Final Report APMP-T-S1-04

APMP Regional Comparison of Type R (Pt-Pt13%Rh) Thermocouples from 0 to 1100°C

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1. INTRODUCTION

The Pt/PtRh thermocouple is a precision sensor used to measure temperatures as high as 1600°C and is widely used in many industries. They can be calibrated by using metal fixed points (Ga, Sn, Al, Ag) or a comparison method using a calibrated standard sensor (SPRT or Type S or R thermocouple) and a variable temperature enclosure, or a combination of both. Different laboratories have adopted different methods for the calibration of thermocouples.

In 2004, the National Measurement Institute of Australia (Pilot Lab) organised a regional intercomparison of Type R thermocouple calibration from 0 to 1100°C for national laboratories in the Asia/Pacific region. The objective of this APMP intercomparison is to assess the equivalence of the calibration results obtained by the various procedures and methods of calibration of rare metal thermocouple up to 1100°C. This comparison is partially funded by APEC (Asia Pacific Economical Committee); purchase of the thermocouple wires and insulator and transport of the artefacts from the pilot lab to the participating laboratories were funded by an APEC grant.

Twelve laboratories of the Asia Pacific region including NMI, Australia took part in this comparison. The names of the participating laboratories and the contact persons are given in Appendix A.

The protocol of this intercomparison was circulated in February 2005 by the pilot lab. After initial calibration the thermocouples were sent out to the participating labs in June 2005. They were calibrated again by the pilot lab after they came back from the participating labs to check the stability of the artefacts.

2. Summary of Comparison

A star type comparison was used to make the intercomparison process quicker. The pilot laboratory, NMIA (Australia) constructed 11 type R thermocouples (serial numbers: APMP-01 to APMP-11). The thermocouples were calibrated by NMIA using a salt bath up to 550°C and then Ag and Au fixed points [1]. The inhomogeneities of the thermocouples were measured by scanning in oil bath at 200°C [2]. They were then sent to 11 participating laboratories, (one to each laboratory) in June 2005. The measured inhomogeneity of the thermocouple was supplied to the participants by NMIA to use in the calculation of uncertainty.

All thermocouples arrived safely except two cases – NIM and NIMT. They reported that the insulator had broken during transportation. NIMT decided to carry out the calibration, using a protected alumina tube around the broken insulator. However, NIM sent back the broken thermocouple to the pilot laboratory. The pilot laboratory then replaced the insulator, recalibrated the thermocouple and sent back to NIM.

The APMP Thermocouple Intercomparison protocol (circulated in February 2005) is given in **Appendix A**. In the protocol, it was mentioned that the thermocouples are at **450°C annealed state and should be calibrated from lower to higher temperatures**. Each laboratory calibrated the given thermocouple from 0 to 1100°C, using their own test method. Calibration procedure used by the individual laboratory is given in **Appendix B**. The raw calibration data from the participating laboratories are given in **Appendix C**. The instruments used by each participant are given in **Appendix D** and the uncertainty calculations as supplied by each individual laboratory, is given in **Appendix E**.

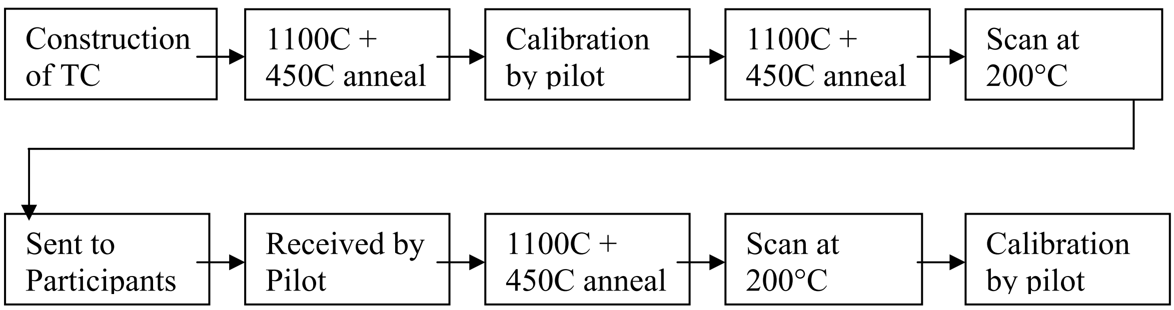
After the thermocouples were returned to the pilot laboratory by the participating laboratories, the thermocouples were given 1 hour anneal at 1100°C and approximately 16 hours anneal at 450°C. All 11 thermocouples were again scanned at 200°C and calibrated from 0 to 1100°C by the pilot laboratory NMIA.

3. Measurement Schedule

The measurement schedule was set in the protocol, however several unavoidable delays led to some changes. The actual schedule is summarised below.

- **March – May 2005** – Design and calibration of the artefacts by the pilot lab.
- **June 2005** – Artefacts sent out to the participating labs.
- **August – September 2005** – Artefacts back from the participating labs (except NIM, China sent in October and NPLI, India sent in November).
- **August – September 2005** – The participating laboratories submitted the comparison results (except NIM, China submitted in December and NPLI, India submitted in November).
- **October- November 2005** – Calibration of the artefacts by the pilot lab.
- **December 2005** – Draft report prepared by the pilot lab.
- **February 2006** – Draft A circulated to the participating labs.

The measurement sequence and the annealing of a particular thermocouple are as given below:



4. Description of the Artefacts

The artefacts were Type R thermocouples. Each of them was constructed from 1400 mm long Pt and Pt13%Rh wires of 0.5 mm diameter, purchased from Sigmund Cohn Corp. (USA). The insulators used were high purity, alumina, purchased from Ceramic Oxide Fabricators (Australia). They are 750 mm long and 4.1 mm in diameter with two bores of 1.1 mm diameter. They were pre-baked at 1100°C for 6 hours.

For NMIJ, the thermocouple wires were 2300 mm long, upon special request from the lab to make the thermocouple with longer wires but with same insulator length.

The thermocouples wires were bare wire annealed at 1400 °C for 1 hour and 1100°C for 1 hour. After assembled into the insulator, they were given another 1 hour anneal at 1100°C and 16 hours anneal at 450 °C.

5. Calibration of the thermocouples by the Pilot lab

The thermocouples were initially scanned [2, 3] and calibrated [1] by the pilot lab (NMIA). Table 1 and figure 1 give the values of calibration results, $E\text{-}E_{ref}$ as a function of temperature for each of the thermocouples whilst the calibration uncertainty of the pilot laboratory is given in Table 2. The values of $E\text{-}E_{ref}$ of all thermocouples were within ±0.5μV (standard deviation ≤ 0.2 μV) for temperatures up to 1000°C. This shows the good reproducibility of the pilot lab measurements. Above 1000°C, the standard deviation is slightly larger, about 0.4 μV. These results are consistent with the fact that all the thermocouples were made in the same way from the same reel of wire.

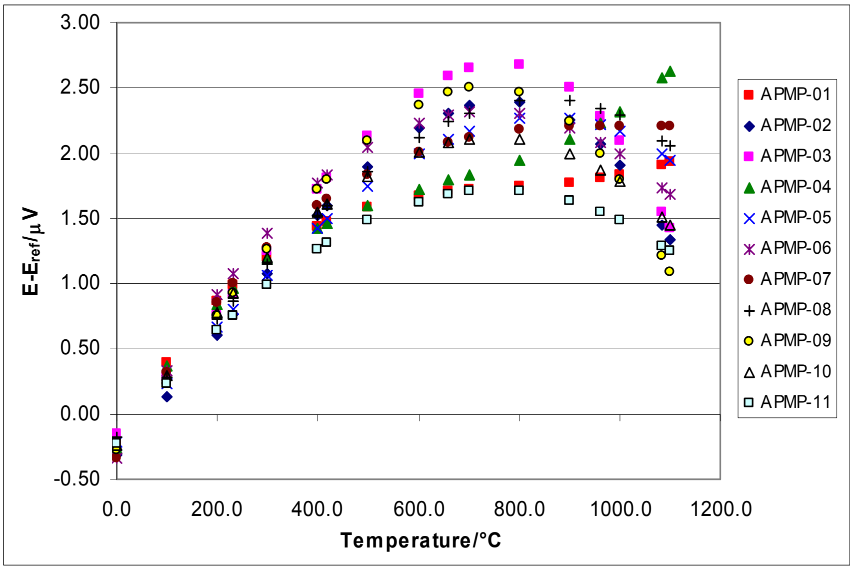


Figure 1. Initial calibration results of 11 thermocouples used for the intercomparison.

The inhomogeneity of the thermocouples was measured from tip to 600 mm at 200°C in an oil bath [2, 7]. The values of the inhomogeneity of all thermocouples, which was calculated using the following equation are given in Table 6.

$$\text{Inhomogeneity }(\%) = \pm\frac{1}{2}\left(\frac{E_{max} - E_{min}}{E_{ref}}\right)\times 100 \qquad \textbf{(1)}$$

The initial inhomogenity **within** each of the thermocouples varies from ±0.008% to ±0.012%, which is corresponds to ±0.84 μV to ±1.26 μV at 1000°C. This is comparable to the calibration differences **between** the thermocouples as discussed.

Table 1. The initial calibration results of the 11 thermocouples by the Pilot lab.

T/°C	APMP-01	APMP-02	APMP-03	APMP-04	APMP-05	APMP-06	APMP-07	APMP-08	APMP-09	APMP-10	APMP-11
0.00	-0.23	-0.31	-0.15	-0.26	-0.21	-0.34	-0.34	-0.18	-0.28	-0.24	-0.23
100.00	0.39	0.14	0.28	0.37	0.24	0.33	0.32	0.28	0.23	0.30	0.24
200.00	0.86	0.61	0.75	0.84	0.67	0.91	0.85	0.73	0.76	0.78	0.64
231.93	0.99	0.76	0.91	0.96	0.80	1.07	1.00	0.87	0.92	0.92	0.76
300.00	1.20	1.08	1.25	1.18	1.07	1.39	1.27	1.15	1.26	1.20	0.99
400.00	1.44	1.52	1.72	1.43	1.43	1.77	1.60	1.53	1.72	1.55	1.27
419.53	1.47	1.60	1.80	1.47	1.50	1.83	1.65	1.60	1.80	1.61	1.32
500.00	1.59	1.90	2.13	1.60	1.74	2.05	1.84	1.86	2.10	1.82	1.48
600.00	1.67	2.19	2.45	1.73	1.99	2.23	2.01	2.12	2.37	2.01	1.63
660.32	1.70	2.31	2.59	1.79	2.11	2.30	2.08	2.24	2.47	2.08	1.68
700.00	1.72	2.36	2.65	1.83	2.17	2.32	2.11	2.31	2.50	2.10	1.70
800.00	1.74	2.39	2.68	1.95	2.27	2.31	2.18	2.40	2.47	2.10	1.71
900.00	1.77	2.25	2.51	2.10	2.27	2.20	2.20	2.40	2.24	2.00	1.63
961.78	1.80	2.07	2.29	2.23	2.22	2.08	2.21	2.35	1.99	1.88	1.55
1000.00	1.83	1.91	2.10	2.32	2.17	1.99	2.21	2.29	1.79	1.78	1.48
1084.62	1.91	1.44	1.55	2.57	1.99	1.74	2.21	2.10	1.21	1.51	1.29
1100.00	1.93	1.34	1.42	2.63	1.95	1.69	2.21	2.05	1.09	1.45	1.25

Table 2. The pilot lab's initial calibration uncertainty (k=2), and the average uncertainty over the 11 thermocouples.

T/°C	APMP-01	APMP-02	APMP-03	APMP-04	APMP-05	APMP-06	APMP-07	APMP-08	APMP-09	APMP-10	APMP-11	average
0.00	0.260	0.310	0.450	0.530	0.320	0.320	0.320	0.260	0.260	0.260	0.260	0.323
100.00	0.338	0.388	0.521	0.594	0.398	0.384	0.391	0.325	0.331	0.325	0.344	0.394
200.00	0.436	0.486	0.612	0.675	0.496	0.465	0.482	0.407	0.422	0.407	0.451	0.485
231.93	0.471	0.521	0.643	0.704	0.531	0.494	0.513	0.436	0.453	0.436	0.488	0.517
300.00	0.548	0.598	0.714	0.768	0.608	0.558	0.584	0.500	0.524	0.500	0.572	0.589
400.00	0.669	0.719	0.825	0.867	0.729	0.657	0.695	0.601	0.635	0.601	0.703	0.700
419.53	0.693	0.743	0.847	0.888	0.753	0.678	0.717	0.621	0.657	0.621	0.729	0.723
500.00	0.797	0.847	0.942	0.973	0.857	0.763	0.812	0.707	0.752	0.707	0.841	0.818
600.00	0.930	0.980	1.064	1.083	0.990	0.873	0.934	0.818	0.874	0.818	0.986	0.941
660.32	1.013	1.063	1.140	1.151	1.073	0.941	1.010	0.888	0.950	0.888	1.076	1.018
700.00	1.069	1.119	1.192	1.198	1.129	0.988	1.062	0.934	1.002	0.934	1.137	1.069
800.00	1.214	1.264	1.324	1.317	1.274	1.107	1.194	1.055	1.134	1.055	1.293	1.203
900.00	1.365	1.415	1.463	1.441	1.425	1.231	1.333	1.180	1.273	1.180	1.457	1.342
961.78	1.460	1.510	1.550	1.520	1.520	1.310	1.420	1.260	1.360	1.260	1.560	1.430
1000.00	1.521	1.571	1.606	1.570	1.581	1.360	1.476	1.311	1.416	1.311	1.626	1.486
1084.62	1.657	1.707	1.730	1.682	1.717	1.472	1.600	1.424	1.540	1.424	1.773	1.612
1100.00	1.682	1.732	1.753	1.703	1.742	1.493	1.623	1.445	1.563	1.445	1.800	1.635

6. Measurements by the Participating Labs

Table 3 gives a summary of the calibration procedure used by each of the participants in the comparison.

The values of calibration results, $E-E_{ref}$ as a function of temperature for each of the thermocouples as provided by the participant are given in Table 4, in the same format as given in the protocol. The calibration results are compared at these specified nominal temperature points as in Table 4. The uncertainty values supplied by the participants are given in Table 5.

Some laboratories did not perform the fixed point measurements. In these cases, the values of $E - E_{ref}$ at the fixed point temperatures were calculated by interpolating the two adjacent points. The interpolated values of $E - E_{ref}$ are given in bold in Table 4. The uncertainty values at the temperatures which were not given by the participants are also obtained in the same way. Some laboratories have given the uncertainty in degrees Celsius. In these cases, the uncertainty in °C was converted to µV, using the appropriate Seebeck Coefficient.

Table 3. Calibration procedure used by the Participating laboratories

Name of Laboratory	**Calibration Process**
NMIA – Australia	Salt bath up to 550°C against a SPRT and Ag and Au fixed points
NIM – China	Fixed points used : TPW, Sn, Zn, Al, Ag and Cu.
SCL – HongKong	TPW, stirred liquid bath up to 500°C against a SPRT & from 600 to 1100°C using Na heat pipe and type R thermocouple
NPLI – India	Furnace calibration against a SPRT up to 600°C and above 600°C against a Type R thermocouple
KIMLIPI – Indonesia	Furnace calibration against a SPRT up to 400°C and above against a Type S thermocouple
NMIJ – Japan	Furnace calibration up to 300°C against a SPRT and fixed points of Zn, Al, Ag and Cu.
KRISS – Korea	Fixed point calibration using Cu, Ag, Al, Zn and Sn
SIRIM – Malaysia	Furnace calibration against a Type S thermocouple
SPRING –Singapore	Fixed points used : Sn, Zn, Al and Ag
CSIR – South Africa	Stirred salt bath up to 540°C, against an SPRT and fixed points of Al, Ag and Cu.
CMS – Taiwan	Fixed points of Sn, Zn, Al and Ag.
NIMT – Thailand	Fixed point used Sn, Zn, Al and Ag, furnace calibration up to 500°C against a SPRT and from 600 to 1100°C against a Type S thermocouple

Table 4. Values of E-E_{ref} in μV as given by the participating laboratories.

