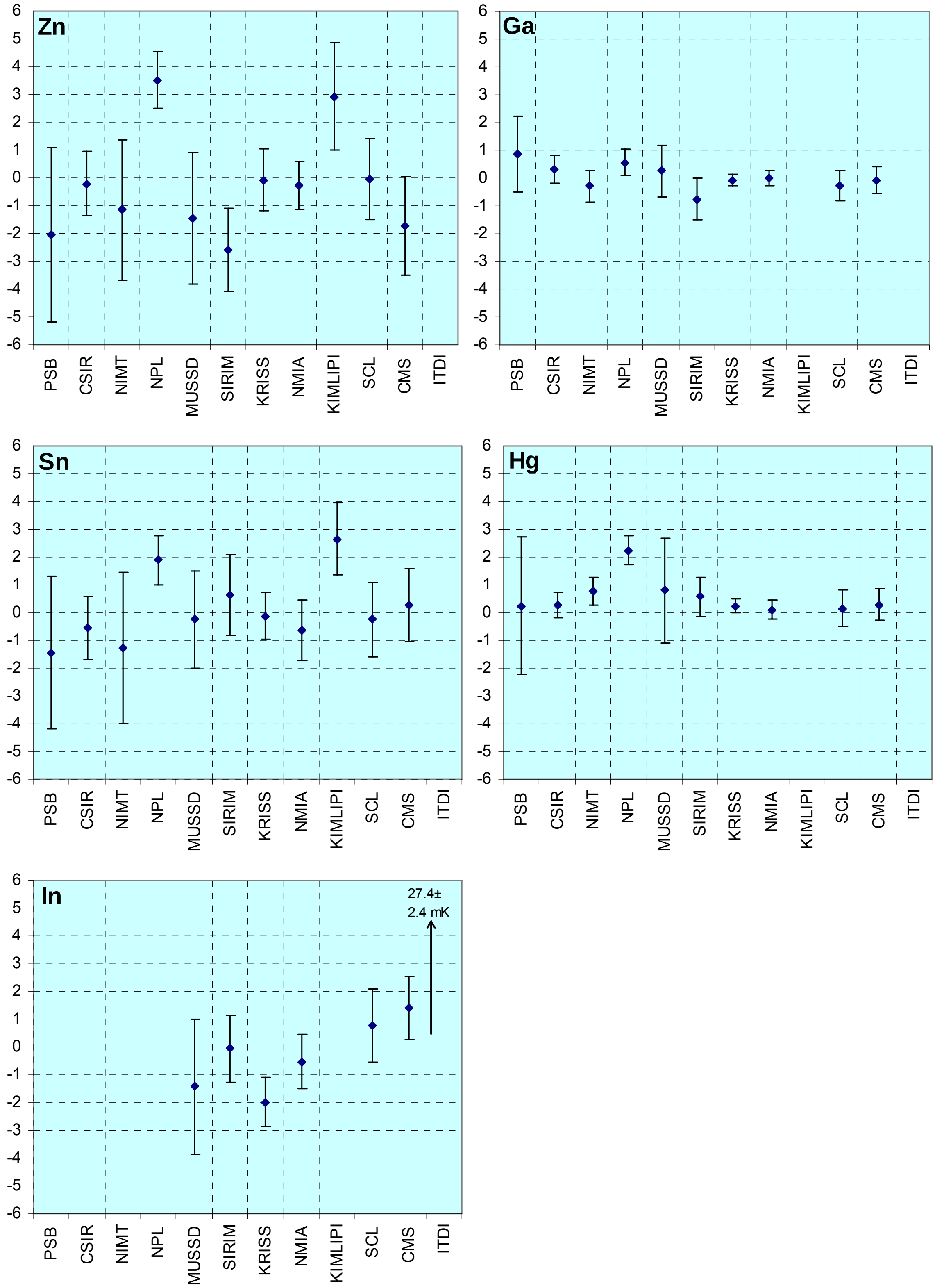
$U(Lab_{APMP})$	from Table 3
$U(ARV–NMIA)_{KRISS\&NMIA}$	from Table 11
$U_{Loop,i}$	from Table 13

The differences in mK between APMP-KC3 participants and the ARV of the CCT-KC3 are plotted in Graph 10 and tabulated in Table 14.

Table 14: Difference in resistance ratios W of APMP-KC3 participants to ARV CCT-KC3, their uncertainties U(k=2) for each laboratory, expressed in temperature equivalent mK. Values of ΔT/U(k=2)>1 are highlighted. The uncertainty includes the reported lab uncertainty, and the uncertainties of the ARV, link from APMP-KC3 toCCT-KC3 and artefact instability.

$U_{k=2}$ /mK	PSB	CSIR	NIMT	NPL	MUSSD	SIRIM	KRISS	NMIA	KIMLIP	SCL	CMS	ITDI
ΔT(Zn)	-2.04	-0.21	-1.15	3.51	-1.44	-2.57	-0.09	-0.28	2.93	-0.05	-1.71	
U(Zn)	3.15	1.16	2.54	1.03	2.36	1.50	1.11	0.85	1.93	1.44	1.77	
ΔT/U	-0.65	-0.18	-0.45	**3.42**	-0.61	**-1.71**	-0.08	-0.33	**1.52**	-0.03	-0.96	
ΔT(Sn)	-1.45	-0.53	-1.29	1.89	-0.23	0.65	-0.12	-0.63	2.65	-0.23	0.29	
U(Sn)	2.75	1.14	2.73	0.89	1.75	1.46	0.85	1.10	1.29	1.34	1.31	
ΔT/U	-0.53	-0.47	-0.47	**2.12**	-0.13	0.44	-0.14	-0.57	**2.05**	-0.17	0.22	
ΔT(In)					-1.42	-0.06	-1.98	-0.54		0.77	1.39	27.36
U(In)					2.43	1.21	0.87	0.98		1.30	1.13	2.38
ΔT/U					-0.58	-0.05	**-2.28**	-0.55		0.60	**1.23**	**11.52**
ΔT(Ga)	0.86	0.31	-0.28	0.56	0.26	-0.77	-0.08	0.00		-0.28	-0.07	
U(Ga)	1.36	0.50	0.57	0.48	0.95	0.75	0.19	0.29		0.55	0.48	
ΔT/U	0.64	0.63	-0.49	**1.17**	0.27	**-1.03**	-0.40	-0.01		-0.52	-0.14	
ΔT(Hg)	0.25	0.29	0.78	2.25	0.80	0.57	0.25	0.10		0.14	0.28	
U(Hg)	2.49	0.45	0.51	0.51	1.87	0.71	0.25	0.34		0.66	0.56	
ΔT/U	0.10	0.64	**1.54**	**4.43**	0.43	0.80	**1.01**	0.30		0.21	0.50	

Graph 10: ΔT(Lab$_{APMP}$−ARV) in mK (k=2 error bars include lab, link, artefact and ARV uncertainties)



9 BILATERAL DIFFERENCES BETWEEN LABORATORIES

The results given in section 8 are for the difference between APMP laboratories and the "ARV" defined for CCT-KC3 comparison by WG8 for the purposes of evaluating CMCs ("Calibration and Measurement Capability") for approval into Appendix-C of the MRA. As no consensus was obtained for the use of the "ARV" in Appendix-B of the MRA, simple bilateral differences (i) between APMP-KC3 participants and (ii) APMP-KC3 and CCT-KC3 participants have been calculated. This section presents these bilateral differences and their uncertainties and discusses how they were calculated.

9.1 Bilateral differences within APMP-KC3.

For participants of the APMP-KC3 comparison, the bilateral differences are obtained simply by the differences of the results for each lab with respect to the pilot laboratory NMIA.

$$\mathbf{\Delta T(Lab_1 - Lab_2) = \Delta T(Lab_1 - NMIA)_{APMPKC3} - \Delta T(Lab_2 - NMIA)_{APMPKC3}}$$

where the two differences on the RHS have already been calculated (Graph 8 of section 7.5).

The uncertainty in this bilateral difference depends upon whether the two laboratories were within the same loop of APMP-KC3 (Graph 2 section 6.2). If they were, then we need only consider the SPRT instability within that loop. However, if the two APMP laboratories were in different loops, we need to consider the instability (i) between Lab_1 and NMIA (ii) between Lab_2 and NMIA.

$$\mathbf{U^2(Lab_1 - Lab_2) = U^2(Lab_1) + U^2(Lab_2) + U^2_{LoopX}}$$

if both Lab_1 and Lab_2 were in loop X

or

$$\mathbf{U^2(Lab_1 - Lab_2) = U^2(Lab_1) + U^2(Lab_2) + U^2_{LoopX} + U^2_{LoopY}}$$

if Lab_1 and Lab_2 were in loop X and loop Y respectively

where

$U_{Loop,i}$ is the stability of the APMP transfer SPRT (given in Table 13 of section 8.1) determined for the APMP-KC3 loop in which the APMP-KC3 laboratory participated.

$U(Lab_i)$ is the uncertainty of Lab_i in the APMP-KC3 (Table 3 of section 5).

9.2 Bilateral differences between APMP-KC3 and CCT-KC3

The bilateral differences from a given APMP-KC3 participant to a given CCT-KC3 participant is given by the difference between (i) the APMP-KC3 participant and APMP pilot (NMIA), and (ii) the APMP pilot and the CCT-KC3 participant.

$$\mathbf{\Delta T(Lab_{APMP} - Lab_{CCT}) = \Delta T(Lab_{APMP} - NMIA)_{APMPKC3} - \Delta T(Lab_{CCT} - NMIA)_{KRISS\&NMIA}}$$

and its uncertainty is given by

$$\mathbf{U^2(Lab_{APMP} - Lab_{CCT}) = U^2(Lab_{APMP}) + U^2_{loop} + U^2(Lab_{CCT} - NMIA)_{KRISS\&NMIA}}$$

where,

$U(Lab_{APMP})$	is the uncertainty given in the APMPKC3 results (Table 3 of section 5) for the given APMPKC3 participant
$\Delta T(Lab_{CCT} - NMIA)_{KRISS\&NMIA}$	is the difference between the APMP pilot lab, NMIA and CCTKC3 participant labs through a linkage via both KRISS and NMIA.

Because two laboratories, KRISS and NMIA are used to link APMP-KC3 and CCT-KC3 we can choose to determine the difference from the APMP pilot (NMIA) to each CCT-KC3 participant via either (i) the direct value of NMIA in CCT-KC3, or (ii) the value of KRISS in CCT-KC3 together with the value of KRISS-NMIA found in APMP-KC3. As both these links have similar uncertainty, and we have no reason to choose one in preference to the other, we choose to use the simple average of the two links.

In order to link between APMP-KC3 and CCT-KC3 we need to correct for the fact that a link laboratory may have used a different fixed point cell to define the national reference in their APMP-KC3 results than was used in the CCT-KC3 comparison results. In the APMP-KC3 this only occurs for the indium fixed point, which both link laboratories, KRISS and NMIA, have changed. The APMP-KC3 results are corrected by the difference in cell temperatures given by the link laboratories (Table 6 of section 7.1).

$$\mathbf{\Delta T(Lab_{CCT} - NMIA)_{KRISS\&NMIA} = 1/2\,[\,\Delta T(Lab_{CCT} - NMIA)_{CCTKC3} + \Delta T(old\text{-}new)_{NMIA} + \Delta T(Lab_{CCT} - KRISS)_{CCTKC3} + \Delta T(old\text{-}new)_{KRISS} + \Delta T(KRISS - NMIA)_{APMPKC3}\,]}$$

and

$$\mathbf{U^2(Lab_{CCT} - NMIA)_{KRISS\&NMIA} = (1/2)^2\,[\,U^2(Lab_{CCT} - NMIA)_{CCTKC3} + U^2(old\text{-}new)_{NMIA} + U^2(Lab_{CCT} - KRISS)_{CCTKC3} + U^2(old\text{-}new)_{KRISS} + U^2(KRISS)_{APMPKC3}\,]}$$

For the indium point, the differences between cells used in APMP-KC3 and CCT-KC3s are

$\Delta T(\text{old-new})_{NMIA} = -0.34$ mK $\quad$ $U(\text{old-new})_{NMIA} = 0.1$ mK

$\Delta T(\text{old-new})_{KRISS} = 3.46$ mK $\quad$ $U(\text{old-new})_{KRISS} = 0.09$ mK

whilst for Hg, Ga, Sn, and Zn cells the old-new differences and uncertainties are zero.

$\Delta T(\text{old-new})_{NMIA} = 0$ mK $\qquad U(\text{old-new})_{NMIA} = 0$ mK

$\Delta T(\text{old-new})_{KRISS} = 0$ mK $\qquad U(\text{old-new})_{KRISS} = 0$ mK

These results of these calculations are presented in Tables 15 to 19.

Note1: For simplicity we have assumed in the above calculations that the differences between KC3 laboratories are uncorrelated.

Note2: The bilateral differences between KRISS or NMIA and the CCT-KC3 comparison participants is given in the CCT-KC3 report, and therefore not recalculated or re-evaluated here. This is because the data in the APMP-KC3 is not a new evaluation or test of these differences: The NMIA and KRISS CCT-KC3 results are used as links.

Table 15: Bilateral differences and their expanded uncertainties U/mK (k=2) between laboratories for Zn, where ΔT/mK = column – row.

T(Zn)	PSB	CSIR	NIMT	NPL	MUSSD	SIRIM	KRISS	NMIA2	KIMLIPI	SCL	CMS	ITDI	
PSB		**1.83**	**0.89**	**5.55**	**0.60**	**-0.53**	**1.95**	**1.76**	**4.97**	**1.99**	**0.33**		ΔT
		3.30	3.99	3.25	3.88	3.44	3.29	3.21	3.65	3.42	3.57		U
CSIR	**-1.83**		**-0.95**	**3.72**	**-1.23**	**-2.37**	**0.12**	**-0.08**	**3.13**	**0.16**	**-1.51**		ΔT
	3.30		2.72	1.41	2.55	1.81	1.50	1.33	2.18	1.76	2.04		U
NIMT	**-0.89**	**0.95**		**4.66**	**-0.29**	**-1.42**	**1.07**	**0.87**	**4.08**	**1.10**	**-0.56**		ΔT
	3.99	2.72		2.66	3.41	2.89	2.71	2.62	3.14	2.86	3.04		U
NPL	**-5.55**	**-3.72**	**-4.66**		**-4.95**	**-6.08**	**-3.60**	**-3.80**	**-0.58**	**-3.56**	**-5.22**		ΔT
	3.25	1.41	2.66		2.49	1.73	1.40	1.21	2.11	1.67	1.97		U
MUSSD	**-0.60**	**1.23**	**0.29**	**4.95**		**-1.13**	**1.35**	**1.15**	**4.37**	**1.39**	**-0.27**		ΔT
	3.88	2.55	3.41	2.49		2.74	2.55	2.44	2.99	2.71	2.90		U
SIRIM	**0.53**	**2.37**	**1.42**	**6.08**	**1.13**		**2.49**	**2.29**	**5.50**	**2.52**	**0.86**		ΔT
	3.44	1.81	2.89	1.73	2.74		1.67	1.52	2.30	1.91	2.25		U
KRISS	**-1.95**	**-0.12**	**-1.07**	**3.60**	**-1.35**	**-2.49**		**-0.20**	**3.01**	**0.04**	**-1.63**		ΔT
	3.29	1.50	2.71	1.40	2.55	1.67		1.13	2.06	1.62	2.01		U
NMIA2	**-1.76**	**0.08**	**-0.87**	**3.80**	**-1.15**	**-2.29**	**0.20**		**3.21**	**0.24**	**-1.43**		ΔT
	3.21	1.33	2.62	1.21	2.44	1.52	1.13		1.94	1.45	1.88		U
KIMLIPI	**-4.97**	**-3.13**	**-4.08**	**0.58**	**-4.37**	**-5.50**	**-3.01**	**-3.21**		**-2.98**	**-4.64**		ΔT
	3.65	2.18	3.14	2.11	2.99	2.30	2.06	1.94		2.26	2.56		U
SCL	**-1.99**	**-0.16**	**-1.10**	**3.56**	**-1.39**	**-2.52**	**-0.04**	**-0.24**	**2.98**		**-1.66**		ΔT
	3.42	1.76	2.86	1.67	2.71	1.91	1.62	1.45	2.26		2.21		U
CMS	**-0.33**	**1.51**	**0.56**	**5.22**	**0.27**	**-0.86**	**1.63**	**1.43**	**4.64**	**1.66**			ΔT
	3.57	2.04	3.04	1.97	2.90	2.25	2.01	1.88	2.56	2.21			U
ITDI													ΔT
													U
BIPM							see	see					
							CCT-KC3	CCT-KC3					
BNM	**-2.65**	**-0.82**	**-1.76**	**2.90**	**-2.05**	**-3.18**	see	see	**2.32**	**-0.66**	**-2.32**		ΔT
	3.30	1.53	2.73	1.43	2.56	1.80	CCT-KC3	CCT-KC3	2.17	1.75	2.04		U
IMGC	**-1.36**	**0.47**	**-0.48**	**4.19**	**-0.76**	**-1.90**	see	see	**3.60**	**0.63**	**-1.04**		ΔT
	3.29	1.50	2.71	1.40	2.54	1.78	CCT-KC3	CCT-KC3	2.15	1.73	2.01		U
MSL	**-1.87**	**-0.04**	**-0.99**	**3.68**	**-1.27**	**-2.41**	see	see	**3.09**	**0.12**	**-1.55**		ΔT
	5.01	4.07	4.65	4.03	4.56	4.18	CCT-KC3	CCT-KC3	4.35	4.16	4.29		U
NIM	**-3.04**	**-1.21**	**-2.15**	**2.51**	**-2.44**	**-3.57**	see	see	**1.93**	**-1.05**	**-2.71**		ΔT
	3.33	1.59	2.76	1.49	2.60	1.85	CCT-KC3	CCT-KC3	2.21	1.80	2.08		U
NIST	**-2.67**	**-0.84**	**-1.78**	**2.88**	**-2.07**	**-3.20**	see	see	**2.30**	**-0.68**	**-2.34**		ΔT
	3.23	1.37	2.64	1.26	2.47	1.67	CCT-KC3	CCT-KC3	2.06	1.61	1.92		U
NPL	**-2.53**	**-0.70**	**-1.64**	**3.02**	**-1.93**	**-3.06**	see	see	**2.44**	**-0.54**	**-2.20**		ΔT
	3.29	1.50	2.71	1.40	2.54	1.78	CCT-KC3	CCT-KC3	2.15	1.73	2.01		U
NRC	**-1.51**	**0.32**	**-0.62**	**4.04**	**-0.91**	**-2.04**	see	see	**3.46**	**0.48**	**-1.18**		ΔT
	3.25	1.43	2.67	1.32	2.50	1.71	CCT-KC3	CCT-KC3	2.10	1.66	1.96		U
NRLM	**-0.19**	**1.64**	**0.70**	**5.36**	**0.41**	**-0.72**	see	see	**4.78**	**1.80**	**0.14**		ΔT
	3.54	1.99	3.01	1.92	2.86	2.21	CCT-KC3	CCT-KC3	2.52	2.17	2.40		U
PTB	**-1.48**	**0.35**	**-0.59**	**4.07**	**-0.88**	**-2.01**	see	see	**3.49**	**0.51**	**-1.15**		ΔT
	3.35	1.64	2.79	1.55	2.63	1.90	CCT-KC3	CCT-KC3	2.25	1.85	2.12		U
SMU	**-2.19**	**-0.36**	**-1.30**	**3.36**	**-1.59**	**-2.72**	see	see	**2.78**	**-0.20**	**-1.86**		ΔT
	3.28	1.48	2.70	1.37	2.53	1.76	CCT-KC3	CCT-KC3	2.13	1.71	1.99		U
VNIIM	**-2.69**	**-0.86**	**-1.80**	**2.86**	**-2.09**	**-3.22**	see	see	**2.28**	**-0.70**	**-2.36**		ΔT
	3.38	1.70	2.82	1.60	2.66	1.94	CCT-KC3	CCT-KC3	2.29	1.90	2.16		U
VSL	**-2.36**	**-0.53**	**-1.47**	**3.19**	**-1.76**	**-2.89**	see	see	**2.61**	**-0.37**	**-2.03**		ΔT
	3.30	1.53	2.72	1.43	2.56	1.80	CCT-KC3	CCT-KC3	2.17	1.75	2.03		U
$U(\text{Lab})_{APMP}$	**3.11**	**1.05**	**2.49**	**0.90**	**2.31**	**1.31**	**0.84**	**0.45**	**1.79**	**1.24**	**1.35**		

Table 16: Bilateral differences and their expanded uncertainties U/mK (k=2) between laboratories for Sn, where ΔT/mK = column – row.

T(Sn)	PSB	CSIR	NIMT	NPL	MUSSD	SIRIM	KRISS	NMIA2	KIMLIPI	SCL	CMS	ITDI	
PSB		**0.91**	**0.16**	**3.34**	**1.21**	**2.09**	**1.33**	**0.82**	**4.09**	**1.21**	**1.74**		ΔT
		2.85	3.78	2.76	3.15	2.99	2.75	2.84	2.92	2.94	2.93		U
CSIR	**-0.91**		**-0.75**	**2.43**	**0.30**	**1.18**	**0.41**	**-0.10**	**3.18**	**0.30**	**0.82**		ΔT
	2.85		2.83	1.16	1.91	1.64	1.14	1.34	1.49	1.54	1.52		U
NIMT	**-0.16**	**0.75**		**3.18**	**1.05**	**1.93**	**1.16**	**0.66**	**3.93**	**1.05**	**1.57**		ΔT
	3.78	2.83		2.74	3.13	2.97	2.73	2.82	2.90	2.92	2.91		U
NPL	**-3.34**	**-2.43**	**-3.18**		**-2.13**	**-1.25**	**-2.02**	**-2.52**	**0.75**	**-2.13**	**-1.60**		ΔT
	2.76	1.16	2.74		1.77	1.48	0.89	1.13	1.31	1.37	1.34		U
MUSSD	**-1.21**	**-0.30**	**-1.05**	**2.13**		**0.88**	**0.11**	**-0.39**	**2.88**	**0.00**	**0.52**		ΔT
	3.15	1.91	3.13	1.77		2.11	1.75	1.89	2.00	2.04	2.02		U
SIRIM	**-2.09**	**-1.18**	**-1.93**	**1.25**	**-0.88**		**-0.77**	**-1.27**	**2.00**	**-0.88**	**-0.36**		ΔT
	2.99	1.64	2.97	1.48	2.11		1.43	1.59	1.73	1.77	1.76		U
KRISS	**-1.33**	**-0.41**	**-1.16**	**2.02**	**-0.11**	**0.77**		**-0.51**	**2.77**	**-0.11**	**0.41**		ΔT
	2.75	1.14	2.73	0.89	1.75	1.43		1.07	1.26	1.31	1.31		U
NMIA2	**-0.82**	**0.10**	**-0.66**	**2.52**	**0.39**	**1.27**	**0.51**		**3.28**	**0.39**	**0.92**		ΔT
	2.84	1.34	2.82	1.13	1.89	1.59	1.07		1.44	1.49	1.49		U
KIMLIPI	**-4.09**	**-3.18**	**-3.93**	**-0.75**	**-2.88**	**-2.00**	**-2.77**	**-3.28**		**-2.88**	**-2.36**		ΔT
	2.92	1.49	2.90	1.31	2.00	1.73	1.26	1.44		1.63	1.63		U
SCL	**-1.21**	**-0.30**	**-1.05**	**2.13**	**0.00**	**0.88**	**0.11**	**-0.39**	**2.88**		**0.52**		ΔT
	2.94	1.54	2.92	1.37	2.04	1.77	1.31	1.49	1.63		1.67		U
CMS	**-1.74**	**-0.82**	**-1.57**	**1.60**	**-0.52**	**0.36**	**-0.41**	**-0.92**	**2.36**	**-0.52**			ΔT
	2.93	1.52	2.91	1.34	2.02	1.76	1.31	1.49	1.63	1.67			U
ITDI													ΔT
													U

BIPM							see CCT-KC3	see CCT-KC3					
BNM	**-1.40**	**-0.49**	**-1.24**	**1.94**	**-0.19**	**0.69**	see	see	**2.69**	**-0.19**	**0.33**		ΔT
	2.83	1.32	2.81	1.11	1.87	1.60	CCT-KC3	CCT-KC3	1.45	1.50	1.47		U
IMGC	**-1.78**	**-0.86**	**-1.62**	**1.56**	**-0.56**	**0.32**	see	see	**2.32**	**-0.56**	**-0.04**		ΔT
	2.77	1.19	2.75	0.95	1.78	1.49	CCT-KC3	CCT-KC3	1.33	1.38	1.35		U
MSL	**-0.94**	**-0.03**	**-0.78**	**2.40**	**0.27**	**1.15**	see	see	**3.15**	**0.27**	**0.79**		ΔT
	2.88	1.41	2.85	1.22	1.94	1.67	CCT-KC3	CCT-KC3	1.53	1.58	1.55		U
NIM	**-0.85**	**0.06**	**-0.69**	**2.49**	**0.36**	**1.24**	see	see	**3.24**	**0.36**	**0.88**		ΔT
	4.85	4.15	4.84	4.09	4.36	4.25	CCT-KC3	CCT-KC3	4.20	4.21	4.20		U
NIST	**-1.91**	**-0.99**	**-1.75**	**1.43**	**-0.69**	**0.19**	see	see	**2.19**	**-0.69**	**-0.17**		ΔT
	2.75	1.14	2.73	0.90	1.75	1.46	CCT-KC3	CCT-KC3	1.29	1.34	1.31		U
NPL	**-1.64**	**-0.72**	**-1.48**	**1.70**	**-0.42**	**0.46**	see	see	**2.46**	**-0.42**	**0.10**		ΔT
	2.80	1.25	2.78	1.03	1.83	1.54	CCT-KC3	CCT-KC3	1.38	1.43	1.41		U
NRC	**-0.56**	**0.36**	**-0.40**	**2.78**	**0.66**	**1.54**	see	see	**3.54**	**0.66**	**1.18**		ΔT
	2.81	1.26	2.78	1.04	1.84	1.55	CCT-KC3	CCT-KC3	1.40	1.45	1.42		U
NRLM	**-0.58**	**0.34**	**-0.42**	**2.76**	**0.64**	**1.52**	see	see	**3.52**	**0.64**	**1.16**		ΔT
	2.82	1.29	2.79	1.07	1.85	1.57	CCT-KC3	CCT-KC3	1.42	1.47	1.44		U
PTB	**-2.11**	**-1.19**	**-1.95**	**1.23**	**-0.89**	**-0.01**	see	see	**1.99**	**-0.89**	**-0.37**		ΔT
	2.82	1.29	2.80	1.08	1.86	1.58	CCT-KC3	CCT-KC3	1.43	1.47	1.45		U
SMU	**-1.77**	**-0.86**	**-1.61**	**1.57**	**-0.56**	**0.32**	see	see	**2.32**	**-0.56**	**-0.04**		ΔT
	2.82	1.29	2.80	1.08	1.86	1.58	CCT-KC3	CCT-KC3	1.43	1.47	1.45		U
VNIIM	**-2.11**	**-1.19**	**-1.95**	**1.23**	**-0.89**	**-0.01**	see	see	**1.99**	**-0.89**	**-0.37**		ΔT
	2.80	1.25	2.78	1.03	1.82	1.54	CCT-KC3	CCT-KC3	1.38	1.43	1.41		U
VSL	**-1.48**	**-0.56**	**-1.32**	**1.86**	**-0.26**	**0.62**	see	see	**2.62**	**-0.26**	**0.26**		ΔT
	2.80	1.26	2.78	1.03	1.83	1.55	CCT-KC3	CCT-KC3	1.39	1.44	1.41		U

$U(Lab)_{APMP}$	**2.68**	**0.96**	**2.66**	**0.65**	**1.64**	**1.30**	**0.54**	**0.88**	**1.11**	**1.17**	**1.07**	

Table 17: Bilateral differences and their expanded uncertainties U/mK (k=2) between laboratories for In, where ΔT/mK = column – row.

T(In)	PSB	CSIR	NIMT	NPL	MUSSD	SIRIM	KRISS	NMIA2	KIMLIPI	SCL	CMS	ITDI	
PSB													ΔT
													U
CSIR													ΔT
													U
NIMT													ΔT
													U
NPL													ΔT
													U
MUSSD						**1.36**	**-0.56**	**0.88**		**2.19**	**2.81**	**28.77**	ΔT
						2.61	2.47	2.51		2.65	2.58	3.32	U
SIRIM					**-1.36**		**-1.92**	**-0.48**		**0.83**	**1.45**	**27.42**	ΔT
					2.61		1.27	1.35		1.60	1.48	2.56	U
KRISS					**0.56**	**1.92**		**1.44**		**2.76**	**3.37**	**29.34**	ΔT
					2.47	1.27		1.06		1.36	1.21	2.42	U
NMIA2					**-0.88**	**0.48**	**-1.44**			**1.31**	**1.93**	**27.90**	ΔT
					2.51	1.35	1.06			1.43	1.30	2.46	U
KIMLIPI													ΔT
													U
SCL					**-2.19**	**-0.83**	**-2.76**	**-1.31**			**0.62**	**26.58**	ΔT
					2.65	1.60	1.36	1.43			1.55	2.60	U
CMS					**-2.81**	**-1.45**	**-3.37**	**-1.93**		**-0.62**		**25.96**	ΔT
					2.58	1.48	1.21	1.30		1.55		2.50	U
ITDI					**-28.77**	**-27.42**	**-29.34**	**-27.90**		**-26.58**	**-25.96**		ΔT
					3.32	2.56	2.42	2.46		2.60	2.50		U

BIPM							see	see					
							CCT-KC3	CCT-KC3					
BNM					**-1.24**	**0.12**	see	see		**0.95**	**1.57**	**27.53**	ΔT
					2.50	1.35	CCT-KC3	CCT-KC3		1.42	1.28	9.33	U
IMGC					**-1.62**	**-0.26**	see	see		**0.57**	**1.19**	**27.16**	ΔT
					2.50	1.34	CCT-KC3	CCT-KC3		1.42	1.27	11.27	U
MSL					**-1.20**	**0.16**	see	see		**0.99**	**1.61**	**27.58**	ΔT
					2.53	1.40	CCT-KC3	CCT-KC3		1.48	1.34	13.23	U
NIM					**-0.55**	**0.81**	see	see		**1.64**	**2.26**	**28.23**	ΔT
					2.55	1.43	CCT-KC3	CCT-KC3		1.50	1.36	15.21	U
NIST					**-1.88**	**-0.52**	see	see		**0.31**	**0.93**	**26.90**	ΔT
					2.46	1.27	CCT-KC3	CCT-KC3		1.35	1.19	17.17	U
NPL					**-1.19**	**0.17**	see	see		**1.00**	**1.62**	**27.59**	ΔT
					2.51	1.35	CCT-KC3	CCT-KC3		1.43	1.28	19.16	U
NRC					**-0.85**	**0.51**	see	see		**1.34**	**1.96**	**27.93**	ΔT
					2.47	1.29	CCT-KC3	CCT-KC3		1.37	1.21	21.14	U
NRLM					**-0.60**	**0.76**	see	see		**1.59**	**2.21**	**28.18**	ΔT
					2.55	1.44	CCT-KC3	CCT-KC3		1.51	1.37	23.14	U
PTB					**-1.57**	**-0.21**	see	see		**0.62**	**1.24**	**27.21**	ΔT
					2.58	1.49	CCT-KC3	CCT-KC3		1.56	1.43	25.13	U
SMU							see	see					ΔT
							CCT-KC3	CCT-KC3					U
VNIIM					**-1.99**	**-0.63**	see	see		**0.20**	**0.82**	**26.79**	ΔT
					2.51	1.37	CCT-KC3	CCT-KC3		1.44	1.30	29.10	U
VSL					**-0.66**	**0.70**	see	see		**1.53**	**2.15**	**28.12**	ΔT
					2.51	1.35	CCT-KC3	CCT-KC3		1.43	1.28	31.10	U

$U(Lab)_{APMP}$					**2.37**	**1.07**	**0.66**	**0.80**		**1.17**	**0.94**	**2.29**

Table 18: Bilateral differences and their expanded uncertainties U/mK (k=2) between laboratories for Ga, where ΔT/mK = column − row.

T(Ga)	PSB	CSIR	NIMT	NPL	MUSSD	SIRIM	KRISS	NMIA2	KIMLIPI	SCL	CMS	ITDI	
PSB		**-0.55**	**-1.14**	**-0.30**	**-0.61**	**-1.63**	**-0.94**	**-0.87**		**-1.15**	**-0.93**		ΔT
		1.43	1.46	1.42	1.64	1.54	1.36	1.37		1.45	1.43		U
CSIR	**0.55**		**-0.59**	**0.25**	**-0.06**	**-1.08**	**-0.39**	**-0.32**		**-0.60**	**-0.38**		ΔT
	1.43		0.73	0.66	1.05	0.88	0.50	0.55		0.72	0.67		U
NIMT	**1.14**	**0.59**		**0.84**	**0.53**	**-0.49**	**0.20**	**0.27**		**-0.01**	**0.21**		ΔT
	1.46	0.73		0.72	1.09	0.92	0.57	0.61		0.77	0.72		U
NPL	**0.30**	**-0.25**	**-0.84**		**-0.30**	**-1.33**	**-0.64**	**-0.56**		**-0.84**	**-0.63**		ΔT
	1.42	0.66	0.72		1.04	0.87	0.48	0.53		0.70	0.65		U
MUSSD	**0.61**	**0.06**	**-0.53**	**0.30**		**-1.02**	**-0.33**	**-0.26**		**-0.54**	**-0.32**		ΔT
	1.64	1.05	1.09	1.04		1.19	0.95	0.97		1.08	1.04		U
SIRIM	**1.63**	**1.08**	**0.49**	**1.33**	**1.02**		**0.69**	**0.77**		**0.49**	**0.70**		ΔT
	1.54	0.88	0.92	0.87	1.19		0.75	0.78		0.91	0.87		U
KRISS	**0.94**	**0.39**	**-0.20**	**0.64**	**0.33**	**-0.69**		**0.07**		**-0.21**	**0.01**		ΔT
	1.36	0.50	0.57	0.48	0.95	0.75		0.30		0.55	0.48		U
NMIA2	**0.87**	**0.32**	**-0.27**	**0.56**	**0.26**	**-0.77**	**-0.07**			**-0.28**	**-0.06**		ΔT
	1.37	0.55	0.61	0.53	0.97	0.78	0.30			0.59	0.53		U
KIMLIPI													ΔT
													U
SCL	**1.15**	**0.60**	**0.01**	**0.84**	**0.54**	**-0.49**	**0.21**	**0.28**			**0.22**		ΔT
	1.45	0.72	0.77	0.70	1.08	0.91	0.55	0.59			0.70		U
CMS	**0.93**	**0.38**	**-0.21**	**0.63**	**0.32**	**-0.70**	**-0.01**	**0.06**		**-0.22**			ΔT
	1.43	0.67	0.72	0.65	1.04	0.87	0.48	0.53		0.70			U
ITDI													ΔT
													U

BIPM	**0.91**	**0.36**	**-0.23**	**0.61**	**0.31**	**-0.72**	see	see		**-0.23**	**-0.02**		
	1.38	0.56	0.62	0.54	0.98	0.79	CCT-KC3	CCT-KC3		0.61	0.55		
BNM	**0.84**	**0.29**	**-0.30**	**0.54**	**0.24**	**-0.79**	see	see		**-0.30**	**-0.09**		ΔT
	1.39	0.59	0.65	0.57	1.00	0.81	CCT-KC3	CCT-KC3		0.63	0.57		U
IMGC	**0.73**	**0.18**	**-0.41**	**0.43**	**0.13**	**-0.90**	see	see		**-0.41**	**-0.20**		ΔT
	1.38	0.56	0.62	0.54	0.98	0.79	CCT-KC3	CCT-KC3		0.60	0.54		U
MSL	**0.72**	**0.17**	**-0.42**	**0.41**	**0.11**	**-0.91**	see	see		**-0.43**	**-0.21**		ΔT
	1.40	0.61	0.66	0.59	1.01	0.82	CCT-KC3	CCT-KC3		0.65	0.59		U
NIM	**1.35**	**0.80**	**0.21**	**1.04**	**0.74**	**-0.28**	see	see		**0.20**	**0.42**		ΔT
	1.43	0.68	0.73	0.67	1.05	0.88	CCT-KC3	CCT-KC3		0.72	0.67		U
NIST	**0.82**	**0.27**	**-0.32**	**0.52**	**0.22**	**-0.81**	see	see		**-0.32**	**-0.11**		ΔT
	1.38	0.55	0.61	0.53	0.98	0.78	CCT-KC3	CCT-KC3		0.60	0.54		U
NPL	**0.98**	**0.43**	**-0.16**	**0.68**	**0.38**	**-0.65**	see	see		**-0.16**	**0.05**		ΔT
	1.41	0.62	0.68	0.61	1.02	0.84	CCT-KC3	CCT-KC3		0.67	0.61		U
NRC	**0.96**	**0.41**	**-0.18**	**0.65**	**0.35**	**-0.67**	see	see		**-0.19**	**0.03**		ΔT
	1.39	0.58	0.64	0.57	0.99	0.81	CCT-KC3	CCT-KC3		0.63	0.57		U
NRLM	**1.26**	**0.71**	**0.12**	**0.95**	**0.65**	**-0.37**	see	see		**0.11**	**0.33**		ΔT
	1.38	0.57	0.63	0.55	0.99	0.80	CCT-KC3	CCT-KC3		0.62	0.56		U
PTB	**0.61**	**0.06**	**-0.53**	**0.31**	**0.01**	**-1.02**	see	see		**-0.53**	**-0.32**		ΔT
	1.39	0.58	0.64	0.56	0.99	0.80	CCT-KC3	CCT-KC3		0.62	0.56		U
SMU	**0.78**	**0.23**	**-0.36**	**0.48**	**0.18**	**-0.85**	see	see		**-0.36**	**-0.15**		ΔT
	1.38	0.57	0.63	0.55	0.99	0.80	CCT-KC3	CCT-KC3		0.61	0.55		U
VNIIM	**0.81**	**0.26**	**-0.33**	**0.51**	**0.21**	**-0.82**	see	see		**-0.33**	**-0.12**		ΔT
	1.38	0.57	0.63	0.55	0.98	0.79	CCT-KC3	CCT-KC3		0.61	0.55		U
VSL	**1.04**	**0.49**	**-0.10**	**0.74**	**0.44**	**-0.59**	see	see		**-0.10**	**0.11**		ΔT
	1.41	0.62	0.68	0.61	1.02	0.84	CCT-KC3	CCT-KC3		0.67	0.61		U

$U(Lab)_{APMP}$	**1.35**	**0.48**	**0.55**	**0.46**	**0.94**	**0.73**	**0.14**	**0.26**		**0.53**	**0.46**	

Table 19: Bilateral differences and their expanded uncertainties U/mK (k=2) between laboratories for Hg, where ΔT/mK = column − row.