Temp / °C	APMP-01	APMP-02	APMP-03	APMP-04	APMP-05	APMP-06	APMP-07	APMP-08	APMP-09	APMP-10	APMP-11
	NIM	SCL	NPLI	KIMLIPI	KRISS	SIRIM	SPRING	CSIR	NMIJ	CMS	NIMT
0	-0.87	-0.05	1.60	-0.70	0.00	0.00	-0.53	-0.35	-0.48	0.00	0.84
100	0.57	0.20	4.20	0.40	0.10	-1.10	0.03	-0.19	-0.02	-0.12	1.33
200	1.28	0.52	2.00	1.10	0.20	-1.40	0.51	0.20	0.47	-0.24	1.74
231.93	1.22	**0.74**	4.40	**1.23**	0.30	**-1.27**	0.65	0.35	**0.63**	0.61	1.86
300	1.39	1.20	4.30	1.50	0.30	-1.00	0.93	0.72	0.97	-0.38	2.08
400	1.04	1.70	2.80	1.70	0.50	-0.10	1.27	1.29	1.43	-0.52	2.39
419.527	1.21	**1.74**	3.60	**1.70**	0.70	**0.13**	1.33	1.40	1.38	1.51	2.45
500	0.36	1.90	6.40	1.70	0.70	1.10	1.53	1.81	1.82	-0.67	2.68
600	-0.50	2.20	8.10	1.60	0.90	2.30	1.73	2.18	2.11	-0.82	2.98
660.323	-1.25	**2.26**	6.10	**1.30**	0.90	**3.02**	1.81	2.29	2.17	-2.51	3.17
700	-1.41	2.30	4.50	1.30	1.20	3.50	1.85	2.30	2.27	-0.98	3.31
800	-2.23	2.70	4.40	0.80	1.50	4.30	1.90	2.09	2.26	-1.16	3.69
900	-2.83	2.00	5.10	0.30	1.80	4.40	1.87	1.44	2.05	-1.33	4.16
961.78	-2.86	**1.38**	5.00	**0.07**	1.97	**4.09**	1.82	0.78	2.17	-0.27	4.50
1000	-3.06	1.00	7.00	-0.30	2.10	3.90	1.77	0.26	1.61	-1.28	4.73
1084.62	-2.92	**1.00**	**8.69**	**-0.81**	2.57	**2.80**	**1.63**	-1.22	0.74	**-1.49**	**5.32**
1100	-2.79	1.00	9.00	-0.90	2.60	2.60	1.60	-1.54	0.90	-1.53	5.43

Table 5. The uncertainty values in μV provided by the participants (k=2)

Temp / °C	APMP-01	APMP-02	APMP-03	APMP-04	APMP-05	APMP-06	APMP-07	APMP-08	APMP-09	APMP-10	APMP-11
	NIM	SCL	NPLI	KIMLIPI	KRISS	SIRIM	SPRING	CSIR	NMIJ	CMS	NIMT
0.00	1.02	0.21	0.90	0.30	0.59	0.75	0.40	0.48	0.42	4.11	2.14
100.00	1.48	0.27	2.48	0.50	0.67	4.52	0.40	0.56	0.25	4.02	2.22
200.00	1.76	0.35	2.49	0.60	0.70	5.20	0.50	0.53	0.29	4.06	2.64
231.93	0.91	**0.61**	2.50	**0.66**	0.73	**5.38**	0.50	0.55	**0.31**	1.35	1.83
300.00	2.05	1.17	2.52	0.80	0.78	5.76	0.50	0.59	0.35	4.10	2.93
400.00	2.29	1.35	2.62	1.60	0.83	5.94	0.60	0.63	0.41	4.13	3.13
419.53	1.47	**1.37**	2.68	**1.66**	0.84	**5.99**	0.70	0.63	0.52	1.46	1.89
500.00	2.40	1.42	2.75	1.90	0.87	6.22	0.80	0.69	0.50	4.15	3.28
600.00	2.61	7.50	2.75	2.20	1.02	4.88	1.00	0.77	0.61	4.18	6.82
660.32	1.86	**7.67**	2.75	**2.60**	1.05	**5.00**	1.10	0.81	0.69	1.65	2.02
700.00	2.83	7.79	12.29	2.60	1.18	5.07	1.30	0.87	0.73	4.21	7.08
800.00	2.94	8.09	12.29	2.90	1.23	5.76	1.60	1.03	0.84	4.26	8.59
900.00	3.19	11.61	13.27	3.20	1.40	6.89	1.90	1.20	0.93	4.34	8.93
961.78	2.22	**11.88**	13.58	**3.35**	1.44	**7.63**	2.00	1.31	1.08	2.06	3.92
1000.00	3.31	12.05	13.88	3.60	1.59	8.08	2.20	1.65	1.06	5.14	9.27
1084.62	2.58	**12.37**	**13.38**	**3.94**	1.63	**9.33**	**2.45**	2.45	1.26	**5.71**	**9.52**
1100.00	3.41	12.43	13.29	4.00	1.64	9.56	2.50	2.59	1.31	5.82	9.56

7. Final Calibration by the Pilot Laboratory: Drift and reproducibility

After the thermocouples were returned to the pilot lab, they were given 1 hour anneal at 1100°C followed by a 16 hours anneal at 450°C (the same annealing as these thermocouples were given before sending to the participants). Although the thermoelectric signature of type R thermocouples changes as they experience high temperatures, most of the change (up to 1100°C) is reversible [4] by appropriate annealing. After annealing, the thermocouples were scanned in oil bath at 200°C. A typical inhomogeneity graph is shown in figure 2A for one of the thermocouples, and the values of inhomogeneity for all thermocouples are given in Table 6.

The final inhomogeneity values for 9 of the 11 thermocouples are close to initial values, however in thermocouples, APMP-01 and APMP-03, the inhomogeneity increased from 0.010% to 0.015%. NPLI reported that the insulator of thermocouple (APMP-03) broke during their measurements. The scan shown in figure 2B shows that the inhomogeniety introduced in the wires by this cold work (bending of the wires) at the point of breakage is not fully recovered by annealing.

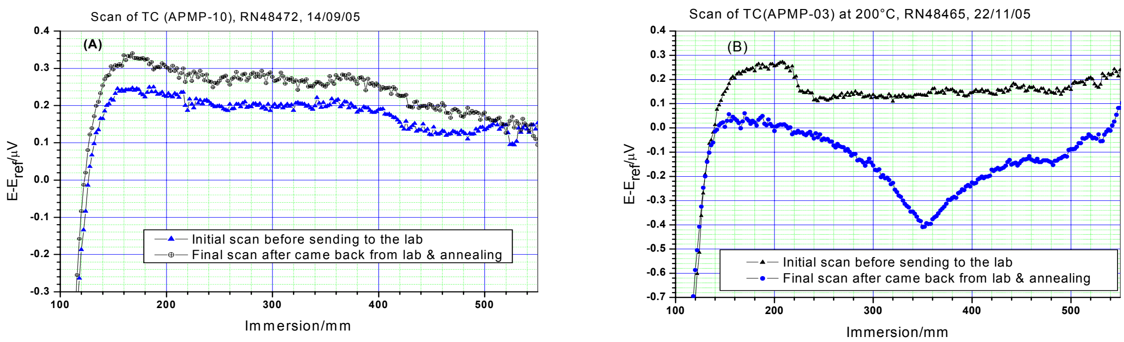


Figure 2. Scan of two APMP Thermocouples (A) TC(APMP-10) (B) TC(APMP-03)

Table 6. Summary of the inhomogeneity values of 11 thermocouples.

Serial number	Initial / %	Final / %
APMP-01	± 0.010	± 0.015
APMP-02	± 0.010	± 0.010
APMP-03	± 0.010	± 0.016
APMP-04	± 0.010	± 0.008
APMP-05	± 0.011	± 0.010
APMP-06	± 0.008	± 0.009
APMP-07	± 0.009	± 0.010
APMP-08	± 0.008	± 0.008
APMP-09	± 0.009	± 0.010
APMP-10	± 0.008	± 0.009
APMP-11	± 0.012	± 0.010

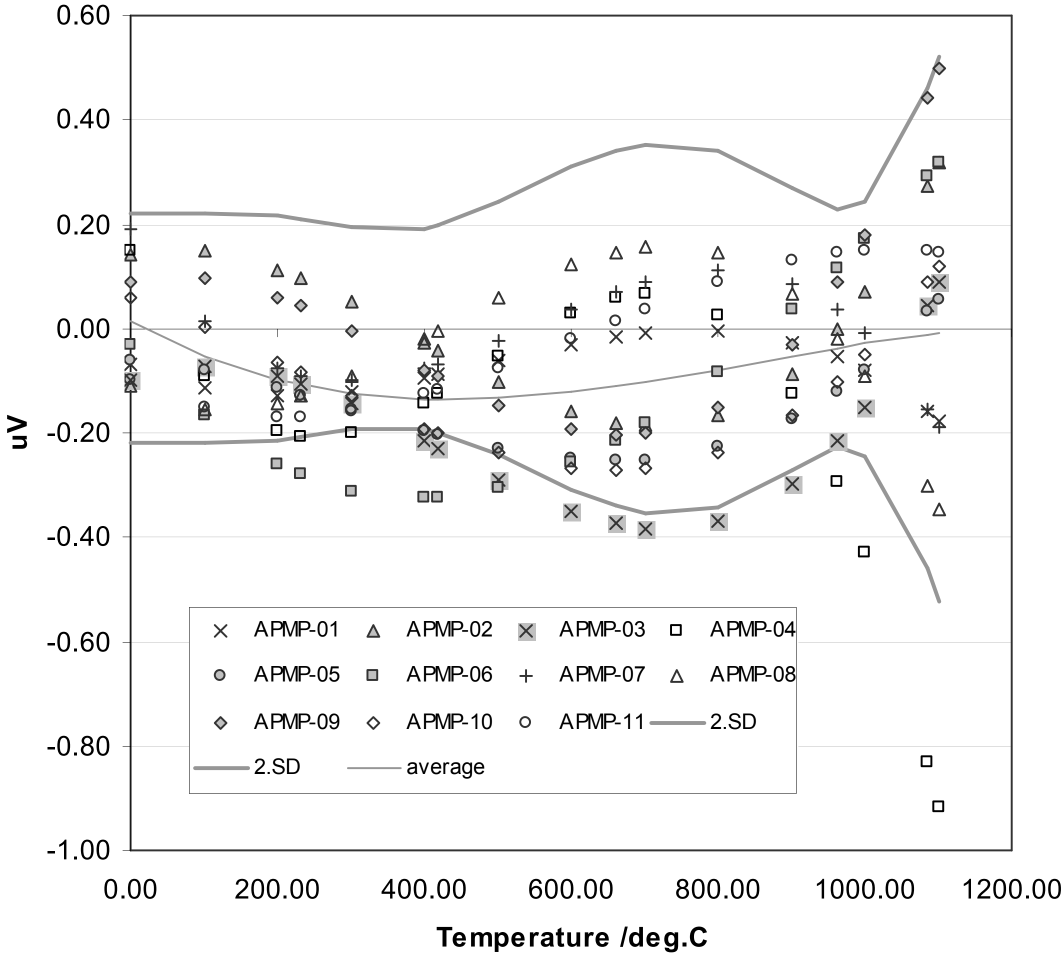


Figure 3. The difference, *drift$_i$* in final and initial calibration of 11 thermocouples plotted as a function of temperature.

All APMP thermocouples were calibrated twice by the pilot lab, initially before sending to the participating laboratories and finally after they came back. Both calibrations were done with thermocouples at the same annealing state and from lower to higher temperatures. The difference, ***drift$_i$*** between initial and final calibration is given in Table 7.

The initial and final calibrations of most of the thermocouples agree to within 0.4µV. However, for one thermocouple, APMP-04, the difference in initial and final calibration is larger above 1000°C. For this thermocouple, after the initial calibration, the insulator broke during packing and it was then replaced by another insulator of unknown origin. The replacement of the insulator may have some impact on the final Au point measurement and hence affects the results above 1000°C.

In analysis of the comparison results, we need to know the reproducibility of the pilot laboratory measurements. The calibration uncertainty analysis given by the pilot lab includes both the reproducibility of the pilot lab measurements and the systematic errors of the pilot laboratory scale. The uncertainties due to some type-B errors are correlated between measurements, so need not be included in estimation of the pilot lab reproducibility. From the submitted uncertainty analysis of the pilot lab [appendix E] the uncorrelated components (type-A, bath uniformity etc) indicate a reproducibility (k=1) of 0.073µV up to 540°C and

0.21μV at 1064°C. A more direct approach is to use the data from the 22 calibrations (figure 3) to estimate the pilot lab reproducibility and any drifts in each thermocouple. This has the advantage of not relying on the pilot lab uncertainty estimates at all in the subsequent analysis: only the actual measurement data is used.

The measured difference between the initial and final calibrations plotted in figure 3 differs from zero because of (a) drifts of the thermocouple and (b) the reproducibility of the measurements made by the pilot laboratory, and it is not directly possible to separate these two effects: the spread of values is due to both these effects. However, if we consider only those 10 thermocouples which were undamaged in the comparisons (ie. excepting APMP-04), the standard deviation of the 10 final-initial calibration values will be an overestimate of the true pilot-lab measurement reproducibility: if drifts did not contribute, the pilot lab reproducibility would be given by

$$u_{pilot.reprod} = \underset{\text{(all but APMP04)}}{STDEV} [\,drift_i\,] / \sqrt{2} \qquad \textbf{(2)}$$

The $\sqrt{2}$ term is because each value of $drift_i$ includes the effects of 2 pilot lab calibrations, so we would expect the variance of $drift_i$ to be $\sqrt{2}$ larger. When we plot a k=2 envelope for this term on Figure 3, several thermocouple's data fall outside for at least some of the temperature range. This suggests that, for some thermocouples, a statistically significant drift is present.

The approach taken here will be to take the comparison uncertainty for a given thermocouple at a given temperature to be the measured drift value given in table 7, together with the pilot lab reproducibility calculated above. This will certainty double count some of the drift, because it is already included in STDEV, used to estimate the pilot lab reproducibility. One approach to reduce this could have been to assign a value of zero to any measured drifts which were not statistically significant (for example, which fell inside the k=2 envelope in figure 3), however, the overall final uncertainties were not significantly improved by this, and the authors felt the additional assumptions and complexity did not justify this.

Table 7. The difference in μV, $drift_i$, between the initial and the final NMIA calibrations of the 11 APMP thermocouples. The standard deviation of the values (without APMP-04) is also given.

T / °C	APMP-01	APMP-02	APMP-03	APMP-04	APMP-05	APMP-06	APMP-07	APMP-08	APMP-09	APMP-10	APMP-11	SD wo. APMP04
0.00	-0.07	0.14	-0.10	0.15	-0.06	-0.03	0.19	-0.11	0.09	0.06	-0.10	0.11
100.00	-0.12	0.15	-0.07	-0.09	-0.08	-0.17	0.01	-0.15	0.10	0.00	-0.15	0.11
200.00	-0.13	0.11	-0.09	-0.20	-0.12	-0.26	-0.08	-0.14	0.06	-0.06	-0.17	0.11
231.93	-0.13	0.10	-0.11	-0.21	-0.13	-0.28	-0.09	-0.13	0.04	-0.09	-0.17	0.10
300.00	-0.12	0.05	-0.14	-0.20	-0.16	-0.31	-0.10	-0.09	0.00	-0.13	-0.16	0.10
400.00	-0.09	-0.03	-0.22	-0.14	-0.20	-0.33	-0.08	-0.02	-0.08	-0.19	-0.13	0.10
419.53	-0.09	-0.04	-0.23	-0.13	-0.20	-0.32	-0.07	0.00	-0.09	-0.20	-0.12	0.10
500.00	-0.06	-0.10	-0.29	-0.05	-0.23	-0.31	-0.02	0.06	-0.15	-0.24	-0.08	0.12
600.00	-0.03	-0.16	-0.35	0.03	-0.25	-0.26	0.04	0.12	-0.19	-0.27	-0.02	0.15
660.32	-0.02	-0.18	-0.37	0.06	-0.25	-0.21	0.07	0.15	-0.20	-0.27	0.01	0.17
700.00	-0.01	-0.19	-0.38	0.07	-0.25	-0.18	0.09	0.16	-0.20	-0.27	0.04	0.18
800.00	0.00	-0.17	-0.37	0.03	-0.23	-0.08	0.11	0.14	-0.15	-0.24	0.09	0.17
900.00	-0.03	-0.09	-0.30	-0.13	-0.17	0.04	0.08	0.07	-0.03	-0.17	0.13	0.13
961.78	-0.05	0.00	-0.22	-0.29	-0.12	0.12	0.04	-0.02	0.09	-0.10	0.14	0.11
1000.00	-0.08	0.07	-0.15	-0.43	-0.08	0.17	-0.01	-0.09	0.18	-0.05	0.15	0.12
1084.62	-0.16	0.27	0.05	-0.83	0.03	0.29	-0.16	-0.30	0.44	0.09	0.15	0.23
1100.00	-0.18	0.32	0.09	-0.92	0.06	0.32	-0.19	-0.35	0.50	0.12	0.14	0.26

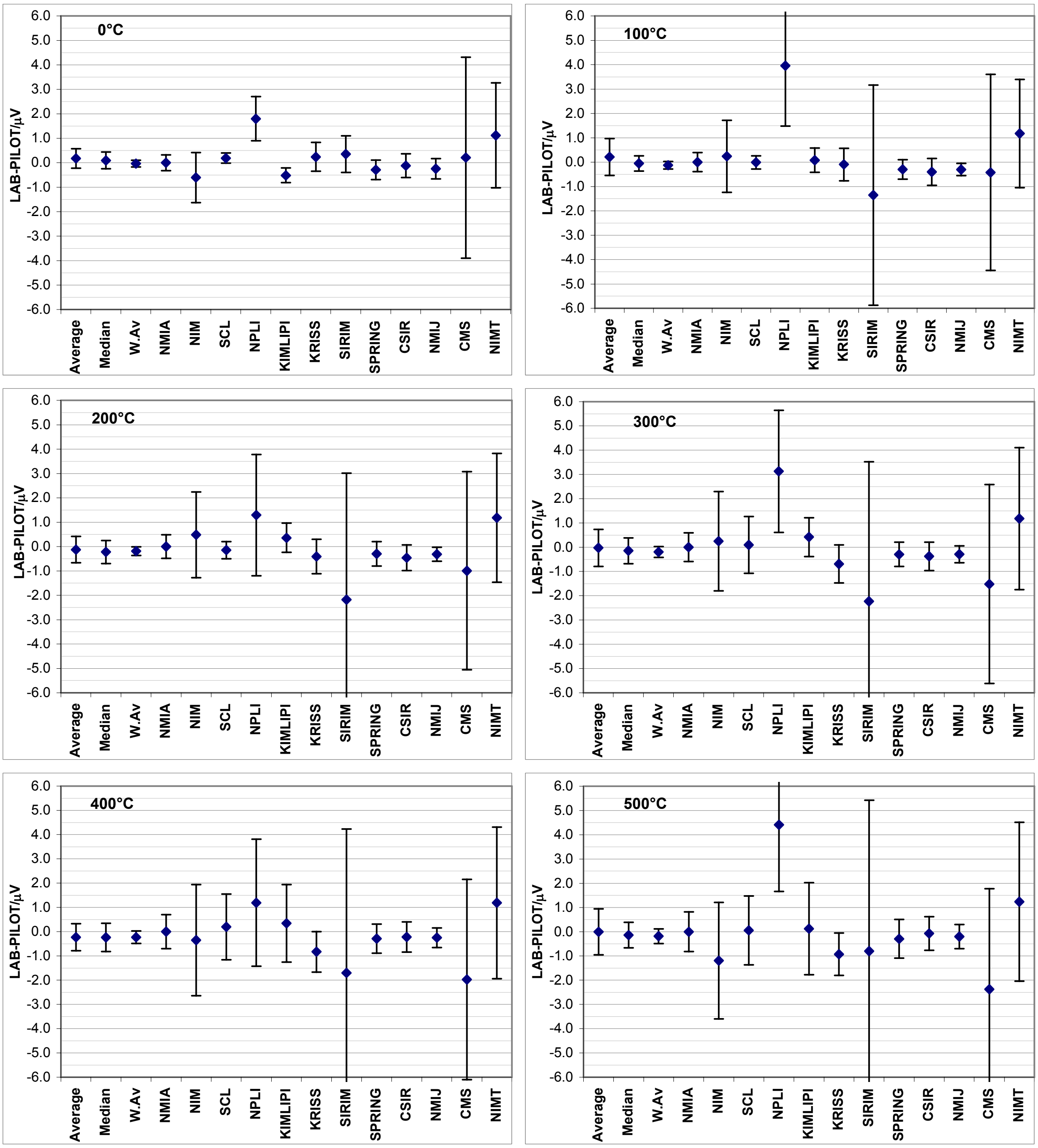
8. Comparison Data Analysis

Table 8 gives the difference $X_i = E_{lab} - E_{pilot}$ between the participants results and the pilot laboratory, and figure 4 shows the same data plotted at 100 °C intervals (including several different calculated reference values, calculated in section 9). $(E - E_{ref})_{pilot}$ is the average of the initial and final calibration values obtained by the pilot lab.

$$X_i = (E - E_{ref})_{lab} - (E - E_{ref})_{pilot} = E_{lab} - E_{pilot} \quad (3)$$

Table 8. Difference of E-E_{ref} in μV between the participating laboratories and the pilot lab(NMIA), $X_i = E_{lab} - E_{pilot}$ (E_{pilot} is the average of initial and final calibration).