T(Hg)	PSB	CSIR	NIMT	NPL	MUSSD	SIRIM	KRISS	NMIA2	KIMLIPI	SCL	CMS	ITDI	
PSB		**0.04**	**0.53**	**2.00**	**0.56**	**0.32**	**0.00**	**-0.14**		**-0.11**	**0.04**		ΔT
		2.52	2.53	2.53	3.10	2.58	2.49	2.50		2.56	2.54		U
CSIR	**-0.04**		**0.49**	**1.96**	**0.52**	**0.28**	**-0.04**	**-0.18**		**-0.15**	**0.00**		ΔT
	2.52		0.63	0.63	1.91	0.81	0.45	0.51		0.76	0.68		U
NIMT	**-0.53**	**-0.49**		**1.47**	**0.03**	**-0.21**	**-0.53**	**-0.67**		**-0.64**	**-0.49**		ΔT
	2.53	0.63		0.67	1.92	0.84	0.50	0.56		0.79	0.72		U
NPL	**-2.00**	**-1.96**	**-1.47**		**-1.44**	**-1.68**	**-2.00**	**-2.14**		**-2.11**	**-1.96**		ΔT
	2.53	0.63	0.67		1.92	0.84	0.51	0.56		0.79	0.72		U
MUSSD	**-0.56**	**-0.52**	**-0.03**	**1.44**		**-0.23**	**-0.56**	**-0.70**		**-0.66**	**-0.52**		ΔT
	3.10	1.91	1.92	1.92		1.99	1.87	1.89		1.97	1.94		U
SIRIM	**-0.32**	**-0.28**	**0.21**	**1.68**	**0.23**		**-0.32**	**-0.47**		**-0.43**	**-0.29**		ΔT
	2.58	0.81	0.84	0.84	1.99		0.71	0.75		0.94	0.87		U
KRISS	**0.00**	**0.04**	**0.53**	**2.00**	**0.56**	**0.32**		**-0.14**		**-0.11**	**0.04**		ΔT
	2.49	0.45	0.50	0.51	1.87	0.71		0.33		0.66	0.56		U
NMIA2	**0.14**	**0.18**	**0.67**	**2.14**	**0.70**	**0.47**	**0.14**			**0.04**	**0.18**		ΔT
	2.50	0.51	0.56	0.56	1.89	0.75	0.33			0.70	0.61		U
KIMLIPI													ΔT
													U
SCL	**0.11**	**0.15**	**0.64**	**2.11**	**0.66**	**0.43**	**0.11**	**-0.04**			**0.14**		ΔT
	2.56	0.76	0.79	0.79	1.97	0.94	0.66	0.70			0.83		U
CMS	**-0.04**	**0.00**	**0.49**	**1.96**	**0.52**	**0.29**	**-0.04**	**-0.18**		**-0.14**			ΔT
	2.54	0.68	0.72	0.72	1.94	0.87	0.56	0.61		0.83			U
ITDI													ΔT
													U
BIPM							see	see					
							CCT-KC3	CCT-KC3					
BNM	**0.67**	**0.71**	**1.20**	**2.67**	**1.22**	**0.99**	see	see		**0.56**	**0.70**		ΔT
	2.53	0.64	0.68	0.68	1.93	0.84	CCT-KC3	CCT-KC3		0.80	0.72		U
IMGC	**0.39**	**0.43**	**0.92**	**2.39**	**0.94**	**0.71**	see	see		**0.28**	**0.42**		ΔT
	2.50	0.53	0.58	0.58	1.89	0.77	CCT-KC3	CCT-KC3		0.72	0.63		U
MSL	**0.16**	**0.20**	**0.69**	**2.16**	**0.71**	**0.48**	see	see		**0.05**	**0.19**		ΔT
	2.51	0.57	0.62	0.62	1.91	0.80	CCT-KC3	CCT-KC3		0.75	0.67		U
NIM	**-0.03**	**0.01**	**0.50**	**1.97**	**0.52**	**0.29**	see	see		**-0.14**	**0.00**		ΔT
	2.52	0.61	0.65	0.65	1.92	0.82	CCT-KC3	CCT-KC3		0.78	0.70		U
NIST	**0.30**	**0.34**	**0.83**	**2.30**	**0.85**	**0.62**	see	see		**0.19**	**0.33**		ΔT
	2.50	0.50	0.55	0.55	1.89	0.74	CCT-KC3	CCT-KC3		0.69	0.60		U
NPL	**0.20**	**0.24**	**0.73**	**2.20**	**0.75**	**0.52**	see	see		**0.09**	**0.23**		ΔT
	2.51	0.56	0.61	0.61	1.90	0.79	CCT-KC3	CCT-KC3		0.74	0.66		U
NRC	**0.08**	**0.12**	**0.61**	**2.08**	**0.64**	**0.40**	see	see		**-0.02**	**0.12**		ΔT
	2.50	0.51	0.56	0.56	1.89	0.75	CCT-KC3	CCT-KC3		0.70	0.62		U
NRLM	**0.53**	**0.57**	**1.06**	**2.53**	**1.08**	**0.85**	see	see		**0.42**	**0.56**		ΔT
	2.53	0.64	0.68	0.68	1.93	0.85	CCT-KC3	CCT-KC3		0.80	0.73		U
PTB	**0.36**	**0.40**	**0.89**	**2.36**	**0.91**	**0.68**	see	see		**0.25**	**0.39**		ΔT
	2.50	0.54	0.58	0.58	1.90	0.77	CCT-KC3	CCT-KC3		0.72	0.63		U
SMU							see	see					ΔT
							CCT-KC3	CCT-KC3					U
VNIIM							see	see					ΔT
							CCT-KC3	CCT-KC3					U
VSL	**0.26**	**0.30**	**0.79**	**2.26**	**0.81**	**0.58**	see	see		**0.15**	**0.29**		ΔT
	2.51	0.58	0.62	0.62	1.91	0.80	CCT-KC3	CCT-KC3		0.75	0.67		U
$U(Lab)_{APMP}$	**2.48**	**0.41**	**0.47**	**0.47**	**1.86**	**0.69**	**0.16**	**0.28**		**0.63**	**0.52**		

10 INCOMPLETE SUBMISSION

Laboratories failing to submit data for APMP- KC3 report draft A:

(1) PSB Immersion curve for Water triple point (WTP)
(2) NIMT: Instrumentation list 2,3; Immersion curve for Sn, WTP
(3) MUSSD: Immersion curve for WTP
(4) SIRIM: Immersion curve for WTP
(5) KIM-LIPI: Immersion curve for WTP
(6) SCL: Immersion curve for WTP
(7) CMS: Instrumentation list, Immersion curves for In
(8) ITDI: Instrumentation list, Immersion curves for In, WTP

APPENDIX 1: PROTOCOL FOR THE APMP-KC3
As given in APMP-KC3 Report Draft A (Nov 2003)

APPENDIX 2: MEASUREMENT DATA
As given in APMP-KC3 Report Draft A (Nov 2003)

APPENDIX 3: UNCERTAINTY OF MEASUREMENTS

APPENDIX 4: IMMERSION CURVE

APPENDIX 5: INSTRUMENTATION

APPENDIX 1: INSTRUCTION FOR THE APMP KC3, RESULT AND UNCERTAINTY TEMPLATE.

11 *INTRODUCTION*

This APMP regional comparison is being coordinated by National Measurement Laboratory (NML), CSIRO, Australia, and extends from the triple point of Hg (–38.8344 °C) to the freezing point of Zn (419.527 °C). As mentioned in the Preliminary Questionnaire sent out in February 2000, each participant will calibrate a long stem Standard Platinum Resistance Thermometer (SPRT), and arrange for it to be hand carried to the next participating laboratory. The Laboratory Schedule for the APMP regional KC-3, dated 9 May 2000 has been included. The comparison results will be analysed by NML.

The instructions which are given below should be followed by all participants in this comparison. Moreover, each laboratory should follow its normal practice when realizing the ITS-90. The instructions are based on Appendix 1 of Report to the CCT on Key Comparison 3 by B. W. Mangum et al. of NIST (November 1999). The comparison strictly follows the protocols given in the Guidelines for CIPM key comparisons, Appendix F to the MRA, 1 March 1999.

The travelling SPRT is to pass through the following sequence:

1) *a measurement at the triple point of water (TPW)*
2) *a stabilisation procedure*
3) *a second measurement at the triple point of water*
4) *measurements at metal fixed points in order of decreasing temperatures alternating with a measurement at the triple point of water. There are four options:*
    - *Option 1: Zn point, TPW, Sn point, TPW, In point, TPW, Ga point, TPW, Hg point and TPW, or*
    - *Option 2, if the In cell is not available: Zn point, TPW, Sn point, TPW, Ga point, TPW, Hg point and TPW, or*
    - *Option 3, if the Zn and Sn cells are not available: In point, TPW, Ga point, TPW, Hg point and TPW, or*
    - *Option 4, if the In, Ga and Hg cells are not available: Zn point, TPW, Sn point and TPW.*

The travelling SPRT details are as follows:

S/No: 419/028
Model: 419
Manufacturer: Isotech
Description: Nominal resistance 25.5 ohm at 0 °C, 4 wires with spade terminals, quartz sheath , 550 mm long, 7.5 mm OD.

The SPRT artefact is very fragile so it must be handled with extreme care. When not in use, it should be stored horizontally in the groove of the protecting foam inside its hard travelling case. For transport, the SPRT must be hand carried in its case to the next *destination, accompanied by its ATA Carnet. The case is 94 cm long $\times$ 16 cm wide $\times$ 7 cm high and weighs about 2kg.*

12

13 DETAILED INSTRUCTIONS

1. *Upon receipt of the SPRT, the host laboratory must inspect the artefact for damage. Then the host must complete and forward (by e-mail or fax) the attached Artefact Received Form to NML to report the condition of the artefact. If the travelling SPRT is damaged, NML will give instructions on how to proceed.*

2. *If no damage has been sustained, and after reporting to NML, the host must measure the resistance of the travelling SPRT in a TPW cell at two measuring currents (to determine the zero-current value). The ice mantle of the TPW cell must have been prepared and aged according to the host's existing practice. Correct the resistance at zero current for the hydrostatic head to obtain R_{TPW1}, expressed in terms of the host's national ohm.*

3. *Before proceeding further, forward to NML the value of R_{TPW1}. After receiving this information, NML will advise the host as to the next step to be taken.*

4. *If the host laboratory does not possess Zn and Sn cells, and after receiving approval from NML to continue with the comparison following completion of instruction 3, the host should proceed to instruction 10.*

5. *If the host does have a Zn cell: Carefully insert the SPRT into a furnace at 440°C. Anneal the SPRT for two hours at 440°C, then carefully remove the SPRT from the furnace directly to the room environment. After the SPRT has cooled to room temperature, re-determine its TPW resistance as per instruction 2 to give R_{TPW2}.*

6. *If the decrease in the calculated TPW resistance of the SPRT after annealing, ($R_{TPW2} - R_{TPW1}$), is equivalent to 0.5mK or greater, proceed to instruction 8. If the decrease is less than 0.5mK, notify NML and proceed to instruction 10.*

7. *If the resistance at TPW increases after annealing, ie if R_{TPW2} is larger than R_{TPW1}, contact NML for further instructions.*

8. *Repeat step 5 to give R_{TPW3}. If the additional decrease in the resistance at the TPW, ($R_{TPW3} - R_{TPW2}$), is equal to or less than the equivalent of 0.2mK, continue with instruction 10. If not, communicate with NML for further instructions.*

9. *If the resistance at TPW increases after the second annealing, ie if R_{TPW3} is larger than R_{TPW2}, contact NML for further instructions.*

10. *Calibrate the SPRT over the entire temperature range, using the appropriate fixed point option (see page 3). Existing techniques as practised by the host laboratory must be used. For each metal fixed point, determine $W = R_t/R_{TPW}$, where R_t is the*

resistance at the fixed point and R_{TPW} is the TPW resistance obtained immediately after the measurement of R_t. Both R_t and R_{TPW} should have been corrected for self-heating, the hydrostatic head and, if any, the pressure effect.

11. *After completing the calibration, the host laboratory must transmit the data and computations to NML.*

12. *After receiving approval from NML, the host laboratory must inform the next laboratory in advance of the arrival of the SPRT, send the Artefact Shipped Form to NML, pack the SPRT in its travelling case and hand carry it to the next laboratory listed on the schedule.*

13. *The SPRT must be hand carried to the next participating laboratory accompanied by an ATA Carnet, which consists of several forms relating to the exportation and importation of the artefact. The procedures required by the Department of Customs of various countries must be strictly obeyed. The Carnet forms must be carefully and accurately completed. It is the responsibility of the laboratory carrying the transfer SPRT to the next laboratory to present the Carnet to Customs when leaving the country and upon arrival in the country of destination. Personnel at the receiving laboratory must check the Carnet forms very carefully upon receipt.*

14. *The host laboratory should ensure that calibration and delivery of the SPRT are carried out in accordance with the Laboratory Schedule for the APMP regional KC-3, dated 9 May 2000. The host laboratory should inform NML immediately if any of the scheduled dates can not be met.*

14 *REPORTING OF DATA TO NML*

The participating host must send to NML the following information. If all of them are not received, the host's data will not be included in the report.

1. *For each fixed point cell that was used in the comparison, determine (using the host's own SPRT) and plot the change of phase transition temperature, dT, versus immersion, dh. On the same graph, plot the theoretical dT/dh curve using the hydrostatic pressure coefficients (mK/m of liquid) given in the ITS-90 text.*

2. *Freezing curves of the travelling SPRT in In, Sn and Zn cells, freezing/melting curve in Hg cell and melting curve in Ga cell.*

3. *Using the attached spreadsheet named 'Calibrationdata.xls' to report the resistance ratio $W = R_t / R_{TPW}$ where R_t is the resistance of the SPRT at each of the fixed points, and R_{TPW} is the resistance in the TPW cell obtained after the measurement of R_t. The values of R_t and R_{TPW} must be corrected for self heating, the hydrostatic head and if applicable, the pressure effect.*

4. *Uncertainty analysis using the attached spreadsheet named 'Uncertainty.xls.'*

5. *Details of instrumentation, fixed point cells and techniques used in the realisation of the fixed points for this comparison should be given in the attached sheet 'Instrument.xls.'*

The immersion curves, the freezing/melting curves and the completed forms 'Calibrationdata.xls', 'Uncertainty.xls' and 'Instrument.xls' should be e-mailed to kimn@tip.csiro.au

15 *UNCERTAINTY ANALYSIS*

Participants are requested to use the attached spreadsheet 'Uncertainty.xls' to calculate and report their estimated uncertainties for the determination of resistance ratios obtained from the SPRT artefact at the fixed points that were used in this comparison. Calculations of uncertainties should follow the guidelines set out in the ISO Guide to the Expression of Uncertainty in Measurement.
For each uncertainty component, a standard uncertainty u_i and its associated degrees of freedom must be provided. The value of u_i should be given in terms of temperature, μK. For type A evaluation, the number of degrees of freedom, $\nu_{i(A)}$, is n-1 where n is the the number of measurements. For type B evaluation, the number of degrees of freedom, $\nu_{i(B)}$, is based on the relative uncertainty of the component and defined by the ISO Guide as $\nu_{i(B)} \approx 1/2\ [\Delta u_i/u_i]^{-2}$. The combined uncertainty U_c, the effective degrees of freedom ν_{eff} and subsequently, the expanded uncertainty U_{exp} at 95% level of confidence are calculated as set out in the Guide.
To assist with the determination of measurement uncertainties, the following section explains the meanings of the uncertainty components given in 'Uncertainty.xls.' Participants should note that not all components are applicable to every fixed point.

1. *Measurement scatter*
   This type A evaluation is the random variation in n readings of resistances, or resistance ratios, with a standard deviation of the mean of s.

2. *Chemical impurity*
   Considered a type B evaluation, the uncertainty due to the impurity in the metal sample used in the fixed point is estimated from the manufacturer's essay, the melting range of the fixed point, the flatness of the freezing curve and the agreement between melting/freezing temperatures.

3. *FP realisation*
   This type B uncertainty is associated with the realisation of the fixed point. It may be taken as the resistance values believed to be of the flattest region of the melting/freezing curve.

4. *Isotope variations*
   This, regarded as type B, refers to the variation in the concentration of deuterium in water hence is applicable only to the triple point of water.

5. *Reference resistor*
Another type B component, this arises from the instability (such as temporal drift) and the fluctuation in temperature of the reference resistor used with the resistance measuring devices.

6. *Self-heating*
Resistance ratio W is determined from zero-current values that are extrapolated from measurements at two values of the sensing current, I and $\sqrt{2}$ *of I. The self-heating correction obtained from a SPRT in a fixed point tends to vary slightly. This type B uncertainty may be due to the variation in the sensing current (covered in item 1) and the* $\sqrt{2}$ *multiplier.*

7. *Quadrature effect*
This effect, a type B consideration, is applicable only to AC bridges, due to imperfect quadrature balance in such bridges.

8. *Hydrostatic head*
The effect of the hydrostatic head pressure of a column of metallic liquid on the SPRT sensor is corrected for, according to Clausius-Clapeyron. However, this type B factor arises from the uncertainty in determining the hydrostatic head of liquid above the mid point of the SPRT sensor in the fixed point cell.

9. *Conduction error*
If the change in the temperature, dT, to the change in the immersion, dh, of the SPRT follows the hydrostatic head pressure effect then it can be assumed that thermal conduction error is negligible. Otherwise, it can be determined as a type B deviation from the dT/dh line.

10. *Insulation degradation*
This, type B evaluation, is mainly due to the presence of moisture in the insulating material, causing shunting of the platinum sensor.

11. *Gas pressure*
The temperature of the freezing/melting point is defined at a pressure of 1 atm. A flow of inert gas at 1 atm is usually used to regulate the pressure of open cells. This item relates to the uncertainty in maintaining a constant pressure at 1 atm in the cell at the freezing/melting temperature. It is more difficult to determine the pressure inside a closed cell. If such a cell is used in this comparison, then the measured resistance should be corrected for the effect of deviation from 1 atm to the fixed point temperature and a type B uncertainty associated with such determination is included.

12. *SPRT instability at TPW*
Prior to calibration, a SPRT is subject to a stabilisation process by annealing to remove mechanical shock and defects in the Pt wire through use. Even so, there remains some detectable instability in the SPRT indicated by variations in values of R_{TPW} *after repeated exposures to a given fixed point. This is considered a type B uncertainty.*

13. *Propagation of SPRT instability into the fixed point ratios*
Resistance ratio $W = R_t/R_{TPW}$ *requires the* R_{TPW} *value obtained immediately after each fixed point determination. The drift in* R_{TPW} *after each fixed point (item 12) results in a type B uncertainty component to the resistance ratios.*

14. *TPW realisation*
Similarly to item 3, this is a type B uncertainty in the realisation of the triple point of water.

15. *Propagation of TPW uncertainty into the fixed point ratios*
Uncertainty incurred at the triple point of water causes an additional type B uncertainty component to the resistance ratios since $W = R_t/R_{TPW}$.

16. *Other factors that are applicable to a particular laboratory should be added with a brief explanation for their inclusion.*

APMP KC3
CALIBRATION DATA
Laboratory Name
W=Rt/Rtp where Rtp is the resistance at TPW immediately after the fixed point used to obtain Rt
Correction for pressure effect may/may not be necessary

Point	$R_{measured}$ (Ω)	*Self Heating* (Ω)	*Hydrostatic* (Ω)	*Pressure* (Ω)	$R_{corrected}$ (Ω)	*W*
Zn						
TPW						
Sn						
TPW						
In						
TPW						
Ga						
TPW						
Hg						
TPW						

APMP KC-3

UNCERTAINTY ANALYSIS

Laboratory Name

Standard Uncertainties u_i *in* μK

ν_i*: degrees of freedom*

		Hg		**TPW**		**Ga**		**In**		**Sn**		**Zn**	
Components	***Type***	u_i	ν_i	u_i	ν_i	u_i	ν_i	u_i	ν_i	u_i	ν_i	u_i	ν_i
Measurement scatter	*A*												
Chemical Impurity	*B*												
FP realization	*B*												
Isotope (TPW only)	*B*												
Reference Resistor	*B*												
Self heating	*B*												
Quadrature effect	*B*												
Hydrostatic head	*B*												
Conduction	*B*												
Insulation degradation	*B*												
Gas Pressure	*B*												
SPRT instability at TPW	*B*												
Propagation of SPRT instability	*B*												
TPW realisation	*B*												
Propagation of TPW realisation	*B*												
Others (please specify)													
Others (please specify)													
Others (please specify)													

APPENDIX 2: MEASUREMENT DATA

Measurement data are presented in the manner they were received.

Appendix 2.1 Measurement data from NML reports RN41585, RN41674, RN41746

	RN41585	RN41674	RN41746
W(Zn)	2.568712231	2.5687119	2.5687123
W(Cd)	2.218984495	2.2189857	2.2189864
W(Sn)	1.892684818	1.8926848	1.8926843
W(In)	1.609724633	1.6097233	1.6097247
W(Ga)	1.118123306	1.118123	1.1181245
W(Hg)	0.844154681	0.8441561	0.8441553

Appendix 2.2 Measurement data from PSB

Point	$R_{measured}$ (Ω)	Self Heating (Ω)	Hydrostatic (Ω)	Pressure (Ω)	$R_{corrected}$ (Ω)	W
Zn	65.60251494	0.00016494	-0.0000412	0.0000006	65.60230941	2.5687060
TPW	25.53918453	0.00015345	0.0000184	0.0000000	25.53904948	
Sn	48.33752493	0.00018029	-0.0000336	-0.0000030	48.33730804	1.8926817
TPW	25.53917692	0.00013666	0.0000184	0.0000000	25.53905866	
In	-	-	-	-	-	-
TPW	-	-	-	-	-	
Ga	28.55607562	0.00017419	0.0000147	0.0000000	28.55591613	1.1181271
TPW	25.53915219	0.00010911	0.0000184	0.0000000	25.53906148	
Hg	21.55923516	0.00017945	-0.0000941	0.0000000	21.55896162	0.8441559
TPW	25.53920347	0.00014727	0.0000184	0.0000000	25.53907459	

Appendix 2.3 Data from CSIR

Point	Rmeasured (ohm)	Self Heating (ohm)	Hydrostatic (ohm)	Pressure (ohm)	Rcorrected (ohm)	W
Zn	65.602,408	-0.000,167	-0.000,033		65.60220750	2.568,712,41
TPW	25.539,073	-0.000,145	0.000,018		25.53894600	
Sn	48.337,568	-0.000,173	-0.000,029		48.33736600	1.892,685,09
TPW	25.539,172	-0.000,147	0.000,018		25.53904300	
In						
TPW						
Ga	28.556,015	-0.000,161	0.000,009		28.55586300	1.118,124,93
TPW	25.539,188	-0.000,143	0.000,018		25.53906300	
Hg	21.559,203	-0.000,154	-0.000,101		21.55894800	0.844,156,06
TPW	25.539,184	-0.000,147	0.000,018		25.53905500	

Appendix 2.4 Data from NIMT

Point	$R_{measured}$ (Ω)	Self Heating (Ω)	Hydrostatic (Ω)	Pressure (Ω)	$R_{corrected}$ (Ω)	W
Zn	65.60256	0.000179	-0.000093		65.602288	2.5687091
TPW	25.539161	0.000168	0.000017		25.539011	
Sn	48.337654	0.000174	-0.000059		48.337421	1.8926823
TPW	25.539233	0.00014	0.000017		25.53911	
In						
TPW						
Ga	28.555992	0.000118	0.000017		28.555891	
TPW	25.539289	0.000166	0.000017		25.539141	1.1181226
Hg	21.559299	0.000153	-0.000086		21.55906	
TPW	25.539259	0.000147	0.000017		25.539129	0.844158

Appendix 2.5 Data from NPL

Point	**R**measured (Ohm)	**Self** Heating (Ohm)*	**Hydr**ostatic (Ohm)*	**Pr**essure	**R**corrected (Ohm)	**W**
Zn	65.602811	0.00022	0.0000446		65.602546	
TPW	25.53912	0.00019	-0.000019		25.538949	2.5687254
Sn	48.337761	0.00023	0.0000356		48.337495	
TPW	25.53917	0.0002	-0.000019		25.538989	1.8926941
In						
TPW						
Ga	28.556074	0.00028	-0.0000228		28.555817	
TPW	25.53918	0.0002	-0.000019		25.538999	1.1181259
Hg	21.559423	0.0002	0.0001065		21.559117	
TPW	25.53919	0.00019	-0.000019		25.539019	0.8441638

Appendix 2.6 Data from MUSSD

Point	$R_{measured}$ (Ω)	Self Heating (Ω)	Hydrostatic (Ω)	Pressure (Ω)	$R_{corrected}$ (Ω)	W
Zn	65.602547	0.0001827	0.00003		65.602334	2.5687081
TPW	25.539139	0.0001187	0.000018		25.539038	
Sn	48.337679	0.0001962	0.00002		48.337463	1.8926862
TPW	25.5392115	0.000151	0.000018		25.539079	
In	41.111091	0.000206	0.00004		41.110845	1.609721
TPW	25.539196	0.0001008	0.000018		25.539111	
Ga	28.555995	0.0001745	0.000024		28.555845	1.1181247
TPW	25.539186	0.0001532	0.000018		25.539051	
Hg	21.559333	0.000174	0.000092		21.559067	0.8441581
TPW	25.539063	0.0001469	0.000018		25.539132	

Appendix 2.7 Data from SIRIM

Point	$R_{measured}$ (Ω)	Self Heating (Ω)	Hydrostatic (Ω)	Pressure (Ω)	$R_{corrected}$ (Ω)	W
TPW	25.5399277	0.00011	-0.000014		25.5391803	
Zn	65.6027003	0.00018	0.000037		65.6024868	2.568699779
TPW	25.539285	0.00016	-0.000014		25.5391393	
Sn	48.3377731	0.00016	0.000032		48.3375859	1.892686568
TPW	25.539278	0.0001	-0.000014		25.5391873	
In	41.1112577	0.00017	0.000049		41.111041	1.609723932
TPW	25.539328	0.00013	-0.000014		25.5392093	
Ga	28.5560784	0.00017	-0.000023		28.555936	1.118121382
TPW	25.539288	0.0001	-0.000014		25.5392016	
Hg	21.5593747	0.00016	0.000113		21.5589602	0.84415169
TPW	25.539325	0.00013	-0.000014		25.5392114	

Appendix 2.8 Data from KRISS

Point	$R_{measured}$ (Ω)	Self Heating (Ω)	Hydrostatic (Ω)	Pressure (Ω)	$R_{corrected}$ (Ω)	W
Zn	65.6028587	65.6026764	65.6026427		65.6026427	2.56870847
TPW	25.5392892	25.5391275	25.5391546		25.5391546	
Sn	48.3378803	48.3376791	48.3376499		48.3376499	1.89268372
TPW	25.5393416	25.5391845	25.5392116		25.5392116	
In	41.111265	41.1110462	41.1109973		41.1109973	1.60971663
TPW	25.5394109	25.5392489	25.539276		25.539276	
Ga	28.5562583	28.5560569	28.5560787		28.5560787	1.11812412
TPW	25.5394145	25.5392472	25.5392743		25.5392743	
Hg	21.5594055	21.5592505	21.5591373		21.5591373	0.84415612
TPW	25.5394092	25.5392502	25.5392773		25.5392773	

Appendix 2.9 Data from NML reports RN42950, RN 43152

	RN42950	RN43152
W(Zn)	2.5687074	2.5687078
W(Cd)	2.2189804	2.2189819
W(Sn)	1.8926803	1.8926827
W(In)	1.6097217	1.6097226
W(Ga)	1.1181245	1.1181243
W(Hg)	0.8441553	0.8441558

Appendix 2.10 Data from KIM-LIPI

Point	$R_{measured}$ (Ω)	Self Heating (Ω)	Hydrostatic (Ω)	Pressure (Ω)	$R_{corrected}$ (Ω)	W
Zn	65.603635	0.000130	0.00003645		65.603117	2.568719
TPW	25.539675	0.000105	-0.00001351		25.539232	
Sn	48.338567	0.000125	0.00002970		48.338060	1.892694
TPW	25.539740	0.000110	-0.00001351		25.539292	

Appendix 2.11 **Data from SCL**

Point	$R_{measured}$ (Ω)	Self Heating (Ω)	Hydrostatic (Ω)	Pressure (Ω)	$R_{corrected}$ (Ω)	W
Zn	65.6030274	-0.0001838	-0.0000422		65.6028014	2.5687086
TPW	25.539362	-0.0001674	0.0000205		25.539215	
Sn	48.3379666	-0.0001936	-0.0000365		48.3377364	1.8926833
TPW	25.5393939	-0.0001511	0.0000204		25.5392632	
In	41.1115762	-0.000196	-0.000056		41.1113242	1.6097271
TPW	25.5394596	-0.000167	0.0000205		25.5393129	
Ga	28.5563072	-0.0001686	0.0000212		28.5561597	1.1181233
TPW	25.5395082	-0.0001637	0.0000204		25.5393649	
Hg	21.559466	-0.000155	-0.0001134		21.5591974	0.8441557
TPW	25.539497	-0.0001562	0.0000204		25.5393613	

Appendix 2.12 Data from CMS

	0mA
R_{TPW1}	25.5394378Ω
R_{TPW2}	25.5393383Ω
R_{TPW3}	25.5393233Ω
W(Zn)	2.56869356
W(Sn)	1.89268231
W(In)	1.60972734
W(Ga)	1.11812370
W(Hg)	0.84415748
R_{FINAL}	25.5396493Ω

Appendix 2.13 Data from ITDI

Initial Value of R (Water TP) in ohms = 25. 53997
Final Value of R (Water TP) in ohms = 25.539732

W Indium (156.985) = 1.609826

Appendix 2.14 **Data from NML RN46070, RN46277, RN46278**

	RN46070	RN46277	RN46278
W(Zn)	2.56869899	2.568698	2.56869838
W(Cd)	2.218976177	2.218977	2.21897692
W(Sn)	1.892679038	1.892679	1.89267871
W(In)	1.609719094	1.609721	1.60971923
W(Ga)	1.118123979	1.118124	1.11812381
W(Hg)	0.844157065	0.844157	0.84415661

APPENDIX 3 Corrected Uncertainties as given in Draft B version 2

Appendix 3.1 Uncertainty analysis by NML RN41585

RN41585		**Hg**	**TPW**	**Ga**	**In**	**Sn**	**Cd**	**Zn**
Components	**Type**	**u_i**	**u_i**	**u_i**	**u_i**	**u_i**		**u_i**
Measurement scatter	A	26	26	26	27	28	29	30
Chemical Impurity	B	200	50	300	500	300	300	300
FP realization	B	100	10	50	100	100	100	100
Isotope (TPW only)	B	n/a	50	n/a	n/a	n/a	n/a	n/a
Reference Resistor	B	10	10	10	10	10	10	10
Self heating	B	10	10	10	10	10	20	20
Quadrature effect	B	20	20	20	21	22	22	23
Hydrostatic head	B	71	7.3	12	33	22	48	27
Conduction	B	10	0	10	10	10	10	10
Insulation degradation	B		10	10	10	10	10	10
Gas Pressure	B	n/a	n/a	40	98	66	126	86
SPRT instability at TPW	B	194	10	194	92	79	165	149
Propagation of SPRT instability	B	162	10	218	155	162	404	437
TPW realisation	B	83	83	83	83	83	83	83
Propagation of TPW realisation	B	69	83	93	140	168	203	242
Bridge nonlinearity	B	40		40	42	43	44	46
AC/DC	B	20	20	20	30	40	50	50
U95(mK)		**0.30**	**0.12**	**0.39**	**0.56**	**0.41**	**0.57**	**0.60**
k		2	2	2	2	2	2	2

Appendix 3.2 Uncertainty analysis by NML RN41671

RN46171		**Hg**	**TPW**	**Ga**	**In**	**Sn**	**Cd**	**Zn**
Components	**Type**	**u_i**	**u_i**	**u_i**	**u_i**	**u_i**		**u_i**
Measurement scatter	A	26	26	26	27	28	29	30
Chemical Impurity	B	200	50	200	800	200	200	200
FP realization	B	200	10	100	150	100	100	150
Isotope (TPW only)	B		50					
Reference Resistor	B	10	10					0
Self heating	B	10	10	10	10	10	20	20
Quadrature effect	B	20	20	20	21	22	22	23
Hydrostatic head	B	71	7.3	12	33	22	48	27
Conduction	B	10	0	10	10	10	10	10
Insulation degradation	B		10	10	10	10	10	10
Gas Pressure	B			40	98	66	126	86
SPRT instability at TPW	B	80	10	6	13	82	62	82
Propagation of SPRT instability	B	67	10	7	22	167	153	241
TPW realisation	B	83	83	83	83	83	83	83
Propagation of TPW realisation	B	69	83	93	140	168	203	242
Bridge nonlinearity	B	40		40	42	43	44	46
AC/DC	B	20	20	20	30	40	50	50
U95(mK)		**0.31**	**0.12**	**0.25**	**0.84**	**0.34**	**0.37**	**0.44**
k		2	2	2	2	2	2	2

Appendix 3.3 **Uncertainty analysis by NML RN41746**

RN41746		Hg	TPW	Ga	In	Sn	Cd	Zn
Components	**Type**	**u_i**	**u_i**	**u_i**	**u_i**	**u_i**		**u_i**
Measurement scatter	A	26	26	26	27	28	29	30
Chemical Impurity	B	200	50	200	800	200	200	200
FP realization	B	100	10	100	150	100	100	150
Isotope (TPW only)	B		50					
Reference Resistor	B	10	10					0
Self heating	B	10	10	10	10	10	20	20
Quadrature effect	B	20	20	20	21	22	22	23
Hydrostatic head	B	71	7.3	12	33	22	48	27
Conduction	B	10	0	10	10	10	10	10
Insulation degradation	B		10	10	10	10	10	10
Gas Pressure	B			40	98	66	126	86
SPRT instability at TPW	B	6	10	6	45	284	34	68
Propagation of SPRT instability	B	5	10	7	77	577	84	200
TPW realisation	B	83	83	83	83	83	83	83
Propagation of TPW realisation	B	69	83	93	140	168	203	242
Bridge nonlinearity	B	40		40	42	43	44	46
AC/DC	B	20	20	20	30	40	50	50
U95(mK)		**0.25**	**0.12**	**0.25**	**0.84**	**0.65**	**0.35**	**0.42**
k		2	2	2	2	2	2	2

Appendix 3.4 Uncertainty analysis by PSB

PSB		**Hg**		**TPW**		**Ga**		**Sn**		**Zn**	
Components	**Type**	**u_i**	ν_i	**u_i**	ν_i	**u_i**	ν_i	**u_i**	ν_i	**u_i**	ν_i
Measurement scatter	A	200	50	110	50	180	50	250	50	260	50
Chemical Impurity	B	1000	10000	20	10000	200	10000	1000	10000	1000	10000
FP realization	B	284	10000	120	10000	376	10000	290	10000	361	10000
Isotope (TPW only)	B	-	-	30	10000	-	-	-	-	-	-
Reference Resistor	B	209	10000	271	10000	303	10000	530	10000	755	10000
Self heating	B	268	10000	194	10000	51	10000	65	10000	108	10000
Quadrature effect	B	-	-	-	-	-	-	-	-	-	-
Hydrostatic head	B	71	10000	8	10000	12	10000	22	10000	27	10000
Conduction	B	129	10000	-	-	200	10000	86	10000	320	10000
Insulation degradation	B	-	-	-	-	-	-	-	-	-	-
Gas Pressure	B	15	10000	10	10000	15	10000	30	10000	20	10000
SPRT instability at TPW	B	-	-	115	10000	-	-	-	-	-	-
ation of SPRT instability	B	90	10000	-	-	122	10000	219	10000	315	10000
TPW realisation	B	-	-	134	10000	-	-	-	-	-	-
ation of TPW realisation	B	105	10000	-	-	142	10000	256	10000	269	10000
C Bridge measurement)	B	66	10000	76	10000	84	10000	143	10000	190	10000
Others (Historical trend)	B	566	10000	-	-	288	10000	548	10000	652	10000
Others (please specify)											
U95(mK)		**2.48**		**0.82**		**1.35**		**2.68**		**3.11**	
k			1.96		1.96		1.96		1.96		1.96

Appendix 3.5 Uncertainty analysis by CSIR

Components	Type	u_i	n_i	u_i	n_i	u_i	n_i	u_i	n_i	u_i	n_i
Measurement scatter	A	14.4	6.0	18.1	6.0	23.0	7.0	7.5	10.0	8.0	4.0
Chemical Impurity	B	84.5	1.0		1.0	20.1	9.9	153.8	51.8	242.6	738.7
FP realization	B	77.0	154.0		1.0	73.0	236.0	187.0	106.0	223.0	215.0
Isotope (TPW only)	B		1.0	66.0	5.6		1.0		1.0		1.0
Reference Resistor	B	20.9	8.0		1.0	28.3	8.0	51.0	8.0	73.5	8.0
Self heating	B	51.8	13.0	58.2	19.0	50.5	11.0	89.2	16.8	63.6	16.6
Quadrature effect	B		1.0		1.0		1.0		1.0		1.0
Hydrostatic head	B	71.0	8.0	7.3	8.0	12.0	8.0	22.0	8.0	27.0	8.0
Conduction	B	28.9	3.0	10.0	2.0	101.0	3.0	274.2	3.0	187.6	3.0
Insulation degradation	B		1.0		1.0		1.0		1.0		1.0
Gas Pressure	B	54.0	2.0	37.5	2.0	20.0	2.0	33.0	2.0	43.0	2.0
SPRT instability at TPW	B		1.0		1.0		1.0		1.0		1.0
Propagation of SPRT instability	B	46.3	2.0		1.0	109.7	2.0	70.6	2.0	101.7	2.0
TPW realisation	B		1.0	54.0	4.0		1.0		1.0		1.0
Propagation of TPW realisation	B	98.3	25.3		1.0	130.1	25.3	220.3	25.3	299.0	25.3
Bridge linearity & resolution	B	26.9	10.6	31.6	9.8	35.4	9.4	62.1	8.5	88.9	8.3
Others (please specify)			1.0		1.0		1.0		1.0		1.0
Others (please specify)			1.0		1.0		1.0		1.0		1.0

Combined std uncert uc (µK):	194.2	20.9	116.4	25.3	224.9	21.4	451.0	20.5	513.4	85.4
Coverage factor for 95.45% c.i.:	2.13		2.11		2.13		2.13		2.05	
U95(mK)	**0.41**		**0.25**		**0.48**		**0.96**		**1.05**	

Appendix 3.6 Uncertainty analysis by NIMT

NIMT		Hg		TPW		Ga		Sn		Zn	
Components	**Type**	u_i	n_i	u_i	n_i	u_i	n_i	u_i	n_i	u_i	n_i
Measurement scatter	A	2.27	5	2.50	5	2.26	5	2.71	5	2.69	5
Chemical Impurity	B	57.74	####	-	-	57.74	####	230.94	#####	57.74	#####
FP realization	B	160.00	####	-	-	#####	####	550.00	#####	995.00	#####
Isotope (TPW only)	B	-	-	28.87	#####	-	-	-	-	-	-
Reference Resistor	B	2.17	####	2.17	#####	2.17	####	2.17	#####	2.17	#####
Self heating	B	23.06	####	6.73	#####	7.12	####	37.66	#####	78.01	#####
Quadrature effect	B	-	-	-	-	-	-	-	-	-	-
Hydrostatic head	B	141.45	####	14.15	#####	24.25	####	66.68	#####	44.46	#####
Conduction	B	0.05	####	0.01	#####	0.03	####	0.01	#####	0.01	#####
Insulation degradation	B	-	-	-	-	-	-	-	-	-	-
Gas Pressure	B	-	-	-	-	-	-	-	-	-	-
SPRT instability at TPW	B	751.23	####	751.23	#####	#####	####	751.23	#####	751.23	#####
Propagation of SPRT instability	B	66.01	####	0.41	#####	#####	####	1214.79	#####	778.88	#####
TPW realisation	B	75.08	####	75.08	#####	75.08	####	75.08	#####	75.08	#####
Propagation of TPW realisation	B	66.51	####	66.51	#####	64.66	####	53.35	#####	57.27	#####
Bridge calibration	B	12.45	####	14.75	#####	16.49	####	27.91	#####	37.88	#####
Bridge linearity	B	2.49	####	2.95	#####	3.30	####	5.58	#####	7.58	#####
U95, mK		**0.47**		**0.15**		**0.55**		**2.66**		**2.49**	
k		1.96		1.96		1.96		1.96		1.96	

denotes infinite

Appendix 3.7 Uncertainty analysis by NPL

NPL		**Hg**		**TPW**		**Ga**		**Sn**		**Zn**	
Components	**Type**	**Ui**	**Vi**	**Ui**	**Vi**	**Ui**	**Vi**	**Ui**	**Vi**	**Ui**	**Vi**
Measurement Scatter	A	10	19	7	14	11	21	12	38	21	26
Chemical Impurity	B	58	#####	23	#####	12	#####	173	####	289	####
F.P. Realization	B	115	#####	58	#####	115	#####	115	####	173	####
Isotope (TPW Only)	B			29	#####						
Reference Register	B	156	#####	156	#####	156	#####	156	####	156	####
Self Heating	B	58	#####	58	#####	58	#####	115	####	115	####
Quadrature Effect	B	115	#####	115	#####	115	#####	115	####	115	####
Hydrostatic Head	B	21	#####	2	#####	4	#####	6	####	8	####
Conduction*	B										
Insulation degradation**	B										
Gas Pressure***	B										
SPRT Instability at TPW	B			115	#####						
Propagation of SPRT Instability	B	19	#####			14	#####	104	####	191	####
TPW Realization	B			58	#####						
Propogation of TPW realization	B	11	#####			7	#####	58	####	92	####
U95(mK)		**0.47**		**0.49**		**0.46**		**0.65**		**0.90**	
k		1.96		1.96		1.96		1.96		1.96	