	APMP-01	APMP-02	APMP-03	APMP-04	APMP-05	APMP-06	APMP-07	APMP-08	APMP-09	APMP-10	APMP-11
Temp/°C	NIM	SCL	NPLI	KIMLIPI	KRISS	SIRIM	SPRING	CSIR	NMIJ	CMS	NIMT
0.00	-0.605	0.190	1.800	-0.515	0.240	0.355	-0.290	-0.115	-0.247	0.210	1.115
100.00	0.235	-0.012	3.958	0.079	-0.096	-1.351	-0.298	-0.399	-0.304	-0.421	1.171
200.00	0.481	-0.148	1.291	0.359	-0.408	-2.181	-0.299	-0.463	-0.316	-0.992	1.182
231.93	0.299	-0.073	3.541	0.370	-0.434	-2.206	-0.298	-0.448	-0.313	-0.272	1.180
300.00	0.245	0.094	3.125	0.417	-0.690	-2.233	-0.296	-0.379	-0.294	-1.517	1.176
400.00	-0.351	0.194	1.190	0.343	-0.832	-1.705	-0.292	-0.225	-0.251	-1.975	1.185
419.53	-0.220	0.161	1.911	0.296	-0.694	-1.534	-0.292	-0.193	-0.369	0.001	1.190
500.00	-1.196	0.053	4.412	0.127	-0.928	-0.796	-0.291	-0.074	-0.201	-2.372	1.236
600.00	-2.158	0.091	5.821	-0.140	-0.969	0.196	-0.295	0.000	-0.155	-2.694	1.360
660.32	-2.946	0.041	3.699	-0.521	-1.085	0.836	-0.302	-0.025	-0.193	-4.451	1.483
700.00	-3.123	0.030	2.044	-0.567	-0.848	1.273	-0.308	-0.079	-0.126	-2.949	1.587
800.00	-3.972	0.390	1.908	-1.164	-0.656	2.035	-0.333	-0.386	-0.127	-3.143	1.945
900.00	-4.592	-0.209	2.743	-1.740	-0.386	2.186	-0.372	-0.995	-0.171	-3.243	2.464
961.78	-4.637	-0.684	2.823	-2.010	-0.192	1.952	-0.406	-1.555	0.136	-2.096	2.879
1000.00	-4.850	-0.945	4.975	-2.405	-0.030	1.825	-0.430	-1.982	-0.270	-3.035	3.175
1084.62	-4.755	-0.579	7.124	-2.965	0.561	0.914	-0.503	-3.166	-0.692	-3.042	3.956
1100.00	-4.636	-0.498	7.533	-3.068	0.620	0.755	-0.513	-3.419	-0.437	-3.037	4.105


0°C
100°C
200°C
300°C
400°C
500°C
LAB-PILOT/μV
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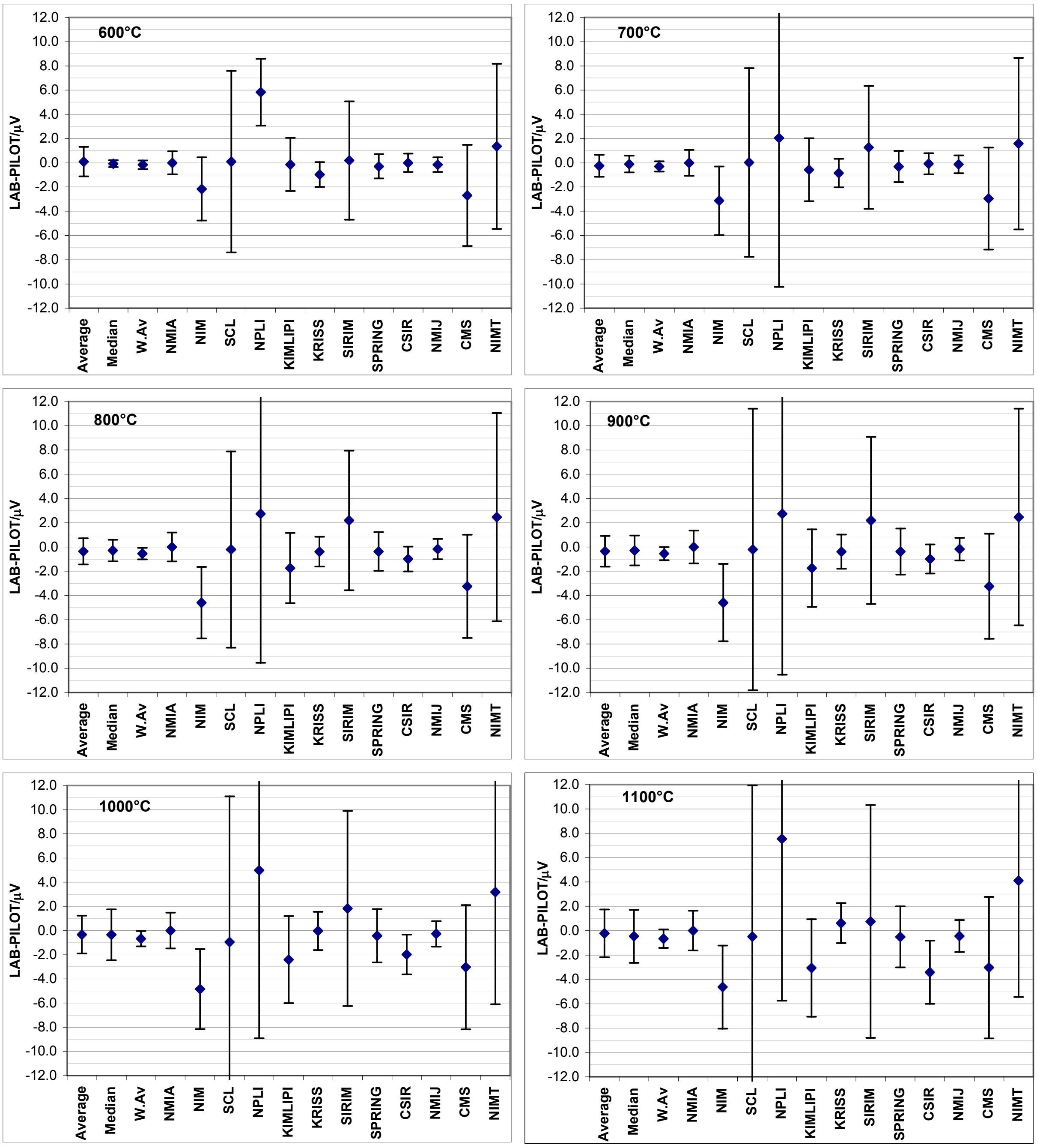
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
Average
Median
W.Av
NMIA
NIM
SCL
NPLI
KIMLIPI
KRISS
SIRIM
SPRING
CSIR
NMIJ
CMS
NIMT


600°C
700°C
800°C
900°C
1000°C
1100°C
LAB-PILOT/μV
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
Average
Median
W.Av
NMIA
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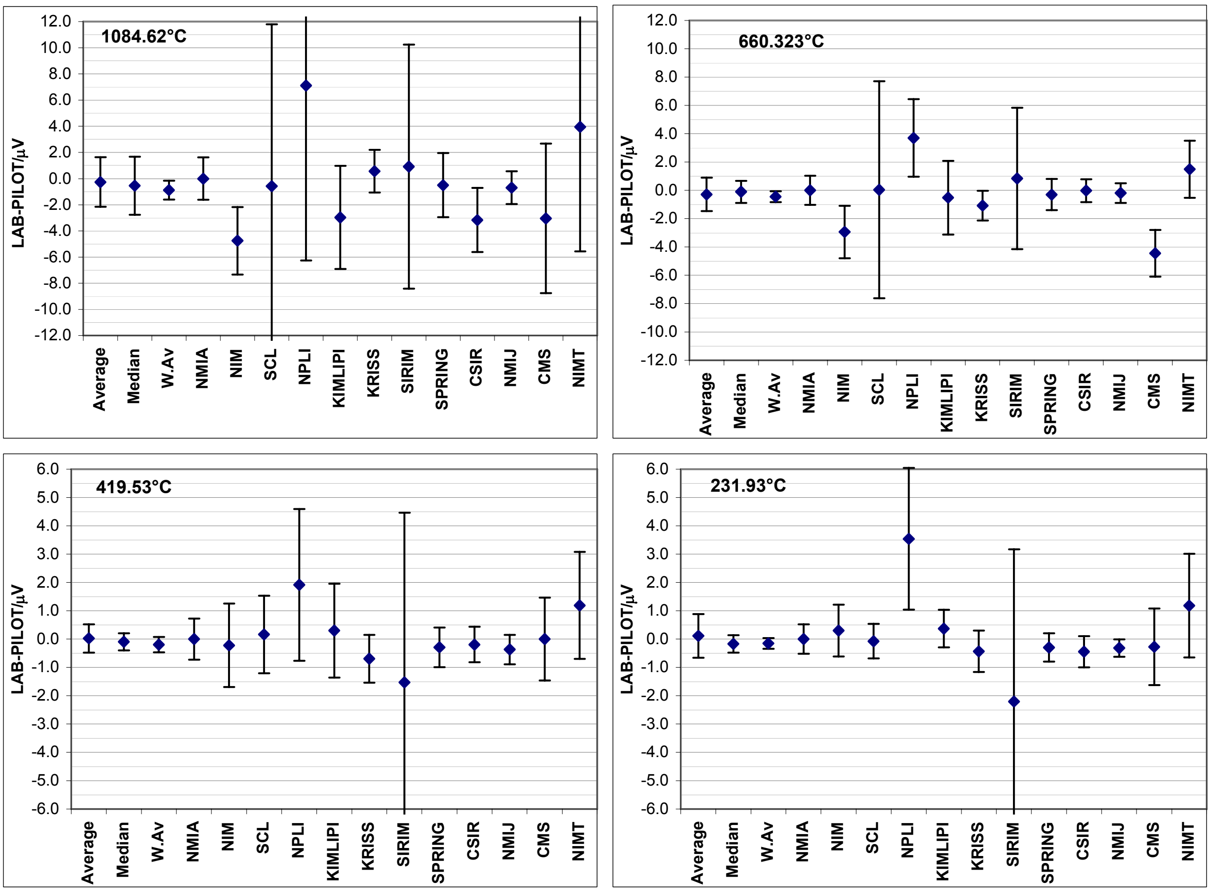

Figure 4. Difference of E-E_{ref} between the pilot laboratory and 11 participants together with the calculated values of simple mean, weighted mean and the median. The uncertainties for each lab are those reported by each participant. For NMIA, the average of its 11 reported initial uncertainties is plotted (table 2). The uncertainties of the 3 proposed reference values exclude any systematic errors (ie. offsets) in the pilot lab scale.

9. Calculation of a Comparison Reference Value

The comparison reference value has been calculated by three different methods: Simple mean, Median, and Weighted mean, as given by the 3 equations below:

i) **Simple Mean:**

$$X_{simple} = \sum X_i / n \quad (4)$$

$$u(X_{simple}) = STDEV(X_i) / \sqrt{n} \quad (5)$$

ii) **Median:** Computed using the MEDIAN function on Microsoft EXCEL. The uncertainty was calculated using equation given in reference [5]

$$X_{median} = median\{x_i\} \quad (6)$$

$$u(X_{median}) \cong \frac{1.9}{\sqrt{n-1}} median\{|X_{median} - X_i|\} \quad (7)$$

iii) **Weighted mean:**

$$X_{weighted} = \sum X_i . u(X_i)^{-2} / \sum u(X_i)^{-2} \quad (8)$$

$$u(X_{weighted})^2 = 1/\sum u(X_i)^{-2} \quad (9)$$

where, $u(X_i)^2 = u(E_{lab,i})^2 + (drift_i / 2\sqrt{3})^2 + (u_{pilot.reprod})^2$ **(10)**

In the case of the simple mean and the median, all of the (lab-pilot) values (X_i's) are given an equal weighting. That is, each lab contributes equally to the calculation of the reference value. The uncertainties given for the simple mean and median provide an estimate of combined effect of lab uncertainties, thermocouple drift and pilot lab reproducibility: for the simple mean this is the standard deviation of the set of X_i's ; for the median it is the width of the set of deviations. Note that these variance measures are statistically sound because the X_i's are fully uncorrelated: each $X_i=E_{lab}-E_{pilot}$ arises from a separate calibration of a separate thermocouple by both pilot and participant lab. Any "scale uncertainty" of the pilot lab is obviously fully correlated between all the X_i's, and so cancels out (it just makes an offset on the graphs of X_i).

For the weighted mean, the contributions from each laboratory are weighted according to the estimated uncertainty of their contribution to the mean. For the pilot, this is just their estimated calibration uncertainty. For the other participants the uncertainty due to the link to the pilot must be included (see Figure 5). (ie. a laboratory linked to the reference value by a thermocouple with a large drift should affect the weighted mean less.). The **Weight** for a given lab thus includes:

a) $u(E_{lab,i})$**:** the uncertainty of calibration estimated by the participant (given in table 5). Note that the inhomogeneity of the thermocouple is already included in the calibration uncertainty given by the participant.
b) $drift_i$: The measured difference between the final and initial pilot lab calibrations of the thermocouple used by lab ***i*** (Figure 3 and Table 7).
c) $u_{pilot.reprod}$: the reproducibility of the calibrations made by the pilot laboratory (given by equation 2).

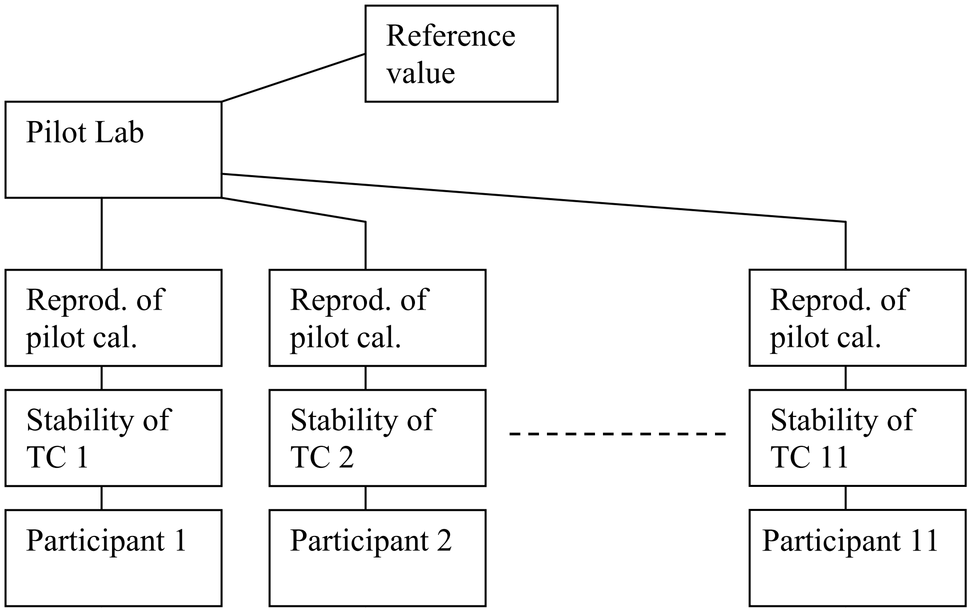

Figure 5: Linkage mechanism from the comparison.

As the pilot laboratory performed calibrations on all 11 thermocouples, it is unclear which uncertainty is most appropriate to use for the pilot-lab weighting in the calculation of the weighted mean. The purpose of the weighting is to generate a reference value which is the best estimate of the "true" calibration value, so we have chosen to use the average of the uncertainties (last column in Table 2). In practical terms, the uncertainties were very similar, so the choice is not important.

The calculated reference value by the above three methods and their associated uncertainties are given in table 9 and are plotted in figure 4. All 3 reference values are consistent with each other, however, as expected, the weighted mean offers the lowest comparison reference uncertainty, as it makes full use of the available data (ie. it includes the laboratories uncertainty estimates). As such, it is preferable to use the weighted mean as the **reference value** for this intercomparison.

However, before the weighted mean can be used, the self-consistency of the comparison data set must be checked. That is, we must check that the uncertainty estimates made by the laboratory are consistent with the measured variance of the comparison data. The Birge ratio [6], which is a measure of how well the estimated measurement uncertainties explain the measured dispersion of the actual data values, and is given by,

$$\textbf{Birge Ratio} = \sqrt{\left[\sum (X_i - X_{weighted})^2 \, u(X_i)^{-2} / (n-1) \right]} \qquad \textbf{(11)}$$

If the deviation of the data points X_i from the weighted mean is within all the uncertainties $u(X_i)$ on the data, then the Birge ratio will be less than 1, and if the deviation of the data is larger than expected from the error bars, the Birge ratio will be greater than 1. A statistical criterion for a Birge ratio for n data points is given by:

$$\text{Birge Criterion} < \sqrt{\left[1 + \sqrt{8} / (n-1)\right]} \qquad \textbf{(12)}$$

which is 1.38 for 11 laboratories.

In this comparison, when the Birge ratio was calculated, it was less than or equal to 1 at all temperature points (Table 9), (except at 660.32°C, but still 1.08 < 1.38) suggest that the results are consistent. As the Birge criterion is satisfied, it is justifiable to use the **weighted mean as the reference value** for the comparison.

Table 9. Calculated reference values and their associated uncertainties (k=2), and calculated Birge Ratio.

Temperature/°C	Simple Mean		Median		Weighted Mean		Birge Ratio
	x_{ref}	U	x_{ref}	U	x_{ref}	U	
0.00	0.178	0.395	0.095	0.345	-0.034	0.139	0.91
100.00	0.213	0.757	-0.054	0.309	-0.125	0.154	0.65
200.00	-0.124	0.538	-0.223	0.471	-0.185	0.177	0.49
231.93	0.112	0.769	-0.173	0.308	-0.155	0.191	0.67
300.00	-0.029	0.768	-0.147	0.535	-0.197	0.219	0.59
400.00	-0.227	0.555	-0.238	0.580	-0.230	0.255	0.40
419.53	0.022	0.502	-0.096	0.304	-0.195	0.274	0.44
500.00	-0.002	0.949	-0.137	0.528	-0.186	0.302	0.65
600.00	0.088	1.214	-0.070	0.282	-0.161	0.366	0.80
660.32	-0.289	1.176	-0.109	0.777	-0.452	0.377	1.08
700.00	-0.256	0.907	-0.103	0.693	-0.297	0.432	0.45
800.00	-0.292	1.079	-0.230	0.890	-0.403	0.485	0.50
900.00	-0.360	1.265	-0.291	1.234	-0.546	0.542	0.54
961.78	-0.316	1.254	-0.299	1.700	-0.724	0.555	0.78
1000.00	-0.331	1.561	-0.350	2.112	-0.677	0.630	0.60
1084.62	-0.262	1.895	-0.541	2.222	-0.877	0.723	0.72
1100.00	-0.216	1.958	-0.468	2.172	-0.660	0.755	0.66

10. Deviation from the Reference Value

The degree of equivalence D_i of the participating lab with respect to the comparison reference value and its uncertainty u_{Di} are calculated from the following equations :

$$D_i = X_i - X_{weighted} \qquad (13)$$

$$(\text{ Noting that } X_i = E_{lab} - E_{pilot})$$

The uncertainty in the difference between each participant and the reference value includes the following:

a) $u(E_{lab,i})$ the uncertainty of the participant: Given by participant (Table 5)
b) $u(X_{weighted})$ the uncertainty of the reference value with respect to the pilot laboratory: calculated in section 9, and given in Table 9.
c) $u_{pilot.reprod}$ the reproducibility of the pilot laboratory calibration: Calculated using equation 2.
d) $drift_i$ the drift of the thermocouple used by the participant between initial and final calibrations by the pilot: given ***for each thermocouple*** in table 7 .

and is given by the equation:

$$u_{Di}^2 = u(E_{lab,i})^2 + u(X_{weighted})^2 + u_{pilot.reprod}^2 + (drift_i / 2\sqrt{3})^2 \qquad (14)$$

Note1: Participants (other than the pilot) are linked to the reference value by a thermocouple calibrated by the pilot and then by the participant, so any thermocouple drift and the reproducibility of the pilot lab's calibration must be included (see Figure 5).

Note 2: For the pilot laboratory, the last 2 terms are omitted, since the reference value is *calculated* from the 11 measured differences to the pilot laboratory scale. No physical artefact links the reference value to the pilot lab as with the other participants. The effects of drifts in the 11 thermocouples and the pilot lab reproducibility of their calibration are included in the calculation of the uncertainty of the weighted mean $u(X_{weighted})$ with respect to the pilot lab scale.

Note 3: The terms for the pilot lab reproducibility and thermocouple drift contribute in 2 places, first in their contribution to the uncertainty of the (pilot-reference) value, and secondly in determining the (participant-pilot) difference. This is NOT double counting, because in the weighted average, this term is significantly diluted because we use the average of the 11 values, whereas for a particular lab we need the full uncertainty of the difference.

It is important to note that the overall uncertainty in the deviation from the reference value is dominated by the calibration uncertainty of the laboratory, and that the contribution from the "comparison" itself (the other 3 terms) is relatively minor for all but the laboratories with very low uncertainties such as NMIJ, KRISS and NMIA.

The calculated values of degree of equivalence D_i and the expanded (k=2) uncertainty $U_{Di} = 2\,u_{Di}$, for each participants are given in Table 10. The shaded values represent the labs for which the deviation from the reference value is larger than its expanded (k=2) uncertainty (i.e. $|D_i| / U_{Di} = En > 1$). The degree of equivalence D_i for each participating labs are plotted in figure 6, as a function of temperature.

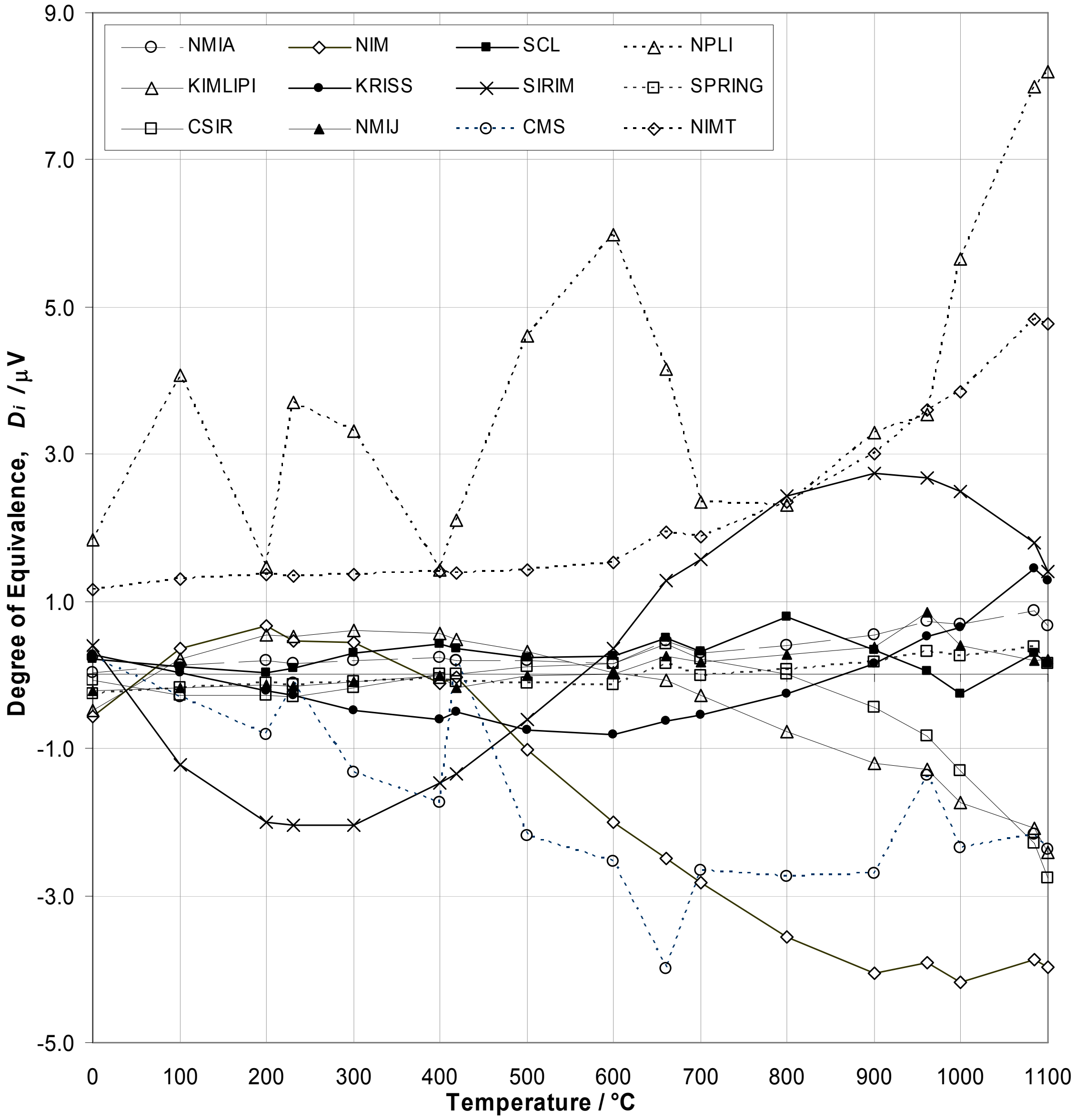

Figure 6. The Degree of Equivalence D_i, for each participant is plotted as a function of temperature.

Table 10. The values of Degree of Equivalence and its uncertainty in μV.

T/ °C	NMIA	NIM	SCL	NPLI	KIMLIPI	KRISS	SIRIM	SPRING	CSIR	NMIJ	CMS	NIMT
0	0.03 0.35	-0.57 1.04	0.22 0.31	1.83 0.93	-0.48 0.38	0.27 0.63	0.39 0.78	-0.26 0.46	-0.08 0.53	-0.21 0.47	0.24 4.11	1.15 2.15
100	0.12 0.42	0.36 1.50	0.11 0.36	4.08 2.49	0.20 0.55	0.03 0.70	-1.23 4.52	-0.17 0.46	-0.27 0.60	-0.18 0.34	-0.30 4.03	1.30 2.23
200	0.19 0.52	0.67 1.78	0.04 0.43	1.48 2.50	0.54 0.65	-0.22 0.75	-2.00 5.20	-0.11 0.55	-0.28 0.58	-0.13 0.37	-0.81 4.07	1.37 2.65
231.93	0.16 0.55	0.45 0.95	0.08 0.66	3.70 2.51	0.52 0.72	-0.28 0.77	-2.05 5.38	-0.14 0.56	-0.29 0.60	-0.16 0.39	-0.12 1.38	1.34 1.85
300	0.20 0.63	0.44 2.07	0.29 1.20	3.32 2.53	0.61 0.85	-0.49 0.83	-2.04 5.77	-0.10 0.57	-0.18 0.64	-0.10 0.43	-1.32 4.11	1.37 2.94
400	0.23 0.75	-0.12 2.31	0.42 1.39	1.42 2.64	0.57 1.63	-0.60 0.89	-1.48 5.95	-0.06 0.67	0.00 0.69	-0.02 0.50	-1.75 4.14	1.41 3.14
419.527	0.19 0.77	-0.02 1.51	0.36 1.40	2.11 2.70	0.49 1.69	-0.50 0.90	-1.34 6.01	-0.10 0.77	0.00 0.70	-0.17 0.60	0.20 1.50	1.39 1.91
500	0.19 0.87	-1.01 2.43	0.24 1.46	4.60 2.78	0.31 1.93	-0.74 0.95	-0.61 6.24	-0.10 0.87	0.11 0.77	-0.01 0.61	-2.19 4.17	1.42 3.29
600	0.16 1.01	-2.00 2.65	0.25 7.51	5.98 2.79	0.02 2.24	-0.81 1.12	0.36 4.90	-0.13 1.09	0.16 0.88	0.01 0.75	-2.53 4.20	1.52 6.83
660.323	0.45 1.09	-2.49 1.91	0.49 7.68	4.15 2.79	-0.07 2.64	-0.63 1.15	1.29 5.02	0.15 1.19	0.43 0.93	0.26 0.83	-4.00 1.72	1.93 2.07
700	0.30 1.15	-2.83 2.87	0.33 7.80	2.34 12.30	-0.27 2.65	-0.55 1.29	1.57 5.10	-0.01 1.39	0.22 1.01	0.17 0.89	-2.65 4.24	1.88 7.10
800	0.40 1.30	-3.57 2.99	0.79 8.11	2.31 12.30	-0.76 2.95	-0.25 1.35	2.44 5.79	0.07 1.69	0.02 1.17	0.28 1.00	-2.74 4.29	2.35 8.60
900	0.55 1.45	-4.05 3.24	0.34 11.63	3.29 13.28	-1.19 3.25	0.16 1.52	2.73 6.91	0.17 1.99	-0.45 1.33	0.37 1.09	-2.70 4.38	3.01 8.95
961.78	0.72 1.53	-3.91 2.29	0.04 11.90	3.55 13.59	-1.29 3.41	0.53 1.55	2.68 7.65	0.32 2.08	-0.83 1.43	0.86 1.23	-1.37 2.14	3.60 3.96
1000	0.68 1.61	-4.17 3.38	-0.27 12.07	5.65 13.90	-1.73 3.67	0.65 1.72	2.50 8.11	0.25 2.29	-1.30 1.78	0.41 1.25	-2.36 5.18	3.85 9.30
1084.62	0.88 1.77	-3.88 2.70	0.30 12.40	8.00 13.40	-2.09 4.05	1.44 1.81	1.79 9.37	0.37 2.58	-2.29 2.58	0.18 1.51	-2.17 5.77	4.83 9.55
1100	0.66 1.80	-3.98 3.52	0.16 12.46	8.19 13.32	-2.41 4.12	1.28 1.84	1.41 9.60	0.15 2.64	-2.76 2.73	0.22 1.59	-2.38 5.88	4.76 9.60

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APPENDIX A : APMP Type R Thermocouple Intercomparison Protocol

1. INTRODUCTION

This APMP regional comparison of the calibration of rare metal (Pt-Pt13%Rh) thermocouples from 0 to 1100°C is coordinated by the National Measurement Institute of Australia and is partially funded by APEC (Asia Pacific Economical Committee).

The Pt/PtRh thermocouple is a precision sensor used to measure temperatures as high as 1100°C and is widely used in many industries. In general, a thermocouple calibration consists of measuring the thermocouple emf, E, at several values of tip temperature and comparing the emf with the corresponding value, E_{ref},. The calibration is represented as a smooth curve fitted to the measured values of the deviation $E - E_{ref}$ and generally given as a function of temperature, T. Different laboratories have adopted different methods for calibration of thermocouples. Thermocouples can be calibrated by using metal fixed points (Ga, Sn, Al, Ag) or a comparison method using a calibrated standard sensor (SPRT or Type S or R thermocouple) and a variable temperature enclosure, or a combination of both.

The objective of this comparison is to assess the equivalence of the calibration results obtained by the various procedures and methods of calibration of rare metal thermocouple up to 1100°C among the participating laboratories.

Twelve laboratories of the Asia Pacific region will take part in this comparison. The name of the laboratory and the calibration schedule are given in **Appendix A**. To make the intercomparison process quicker, it has been decided to do a star type comparison. The pilot laboratory, NMIA (Australia) will construct 11 type R thermocouples. After checking the inhomogeneity of the thermocouples, they will be calibrated according to NMIA test method. The 11 thermocouples will then be sent to the 11 other participant participating laboratories, (one to each laboratory). Each laboratory will calibrate the thermocouple from 0 to 1100°C, using their own test method. The calibration results will then be sent to the pilot laboratory in the format given in the **Appendix C**. After calibration the thermocouple should be send back to NMIA. The pilot laboratory will measure the inhomogeneity of the thermocouple again and calibrate them. The results of the calibration from different laboratories will be analysed and compared by NMIA, and NMIA will then prepare a report on the intercomparison.

Please note: this project is partially externally funded by APEC, and they have applied a time constraint for the completion of this project and preparation of a report. Accordingly, the participant laboratories must accept the constraint that their data ***may not be included*** in the final comparison report ***if it arrives later than the specified cutoff*** date.

2. DESCRIPTION OF THE THERMOCOUPLES

2.1 Construction of the Thermocouples:

- The Platinum and Platinum-13% Rhodium wires (Reference Grade) were obtained from Sigmund Cohn Corp.(USA).
- The thermocouples were constructed from the same spool of wire.

- The wires (1400 mm long) were cut from the spool and cleaned by wiping with acetone and ethanol to remove any grease.
- Bare wire annealed at 1400°C for 1 hour and at 1100°C for 1 hour by passing electric current, and then quenched.
- Installed into a twin bore insulator of 750 mm long, OD = 4.1 mm and the tip of the thermocouple was welded. The insulator was pre baked at 1100°C for 6 hours.
- The thermocouple wires emerging from the alumina tube were insulated with PVC sleeves.
- The thermocouples in alumina insulators, were then annealed at 1100°C for 30 minutes to remove any cold work effect during installation and quenched.
- Annealed at 450°C for 16 hours.

3) CALIBRATION PROCEDURE USED BY THE PILOT LAB:

- Thermocouples will be calibrated by intercomparison method against a standard platinum resistance thermometer up to 550°C using a salt bath. Then calibrate at Ag and Au (minicoil method) fixed points. Use 3rd order polynomial to calculate the deviation from the reference function from 0 to 1100°C.
- Inhomogeneity of the thermocouples will be measured at 240°C in a oil bath. The bath temperature is stable to 5 mK. The thermocouple will be scan from 100 mm to 650 mm. The inhomogeniety value up to **600 mm** of the thermocouple will be considered in the calculation of uncertainty in this intercomparison.
- At NMI, Australia, the inhomogeneity of a thermocouple is defined as the difference between the maximum and minimum emf of the thermocouple over the calibration length, divide by 4, to get standard uncertainty, ui.
- The measured inhomogeneity value will be expressed as a percentage of TC emf, e.g**. ± 0.024% of E**. The percentage of emf at a particular temperature (for example, at 500°C, for a type R thermocouple, 0.024% of E = 1.073μV) is an expanded uncertainty [Ui] with k = 2.

4) MEASUREMENT SEQUENCE IN THE COMPARISON:

- Calibration of 11 thermocouples by the pilot laboratory, NMIA
- Measurement of the inhomogeneity of 11 thermocouples at 240°C by the pilot laboratory, NMIA
- **April 2005:** Send thermocouples to the participating laboratories with the inhomogeneity values
- **May 2005:** Calibration of the thermocouples by the participating laboratories
- **June 2005:** Thermocouples returned to the pilot laboratory, NMIA
- Measurement of the inhomogeneity of 11 thermocouples at 240°C
- Calibration of the thermocouples again by the pilot laboratory.
- **August 2005:** Completion of the data analysis and preparation of the intercomparison report.