#

denotes infinite

Appendix 3.8: Uncertainty analysis by MUSSD

MUSSD		**Hg**		**TPW**		**Ga**		**In**		**Sn**		**Zn**	
Components	**Type**	**ui**	**ni**	**ui**	**ni**	**ui**	**ni**	**ui**	**ni**	**ui**	**ni**	**ui**	**ni**
Measurement scatter	A	0.05	13	0.05	24	0.05	24	0.05	7	0.05	12	0.07	9
Chemical Impurity	B	0.25	50	0.1	50	0.2	50	0.8	50	0.52	50	0.71	50
FP realization	B	0.02	13	0.1	11	0.03	24	0.36	7	0.13	12	0.22	9
Isotope (TPW only)	B			0.17	50								
Reference Resistor	B	0.3	50	0.3	50	0.3	50	0.3	50	0.3	50	0.3	50
Self heating	B	0.03	8	0.06	8	0.09	8	0.42	8	0.3	8	0.3	8
Quadrature effect	B	N/A											
Hydrostatic head	B	0.7	50	0.01	50	0.01	50	0.03	50	0.02	50	0.02	50
Conduction	B	0.4	8	0.01	8	0.08	8	0.5	8	0.14	8	0.5	8
Insulation degradation	B	0.1	8	0.08	8	0.08	8	0.06	8	0.05	8	0.04	8
Gas Pressure	B	N/A											
SPRT instability at TPW	B	0.22	6	0.06	6	0.05	6	0.05	6	0.05	6	0.07	6
Propagation of SPRT instability	B	0.18	8			0.06	8	0.08	8	0.09	8	0.18	8
TPW realisation	B	0.05	13	0.05	11	0.05	24	0.05	7	0.05	12	0.05	9
Propagation of TPW realisation	B	0.18	8	0		0.25	8	0.35	8	0.42	8	0.56	8
U95(mK)		**1.86**		**0.77**		**0.94**		**2.37**		**1.64**		**2.31**	
k		1.99		1.98		1.99		1.99		1.99		2.00	

Appendix 3.9: Uncertainty analysis by SIRIM

SIRIM		**Hg**		**TPW**		**Ga**		**In**		**Sn**		**Zn**	
Components	**Type**	u_i	n_i	u_i	n_i	u_i	n_i	u_i	n_i	u_i	n_i	u_i	n_i
Measurement scatter	A	0.19	8	0.01	7	0.28	8	0.09	8	0.35	8	0.17	8
Chemical Impurity	B	0.05	####	0.05	####	0.06	####	0.50	####	0.40	#####	0.60	#####
FP realisation	B	0.19	10			0.13	10	0.08	10	0.33	10	0.16	10
Isotope (TPW only)	B												
Reference Resistor	B	0.15	####	0.15	####	0.15	####	0.15	####	0.15	#####	0.15	#####
Self heating	B	0.09	8	0.04	35	0.04	8	0.06	8	0.02	8	0.03	8
Quadrature effect	B												
Hydrostatic head	B	0.07	####	0.01	####	0.01	####	0.03	####	0.02	#####	0.03	#####
Conduction	B	0.00	####	0.00	####	0.00	####	0.02	####	0.02	#####	0.03	#####
Insulation degradation	B												
Gas Pressure	B	0.09	####	0.05	####	0.03	####	0.08	####	0.05	#####	0.07	#####
SPRT instability at TPW	B	0.1	10	0.31	7	-0.1	10	0.22	10	0.48	10	0.41	10
Propagation of SPRT instability	B	0.01	10	0.00	10	0.01	10	0.02	10	0.02	10	0.03	10
TPW realisation	B			0.01	7								
Bridge Linearity	B	0.02	####	0.02	####	0.02	####	0.03	####	0.04	#####	0.06	#####
U95(mK)		**0.69**		**0.34**		**0.73**		**1.07**		**1.30**		**1.31**	
k		2.01		1.96		2.09		1.96		2.00		1.96	

denotes infinite

Appendix 3.10: Uncertainty analysis by KRISS

Values taken from NIST KC3 report Table IV.5(a) page 347 and IV.5(b) page 348

KRISS	**Hg**	**WTP**	**Ga**	**In**	**Sn**	**Zn**
Uc (mK)	0.08	0.031	0.07	0.33	0.27	0.42
k	2	2	2	2	2	2
U95 (mK)	**0.16**	**0.062**	**0.14**	**0.66**	**0.54**	**0.84**

Appendix 3.11 Uncertainty analysis NML RN42950

RN42950		**Hg**	**TPW**	**Ga**	**In**	**Sn**	**Cd**	**Zn**
Components	**Type**	u_i	u_i	u_i	u_i	u_i		u_i
Measurement scatter	A	100	26	26	27	28	29	30
Chemical Impurity	B	200	50	200	500	200	200	200
FP realization	B	100	10	100	100	100	100	150
Isotope (TPW only)	B		50					
Reference Resistor	B	10	10					0
Self heating	B	10	10	10	10	10	20	20
Quadrature effect	B	20	20	20	21	22	22	23
Hydrostatic head	B	71	7.3	12	33	22	48	27
Conduction	B	10	0	10	10	10	10	10
Insulation degradation	B		10	10	10	10	10	10
Gas Pressure	B			40	98	66	126	86
SPRT instability at TPW	B	97	10	10	320	497	283	516
Propagation of SPRT instability	B	81	10	11	540	1009	693	1512
TPW realisation	B	83	83	83	83	83	83	83
Propagation of TPW realisation	B	69	83	93	140	168	203	242
Bridge nonlinearity	B	40		40	42	43	44	46
AC/DC	B	20	20	20	30	40	50	50
U95(mK)		**0.28**	**0.12**	**0.25**	**0.77**	**1.05**	**0.77**	**1.56**
k		**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**

Appendix 3.12 Uncertainty analysis by NML RN43152

RN43512		Hg	TPW	Ga	In	Sn	Cd	Zn
Components	**Type**	u_i	u_i	u_i	u_i	u_i		u_i
Measurement scatter	A	100	26	26	27	28	29	30
Chemical Impurity	B	200	50	200	500	200	200	200
FP realization	B	100	10	100	100	100	100	150
Isotope (TPW only)	B		50					
Reference Resistor	B	10	10					0
Self heating	B	10	10	10	10	10	20	20
Quadrature effect	B	20	20	20	21	22	22	23
Hydrostatic head	B	71	7.3	12	33	22	48	27
Conduction	B	10	0	10	10	10	10	10
Insulation degradation	B		10	10	10	10	10	10
Gas Pressure	B			40	98	66	126	86
SPRT instability at TPW	B	97	10	79	382	359	141	34
Propagation of SPRT instability	B	81	10	90	645	730	346	99
TPW realisation	B	83	83	83	83	83	83	83
Propagation of TPW realisation	B	69	83	93	140	168	203	242
Bridge nonlinearity	B	40		40	42	43	44	46
AC/DC	B	20	20	20	30	40	50	50
U95(mK)		**0.28**	**0.12**	**0.27**	**0.84**	**0.79**	**0.49**	**0.38**
k		**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**

Appendix 3.13: Uncertainty analysis by KIM-LIPI

KIM-LIPI	Type	TWP		Sn		Zn	
Component		u_i	ν_i	u_i	ν_i	u_i	ν_i
Measurement scatter	A	8	9	13	9	23	9
Chemical ipurity	B	2.89	####	11.55	#######	11.55	1.00E+08
FP realisation	B	20	####	20	#######	50	1.00E+08
Isotope WTP	B	2.89	####	n/a	n/a	n/a	n/a
reference resistor	B	10	####	10	#######	10	1.00E+08
Self heating	B	110	8	125	8	130	8
Quadrature effect	B	n/a	n/a	n/a	n/a	n/a	n/a
Hydrostatic head	B	-13.5	####	29.7	#######	36.5	1.00E+08
Cnduction	B	n/a	n/a	n/a	n/a	382.5	1.00E+08
Insulation degradation	B	n/a	n/a	n/a	n/a	n/a	n/a
Gas pressure	B	n/a	n/a	n/a	n/a	n/a	n/a
SPRT instability at TPW	B	n/a	n/a	188.9	#######	200	1.00E+08
Propagation of SPRT instability	B	n/a	n/a	377.2	#######	575.5	1.00E+08
TWP realisation	B	20	####	20	#######	20	1.00E+08
Propagation of TPW relisation	B	n/a	n/a	399.4	#######	575.5	1.00E+08
U95(mK)		**0.26**		**1.11**		**1.79**	
k		2.26		1.96		1.96	

denotes infinite

Appendix 3.14 **Uncertainty analysis by SCL**

SCL		**Hg**		**TPW**		**Ga**		**In**		**Sn**		**Zn**	
Components	**Type**	u_i	ν_i	u_i	ν_i	u_i	ν_i	u_i	ν_i	u_i	ν_i	u_i	ν_i
Measurement scatter	A												
Chemical Impurity	B												
FP realization	B												
Isotope (TPW only)	B												
Reference Resistor	B	21	50	25	50	29	50	42	50	51	50	74	50
Self heating	B	10	50	10	50	10	50	10	50	10	50	10	50
Quadrature effect	B												
Hydrostatic head	B	178	50	19	50	30	50	83	50	55	50	68	50
Conduction	B												
Insulation degradation	B												
Gas Pressure	B												
SPRT instability at TPW	B	31	50			31	50	140	50	107	50	12	50
Propagation of SPRT instability	B	17	50			16	50	223	50	172	50	29	50
TPW realisation	B	150	50	150	50	150	50	150	50	150	50	150	50
Propagation of TPW realisation	B	81	50			75	50	190	50	241	50	355	50
AC Bridge		21	50	25	50	29	50	42	50	51	50	74	50
Fixed point cell		250	50			250	50	500	50	500	50	500	50
U95(mK)		**0.63**		**0.31**		**0.53**		**1.17**		**1.17**		**1.24**	
k		1.98		2.00		2.00		1.99		1.99		1.98	

Appendix 3.15: Uncertainty analysis by CMS

CMS		**Hg**		**TPW**		**Ga**		**In**		**Sn**		**Zn**	
Components	**Type**	u_i	ν_i	u_i	ν_i	u_i	ν_i	u_i	ν_i	u_i	ν_i	u_i	ν_i
Reproducibility	A	20	29	20	54	100	21	170	17	70	39	200	29
Chemical Impurity	B	2	###	59.64	####	8	####	280	###	373	###	426	####
FP realization	B	140	###			85.8	####	208	###	184	###	289	####
Isotope (TPW only)	B												
Reference Resistor	B												
Self heating	B	5	31	3.098	54	20	20	20	17	10	39	20	30
Quadrature effect	B												
Hydrostatic head	B	30	###	2.11	####	4	####	10	###	7	###	8	####
Conduction	B	200	###	65.33	####	####	####	200	###	200	###	200	####
Insulation degradation	B												
Gas Pressure	B					6	####	20	###	10	###	20	####
SPRT instability at TPW	B												
Propagation of SPRT instability	B												
TPW realisation	B												
Propagation of TPW realisation	B	90	###			150	####	170	###	200	###	300	####
Electrical measurement	B	50	###	56.67	####	70	####	100	###	200	###	200	####
U95(mK)		**0.52**		**0.21**		**0.46**		**0.94**		**1.07**		**1.35**	
k		1.96		1.96		1.96		1.96		1.96		1.96	

denotes infinite

Appendix 3.16: Uncertainty analysis by NML RN46070

RN46070		Hg	TPW	Ga	In	Sn	Cd	Zn
Components	**Type**	u_i	u_i	u_i	u_i	u_i		u_i
Measurement scatter	A	26	26	26	27	28	29	30
Chemical Impurity	B	200	50	200	300	200	200	200
FP realization	B	100	10	100	100	100	100	150
Isotope (TPW only)	B		50					
Reference Resistor	B	10	10					0
Self heating	B	10	10	10	10	10	20	20
Quadrature effect	B	20	20	20	21	22	22	23
Hydrostatic head	B	71	7.3	12	33	22	48	27
Conduction	B	10	0	10	10	10	10	10
Insulation degradation	B		10	10	10	10	10	10
Gas Pressure	B			40	98	66	126	86
SPRT instability at TPW	B	30	10	90	540	120	230	230
Propagation of SPRT instability	B	25	10	102	912	244	564	674
TPW realisation	B	83	83	83	83	83	83	83
Propagation of TPW realisation	B	69	83	93	140	168	203	242
Bridge nonlinearity	B	40		40	42	43	44	46
AC/DC	B	20	20	20	30	40	50	50
U95(mK)		**0.25**	**0.12**	**0.27**	**0.98**	**0.38**	**0.66**	**0.77**
k		2	2	2	2	2	2	2

Appendix 3.17 Uncertainty analysis by NML RN46277

RN46277		Hg	TPW	Ga	In	Sn	Cd	Zn
Components	**Type**	u_i	u_i	u_i	u_i	u_i		u_i
Measurement scatter	A	26	26	26	27	28	29	30
Chemical Impurity	B	200	50	200	300	200	200	200
FP realization	B	100	10	100	100	100	100	300
Isotope (TPW only)	B		50					
Reference Resistor	B	10	10					0
Self heating	B	10	10	10	10	10	20	20
Quadrature effect	B	20	20	20	21	22	22	23
Hydrostatic head	B	71	7.3	12	33	22	48	27
Conduction	B	10	0	10	10	10	10	10
Insulation degradation	B		10	10	10	10	10	10
Gas Pressure	B			40	98	66	126	86
SPRT instability at TPW	B	70	10	20	330	460	160	650
Propagation of SPRT instability	B	58	10	23	557	935	392	1905
TPW realisation	B	83	83	83	83	83	83	83
Propagation of TPW realisation	B	69	83	93	140	168	203	242
Bridge nonlinearity	B	40		40	42	43	44	46
AC/DC	B	20	20	20	30	40	50	50
U95(mK)		**0.26**	**0.12**	**0.25**	**0.67**	**0.98**	**0.52**	**1.96**
k		2	2	2	2	2	2	2

Appendix 3.18 Uncertainty analysis by NML RN46278

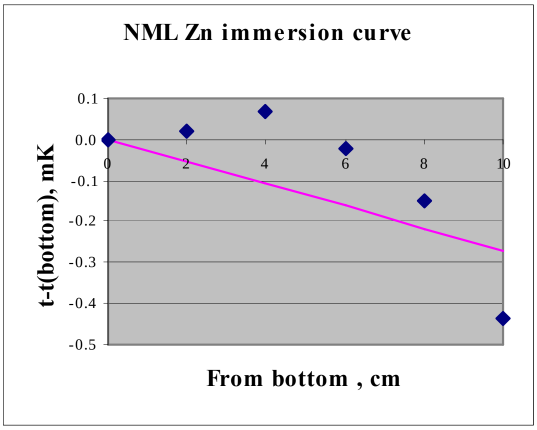
RN46278		Hg	TPW	Ga	In	Sn	Cd	Zn
Components	**Type**	u_i	u_i	u_i	u_i	u_i		u_i
Measurement scatter	A	26	26	26	27	28	29	30
Chemical Impurity	B	200	50	200	300	200	200	200
FP realization	B	200	10	100	100	200	200	400
Isotope (TPW only)	B		50					
Reference Resistor	B	10	10					0
Self heating	B	10	10	10	10	10	20	20
Quadrature effect	B	20	20	20	21	22	22	23
Hydrostatic head	B	71	7.3	12	33	22	48	27
Conduction	B	10	0	10	10	10	10	10
Insulation degradation	B		10	10	10	10	10	10
Gas Pressure	B			40	98	66	126	86
SPRT instability at TPW	B	220	20	80	750	220	100	70
Propagation of SPRT instability	B	183	20	90	1266	447	245	205
TPW realisation	B	83	83	83	83	83	83	83
Propagation of TPW realisation	B	69	83	93	140	168	203	242
Bridge nonlinearity	B	40		40	42	43	44	46
AC/DC	B	20	20	20	30	40	50	50
U95(mK)		**0.36**	**0.12**	**0.27**	**1.32**	**0.56**	**0.45**	**0.56**
k		2	2	2	2	2	2	2

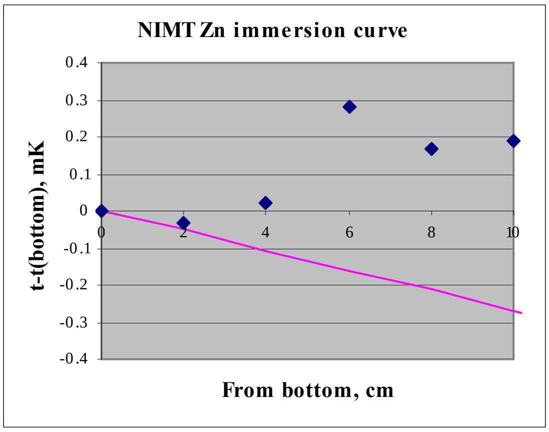
Appendix 3.19 Uncertainty analysis by ITDI

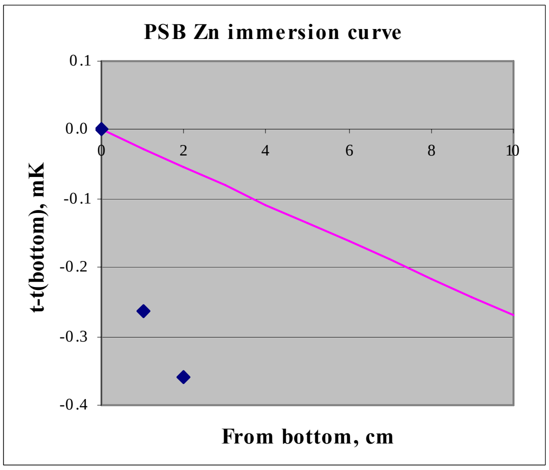
ITDI		**TPW**			**Indium**		
Components	**Type**	***ui***	***ui^2***	**ni**	***ui***	**ui^2**	***ni***
Measurement scatter	A	0.03	9.00E-04	?	0.2	4.00E-02	?
Chemical Impurity	B	0.1	1.00E-02	?	0.78	6.08E-01	?
FP realization	B		0.00E+00	?		0.00E+00	?
Isotope (TPW only)	B	0.03	9.00E-04	?		0.00E+00	?
Reference Resistor	B	0.3	9.00E-02	?	0.3	9.00E-02	?
Self heating	B	0.0015	2.25E-06	?	0.15	2.25E-02	?
Bridge measurement	B	0.4	1.60E-01	?	0.27	7.29E-02	?
Hydrostaic head	B	0.0002	4.00E-08	?	0.02	4.00E-04	?
Insulation degradation	B	0.02	4.00E-04	?	0.2	4.00E-02	?
Gas Pressure	B	0.15	2.25E-02	?	0.63	3.97E-01	?
SPRT Instability at TPW	B	0.5	2.50E-01	?		0.00E+00	?
Propagation of SPRT instability	B	0.03	9.00E-04	?	0.2	4.00E-02	?
TPW Realization	B	0.15	2.25E-02	?		0.00E+00	?
Uc(mK)		**0.75**			**1.15**		
U95		?			?		
k		?			?		