5) INSTRUCTIONS TO THE PARTICIPATING LABORATORY:

- Each participating laboratory will receive one thermocouple, which is in ‘‘450°C annealed state”, that is, annealed at 450 °C for 16 hour.
- Upon receiving the thermocouple, the participating laboratory must inspect the thermocouple for any damage and report to NMIA, if any damage is detected. NMIA will give instructions how to proceed.
- A pair of Cu- wires should be connected to the CJ ends (open end) of the thermocouple.
- Calibrate the thermocouple from 0 to 1100°C using the existing technique as practiced by the participate laboratory.
- The calibration sequence should be from **lower to higher** temperatures.
- The immersion depth of the thermocouple in the calibration enclosure should be **600 mm or less** from the tip.
- During calibration CJ ends of the thermocouple should be immersed in to an ice point at least up to an immersion of **150 mm**.
- A calibrated DVM should be used to measure thermocouple EMF.
- After completion of the calibration, the participant laboratory should transfer the data and the thermocouple to NMIA.

Note: The participating laboratory **should not dismantle** the thermocouple and the thermocouple **should not be subject to any further annealing before or after the calibration**.

6) REPORTING DATA TO NMIA:

The participating laboratory must send to NMIA the following information **within 6 weeks** of receiving the thermocouple:

1. A general outline of the calibration procedure consisting of no more than one page and send this as an electronic file named **'procedure.doc'**.
2. Details of instrumentation used in the comparison calibration as an attached Excel spreadsheet named '**Instrument.xls' as in Appendix B.**
3. The values of calibration results as an Excel spreadsheet named **'Calibrationdata.xls'.** This should be in the format given in **Appendix C.**
4. The uncertainty analysis according to the 'ISO Guide to the expression of Uncertainty in Measurement' in terms of microvolt. Please send an electronic file named **'Uncertainty.xls'**. The terms in the **Appendix D** should be used as a guide.

Note: Use the inhomogeneity value of the test thermocouple as given by the NMIA with the thermocouple.

7) TRANSPORTATION OF THERMOCOUPLES:

- The pilot laboratory, NMIA will send a thermocouple in its wooden box to each participating laboratory.
- It is the responsibility of each participant laboratory to arrange transport of the thermocouple after calibration, back to the pilot laboratory.
- It is the responsibility of each laboratory to obtain insurance for the artifacts for transport.
- The instrument should be accompanied by an ATA carnet or customs declaration document and Received/Dispatched form as given in **Appendix E.**

Appendix A: List of Participating Laboratories

Name of Laboratory	**Contact Person**	**Address**
NMIA – Australia	Ferdouse Jahan ferdouse.jahan@measurement.gov.au	
NIM – China	Zheng wei zhengw@nim.ac.cn	
SCL – HongKong	CM Tsui cmtsui@itc.gov.hk	
NPLI – India	Y. P. singh ypsingh@nplindia.ernet.in	
KIMLIPI – Indonesia	Ghufron Zaid Gzaid01@yahoo.com	
NMIJ – Japan	Arai Masaru Masaru-arai@aist.go.jp	
KRISS – Korea	Kim Yong-Gyoo dragon@kriss.re.kr	
SIRIM – Malaysia	Zailani Mahamood Zailani_mahamood@sirim.my	
SPRING – Singapore	Wang Li wangli@spring.gov.sg	
CSIR – South Africa	Hans Liedberg HLiedber@csir.co.za	
CMS – Taiwan	Jiunner/Bor-Jiunn wen jiunner@itri.org.tw	
NIMT – Thailand	Uthai Norranim uthai@nimt.or.th	

Appendix B: Measuring equipments and standards used in the comparison.

Laboratory Name: ______________________________

Devices	Type	Manufacturer	Serial number	Description	Immersion (mm)
Standard used for reference temperature					
AC bridge/DVM for SPRT measurements					
Ice-Point used					
DVM for Test TC					
Scanner (if used)					
Enclosure used					
Fixed Points used					

*** Note: Please write about the traceability of the standard used —**

Appendix C: Calibration Data of the Thermocouple
Serial Number ______________ Inhomogeneity ___________________

Name of the Laboratory:____

Temperature/°C	E_{ref}/ µV	E/ µV	E - E_{ref} / µV	Uncertainty/°C
0.0				
100.0				
200.0				
231.928 (Sn)				
300.0				
400.0				
419.527 (Zn)				
500.0				
600.0				
660.323 (Al)				
700.0				
800.0				
900.0				
961.78 (Ag)				
1000.0				
1100.0				

Appendix D : Uncertainty Analysis

The participating laboratory should send the calculated uncertainty of measurement to the pilot laboratory, NMIA, as an Excel spreadsheet named **'Uncertainty.xls'.** To calculate the uncertainty of calibration, the participants should follow the guideline set out in the 'ISO Guide to the Expression of Uncertainty in Measurement'. The various uncertainty components are given below as a guide:

NOTE: In your uncertainty analysis, please state HOW the number you have given is obtained. For example, "DVM calibration uncertainty: obtained from certificate from XXX", or "TIP temperature difference: estimated by the shift in correction when the TC was withdrawn by 30mm" etc.

Reference temperature measurements:

1) Calibration of the standard (Thermocouple or SPRT) –This is the calibration uncertainty of the standard used (from its calibration report).
2) Interpolation error (if not already included in the report) – Usually calibration is done at several points and a polynomial fit through the calibration points is used. The maximum deviation from the fitting curve should be included in the uncertainty.
3) Inhomogeneity if a thermocouple is used as standard (if this term in not already implicitly included in the report).
4) Drift/use of standard – The standard, especially if it is a thermocouple, may have drifted since its last calibration. This, which will depend on the time and temperature of use. A component should be used to estimate the error associated with this drift.
5) Type A error of mean reading of standard – This type A uncertainty is the random variation of n readings of the EMF of the standard thermocouple [thermocouple not removed from the enclosure during measurements], or (resistance, if a SPRT is used), with a standard deviation of mean.
6) Calibration of DVM or Bridge – This is the calibration uncertainty of the DVM from its calibration report.
7) Ice point error of standard (in case of standard thermocouple) – The cold junction ends of the standard thermocouple is immersed in an ice pot. Depending on the immersion length, there could be some conduction error along the attached Cu-wires, some cold work may have affected the CJ ends of the thermocouple. Another uncertainty related to the icepoint error is the realization of Icepoint.

Test Thermocouple measurements:

8) Inhomogeneity of test thermocouple ***(which is given by the NMIA)*** – The variation of Seebeck coefficient along the thermocouple length of 600mm from the tip is measured by NMIA and the value is given with the thermocouple to each participating laboratory, which is a percentage of emf (e.g. ± 0.024% of E).
9) Type A error of the mean reading – This is the same component for the test thermocouple as the component (5) for the standard.
10) Ice point error of the test thermocouple – This is the same component for the test thermocouple as the component (7) for the standard thermocouple.
11) Calibration of DVM used – this component can be omitted if same DVM is used in same range as in standard thermocouple.

12) Drift of DVM since calibration – The DVM may not be calibrated just before the measurement. In that case, any drift after calibration should be included in the uncertainty.

Other Errors:

13) Tip temperature difference – The tip temperature of the test thermocouple and the standard could be different. The magnitude of this will depend on the uniformity of the enclosure or furnace used.
14) Fitting and interpolation error – Usually calibration is done at several points and a polynomial is fitted through the points. The largest deviation of data points from the fitting curve should be use as one component of uncertainty.
15) AC pickup – The measuring DVM could be affected by the ac pickup from the enclosure, which should be accounted for.
16) Rounding for the report – The reported correction of the test thermocouple in the report may be rounded, resulting in an error.

Appendix E: i) Customs Declaration

TO WHOME IT MAY CONCERN

APMP Regional Comparison

The Asia Pacific Metrology Program (APMP) is an organisation representing the National Measurement/ Standards Laboratories of a large number of countries/territories in the Asia-Pacific region. Its broad objective is to improve the measurement capabilities in the Asia-Pacific region by sharing facilities and experience in metrology.

One very successful method used by the APMP is the comparison of calibrations performed by different laboratories on a given artefact. Successful completion of these intercomparisons adds confidence to the laboratories in the carrying out of standards measurements and leads to international acceptance of the measurements carried out by these laboratories.

As part of a major intercomparison program, the APMP is conducting an intercomparison on the calibration of type R thermocouple from 0 to 1100°C involving the participants given in the Laboratory Schedule (Table 1).
This program is coordinated by,
National Measurement Institute of Australia
Lindfield, NSW 2070
Australia

The following artefact is circulated among the participants for calibration:

A type R Thermocouple, Serial number:

The purchase/manufacturing cost of the artifact was AUS$1500. However it has no commercial value (it is not for sale). It is meant solely for the calibration of national standards and will be re-exported immediately after the calibration is complete (see enclosed Schedule).

We request that the device is not handled or removed from the container/package. If a Customs inspection is required then please contact the relevant person listed in the attached schedule so that he/she can be present and help you unpack it.

Comparison Co-coordinator
Dr. Ferdouse Jahan
NMI, Australia

Appendix E: ii) Received/Dispatched Form

B) ARTEFACT RECEIVED

To:…*(sender / coordinator)*….

APMP Regional Key Comparison 3

The …*(artifact)*…. and its ATA Carnet was received at ……..*(name of laboratory)*…. on …*(date)*..

The condition when it was received was *in good physical and working order

*damaged – *(explain)*

____
(Name of participant)

C) ARTEFACT SHIPPED

To: *(recipient / coordinator)*

APMP Regional Key Comparison 3

The …*(artifact)*…. and its ATA Carnet was hand delivered to….……*(name of person)*..… at …*(name of laboratory)*..….. on …….*(date)*……

____
(Name of Participant)

APPENDIX B : Calibration procedure

Name of Laboratory: NIM - CHINA

Heat Division Thermocouple Lab of National Institute of Metrology participates in the APMP Regional Comparison of Type R (Pt13%Rh -Pt) Thermocouples in 2005.

The thermocouple of type R utilized for the comparison was received from the pilot laboratory NMIA in July 2005 at first. After unpacking the wooden box, we found that the twin-bore alumina insulation tube of thermocouple was broken into two pieces. We claimed immediately to the pilot laboratory for the damage, and sent back the damaged thermocouple to the pilot laboratory in accordance with their requirement. On Aug. 10, 2005, the renewed thermocouple labeled as APMP-01 arrived at NIM. The visual inspection indicated there is no damage for the renewed thermocouple. The comparison calibration was implemented then. After completing the comparison measurement, the thermocouple was sent back through DHL Parcel appointed by pilot laboratory on Sep.16, 2005.

According to the protocol of comparison, the fixed point method was selected to calibrate the thermocouple. Six fixed points were used in the comparison calibration, which were the triple point of water (TPW), Sn Freezing Point, Zn Freezing Point, Al Freezing Point, Ag Freezing Point and Cu Freezing Point. The measurement were implemented in the sequence from low temperature to high temperature with eight temperature plateaus realized in two days for each fixed point (TPW and Sn Freezing Point with four temperature plateaus realized in two days). The final result came from averaging the data of each measurement. Before the measurement, the temperature uniformity of fixed point furnace was examined and the DVM was calibrated.

The calibration data of $E-E_{ref}$ of the thermocouple from 0 to 1100°C with the interval of one hundred degree cesius were calculated with a cubic polynomial fitting function which is fitted deviation between measuring datum and reference table of Type R in fixed point. The value of fixed point by measurement is also given. The E of the thermocouple is E_{ref} corrected by $E-E_{ref}$ in each temperature separately .The measurement uncertainty in fixed point was estimated by GUM of ISO. The measurement uncertainty on the other temperature was presented with considering the uncertainty spread function from the fixed points.

Equipments used in the comparison□

Fixed points : TPW□Sn FP□Zn FP□Al FP□Ag FP□Cu FP traced to NIM ;
DVM: KEITHLEY 182 traced to NIM;
Ice- Point: Ice pot filled with trash ice and distilled water;
Scanner: Mechanical brass brush.

Name of Laboratory: SCL – HongKong

1 At test temperatures at or above 600 °C, the test thermocouple was calibrated in a sodium heat pipe furnace. The temperatures of the furnace were measured by two reference type R thermocouples. The open-circuit emfs of these two type R thermocouples as well as the test thermocouple were measured by a digital voltmeter via a scanner.

2 At test temperatures from 100 °C to 500 °C, the test thermocouple was calibrated in stirred liquid baths. The temperatures of the baths were measured by a standard

platinum resistance thermometer (SPRT) connected to an AC resistance bridge. The open-circuit emf of the test thermocouple was measured by a digital voltmeter.

3. At the test temperature 0.01 °C, the test thermocouple was calibrated in a triple-point-of-water cell.
4. In all the measurements, the cold junctions of the test thermocouple were maintained at 0 °C by immersing in an ice cell.
5. The calibration sequence was from lower to higher temperatures.
6. For measurements at or above 600 °C, the test thermocouple was immersed at a depth of 450 mm. For measurements from 100 °C to 500 °C, the test thermocouple was immersed at a depth of 420 mm. For measurement at 0.01 °C, the test thermocouple was immersed at a depth of 300 mm in the triple-point-of-water cell.

Name of Laboratory: NPLI – INDIA

1. The thermocouple Type-R received under APMP from NMI Australia on 15.07.2005 has been checked for any physical damage to the instrument. The thermocouple was found to be intact and OK. The CJ ends were connected to copper leads of same dimensions to form reference junction. The Ref. Junctions were then inserted in thin glass tube of length 250mm. The junction was prepared to place in the ice point during measurements.
2. In this comparison we have taken a three zone heating controlled furnace Isotech Model 465 having a range of 100 to 1200°C.
3. An alumina ceramic block having four equal length (500mm) and dia. Holes in it was placed in the tubular heating chamber of the furnace.
4. The hot junction end of thermocouple was inserted in one of the holes of the ceramic block.
5. In the other hole, the Standard Type-R thermocouple, or the Standard PRT of our laboratory, are inserted for temperature measurement.
6. The thermocouple has been calibrated in the range 0-600°C against SPRT and from 700°-1100°C against Standard Type-R thermocouple.
7. The immersion depth of the thermocouples in the furnace is 500mm from the tip.
8. The CJ of the thermocouples was immersed in the ice point cell.
9. The ice point cell is a doubled wall Dewar flask containing a mixture of pure ice-water slush. The ice point was prepared using crushed ice of high purity formed in an automatic ice-forming machine.
10. The standard thermocouple as well as the APMP-03 thermocouple was connected to precision digital voltmeter having resolution of 0.1μV, Keithley Model 196 for measurement of thermo-emf.
11. The details of instruments used in the comparison calibration are shown in **Appendix-B** as an attached spreadsheet named **'Instrument.xls'**
12. The furnace is now set to heat at a required temperature point starting from100°C and stabilized to confirm equilibrium at this temperature.
13. At the equilibrium condition, the readings of thermo-emf for standard as well as for APMP-03 thermocouple are observed and recorded.
14. The procedure is repeated for each temperature at every 100C interval in the range 100°-1100°C.

15. The mean reading of 10 stable measurements (E) at each temperature point is evaluated for both the standard and test thermocouple. The difference (E_{ref}-E) is evaluated, taking E_{ref} from standard tables for Type-R thermocouple.
16. The measurement results are described in an Excel spreadsheet named **'Calibrationdata.xls'** as per format given in **Appendix C.**
17. A 10-degree polynomial curve fitting was made for best fit. The uncertainty due to curve fitting has been evaluated and included in the results.
18. The uncertainty analysis according to the 'ISO Guide to the expression of uncertainty in Measurement' in terms of micro volt/deg. C is given at **Appendix- D** with file named **'Uncertainty.xls'** at different temperature points.

Name of Laboratory : KIMLIPI – INDONESIA

The artefact was calibrated against standard thermometers at the requested range (0 - 1100 ^{o}C).
Up to 400 ^{o}C, an SPRT was used as the standard thermometer. The SPRT has been calibrated previously with the ITS-90 fixed points (triple point of water, Sn, and Zn).
Above 400 ^{o}C, the thermocouple was calibrated against a type S thermocouple previously calibrated by NMI Australia.
A Keithley nanovoltmeter was used to read the output of both the artefact and the standard thermocouple. Whilst, the output of the SPRT was read using a Hart Scientific's SPRT electronic indicator.
An ice dewar flask was used to stabilise the reference junction of the artefact and the standard thermocouple at 0 ^{o}C. An immersion of 150 mm was applied. Copper wires were used to connect the reference junctions to the voltmeter through a selector switch.
For calibration at 0 ^{o}C, another ice dewar flask was used as the temperature enclosure. Both the standard and the artefact were immersed about 400mm into the ice bath. The output of the two were recorded when they have been stabilised, as indicated by their indicator.
The standard and the artefact were then pulled out of the ice, dried and inserted 400mm into the 9114 furnace for calibration at 100 ^{o}C - 400 ^{o}C. Initially, the furnace was set at 100 ^{o}C. Records were made when the indicator has stabilised. Next, the furnace temperature was set to the next temperature, i.e. 200 ^{o}C, wait to stabilise, record, and move on to the next temperature setting.
For calibration above 400 ^{o}C, the standard was replaced with a type S thermocouple. The standard and the artefact were inserted 400 mm into the 9116 furnace. The same steps as described in the previous paragraph were carried out.
During calibration the tip of the artefact was always kept as close as possible to the tip of the standard at the same immersion.

Name of Laboratory : NMIJ – JAPAN

The emf of the thermocouple APMP-09 was firstly measured at 0°C using a water bath. It was then calibrated against a standard platinum resistance thermometer at 100°C, 200°C and 300°C using a three-zone furnace utilizing a comparison block, and at Zn, Al, Ag and Cu fixed points using the respective fixed-point cells and fixed-point furnaces.

The calibration was done in a sequence from lower to higher temperatures. Annealing was not done on the thermocouple used in the present work.

MEASUREMENT SET-UP

A water bath was used for the comparison measurement at 0°C, while a furnace consisted of three-zone heaters was used for the comparison measurements at 100°C, 200°C and 300°C. The water bath was also used to cool CJ ends of the thermocouple at 0 °C during calibration.

A pair of copper wires was connected to the CJ ends (open end) of the thermocouple. During calibration the CJ ends of the thermocouple was immersed in the water bath (0 °C). The immersion depth in the water bath was 315 mm.

Name of Laboratory : KRISS – South Korea

After confirming that the DUT was undamaged, it was tested as-received. At KRISS thermocouple was calibrated using fixed-point cells, Cu, Ag, Al, Zn, and Sn from high temperature to low temperature.

Pure cooper wires were soldered to thermocouple wires. These cold junctions were immersed into the glass tubes containing small amount of silicon oil as heat conducting medium. These tubes were immersed into the ice and water mixture.

Using DUT, the melting and freezing of fixed-points were measured. Thermocouple was placed in the furnace at room temperature. After finishing measurement, it was abruptly withdrawn from the cell.

During measurement, immersion depth of the cold junction into the ice point was varied about 5 cm. The emf variation due to this motion was checked and this value was considered as an uncertainty factor.

Measurements were performed two times at each fixed-point. After one cycle (from Cu to Sn), next cycle was done. The calibration data was chosen from the second cycle data.

Name of Laboratory : SIRIM – MALAYSIA

Procedure number: CP-447-301 of NML-SIRIM is used in the calibration of the thermocouple.

The type R thermocouple (APMP-06) is calibrated by comparison with one of the standard reference thermocouples of type S with serial number: NPL6/99/A in a horizontal calibration furnace at a temperature of 100 °C, 200 °C, 300 °C, 400 °C, 500 °C, 600 °C, 700 °C, 800 °C, 900 °C and 1000 °C (1100 °C was omitted due to the furnace failure).

The set point of the controller is preset so that it stabilised temperature is closed (± 1°C) to the acquired calibration temperature i.e. 100 °C, 200 °C, 300 °C, 400 °C, 500 °C, 600 °C, 700 °C, 800 °C, 900 °C and 1000 °C respectively.

Alumina protective tubes are used for both of the thermocouples before placed into the furnace. The immersion depth during the measurement is approximately 400 mm. The insertion hole is about 10 mm apart and the axial and coaxial uniformity of the furnace are previously measured and determined.

A pair of high quality copper wire is connected (twisted) to the CJ ends (open end) of the thermocouple (APMP-06). Two glass rods about 5 mm in diameter and 180 mm in length are used to enclose the CJ ends connection at the positive and the negative leg respectively. The immersion depth for the CJ in this comparison is to about 150 mm.

The emfs generated by the thermocouples are measured with a digital voltmeter model HP3458A through it selector switch. Both thermocouples have their reference junctions at 0 °C (ice prepared from distilled water).

Name of Laboratory : SPRING – SINGAPORE

1. The Type R thermocouple (S/N APMP 07) was calibrated by using fixed point method. Ice, Sn, Zn, Al and Ag fixed points were used for the calibration. The emf of the Type R thermocouple was measured by using a digital nanovoltmeter together with a scanner (see attached file **Instrument.doc** for details of the equipment). The calibration was done from low to high temperatures following SPRING calibration procedure "Calibration of noble metal thermocouples using ice and mini-fixed points" besides the comparison protocol.

2. During ice point measurement, a quartz tube with 6mm O.D. was applied to the thermocouple to protect the thermocouple from water. At other fixed points, the thermocouple was inserted directly into the quartz thermometer well of each fixed point cell.

3. The inhomogeneity of the thermocouple was tested upon arrival at 230°C in liquid bath with immersion up to 300mm. The measurement result was in line with the NMIA result. The NMIA result was used for the uncertainty analysis.

4. The measured emf of the Type R thermocouple at each fixed point was compared with the corresponding reference emf value as given in the NIST Monograph 175. The obtained differences were fitted using a second order polynomial. The obtained polynomial was then used to calculate the differences at all listed temperatures (calculations at 1000 °C and 1100°C are extrapolations). The calculated differences are considered as the final results (see attached file (**Comparisondata.xls**). The fitting errors (differences between the measured results and calculated results using the polynomial) were considered as one part of the measurement uncertainty.

5. Measurement uncertainties were estimated according to SPRING calibration procedure "Calibration of noble metal thermocouples using ice and mini-fixed points" and the comparison protocol. The uncertainties were estimated at a level of confidence of approximately 95% with a coverage factor k=2 (see attached file **Uncertainty.xls**).

Name of Laboratory : CSIR – South Africa

Calibration procedure: Type R thermocouple APMP-08

Multi-strand copper leads were twisted around the Pt-Rh and Pt wires at the reference junction, each was insulated with shrink-sleeve, and they were inserted in a glass tube. (The screen of the copper lead was used for the Pt wire.)
The thermoelectric homogeneity of the thermocouple was scanned by lowering it into a stirred salt bath at 200 °C (at approximately 10 mm / minute). Over the length from 130 to 430 mm from the measuring junction,

$$(emf_{\max} - emf_{\min})/(emf_{mean} - emf_{20°C}) = 0.054\% .$$

Dividing by 4, ui(k=1) = 0.014 %. However, in the uncertainty analysis 'Uncertainty.xls', the NMIA value Ui(k=2) = 0.008 % was used.
The thermocouple was compared to an SPRT in a stirred salt bath at 200, 420 and 540 °C. The thermocouple was inserted in a closed-end alumina tube to prevent contact with the salt.
The thermocouple was measured at the freezing points of aluminium, silver and copper (realised in a sodium heatpipe furnace) and at the ice point.

Name of Laboratory : CMS – TAIWAN

The thermocouple thermometer will be calibrated in turn at the freezing-point temperature of (231.928 °C) Tin (Sn), (419.527 °C) Zinc (Zn), (660.323 °C) Aluminum (Al), and (961.78 °C) Silver (Ag).

1. Inspect the thermocouple for any damage.
2. The thermocouple (**APMP-10**) is annealed at 450 °C for 16 hour.
3. Producing the ice point bath. The thermocouple is immersed in to an ice point up to an immersion of 150 mm.
4. Insert the freezing point cell into the furnace. Set the temperature of the furnace 5 °C higher than the melting point for melting it overnight.
5. After the melting process being completed, set the temperature of the furnace 5 °C lower than the freezing point. Insert the check standard, preheated to the freezing point, into the well of the freezing point cell. The immersion depth of the thermocouple in the calibration is 600 mm from the tip.
6. After the temperature within the cell rising from its minimum value, bring out the check standard and put it into the warming furnace. Thereafter, insert the rods, made of quartz or alumina, into the well of the freezing point cell for instigating the crystallization.
7. Set the temperature of the furnace 0.5 °C lower than the freezing point. Bring out the check standard within the warming furnace and insert it expeditiously and cautiously into the well of the cell.
8. When the temperature variation within the cell is from 10^{-2} K to 10^{-4} K, the temperature thus obtained is the freezing point. Be sure to take the measurement data after the thermometer being inserted into the cell for 15 to 20 minutes.
9. After recording the data measured at the freezing point, bring out the check standard and insert it into the warming furnace. Thereafter, insert the thermocouple thermometer being calibrated into the cell. Connect the thermometer to the multimeter for measuring its emf at the freezing point. Record the measurement data in the data sheet.
10. After the measurement being completed, insert again the check standard into the cell for taking its measurement data.
11. The difference between the measurement values of the check standard at step 8 and at step 10 should be within ±25 mK. If not, reject the measurement data of the unit being calibrated at step 8 and then repeat steps 4~10.
12. Repeat steps 4 to 11 until the thermocouple thermometer is calibrated in turn at 4 freezing-point temperatures from low to high.
13. Finish the calibration report and the uncertainty analysis.

Name of Laboratory : NIMT – THAILAND

1. After receiving the artifact , the artifact will be inspected in any damage . If there is any damage, NIMT will report to NMIA.
2. Install the standard thermometer and the thermocouple artifact in the temperature enclosure.
3. Prepare the first calibration point or Freezing point , which start from lowest to highest temperature. The temperature enclosure and standard thermometer are express in table below.
4. Prepare the ice point in the constant temperature ice bath used for immersing cold junction of thermocouple under calibration, UUC (artifact).
5. Place UUC 's cold junction to the constant temperature ice bath.
6. After warming and Auto-cal, record the reading of short circuit of indicator. Connect UUC to the indicator.
7. Wait until the reading stabilized then record the UUC reading for 10 measurements, in sequences of STD UUC UUC STD. The measurement period of every 30 seconds.
8. Record the reading of short circuit of indicator again after calibration complete at this point.
9. Repeat step 2-6 for the higher calibration point.
10. Disconnect all equipment. End of procedure.

APPENDIX C: Raw Calibration data from the participating Laboratories.

Name of Participating Laboratory: NIM - CHINA,
TC Serial No. APMP-01, Inhomogeneity = ± 0.01%

Temperature/°C	E_{ref}/ μV (microvolt)	E/ μV (microvolt)	E - E_{ref}/μV (microvolt)	Uncertainty/ °C
0.0	0.0	-0.9	-0.9	0.2
0.01(TPW)	0.1	-0.8	-0.9	0.1
100.0	647.4	648.0	0.6	0.2
200.0	1468.6	1469.9	1.3	0.2
231.928 (Sn FP)	1756.2	1757.5	1.2	0.1
300.0	2400.6	2401.9	1.4	0.2
400.0	3407.7	3408.7	1.0	0.2
419.527 (Zn FP)	3611.3	3612.5	1.2	0.1
500.0	4471.3	4471.6	0.4	0.2
600.0	5583.5	5583.0	-0.5	0.2
660.323 (Al FP)	6277.1	6275.8	-1.3	0.2
700.0	6742.7	6741.3	-1.4	0.2
800.0	7949.8	7947.6	-2.2	0.2
900.0	9204.9	9202.0	-2.8	0.2
961.78 (Ag FP)	10003.4	10000.6	-2.9	0.2
1000.0	10506.0	10502.9	-3.1	0.2
1084.62(Cu FP)	11640.4	11637.5	-2.9	0.2
1100.0	11849.6	11846.9	-2.8	0.2

Name of Participating Laboratory: SCL - HongKong,
TC Serial No. APMP-02, Inhomogeneity = ±0.01%

Temperature/°C	Eref/uV	E/uV	E-Eref / uV	Uncertainty / °C
0	0.00	-0.05	-0.05	0.039 °C
100	647.40	647.60	0.20	0.036 °C
200	1468.58	1469.10	0.52	0.040 °C
300	2400.6	2401.8	1.2	0.12 °C
400	3407.7	3409.4	1.7	0.13 °C
500	4471.3	4473.2	1.9	0.13 °C
600	5583.5	5585.7	2.2	0.66 °C
700	6742.7	6745.0	2.3	0.66 °C
800	7949.8	7952.5	2.7	0.66 °C
900	9205	9207	2	0.91 °C
1000	10506	10507	1	0.91 °C
1100	11850	11851	1	0.91 °C

Name of Participating Laboratory: NPLI - INDIA,
TC Serial No. APMP-03 Inhomogeneity = ±0.01%

Temperature/°C	Eref/uV	E/uV	E-Eref/uV	Uncertainty /microvolt	Uncertainty / °C
0.0	0.0	1.6	1.6	± 0.90	± 0.18
100.0	647.0	651.2	4.2	± 2.48	± 0.31
200.0	1469.0	1471.0	2	± 2.49	± 0.31
231.928(Sn)	1756.0	1760.4	4.4	± 2.50	± 0.28
300.0	2401.0	2405.3	4.3	± 2.52	± 0.28
400.0	3408.0	3410.8	2.8	± 2.62	± 0.26
419.527(Zn)	3611.0	3614.6	3.6	± 2.68	± 0.26
500.0	4471.0	4477.4	6.4	± 2.75	± 0.25
600.0	5583.0	5591.1	8.1	± 2.75	± 0.23
660.323(Al)	6277.0	6283.1	6.1	± 2.75	± 0.25
700.0	6743.0	6747.5	4.5	± 12.29	± 1.02
800.0	7950.0	7954.4	4.4	± 12.29	± 1.02
900.0	9205.0	9210.1	5.1	± 13.27	± 1.02
961.78(Ag)	10003.0	10008.0	5	± 13.58	± 1.05
1000.0	10506.0	10513.0	7	± 13.88	± 1.07
1100.0	11850.0	11859.0	9	± 13.29	± 1.02

Name of Participating Laboratory: KIMLIPI - INDONESIA,
TC Serial No. APMP-04, Inhomogeneity = ±0.01%

Laboratory name : Puslit KIM-LIPI

t (oC)	Eref (uV)	E(uV)	E-Eref (uV)	Uncertainty (uV)
0	0	-0.7	-0.7	0.3
100	647	647.4	0.4	0.5
200	1469	1470.1	1.1	0.6
300	2401	2402.5	1.5	0.8
400	3408	3409.7	1.7	1.6
500	4471	4472.7	1.7	1.9
600	5583	5584.6	1.6	2.2
700	6743	6744.3	1.3	2.6
800	7950	7950.8	0.8	2.9
900	9205	9205.3	0.3	3.2
1000	10506	10505.7	-0.3	3.6
1100	11850	11849.1	-0.9	4

Name of Participating Laboratory: SIRIM - MALAYSIA
TC Serial No. APMP-06, Inhomogeneity = ±0.008%

Temperature/°C	E_{ref} / uV	E/ uV	E- E_{ref} /uV	Uncertainty/°C
0.0	0.0	0.0	0.0	0.1
100.0	647.4	646.3	-1.1	0.6
200.0	1468.6	1467.2	-1.4	0.6
300.0	2400.6	2399.6	-1.0	0.6
400.0	3407.7	3407.6	-0.1	0.6
500.0	4471.3	4472.4	1.1	0.6
600.0	5583.5	5585.8	2.3	0.4
700.0	6742.7	6746.2	3.5	0.4
800.0	7949.8	7954.1	4.3	0.5
900.0	9204.9	9209.3	4.4	0.5
1000.0	10506.0	10509.9	3.9	0.6
1100.0	11849.6	11852.2	2.6	0.7

Name of Participating Laboratory: NMIJ - JAPAN
TC Serial NO. APMP-09, Inhomogeneity = ±0.009%

Temperature/°C	E_{ref}/µV	E/µV	E- E_{ref}/µV	Uncertainty/°C
0.0	0.00	- 0.48	- 0.48	0.078
100.0	647.40	647.38	- 0.02	0.034
200.0	1468.58	1469.06	0.47	0.033
300.0	2400.55	2401.52	0.97	0.035
400.0	3407.69	3409.11	1.43	0.039
419.527(Zn)	3611.30	3612.69	1.38	0.049
500.0	4471.26	4473.08	1.82	0.045
600.0	5583.45	5585.57	2.11	0.054
660.323(Al)	6277.09	6279.26	2.17	0.059
700.0	6742.72	6745.00	2.27	0.062
800.0	7949.84	7952.10	2.26	0.068
900.0	9204.86	9206.92	2.05	0.073
961.78(Ag)	10003.43	10005.60	2.17	0.083
1000.0	10505.96	10507.57	1.61	0.080
1084.62(Cu)	11640.43	11641.17	0.74	0.093
1100.0	11849.64	11850.54	0.90	0.096

Name of Participating Laboratory: KRISS - KOREA
TC Serial No. APMP-05, Inhomogeneity = ±0.011%

Temperatu	E_{ref} /µV	E /µV	E-E_{ref} /µV	Uncertainty /°C (k=2)
0.00	0.0	0.0	0.0	0.11
100.00	647.4	647.5	0.1	0.09
200.00	1468.6	1468.8	0.2	0.08
231.93	1756.2	1756.5	0.3	0.08
300.00	2400.6	2400.9	0.3	0.08
400.00	3407.7	3408.2	0.5	0.08
419.53	3611.3	3612.0	0.7	0.08
500.00	4471.3	4472.0	0.7	0.08
600.00	5583.5	5584.4	0.9	0.09
660.32	6277.1	6278.0	0.9	0.09
700.00	6742.7	6743.9	1.2	0.10
800.00	7949.8	7951.3	1.5	0.10
900.00	9204.9	9206.7	1.8	0.11
961.78	10003.4	10005.4	2.0	0.11
1000.00	10506.0	10508.1	2.1	0.12
1084.62	11640.4	11643.0	2.6	0.12
1100.00	11849.6	11852.2	2.6	0.12

Name of Participating Laboratory: SPRING - SINGAPORE
TC Serial No. APMP-07, Inhomogeneity = ±0.009%

Temperature/°C	Eref /μV	Emea /μV	Emea - Eref /μV	Un (emf) k=2	Un (°C) k=2
0.0	0.00	-0.53	-0.53	0.4	0.08
100.0	647.40	647.43	0.03	0.4	0.05
200.0	1468.58	1469.09	0.51	0.5	0.06
231.928	1756.23	1756.88	0.65	0.5	0.05
300.0	2400.55	2401.48	0.93	0.5	0.05
400.0	3407.69	3408.96	1.27	0.6	0.06
419.527	3611.30	3612.63	1.33	0.7	0.07
500.0	4471.26	4472.79	1.53	0.8	0.07
600.0	5583.45	5585.18	1.73	1.0	0.09
660.323	6277.09	6278.90	1.81	1.1	0.09
700.0	6742.72	6744.57	1.85	1.3	0.11
800.0	7949.84	7951.74	1.90	1.6	0.13
900.0	9204.86	9206.73	1.87	1.9	0.15
961.78	10003.43	10005.25	1.82	2.0	0.15
1000.0	10505.96	10507.73	1.77	2.2	0.17
1100.0	11849.64	11851.24	1.60	2.5	0.19

Name of Participating Laboratory: CSIR – SOUTH AFRICA
TC Serial No. APMP-08, Inhomogeneity = ±0.008%