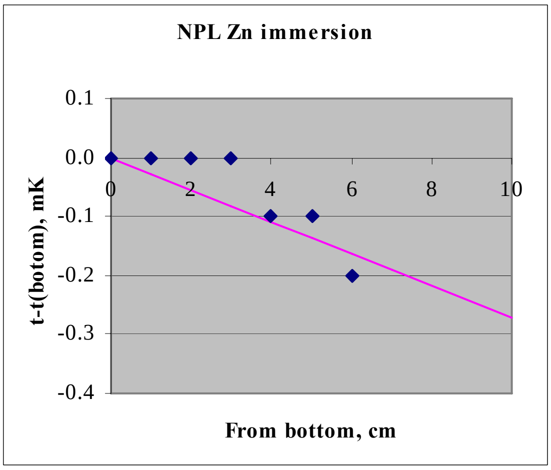
APPENDIX 4: IMMERSION CURVES

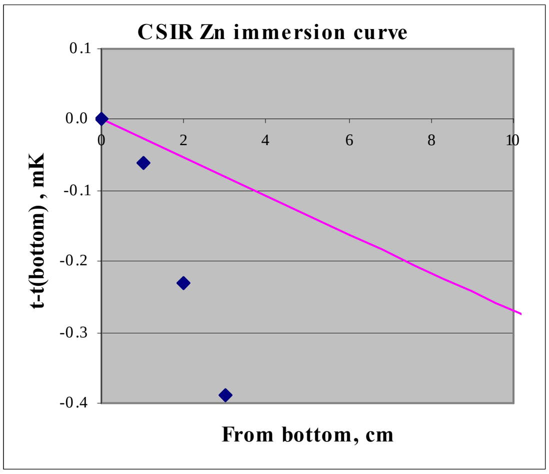
Appendix 4.1: Zn curve

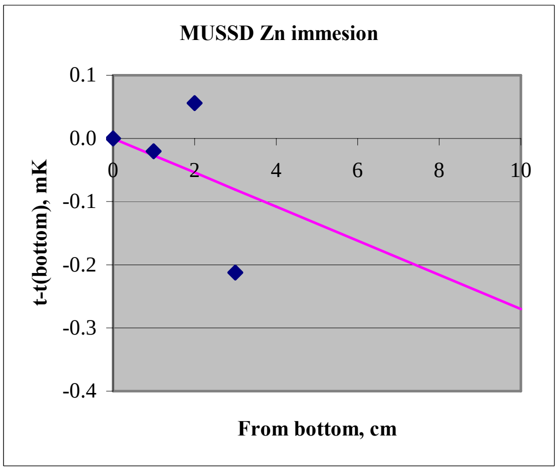


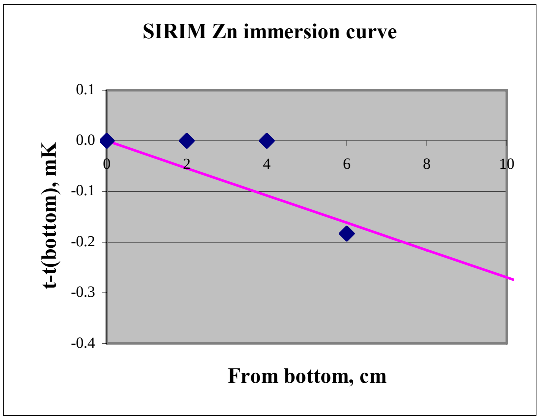


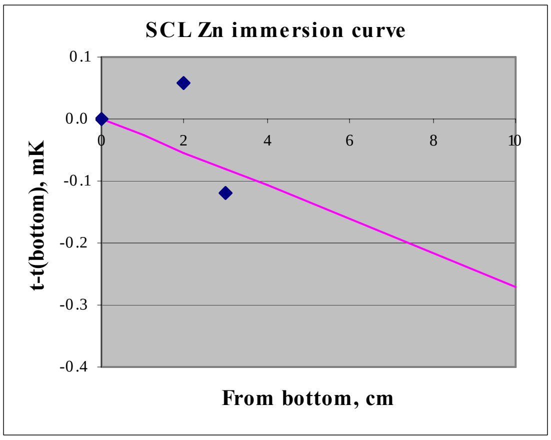


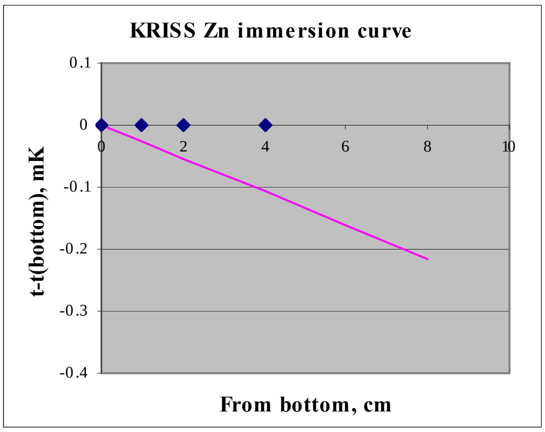


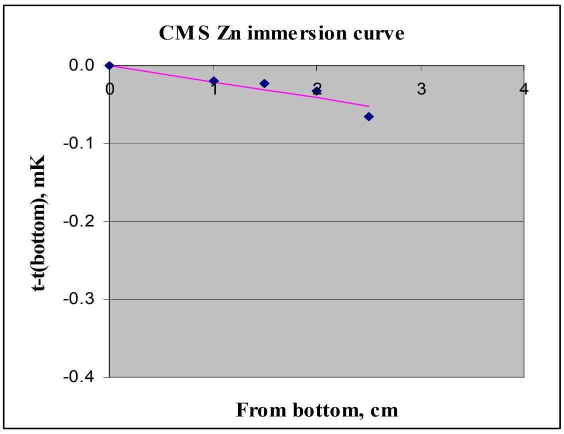


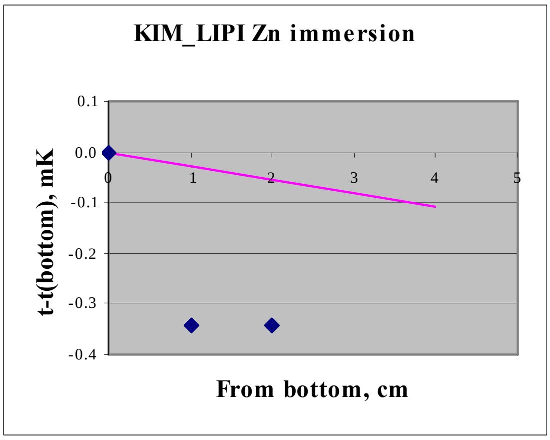



SIRIM Zn immersion curve
t-t(bottom), mK
From bottom, cm

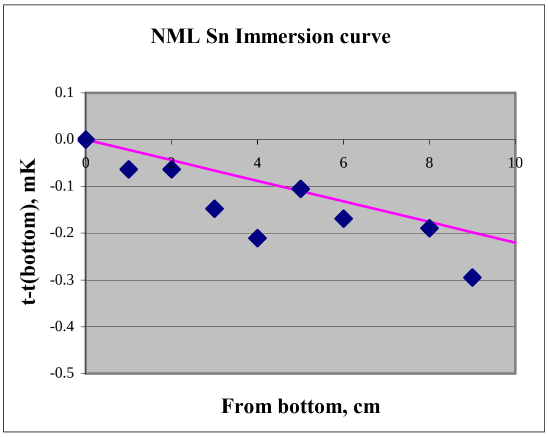

SCL Zn immersion curve
t-t(bottom), mK
From bottom, cm

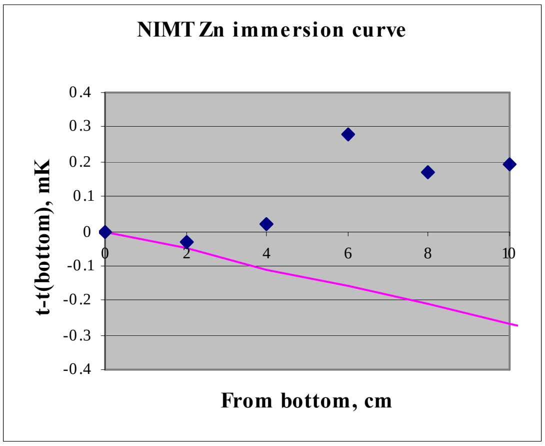

KRISS Zn immersion curve
t-t(bottom), mK
From bottom, cm

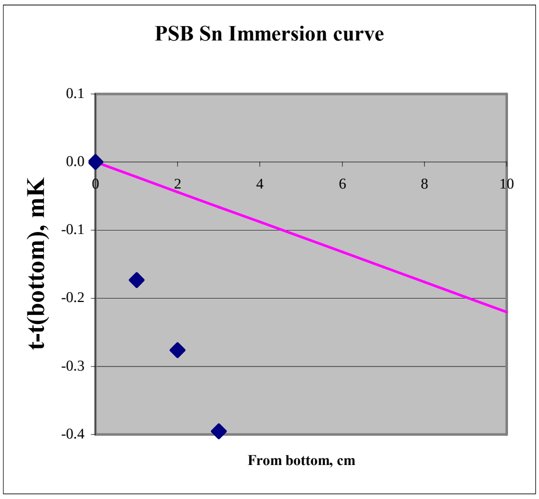

CMS Zn immersion curve
t-t(bottom), mK
From bottom, cm

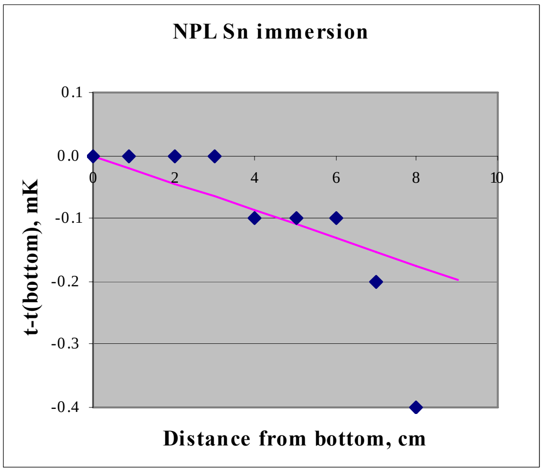

KIM_LIPI Zn immersion
t-t(bottom), mK
From bottom, cm

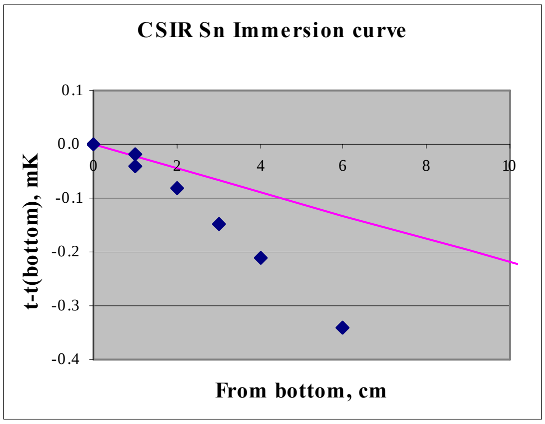
Appendix 4.2 Sn curve

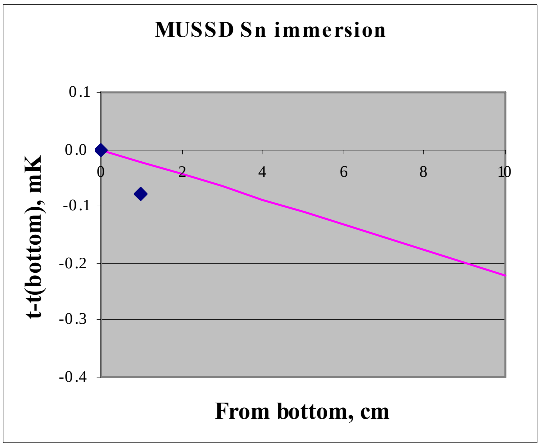


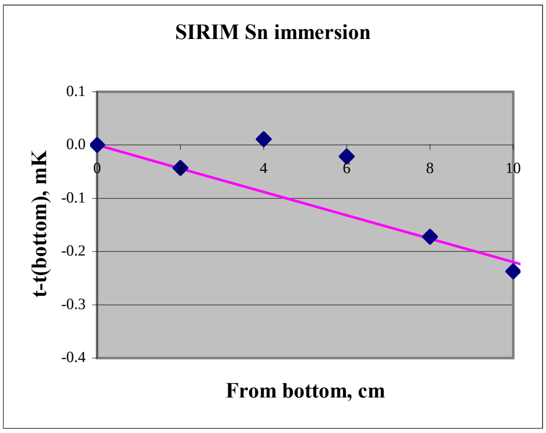


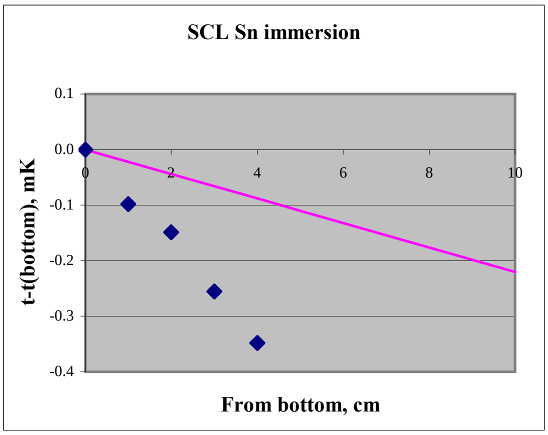


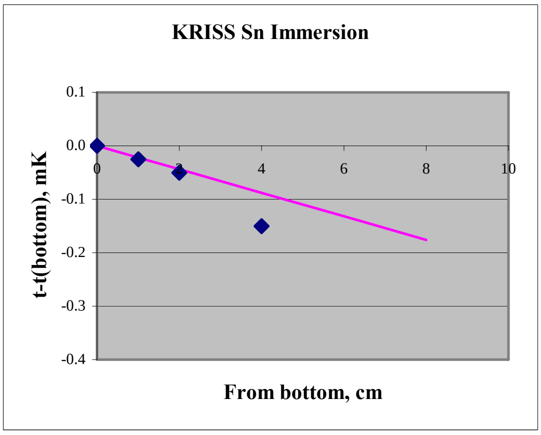


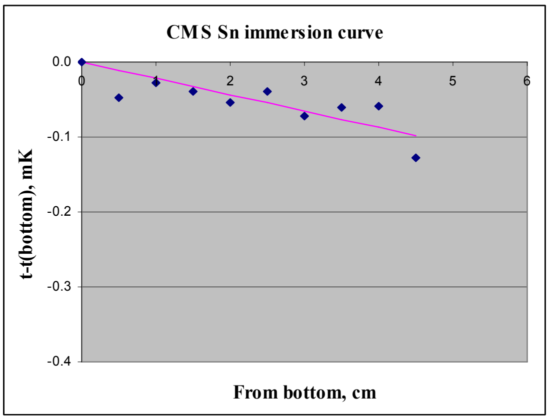


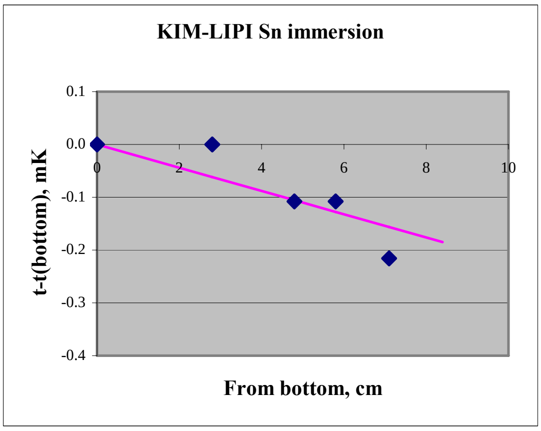



SIRIM Sn immersion
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0
4
6
8
10
t-t(bottom), mK
From bottom, cm

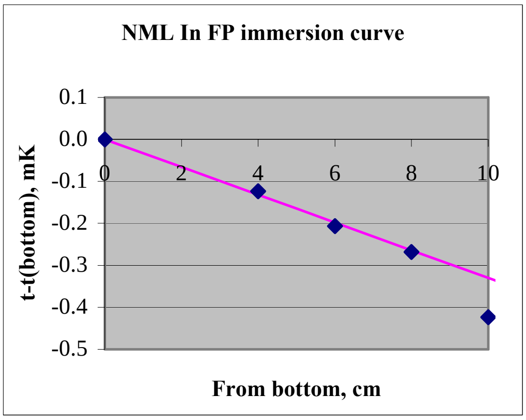

SCL Sn immersion
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0
2
4
6
8
10
t-t(bottom), mK
From bottom, cm

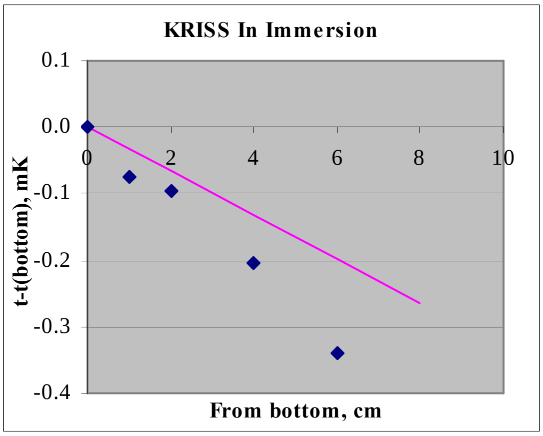

KRISS Sn Immersion
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0
4
6
8
10
t-t(bottom), mK
From bottom, cm

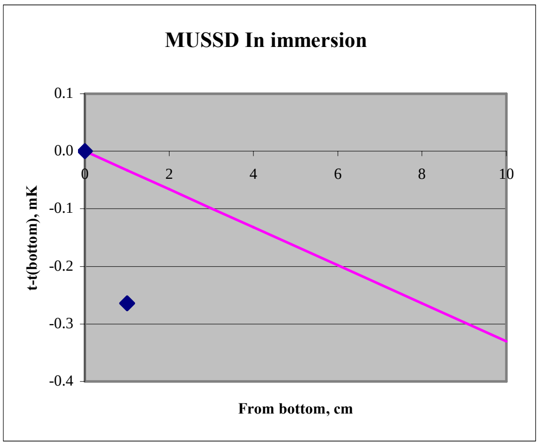

CMS Sn immersion curve
0.0
-0.1
-0.2
-0.3
-0.4
0
2
3
4
5
6
t-t(bottom), mK
From bottom, cm

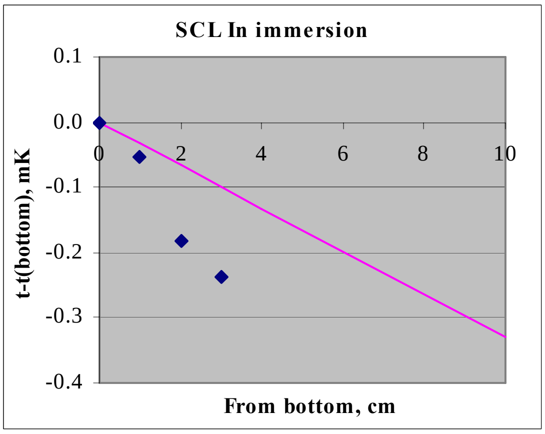

KIM-LIPI Sn immersion
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0
2
4
6
8
10
t-t(bottom), mK
From bottom, cm

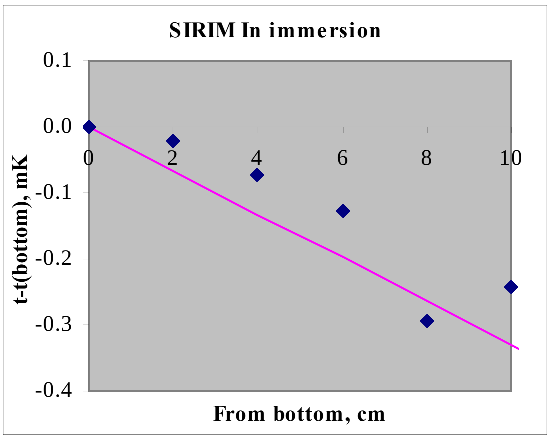
Appendix 4.3 In curve



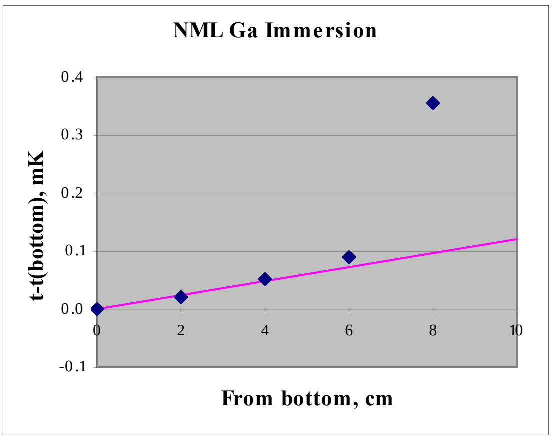


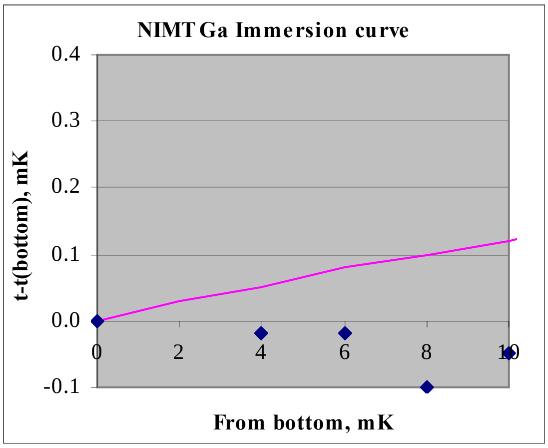


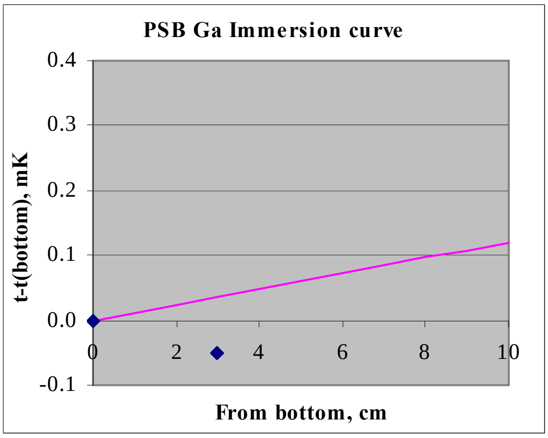


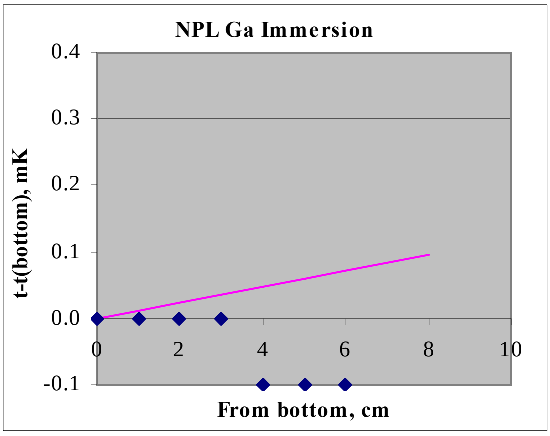


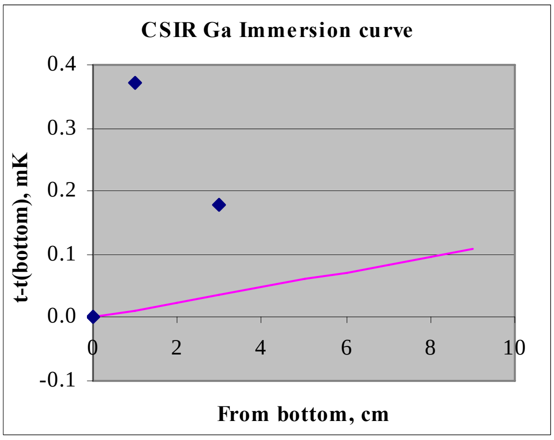
Appendix 4.4 Ga curve

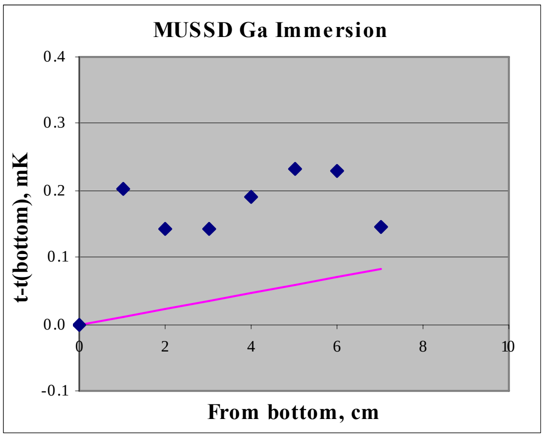


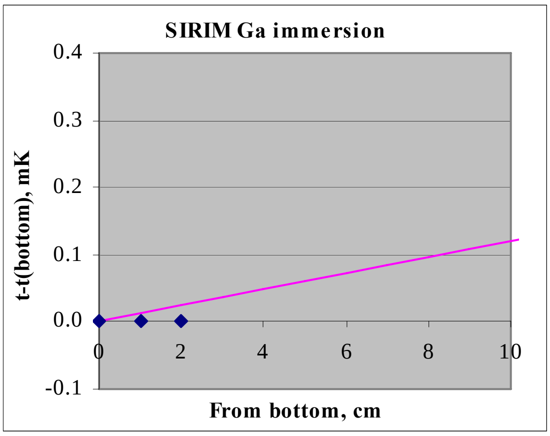


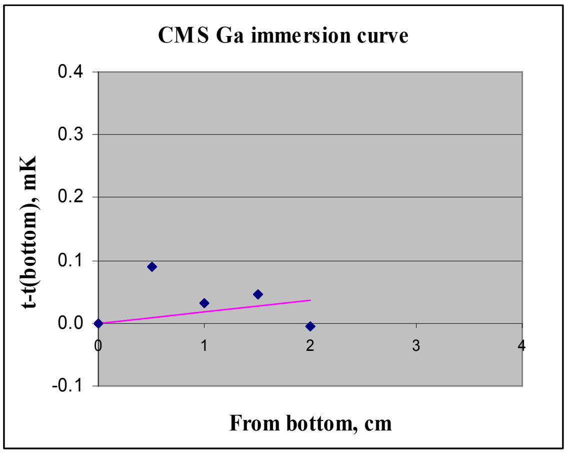


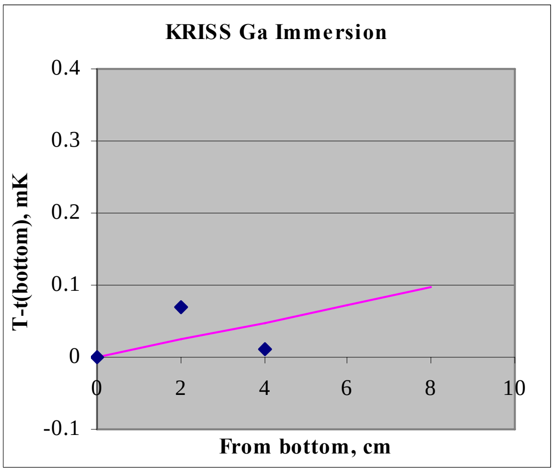


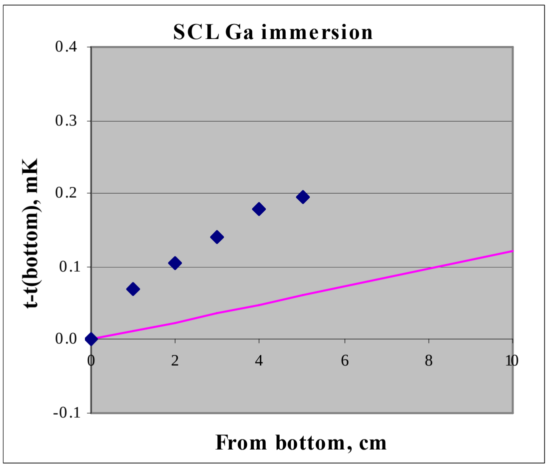




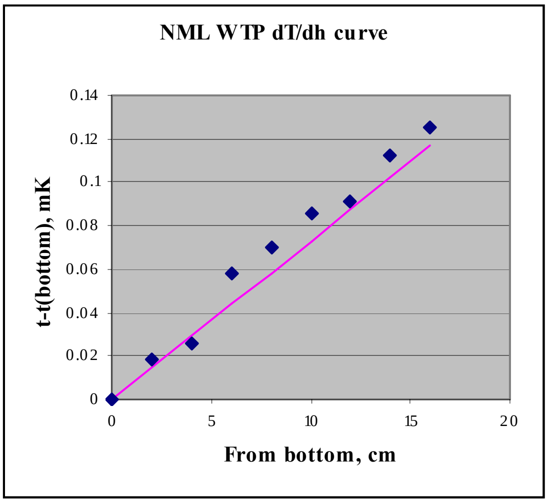

SIRIM Ga immersion
t-t(bottom), mK
0.4
0.3
0.2
0.1
0.0
-0.1
0
2
4
6
8
10
From bottom, cm

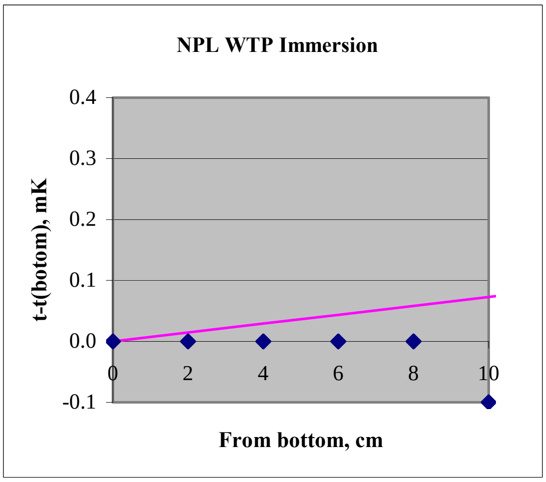

CMS Ga immersion curve
t-t(bottom), mK
0.4
0.3
0.2
0.1
0.0
-0.1
0
1
2
3
4
From bottom, cm

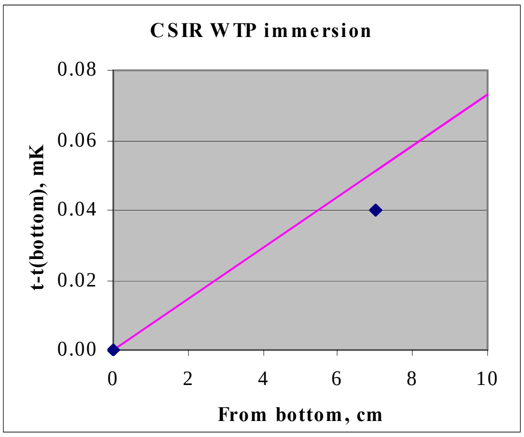

KRISS Ga Immersion
T-t(bottom), mK
0.4
0.3
0.2
0.1
0
-0.1
0
2
4
6
8
10
From bottom, cm

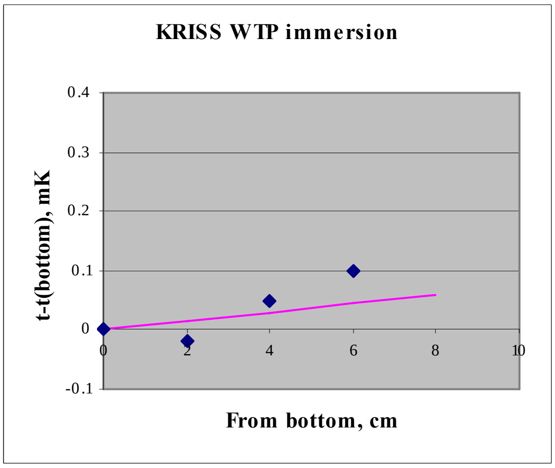

SCL Ga immersion
t-t(bottom), mK
0.4
0.3
0.2
0.1
0.0
-0.1
0
2
4
6
8
10
From bottom, cm

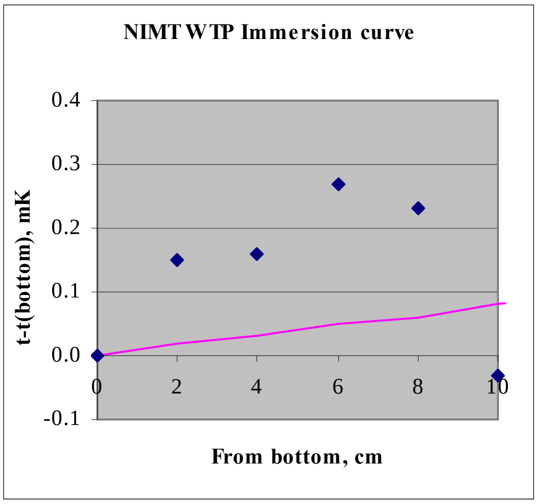
Appendix 4.5 Water triple point curve

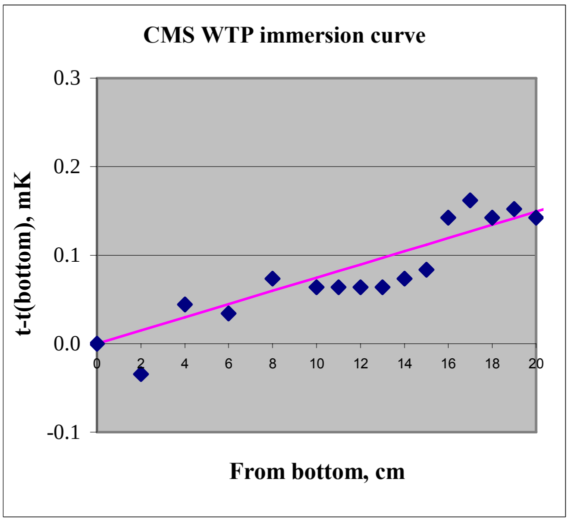




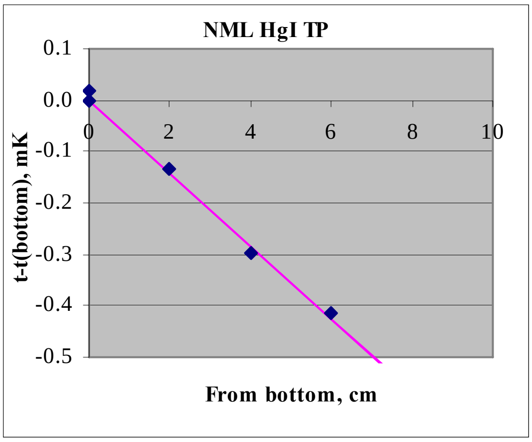


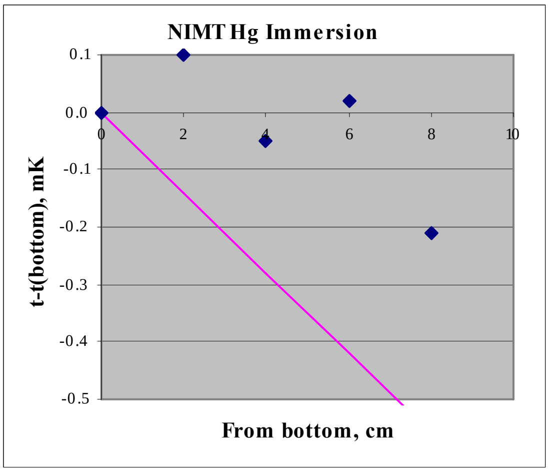


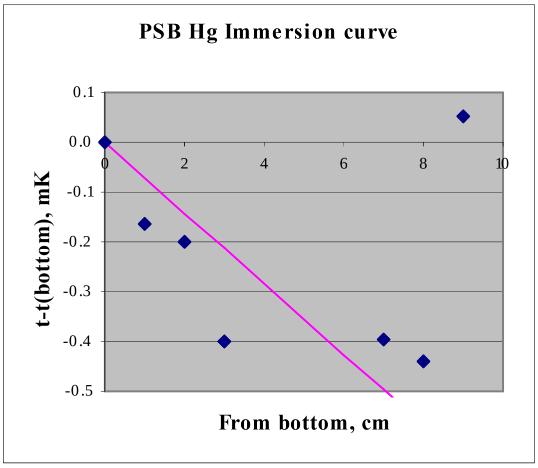


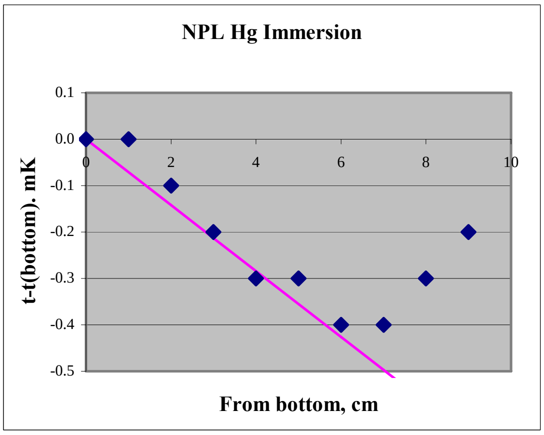


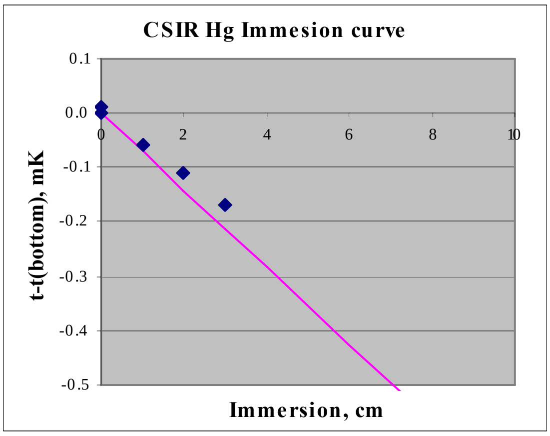
Appendix 4.6 Hg curve

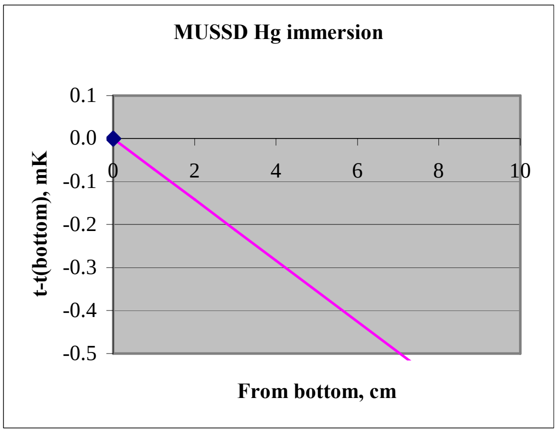


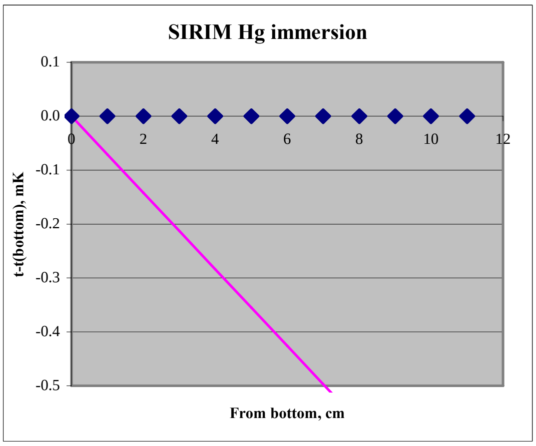


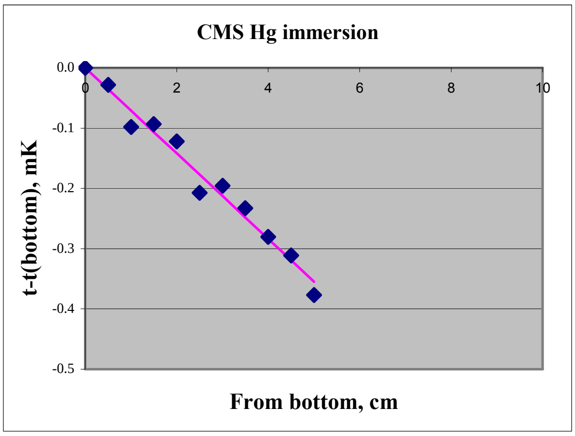


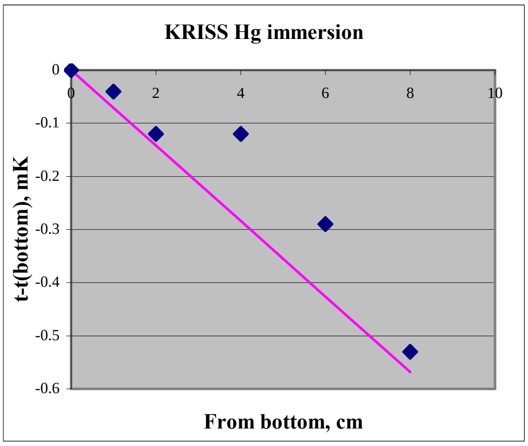


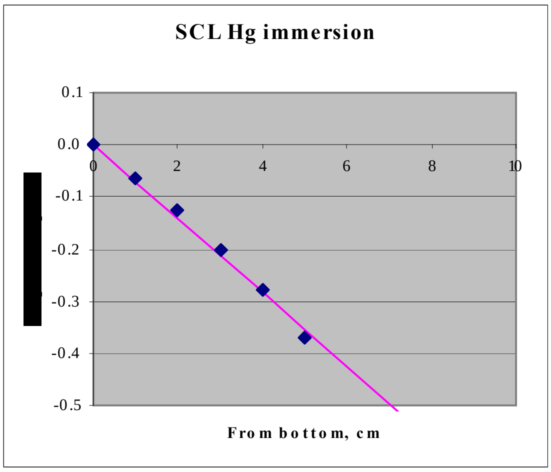





SIRIM Hg immersion
t-t(bottom), mK
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0
2
4
6
8
10
12
From bottom, cm


CMS Hg immersion
t-t(bottom), mK
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0
2
4
6
8
10
From bottom, cm


KRISS Hg immersion
t-t(bottom), mK
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
0
2
4
6
8
10
From bottom, cm


SCL Hg immersion
[redacted]
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0
2
4
6
8
10
From bottom, cm

APPENDIX 5: INSTRUMENTATION

Appendix 5.1 Resistance measuring device

Laboratory Name	**NML**	**PSB**	**CSIR**	**NIMT**
Bridge manufacturer	ASL	MI	ASL	MI
AC/DC	F18	DC Model : MI6010A	AC	DC
If AC, give				
Frequency	75 Hz	-	25 Hz	-
Bandwidth	0.1 Hz	-	0.1 Hz	-
Gain	10^4	-	100 000	-
Quad gain	10	-	10	-
output	IEEE	-	IEEE-488	-
Normal measuring current	1 mA	-	1 mA	-
Self-heating current	1.414 mA	-	v2 mA	-
Unity reading		-	1.000 000 05	-
Zero reading		-	-0.000 000 02	-
Compliment check error		-	-0.000 000 12	-
If DC, give				
Gain		NA		-
Period of reversal		8 second		20 Sec.
output		IEEE-488		IEEE-488
Reference resistor				
Type	9330	AC/DC 5685A 10 Ω	5685A (Wilkins)	5685A (Wilkins: 25 Ω)
Manufacturer	Guildline	Tinsley	Tinsley	H. Tinsley
Temperature?	20 oC oil bath	23.15 +/- 0.15 ° C	approx. 22°C	20° C +/- 0.005° C
Temperature coefficient ?	~ 1 ppm	-1.25 ppm / degree C	(-0.47ppm/°C)	3 ppm/ C
Linearity of bridge		0.2ppm of reading	<0.2ppm ± 0.6ppm	± 0.02 ppm.