Temperature °C	E(ref) μV	E μV	E - E(ref) μV	U(k=2) °C	U(k=2) μV
0.000	0.00	-0.35	-0.35	0.090	0.48
100.000	647.40	647.20	-0.19	0.075	0.56
200.000	1468.58	1468.78	0.20	0.060	0.53
231.928	1756.23	1756.58	0.35	0.060	0.55
300.000	2400.55	2401.28	0.72	0.060	0.58
400.000	3407.69	3408.98	1.29	0.060	0.62
419.527	3611.30	3612.70	1.40	0.060	0.63
500.000	4471.26	4473.07	1.81	0.063	0.69
600.000	5583.45	5585.63	2.18	0.067	0.77
660.323	6277.09	6279.38	2.29	0.070	0.81
700.000	6742.72	6745.03	2.30	0.074	0.87
800.000	7949.84	7951.93	2.09	0.084	1.03
900.000	9204.86	9206.31	1.44	0.094	1.20
961.780	10003.43	10004.22	0.78	0.100	1.31
1000.000	10505.96	10506.22	0.26	0.125	1.65
1100.000	11849.64	11848.10	-1.54	0.190	2.59
1084.620	11640.43	11639.21	-1.22	0.180	2.44

Name of Participating Laboratory: CMS - TAIWAN
TC Serial No. APMP-10, Inhomogeneity = ±0.008%

Temperature/°C	E_{ref}/ µV	E/ µV	E - E_{ref} / µV	Expanded Uncertainty (95%)/°C
0.000	0	0	0	0.766
100.000	647.4	647.28	-0.12	0.543
200.000	1468.58	1468.34	-0.24	0.461
231.928 (Sn)	1756.23	1756.84	0.61	0.148
300.000	2400.55	2400.17	-0.38	0.42
400.000	3407.69	3407.17	-0.52	0.396
419.527 (Zn)	3611.3	3612.81	1.51	0.139
500.000	4471.26	4470.59	-0.67	0.38
600.000	5583.45	5582.63	-0.82	0.368
660.323 (Al)	6277.09	6274.58	-2.51	0.142
700.000	6742.72	6741.74	-0.98	0.357
800.000	7949.84	7948.68	-1.16	0.347
900.000	9204.86	9203.53	-1.33	0.34
961.78 (Ag)	10003.43	10003.16	-0.27	0.158
1000.000	10505.96	10504.68	-1.28	0.388
1100.000	11849.64	11848.11	-1.53	0.426

Name of Participating Laboratory: NIMT - THAILAND
TC Serial No. APMP-11, Inhomogeneity = ±0.012%

Temperature /oC	Eref /uV	E/uV	E-Eref /uV	E-Eref /uV	Uncertainty /	Coverage Factor k,CL=
0.0	0.0	0.8	0.84	0.8	0.4	2.0
100.0	647.4	648.7	1.33	1.3	0.3	2.0
200.0	1468.6	1470.3	1.74	1.7	0.3	2.0
231.928	1756.2	1758.1	1.86	1.9	0.2	2.0
300.0	2400.6	2402.6	2.08	2.1	0.3	2.0
400.0	3407.7	3410.1	2.39	2.4	0.3	2.0
419.527	3611.3	3613.8	2.45	2.4	0.2	2.0
500.0	4471.3	4473.9	2.68	2.7	0.3	2.0
600.0	5583.5	5586.4	2.98	3.0	0.6	2.0
660.323	6277.1	6280.3	3.17	3.2	0.2	2.0
700.0	6742.7	6746.0	3.31	3.3	0.6	2.0
800.0	7949.8	7953.5	3.69	3.7	0.7	2.0
900.0	9204.9	9209.0	4.16	4.2	0.7	2.0
961.78	10003.4	10007.9	4.50	4.5	0.3	2.0
1000.0	10506.0	10510.7	4.73	4.7	0.7	2.0
1100.0	11849.7	11855.2	5.43	5.4	0.7	2.0

Appendix D: The instruments used during calibration by the participating laboratories

Laboratory Name : National Measurement Institute, Australia (NMIA)

Devices	Type	Manufacturer	Serial number	Description	Immersion (mm)
Standard used for reference temperature	SPRT	Hart Scientific	0057		450
AC bridge/DVM for SPRT measurements	AC Bridge	ASL	F17-2	AC bridge	
Ice-Point used	Electronic Icepoint	KAYE	11304	calibration uncetainty 5 mK	150
DVM for Test TC	HP34420A	Agilent	LN68723		
Scanner (if used)	No				
Enclosure used	Salt bath up to 550°C	Hart Scientific	9C029	Horizontal and vertical uniformity = 5 mK	450
Fixed Points used	Ag and Au	Au-point furnace(NMIA) Ag-point furnace (Hart Scientific)		for Au-point, single zone furnace & for Ag point Na-heat pipe liner was used.	300 for Au 450 for Ag

Laboratory Name National Institute of Metrology , P. R. China

Devices	Type	Manufacturer	Serial number	Description	Immersion (mm)
Standard used for reference temperature	----------------------	------------	-----------	---------------	--------
AC bridge/DVM for SPRT measurements	----------------------	------------	------------	---------------	
Ice-Point used	TCM-BDQ	NIM	2005001	distilled water , trash ice , CJ and Cu wire contact in mercury	junction 180mm depth in liquid
DVM for Test TC	182	KEITHLEY	609233	Range 30mV ,sensitivity :0.01microvolt ,calibrated before used ,traced to NIM voltage standard	
Scanner (if used)	B4-65	NIM	86147	machanical Brass brush, parasitical emf<= 0.2microvolt	
Enclosure used	------------------------	-----------	------------	---------------	----------
Fixed Points used	Triple Piont of Water	NIM	NIM-210		250mm depth in the water
	Sn Freezing Piont	NIM	SN9403	matel ingot purity 99.9999% from China;graphite crucible 99.999% in purity;closed cell, traced to NIM	190mm depth in ingot, 440mm in furnace
	Zn Fixed Point	NIM	Zn-98	matel ingot purity 99.9995% from China;graphite crucible 99.999% in purity;open cell ,traced to NIM	120mm depth in ingot, 400mm in furnace
	Al freezing point	NIM	Al-98	matel ingot purity 99.9995% from China;graphite crucible 99.999% in purity;closed cell ,traced to NIM	140 mm depth in ingot, 450mm in furnace
	Ag freezing point	NIM	Ag-98	matel ingot purity 99.9995% from China;graphite crucible 99.999% in purity; open cell ,traced to NIM	120mm depth in ingot, 450mm in furnace
	Cu Freeaing point	NIM	Cu-98	matel ingot purity 99.9995% from China;graphite crucible 99.999% in purity;open cell ,traced to NIM	120mm depth in ingot, 450mm in furnace

Laboratory Name : **Standards and Calibration Laboratory, SCL - HongKong**

Devices	Type	Manufacturer	Serial number	Description	Immersion (mm)
Standard used for reference temperature	Model 5187SA	Tinsley	253085	SPRT (traceability : SCL)	420
	Model 5187SA	Tinsley	245058	SPRT (traceability : SCL)	420
	Model 935-14-77	Isotech	082	SPRT (traceability : SCL)	420
	Model 935-14-77	Isotech	084	SPRT (traceability : SCL)	420
	NPL/R	NPL	NPL6/00/D	Type R thermocouple (traceability :NPL (1100 °C to 962 °C) SCL (962 °C to 0	450
	NPL/R	NPL	NPL6/00/E	Type R thermocouple (traceability :NPL (1100 °C to 962 °C) SCL (962 °C to 0 °C))	450
AC Bridge for SPRT measurement	Model F17A	ASL	520-1/054	Resistance Bridge (traceability : SCL)	N/A
	Model F17A	ASL	1029-3/215	Resistance Bridge(traceability : SCL)	N/A
Ice-point used	N/A	N/A	N/A	Made of crushed ice for immersion of CJ of UUT	200
DVM for Test TC	Model 34420A	Agilent	US36002574	Nano-voltmeter (traceability : SCL)	N/A
	Model 181	Keithley	433347	Nano-voltmeter (traceability : SCL)	N/A
Scanner	Model 160A	Data Proof	297	Thermocouple scanner	N/A
Enclosure used	Model KB12	Heto	8309	Constant temperature bath	420
	Model 6055	Hart	A13039	Constant temperature bath	420
	Model TPK 500	Heraeus	8705483	Sodium heat-pipe furnace	450
Fixed point used	Model A13	Jarrett	1588	Triple point of water cell(traceability : SCL)	300

Laboratory Name : National Physical Laboratory, NPLI - India

Devices	Type	Manufacturer	Serial Number	Description	Immersion (mm)
Standard used for reference temperature	SPRT SPRT R-TC	CHINO, JAPAN TINSLEY, UK ISOTECH, UK	92128 280116 231561/1	Pt-25 Pt-25 Type-R	250 250 500
AC bridge for SPRT measurements	Model F700B	ASL, UK	7175 003 549	Resolution 1x10-7 ohm	
Ice Point measurements	Ice Point Cell	NPL, INDIA	IPC-NPL-01	Ice-water slush in Dewar Flask	180
DVM for test TC	DMM 196	KEITHLEY, USA	[illegible]196	Resolution 0.1uV	NA
Scanner (if used)	No	NA	NA	NA	
Enclosure used	Model 465	ISOTECH, UK	221120-1	High Temp. Metrology Furnace	
Fixed Points used	No				

Laboratory name : Puslit KIM-LIPI - Indonesia

Device	Type	Manufacturer	Serial Number	Description	Immersion (mm)
Standar used for reference temperature	R-800	Chino	RS955-11	SPRT (0 - 400)^{o}C traceable to KIM-LIPI	400
Standar used for reference temperature	5650	Hart Scientific	9126	Type S Thermocouple (400 - 1100)^{o}C traceable to NMI Australia	400
AC bridge for SPRT measurements	1590	Hart Scientific	A3A225	Electronic SPRT Indicator nicknamed Super thermometer	N/A
Ice-Point used	-	-	-	shaved ice mixed with pure water	150
DVM for Test TC	181	Keithley	144305	Digital Nanovoltmeter	N/A
Scanner (if used)	1605	Burster	308521	Nanomat	N/A
Fixed Points used	-	-	-	-	-
Enclosure used	9114	Hart Scientific	A3A069	Furnace (100 -400)^{o}C	
Enclosure used	9116	Hart Scientific	A47021	Furnace (400 - 1100)^{o}C	

Name of Laboratory : NMIJ - Japan

Devices	Type	Manufacturer	Serial number	Description	Immersion (mm)
Standard used for reference temperature	SPRT HTS-21-1000	NETSUSHIN	NS-03060	resistance : 3 Ω	
AC bridge for SPRT measurements	Model F18	ASL	1011-2/056	Used with the combination of a temperature controlled 10 Ω standard resistor (Tinsley 5648 + 5685) Measurement current 2 mA and $2\sqrt{2}$ mA	
Ice-Point used	Model 7312	Hart Scientific	A3B072	TPW maintenance bath is used as a ice-point device stability : ±1 mK at 0 °C uniformity : ±3 mK at 0 °C	315 mm
DVM for Test TC	Model 1281	Wavetek	35876	resolution : 10 nV	
Scanner used	Model 160A	Data Proof	845	Used for inversion of polarity	
Enclosure used	3-zone furnace	NMIJ	MF2-2004	comparison with the calibrated SPRT stability : ±1 mK for 20 min uniformity : ±1 mK over 40 mm	410 mm
Fixed Points used	Zn cell / furnace (MPF09)	NMIJ / Yamari	Zn-1 / 3128-2	Open type / 3 zone	520 mm
	Al cell / furnace (STF-10)	NMIJ / Yamari	Al-1 / 31271	Open type / Na Heat-Pipe	520 mm
	Ag cell / furnace (STF-10)	HART / Yamari	28001 / 121281	Open type / Na Heat-Pipe	565 mm
	Cu cell / furnace	NMIJ / NMIJ	Cu-4 / CuF-1	Open type / 3 zone	582 mm

Name of Laboratory : KRISS - Korea

Devices	Type	Manufacturer	Serial Number	Description	Immersion /mm
Fixed Points used	Cu fixed-point cell	KRISS	LS_CU1	Sealed-type	520
	Ag fixed-point cell	KRISS	LS_AG1	Sealed-type	510
	Al fixed-point cell	KRISS	LS_AL1	Sealed-type	510
	Zn fixed-point cell	KRISS	LS_ZN2	Sealed-type	500
	Su fixed-point cell	KRISS	SN02	Sealed-type	360
DVM for Test TC	DVM	Keithley	772667	2182 model	
Ice-point used	Ice+water mixture	-	-	Max depth 300 mm	200
Enclosure used	Cu freezing furnace	KRISS	FPF-H-01	Na Heat-pipe	520
	Ag freezing furnace	KRISS	FPF-H-02	Na Heat-pipe	510
	Al freezing furnace	KRISS	FPF-M-02	Na Heat-pipe	510
	Zn freezing furnace	KRISS	FPF-M-03	Cs Heat-pipe	500
	Su freezing furnace	KRISS	LS_CU2	Fluidized bath	360

Laboratory name: **Thermocouple Laboratory, National Metrology Laboratory (NML-SIRIM)**

Devices	**Type**	**Manufacturer**	**Serial number**	**Description**	**Immersion (mm)**
Standard used for reference temperature	Thermocouple type S and thermometer readout ASL F250 with pt100	National Physical Laboratory (NPL), U.K and ASL, U.K	NPL6/99/A and 1857A	TC was purchased in year 2000 and is used only once a year for comparison	400
AC bridge/DVM for SPRT measurements	DVM	Hewlett Packard, U.S.A	HP 3458A 2823A 22167	Last date of calibration 16 Dec 2004	
Ice-Point used	Distilled water	KGW, ISOTHERM (Dewar flask)		Purchased in year 2004	400
DVM for Test TC	DVM	Hewlett Packard, U.S.A	2823A 22167	Last date of calibration 16 Dec 2004	
Scanner (if used)	Nil	Nil	Nil	Nil	
Enclosure used	Horizontal Calibration Furnace	Carbolite, U.K	TZF 12/65/550 5/99/1136	Purchased in year 2000 and specifically use for TC calibration range 25 °C to 1100 °C	400 (Max)
Fixed Points used	Nil	Nil	Nil	Nil	Nil

Laboratory Name: NMC, SPRING, Singapore

Devices	**Type**	**Manufacturer**	**Serial number**	**Description**	**Immersion mm**
Ice-Point used	Ice pot	Self made	-	Preparation following SPRING procedure	260
DVM for Test TC	Nanovoltmeter	Keithley	799214	Keithley Model 2182 nanovoltmeter	-
Scanner	Low thermal low current switch scanner	Data Proof	347	Data proof model 320A	-
Enclosure used	One zone tube furnace	ISOTECH	19241/1	ISOTECH Medusa 1	280
	One zone tube furnace with heatpipe	ISOTECH	19241/2	SOTECH Oberon	295
Fixed Points used	Tin slim cell	ISOTECH	SN92	Slim cell realized in ISOTECH Medusa furnace	160 (crucible length)
	Zinc slim cell	ISOTECH	ZN149	Slim cell realized in ISOTECH Medusa furnace	160 (crucible length)
	Aluminum slim cell	ISOTECH	AL135	Slim cell realized in ISOTECH Oberon furnace	160 (crucible length)
	Silver slim cell	ISOTECH	AG105	Slim cell realized in ISOTECH Oberon furnace	160 (crucible length)

Laboratory name: CSIR-NML

Temperature (°C):	0					200, 420, 540				
Devices	Type	Manufacturer	Serial number	Description	Immersion (mm)	Type	Manufacturer	Serial number	Description	Immersion (mm)
Standard used for reference temperature				Crushed ice point	180	5187SA	Tinsley	269581	25 Ω SPRT	365
AC bridge/DVM for SPRT measurements						F18	ASL	1208-1/105	AC bridge	
Ice point used				Crushed ice point	180				Crushed ice point	180
DVM for test TC	34420A	HP	US36000373	Nanovoltmeter		34420A	HP	US36000373	Nanovoltmeter	
Scanner (if used)	705	Keithley	521077	Low-thermal voltage scanner		705	Keithley	521077	Low-thermal voltage scanner	
Enclosure used				Dewar flask		JH02	Heto	87091113	Stirred salt bath	360
Fixed points used	Ice									

Temperature (°C):	660, 962					1085				
Devices	Type	Manufacturer	Serial number	Description	Immersion (mm)	Type	Manufacturer	Serial number	Description	Immersion (mm)
Standard used for reference temperature	17672, 17673	Isotech	AL108, AG36	Sealed cells	400	Open	CSIR-NML	TS-001	Open cell	380
AC bridge/DVM for SPRT measurements										
Ice point used				Crushed ice point	180				Crushed ice point	180
DVM for test TC	34420A	HP	US36000373	Nanovoltmeter		34420A	HP	US36000373	Nanovoltmeter	
Scanner (if used)	705	Keithley	521077	Low-thermal voltage scanner		705	Keithley	521077	Low-thermal voltage scanner	
Enclosure used	17705	Isotech	161371-1	Sodium heat pipe		17705	Isotech	161371-1	Sodium heat pipe	
Fixed points used	Aluminium, silver					Copper				

Laboratory Name: CMS, Taiwan

Devices	Type	Manufacturer	Serial number	Description	Immersion (mm)
Standard used for reference temperature	No	No	No	No	No
SPRT measurements	No	No	No	No	
Ice-Point used	——	□□□□	——	Fill the vessel with ice and pure water	150
DVM for Test TC	DVM	Solartron	7081	7-1/2-Digit DVM; Range: 0 ~ 50 mV DC (Calibrated by the CMS)	
Scanner	705	KEITHLEY	7059	Scanner for 10 channels	
Furnace 1	——	YSI	17701	Range: 100 °C ~ 500 °C	
Furnace 2	ITL	ISOTECH	17705	Range: 500 °C ~ 1100 °C	
Fixed Points used	Sn	CMS	CMS-Sn-I-05	Sn Fixed-Point Cell	600
Fixed Points used	Zn	CMS	CMS-Zn-I-96	Zn Fixed-Point Cell	600
Fixed Points used	Al	CMS	CMS-Al-I-96	Al Fixed-Point Cell	600
Fixed Points used	Ag	CMS	CMS-Ag-6-96	Ag Fixed-Point Cell	600

Laboratory Name : National Institute of Metrology (Thailand) , NIMT

Devices	Type /Model	Manufacturer	Serial Number	Description / Spec.	Immersion (mm)	Traceability
Standard use for reference temperature					-	
- SPRT	25 ohm	Isotech	043	u=4 mK / drift 10 mK/year	200	NIMT-TL
- SPRT	25 ohm	Isotech	1301	u=4 mK / drift 2mK/year	200	NIMT-TL
-Thermocouple	Type S	NPL	NPL5/03/B	above 500oC ; u =0.3 oC	350	NPL
Indicator Use for SPRT Measurement					-	
- Super Thermometer II	1590	Hart Scientific	97045	u= 0.3mK / drift 1mK	-	NIMT-EL
Ice-Point used					-	
-Temperature Ice Bath (Dewar)	D-2000	Rosemount	11021BC	Uniformity = + 0.03 oC	250	NIMT-TL
				Stability = + 0.03 oC	250	
DVM for Test TC/STD TC					-	
- Digital Multimeter	3458A	Hewlett Packard	2823A08029	accuracy=ppm ofRead+ppm ofRange	-	NIMT - EL
				accuracy = 9 +10/ u = 6.5 ppm	-	
- Digital Multimeter	3458A	Hewlett Packard	US28028715	accuracy = 9 +10/ u = 6.5 ppm	-	NIMT - EL
- Scanner (Switch System)	7001	Hewlett Packard	913875	correction within = 1 uV	-	NIMT-TL
Enclosure used					-	
- Liquid calibration bath(0 - 100) C	CB216	Hart Scientific	8806298	Uniformity = + 0.005 oC	200	NIMT-TL
				Stability = + 0.002 oC		
- Liquid calibration bath(100 - 200) C	6022	Hart Scientific	A03098	Uniformity = + 0.010 oC	200	NIMT-TL
				Stability = + 0.009 oC		
- Three zone Furnace (300 - 500) C	2132&2408	NPL	7/01/1699,1839	Uniformity = + 0.020 oC	200	NIMT-TL
				Stability = + 0.015 oC		
-Thermocouple Calibration furnace	9112	Hart Scientific	57017	700 : Uni = +0.2 K /Sta = + 0.1 K	350	NIMT-TL
(600 - 1100) C				1100 : Uni = +0.3 K/Sta = + 0.15 K		NIMT-TL

Measuring equipments and standard used in the comparison.