Laboratory Name	**NPL**	**MUSSD**	**SIRIM**	**SCL**
Bridge manufacturer	ASL	MI	(ASL)	ASL
AC/DC	AC, Model 700B	DC	AC	AC
If AC, give				
Frequency	75 Hz		75 Hz	75 Hz
Bandwidth	1 Hz / 0.1 Hz		0.1 Hz	0.02 Hz
Gain	10 x 10		10^4	10000
Quad gain	Unity			10
output	Manually		IEEE-488	IEEE488
Normal measuring current	1 mA		1 mA	1 mA
Self-heating current	1.41 mA		SQRT 2mA	1.414 mA
Unity reading	1, zero up to six decimal		1.0000000	0.9999999
Zero reading	0, zero up to six decimal		0.0000000	0.0000000
Compliment check error	< / = 0.000004		0.0000000	0.099 ppm
If DC, give				
Gain				
Period of reversal		10 (20 for Hg, Wtc & Ga		
output		manually		
Reference resistor		External Resistor		
Type	Internal 100 Ohm	Vishay Resistor	100 Ohm AC/DC	5685A
Manufacturer	Not Known	Isotech	Tinsley	Tinsley
Temperaturer?	35 C	temp control	25.01°C	23 +/- 0.02 ^{o} C
Temperature coefficient ?	< 1 ppm / C			0.25 ppm / ^{o} C
Linearity of bridge	(+/- 1 least signif digit).	0.01 ppm	7.80E-08	

Laboratory Name	**KRISS**
Bridge manufacturer	ASL model F18
AC/DC	AC
If AC, give	
Frequency	30 Hz
Bandwidth	0.1 Hz
Gain	10^4
Quad gain	1
Read manually or off IEEE-488	IEEE
Normal measuring current	1 mA
Self-heating current	1.414 mA
Unity reading	1
Zero reading	0.00000003
Compliment check error	0.4ppm
If DC, give	
Gain	
Period of reversal	
Read manually, strip chart or off IEEE-488	
Reference resistor	
Type	AC/DC
Manufacturer	Tinsley
Temperature of the ref resistor?	oil bath
Temperature coefficient of the ref resistor?	1.2 ppm/^{o}C
Linearity of bridge	

Appendix 5.2 Water triple point cell

Water triple point cell	NML	PSB	CSIR	NPL, India
Cell manufacturer	Jarrett	Jarrett-Isotech I	Jarrett (type A	NPL, India
Water source and purity		Model B11		Triple Distilled, deionized,
				>18 MΩ,(River , main)
Well diameter	11mm	11 mm	11 mm	12 mm internal Dia.
Immersion depth	280 mm	290 mm	238 mm (midsensor)	300 mm
Heat transfer liquid: water?	Dist. Water	Distilled Water	Distilled water	Triple Distilled Water
Cell maintained in:		Water bath		
Ice bath	ice bath	-		Ice Bath
Water bath		-	Isotech water bath	
Ice mantle:				
Method of preparation	dry ice/imcoller	dry ice	LN-cooled SS rod	Immersion Cooler
Annealing time before use	3 days	Two weeks	>1 day	> 24 Hours

Water triple point cell	MUSSD	SIRIM	SCL	KIM-LIPI
Cell manufacturer	Jarret Isotech	Foxboro, USA	Jarrett	PTB Germany
Water source and purity		NIL		
	+- 0.00015 C**		no information	14 mm
Well diameter	10 mm	10mm	13 mm	
Immersion depth	200 mm	230mm	300 mm	22 cm below surface of water
Heat transfer liquid: water?	water	Water	water	Water
Cell maintained in:				
Ice bath		Ice bath		
Water bath	water bath		water bath	
Ice mantle:				
Method of preparation	Solid Co2	Dry ice	Dry Ice/Imm Cooler	Insertion of cold rod
Annealing time before use	3 to 4 days	3 days	at least 12 hours	2 days

Laboratory Name	KRISS
Cell	**H_2O triple point**
Cell manufacturer	**Hart Scientific**
Water source and purity	?
Well diameter	11 mm
Immersion depth	26.1cm
Heat transfer liquid: water?	water 90%+ethanol 10%
Cell maintained in:	
Ice bath	
Water bath	water bath
Ice mantle:	
Method of preparation	dry ice
Annealing time before use	2 months

Appendix 5.3 Other fixed points

Laboratory Name	**NML**				
Cell	**Zn**	**Sn**	**In**	**Ga**	**Hg**
Cell manufacturer	lab made	lab made	lab made	YSI	lab made
Open/closed?	opem	opem	opem	open	closed
Pressure in cell	1 atm	1 atm	1 atm	1 atm	T?P
Crucible					
Crucible material	graphite	graphite	graphite	Teflon	stainless steel
Crucible manufacturer	Ultra Carbon	Ultra Carbon	Ultra Carbon	?	?
Crucible length	21 cm	21 cm	21 cm		
Metal sample					
Sample source	Johnson Matthey	Johnson Matthey	Johnson Matthey	?	in house
Sample purity	99.9999%	99.9999%	99.9999%	99.9999%	99.9999%
Sample weight	1Kg	1.1 Kg	1Kg		
Thermometer well					
Well material	pyrex	pyrex	pyrex	Teflon	stainless steel
Well ID (mm)	8	8	8	8	
Immersion depth of SPRT	15 cm	15 cm	15 cm		19 cm
Furnace/Bath	furnace	furnace	furnace		bath
Manufacturer	lab made	lab made	lab made		Isotech
Control type	PID	PID	PID		
How many zones?	3	3	3	?	
Furnace heater					
AC/DC?	DC	DC	DC		
Heat pipe liner?	no	no	no		
ITS-90 Realisation					
Freeze/Melt?	freeze	freeze	freeze	melt	freeze
Technique	2 glass rods	cell out of furnace	2 glass rods	heater	Cu rod in liquid N^2
Heat transfering fluid?	no	no	no	water	alcohol
Duration of freeze/melt	~ 2hrs	~ 2hrs	~ 2hrs	5 hrs	2 hrs
Cell used as FP/MP/TP?	FP	FP	FP	MP	TP

Laboratory Name	PSB			
Cell	**Zn**	**Sn**	**Ga**	**Hg**
Cell manufacturer	NIM, China	NIM, China	NIM, China	NIM, China
Open/closed?	Closed	Closed	Closed	Closed
Pressure in cell	101194 Pa	102174 Pa	101325 +/- 533 Pa	NA
Crucible				
Crucible material	Graphite	Graphite	Teflon	Stainless Steel
Crucible manufacturer	NIM	NIM	NIM	NIM
Crucible length	250mm	250mm	210mm	450mm
Metal sample				
Sample source	NIM	NIM	NIM	NIM
Sample purity	99.9999%	99.9999%	99.9999%	99.9999%
Sample weight	Not Availiable	Not Availiable	Not Availiable	Not Availiable
Thermometer well				
Well material	Quartz	Quartz	Quartz	Quartz
Well ID (mm)	8.2 +/- 0.2mm	8.2 +/- 0.2mm	8.0 +/- 0.25mm	8.2 +/- 0.2mm
Immersion depth of SPRT				
Furnace/Bath	Furnace	Furnace	Furnace	Bath
Manufacturer	NIM	NIM	NIM	Heto
Control type	PID controller	PID controller	Automatic Logic Switch	PID controller
How many zones?	Three zones	Three zones	Single zone	NA
Furnace heater				
AC/DC?	AC	AC	DC	AC
Heat pipe liner?	No	No	No	No
ITS-90 Realisation				
Freeze/Melt?	Freeze	Freeze	Melt	Melt
Technique	Insert rod	Insert rod	Insert rod	Insert rod
Heat transfering fluid?	Air	Air	Silicon Oil	Alcohol
Duration of freeze/melt	At least 6 hours	At least 6 hours	At least 6 hours	At least 6 hours
Cell used as FP/MP/TP?	FP	FP	MP	TP

Laboratory name: CSIR

Cell	**Zn**	**Sn**	**Ga**	**Hg**
Cell manufacturer	Isotech	Isotech	Isotech	Isotech
Open/closed?	Closed	Closed	Closed	Closed
Pressure in cell	101.3 kPa at 420°C	101.3 kPa at 232°C	101.3 kPa at 30°C	< 13 Pa
Crucible				
Crucible material	Graphite	Graphite	Teflon	Stainless steel
Crucible manufacturer	Isotech (?)	Isotech (?)	Isotech (?)	Isotech (?)
Crucible length	< 247 mm	< 247 mm	150 mm	215 mm
Metal sample				
Sample source	Leico Industries	Leico Industries		
Sample purity	99,999 97%	99,999 97%	>99,999 99%?	
Sample weight				2.43 kg
Thermometer well				
Well material	Quartz	Quartz	Teflon?	Stainless steel
Well ID (mm)	8	8	10	7.75 mm
			8mmID metal insert	
Immersion depth of SPRT				
Furnace/Bath				
Manufacturer	Isotech	Isotech	Heto	Isotech
Control type	PID	PID	PID	PID
How many zones?	1	1	1	1
Furnace heater				
AC/DC?	AC	AC	AC	
Heat pipe liner?	No	No	No	Yes (evaporator coil)
ITS-90 Realisation				
Freeze/Melt?	Freeze	Freeze	Melt	Freeze & melt
Technique	Cold alumina rods	Removal of cell, cold alumina rods	Water at 39°C	LN-cooled SS rod, room temp. SS rod
Heat transfering fluid?	Air	Air	Water	Ethanol
Duration of freeze/melt	7 hours	5.5 h	12.5 h	5 h, 5 h
Cell used as FP/MP/TP?	FP	FP	MP	TP

Laboratory Name	NPL			
Cell	**Zn**	**Sn**	**Ga**	**Hg**
Cell manufacturer	ISOTECH, USA	ISOTECH, USA	ISOTECH, USA	NPL, INDIA
Open/closed?	CLOSED	CLOSED	CLOSED	CLOSED
Pressure in cell	1 Std. Atm.	1 Std. Atm.	1 Std. Atm.	Sealed under Vacuum
Crucible				
Crucible material	Graphite	Graphite	Teflon	Stainless Steel-304
Crucible manufacturer	ISOTECH, USA	ISOTECH, USA	ISOTECH, USA	NPL, INDIA
Crucible length	225 mm	225 mm	330 mm	240 mm
Metal sample				
Sample source	Lieco, USA	Lieco, USA	Not known	Imported,Not Known
Sample purity	99.99995	99.99995	99.99995	99.9999
Sample weight	965 g	980 g	425 g	2500 g
Thermometer well				
Well material	Graphite lined	Graphite lined	Teflon lined withSS	Stainless Steel-304
	with	with Quartz		
Well ID (mm)	8	8	12	8
Immersion depth of SPRT	200 mm	200 mm	230 mm	190 mm
Furnace/Bath	Furnace	Furnace	Control Apparatus	Bath(N2 cooled cryostat)
Manufacturer	ISOTECH, USA	ISOTECH, USA	ISOTECH, USA	NPL, INDIA
Control type	PID Control	PID Control	TE Heat Pump	Manual
How many zones?	Single	Single	Single	Single
Furnace heater				
AC/DC?	AC	AC	AC	No Heater
Heat pipe liner?				
ITS-90 Realisation				
Freeze/Melt?	Freeze	Freeze	Melt	Melt
Technique	Heat Extraction	Heat Extraction	Heat Input	Heat Input
Heat transfering fluid?	Air	Air	Distilled Water	Alcohol
Duration of freeze/melt	8 Hours.	9 Hours	13 Hours	3 Hours
Cell used as FP/MP/TP?	FP	FP	MP	TP

Laboratory Name	**MUSSD**				
Cell	**Zn**	**Sn**	**In**	**Ga**	**Hg**
Cell manufacturer	Isotech	Isotech	Isotech	Isotech	Isotech
Open/closed?	Sealed	slim cells			
Pressure in cell	1 atm	1 atm	1 atm	1 atm	1 atm
Crucible					
Crucible material	Graphite	Graphite	Graphite	Teflon	Stainless steel
Crucible manufacturer	Isotech			Isotech	
Crucible length	17 cm	17 cm	17 cm	15 cm	14 cm
Metal sample					
Sample source	1.2 mK	0.9 mK	0.8 mK	0.45 mK	0.5 mK
Sample purity	100.00%	100.00%	100.00%	100.00%	< 15 ppb
Sample weight	330 g	340 g	340 g	120 g	1400 g
Thermometer well					
Well material	Quartz	Quartz	Quartz	Stainless steel	Stainless steel
Well ID (mm)	7.5 - 8.0 mm	7.5 - 8.0 mm	7.5 - 8.0 mm	10 mm	8 mm
Immersion depth of SPRT	130 mm	130 mm	120 mm	120 mm	120 mm
Furnace/Bath	MEDUSA				
Manufacturer	Isotech	Isotech	Isotech	Isotech	Isotech
Control type	Micro	processor	digital	control	
How many zones?	any	temperature	between 50 C	and 700 C	
Furnace heater					
AC/DC?	AC	AC	AC	AC	AC
Heat pipe liner?	No	No	No	No	No
ITS-90 Realisation					
Freeze/Melt?	Both	possiblke			
Technique	Outer	interface	on melt	formed	furnace
Heat transfering fluid?	No	No	No	No	No
Duration of freeze/melt	Variable	but > 6 hours	when used on	the melt	
Cell used as FP/MP/TP?	FP	FP	FP	FP	FP

Laboratory	SIRIM				
Cell	**Zn**	**Sn**	**In**	**Ga**	**Hg**
Cell manufacturer	NPL	NPL	NPL	Pond Eng, USA	NIM
Open/closed?	closed	closed	closed	closed	closed
Pressure in cell	1 Atm	1 Atm	1 Atm	1 Atm	1 Atm
Crucible					
Crucible material	Graphite	Graphite	Graphite	Stainless	Stainless
Crucible manufacturer	NPL	NPL	NPL	Pond Eng, USA	NIM
Crucible length	243 mm	243 mm	243 mm	250 mm	450 mm
Metal sample					
Sample source	NPL	metal NPL	NPL	Pond Eng, USA	NIM
Sample purity	99.9999	99.9999	99.9999	99.999999	99.9999
Sample weight					
Thermometer well					
Well material	Quartz	Quartz	Quartz	Stainless Steel	Stainless Steel
Well ID (mm)	10 mm	10 mm	10 mm	9 mm	9 mm
Immersion depth of SPRT	154	154	154	190	350
Furnace/Bath					
Manufacturer	Carbolite	Carbolite	Carbolite	Pond Eng, USA	Heto
Control type	3 zone	3 zone	3 zone	bath	Liquid bath
How many zones?	3	3	3	1	1
Furnace heater					
AC/DC?	AC	AC	AC	AC	AC
Heat pipe liner?					
ITS-90 Realisation					
Freeze/Melt?	F	F	F	M	M/F
Technique	Inducing Rod	Inducing Rod	Inducing Rod	Inducing Sprt	Inducing Sprt
Heat transfering fluid?				Silicon	Silicon
Duration of freeze/melt	1 hr 50 min	2 hrs	2 hrs	more than 3 hrs	3hrs~ 8hrs
Cell used as FP/MP/TP?	FP	FP	FP	MP	TP

Laboratory Name	KRISS				
Cell	**Zn**	**Sn**	**In**	**Ga**	**Hg**
Cell manufacturer	lab made	lab made	lab made	lab made	lab made
Open/closed?	open	open	sealed	open	sealed
Pressure in cell	1 atm	1 atm	1 atm	1 atm	T/P
Crucible					
Crucible material	graphite	graphite	pyrex	Teflon	stainless steel
Crucible manufacturer	Ultra Carbon	Ultra Carbon		?	?
Crucible length	25.5cm	25.5cm	18cm	31cm	23cm
Metal sample					
Sample source	Johnson Matthey	Johnson Matthey	Johnson Matthey	?	in house
Sample purity	99.9999%	99.9999%	99.9999%	99.99999%	99.9999%
Sample weight	1Kg	1.1 Kg	0.7kg	0.8kg	
Thermometer well					
Well material	graphite	graphite	pyrex	Teflon	stainless steel
Well ID (mm)	11	11	10	12	
Immersion depth of SPRT	14cm	14 cm	11.5cm	18cm	15.5cm
Furnace/Bath	furnace	furnace	furnace	bath	refrigerator
Manufacturer	commercial	commercial	commercial	commercial	commercial
Control type	PID	PID	PID	P	P
How many zones?	3	3	3	?	
Furnace heater					
AC/DC?	AC	AC	AC		
Heat pipe liner?	no	no	no		
ITS-90 Realisation					
Freeze/Melt?					
Technique					
Heat transfering fluid?					
Duration of freeze/melt					
Cell used as FP/MP/TP?					

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Cell	**Zn**	**Sn**
Cell manufacturer	Laboratory made	Laboratory made
Open/closed ?	Open	Open
Pressure in cell	1 atm	1 atm
Crucible		
Crucible material	Graphite	graphite
Crucible manufacturer	Ringsdorff Werke GMBH Germany	Ringsdorff Werke GMBH Germany
Crucible length	24 cm	24 cm
Metal Sample		
Sample source	PPM Pure Metal GMBH Germany	Johnson Matthey Canada
Sample purity	99.9999 %	99.9999 %
Sample weight	760 gram	760 gram
Thermometer Well		
Well material	Graphite	Graphite
Well ID (mm)	7.4 mm	7.4 mm
Immersion depth of SPRT	17 cm below surface of metal sample	17 cm below surface of metal sample
Furnace/Bath	Furnace	Furnace
Manufacturer	Yellow Springs Instrument, Co. USA	Yellow Springs Instrument, Co. USA
Control type	PID	PID
How many zones ?	3	3
Furnace heater		
AC/DC	AC	
Heat pipe liner ?		
ITS-90 Realisation Techniques		
Freeze/Melt	Freeze	Freeze
Method of forming solid/liquid interface	Induced freeze	Outside nucleation
Heat transfering fluid ?		
Duration of freeze/melt	25 minutes	40 minutes
Cell used as FP/MP/TP	FP	FP

Laboratory Name	**SCLHongkong**				
Cell	**Zn**	**Sn**	**In**	**Ga**	**Hg**
Cell manufacturer	Isotech	Isotech	Isotech	Isotech	Isotech
Open/closed?	Closed	Closed	Closed	Closed	Closed
Pressure in cell	1 atm	1 atm	1 atm	1 atm	triple point :N/A
Crucible					
Crucible material	graphite	graphite	graphite	Teflon	Stainless steel
Crucible manufacturer	No infomation	No infomation	No infomation	No infomation	No infomation
Crucible length	No infomation	No infomation	No infomation	No infomation	No infomation
Metal sample					
Sample source	Isotech	Isotech	Isotech	Isotech	Isotech
Sample purity	99.9999%	99.9999%	99.9999%	99.9999%	99.9999%
Sample weight	No infomation	No infomation	No infomation	0.425 kg	No infomation
Thermometer well					
Well material	Quartz	Quartz	Quartz	Teflon	Stainless steel
Well ID (mm)	8	8	8	12.5	7.75
Immersion depth of SPRT					
Furnace/Bath					
Manufacturer	Isotech	Isotech	Isotech	Isotech	Isotech
Control type	PID	PID	PID	Proportional	Proportional
How many zones?	1	1	1	1	1
Furnace heater					
AC/DC?	AC	AC	AC	DC	Cryostat : N/A
Heat pipe liner?	No	No	No	No	No
ITS-90 Realisation					
Freeze/Melt?	Freeze	Freeze	Freeze	Melt	decreasing
Technique	Withdraw/re-insert monitoring SPRT	Whole cell withdrawn	Insert cold rod	Add water at 40 o C	cryostat temp
Heat transfering fluid?	No	No	No	Water	Alcohol
Duration of freeze/melt	4 hours	6 hours	3 hours	4 hours	5 hours
Cell used as FP/MP/TP?	FP	FP	FP	MP	TP