Laboratory Name : National Institute of Metrology (Thailand) , NIMT

Devices	Type /Model	Manufacturer	Serial Number	Description / Spec.	mersion (m	Traceability
Fixed Points used					-	
- Tin Freezing point cell (231.928 oC	ITL-M-17669	Isotech	SN75	uncertainty = 0.7mK	200	PTB
- Zinc Freezing point cell (419.527 oC	ITL-M-17671	Isotech	ZN127	uncertainty = 1.4 mK	200	PTB
- Al Freezing point cell(660.323 oC)	ITL-M-17672	Isotech	AL154	uncertainty = 3 mK	200	PTB
- Ag Freezing point cell(961.78 oC)	ITL-M-17673	Isotech	AG74	uncertainty = 4 mK	50	PTB

Appendix E : Uncertainity Calculation by the Participating Labs
Name of Laboratory : NMIA, Australia

Uncertainty calculation in calibration of Rare metal thermocouple

RN 48470 **Serial no. APMP-08** date 4/07/2006

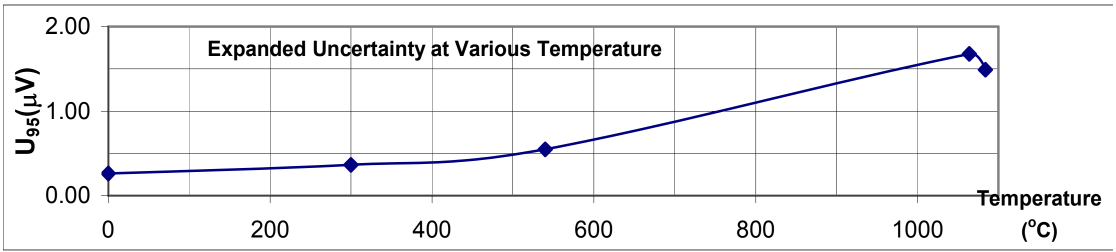
	Source	Uncertainty(uV)	k_i	ui	vi
0 C	DVM(cal+use) 0.1+40ppm	0.10	2.0	0.05	60
300 C	DVM(cal+use) 0.1+40ppm	0.20	2.0	0.10	60
540 C	DVM(cal+use) 0.1+40ppm	0.30	2.0	0.15	60
Up to 540°C	Cal of SPRT	0.03	2	0.02	60
	SPRT ice point	0.02	2	0.01	20
	Calibration of the F-17 bridge	0.01	2	0.01	60
	Mean SPRT reading(type A)*	**0.10**	**-**	0.03	14
	Calibrationof extension lead	0.10	2.0	0.05	60
	Calibration of auto.Icepoint	0.04	2.0	0.02	60
	Measurement of CJ temperature	0.11	2	0.06	20
	Ext. wire mismatch (0.1 for S)	**0.00**	2	0.00	50
	Mean DVM reading(type A)*	**0.11**	**-**	0.03	9
	Bath uniformity	0.05	2	0.03	20
	AC pickup	0.10	2	0.05	8
all Temp	**Inhomogeneity =**	**0.008% of E**		**with**	**20**
1064°C	**Au-pt** from Table 2			0.71	**27.3**
1084°C	**Cu-pt** from Table 3			0.58	**45.7**
1550°C	**Pd-pt** from Table 2			1.3	**43.6**
all Temp	**Data fit and interpolation**	**0.11**	**-**	0.055	20
all Temp	Rounding for report	0.05	1.73	0.03	100

Inhomogeneity of Thermocouple

				ui	vi
0		0	0.00	0.000	20
300	2401		0.19	0.096	20
540	4900		0.39	0.196	20
1064	11307		0.90	0.452	20
1084	11590		0.93	0.464	20
1550	18152		1.45	0.726	20

totals

Temperature	ui for Inhomo	u_c(uV)	eff.v	k	U_{95}
0	0.00	0.13	143.3	1.98	0.26
300	0.10	0.18	146.7	1.98	0.36
540	0.20	0.27	67.8	2.00	0.55
1064	0.45	0.85	250.1	1.97	1.68
1084	0.46	0.75	138.8	1.98	1.49
1550	0.73	1.49	354.9	1.97	2.93



U_{95}(R) $_{(1100)}$ = 0.26 + 0.000103 of E (uV)

Au-point

Source	**Uncertainty**	**ki**	**Description**	**ui**	**vi**
Temperature on ITS-90	-				
Quality of metal	0.50	2.0	normal	0.25	8
Realisation of point/interpretion of	1.00	2.0	normal	0.50	8
flat				0.00	20
Scatter in 6 melting points*	0.60		S.D. of data	0.21	5
DVM calibration & use	0.56	2.0	95% C.L..	0.28	60
Calibration of extension lead	0.10	2.0	95% C.L.	0.05	60
Measurment of CJ temperature	0.11	2.0	normal	0.06	20
Thermal and ac pickup	0.50	2.0	normal	0.25	8
		u_c =	**0.71**		
Expanded Uncertainty U=	**1.46**	**k =**	**2.05**	**eff.v =**	**27.3**

Name of the Laboratory : KRISS, Korea

Uncertainty Analysis

A. Reference temperature determination	Quantity	Distributior	Sensitivity (	Description
A-1. Cell temperature	± 10 mK	Rectangula	1	Compare to the standard cell
A-2. Plateau determination	± 10 mK	Rectangula	1	Plateau slope
Combined uncertainty				
B. Test t/c measurements				
B-1. Inhomogeneity	± 0.011 % /2	Normal	1/Cs	Given by NMIA
B-2. Reproducibility at the fixed-points	± 0.02 oC	Normal	1	From the experience and published data
B-3. Repeatibility	± 0.01 oC	Normal	1	Scattering of data
B-4. Ice point realization	± 0.05 oC	Rectangula	Cs(0 oC)/C	Compare with SPRT
B-5. Ice point immersion	± 0.05 oC	Rectangula	1	Withdrawn by 50 mm
B-6. DVM calibration	6 ppm	Normal	1/Cs	certificate from KRISS
B-7. DVM Short-term accuracy	25 ppm of reading + 3 ppm of range	Rectangula	1/Cs	Manufacturer specification
B-8. DVM resolution	± 0.05 uV	Rectangula	1/Cs	
Combined uncertainty				
C. Interpolation	0.16 uV	Normal	1/Cs	Max. deviation from 2nd order fitting
			Cs : Seebeck coefficient of type R thermocouple	
Combined standard uncertainty				
Expanded uncertainty (k = 2)				

Laboratory name: KIM-LIPI, Indonesia

Calibration range:
(400 - 1100) ^{o}C

No	Uncertainty Budget	Uncertainty a	b*E
1	Calibration of standard	0.28	9.5E-05
2	Interpolation error	0.08	0
3	Inhomogeneity of Thermocouple Standard	0	0
4	Drift of Standard	0.028	9.5E-06
5	Type A error of mean reading of standard	0	0
6	Calibration of DVM or Bridge	0.003385	1.8E-05
7	Ice point error of standard	0.0002	0
8	Inhomogeneity of Test Thermocouple		0.0001
9	Type A error of mean reading	9.930E-16	
10	Ice point error of the Test Thermocouple	0.0002	0
11	Calibration of DVM used	0.003385	1.8E-05
12	Drift of DVM since calibration	0.000339	1.8E-06
13	Tip temperature difference	0.08	
14	Fitting and interpolating error	0.11	
15	AC pickup	0	0
16	Rounding for the report	0.05	0
	Combined uncertainty	0.326507	0.00014
	Expanded uncertainty	**0.65**	**0.00028**

Calibration range:
(0 - 400)^{o}C

No	Uncertainty Budget	Uncertainty a	b*E
1	Calibration of standard	0.032	
2	Interpolation error	0.0104	0
3			
4	Drift of Standard	0.0032	0
5	Type A error of mean reading of standard	0.002	0
6	Calibration of DVM or Bridge	0.048	
7			
8	Inhomogeneity of Test Thermocouple		0.0001
9	Type A error of mean reading	9.93E-16	
10	Ice point error of the Test Thermocouple	0	0
11	Calibration of DVM used	0.048	0
12	Drift of DVM since calibration	0.0048	0
13	Tip temperature difference	0.08	
14	Fitting and interpolating error	0.11	
15	AC pickup	0	0
16	Rounding for the report	0.05	
	Combined uncertainty	0.163638	0.0001
	Expanded uncertainty	**0.33**	**0.00020**

Name of Laboratory : NMIJ, Japan

Source of uncertainty	Standard uncertainty	
Reference temperature measurements		
Calibration of the standard SPRT	3.4 mK	calibrated at Zn fixed point
Drift/use of SPRT	2.4 mK	estimated from the propagation of the drift at the water triple point before and after the calibration to the Zn point
Reading of SPRT at 100°C	0.080 mK	a standard deviation of mean (60 readings of a SPRT)
Reading of SPRT at 200°C	0.066 mK	a standard deviation of mean (60 readings of a SPRT)
Reading of SPRT at 300°C	0.12 mK	a standard deviation of mean (60 readings of a SPRT)
Calibration of Bridge	0.40 mK	estimated at Al fixed point
Test Thermocouple measurements		
Inhomogeneity of test thermocouple	(± 0.009% of E)/2	given by the NMIA
Reading at 0°C	5.2 nV	a standard deviation of mean (10 readings of the thermocouple)
Reading at 100°C	4.7 nV	a standard deviation of mean (10 readings of the thermocouple)
Reading at 200°C	6.2 nV	a standard deviation of mean (10 readings of the thermocouple)
Reading at 300°C	3.8 nV	a standard deviation of mean (10 readings of the thermocouple)
Reading at Zn fixed point	11 nV	a standard deviation of mean (10 readings of the thermocouple)
Reading at Al fixed point	47 nV	a standard deviation of mean (10 readings of the thermocouple)
Reading at Ag fixed point	70 nV	a standard deviation of mean (10 readings of the thermocouple)
Reading at Cu fixed point	18 nV	a standard deviation of mean (10 readings of the thermocouple)
Temperature of CJ ends	1.5 mK	estimated by stability over 82 hours and temperature distribution over 200 mm in the water bath using a SPRT
Ice point error of the test thermocouple	15 nV	estimated by withdrawing the CJ ends over 200 mm
Calibration of DVM used	150 nV	obtained from certificate from Japan Electric Meters Inspection Corporation
Drift of DVM since calibration	0.0000035*E +50 nV	obtained from catalog from manufacturer (Wavetek)
Stability of DVM	5 nV	estimated by stability of DVM over 12 days when an input terminal of the scanner being shorted during the room temperature fluctulating within 9 °C
Resolution of DVM	2.9 nV	obtained from catalog from manufacturer (Wavetek)
Stray emf of DVM	28 nV	estimated by 12 measurements of connection of the copper wires to the input terminal of the voltmeter
Stray emf of the scanner	29 nV	obtained from catalog from manufacturer (Data Proof)
Fixed points measurements		
Uncertainty of the Zn fixed point	3.7 mK	estimated using a Pt/Pd thermocouple
Uncertainty of the Al fixed point	5.8 mK	estimated using a Pt/Pd thermocouple
Uncertainty of the Ag fixed point	15 mK	estimated using a Pt/Pd thermocouple
Uncertainty of the Cu fixed point	21 mK	estimated using a Pt/Pd thermocouple
Furnace for the comparison measurements		
Temperature distribution	3.7 mK	estimated by temperature distribution over 120 mm using a SPRT
Temperature defference between thermometer wells	10 mK	assumed an uncertainty of 10 mK
Other Errors		
Fitting and interpolation error	120 - 380 nV	obtained by applying the law of propagation of uncertainty
AC pick up	0 mK	considered to be negligible

Name of Laboratory: NIM, China

The uncertainty budget for measurement in the fixed points

Item	Uncertainty component	probab. distribution	class.of uncertainty	ndard uncertainty,expressed in micro					
				PW	Sn	Zn	Al	Ag	Cu
1	Type A error of mean reading ,This type A uncertainty is the random variation of readings of the EMF of the thermocouple, with a standard deviation of mean.	normal	A	0.05	0.4	0.1	0.3	0.2	0.1
2	fixed points(1.Sn Fixed point error budget is considered of a factor of metal impurity analysis . 2.Zn,Al,Ag Fixed point errors is obtained from verification with groupe of reference thermcouples in tracing to primary standarad process ,3 Cu Fixed point error is estimated by metal impurity analysis and metal oxidization in atmoshpere ,4 TPW error is obtained from verification traced to primary standarad	rectangular	B	4E-04	0.004	0.61	0.67	0.75	0.78
3	The Inhomogeneity of thermocouple is obtained from data of Pilot Lab. in +/-0.01% of range	rectangular	B	5E-06	0.09	0.18	0.31	0.50	0.58
4	Ice point is obtained from 3 factors .1 realization of Ice Point,2 heat conduction along the the Cj and Cu wire depanded on the depth of immersion ,3 verification by glass thermometer	rectangular	B	0.15	0.15	0.15	0.15	0.15	0.15
5	DVM Error is obtained from a factor of specification in handbook of DVM in 90 days , a factor of drift since calibration and a factor of verification	rectangular	B	0.10	0.14	0.18	0.25	0.33	0.37
6	Scanner error is obtained from parasitical EMF of switch	rectangular	B	0.12	0.12	0.12	0.12	0.12	0.12
7	Cu wire and reference juction of thermocouple ,sacnner connector, DVM connector in measuring loop)	rectangular	B	0.10	0.10	0.10	0.10	0.10	0.10
8	TIP temperature difference estimated by heat conduction from TIP to metal,since the temperature uniformity along the cell is not ideal.	rectangular	B	1E-04	0.001	0.004	0.005	0.015	0.016
9	AC pickup is estimated by measuring DVM affected by the AC pickup from AC heater of furnace	rectangular	B	0.006	0.006	0.006	0.006	0.006	0.006
10	Rounding error is obtained of data rounded in report		B	0.006	0.006	0.006	0.006	0.006	0.006
Combined Standard Uncertainty expressed in microvolt				0.26	0.48	0.70	0.86	1.00	1.07
Combined Standard Uncertainty(℃)				0.049	0.052	0.067	0.074	0.077	0.079
Expanded Uncertainty(℃) in coverage factor *K*=2.0				**0.10**	**0.10**	**0.13**	**0.15**	**0.15**	**0.16**

The uncertainty budget for the interpolation points

Item	Uncertainty component	probab. distribution	class. of uncertainty	Standard uncertainty,expressed in microvolt											
				0°C	100°C	200°C	300°C	400°C	500°C	600°C	700°C	800°C	900°C	1000°C	1100°C
1	Interpolation of uncertainty from uncertainty of fixed piont to other pionts (A cubic polynomial fit function through the fixed points to spread others)		B	0.28	0.34	0.47	0.47	0.44	0.49	0.62	0.74	0.79	0.73	0.68	1.09
2	ftting and interpolation error (The largest deviation of data points from the fitting curve is use))	rectangular	B	0.46	0.65	0.76	0.84	0.90	0.94	0.98	1.02	1.07	1.11	1.14	1.18
3	Rounding error is obtained of data rounded in report	rectangular	B	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Combined Standard Uncertainty				0.54	0.73	0.90	0.96	1.00	1.06	1.16	1.27	1.32	1.32	1.33	1.61
Expanded Uncertainty(℃) in coverage factor *K*=2.0				**0.20**	**0.20**	**0.21**	**0.20**	**0.19**	**0.20**	**0.21**	**0.21**	**0.22**	**0.21**	**0.20**	**0.23**

Tested by: Chen weixin

Name of Laboratory : SPRING, Singapore

Type R thermocouple calibration at ice point final DT final Demf

Sensitive coefficient of test TC at 0 °C (□V/C) 5.29

Sensitive coefficient of test TC at 0 °C (□V/C) 5.29 -0.010 -0.053

No.	Sources of uncertainty	Uncertainty limit [°C/□V]	Units	Probability Distribution	Divisor	Standard uncertainty [u:(°C)]	Sensitivity coefficient [c]	[c* u]	Degrees of freedom
1	Test T (V(t))	0.001	°C	normal	1	0.00129	5.29	0.0068	1000000
2	Repeatability □V_{X1}	0.005	□V	t-distribution	1	0.00500	1	0.0050	9
3	Voltmeter spec □V_{X2}	0.040	□V	rectangular	1.732	0.02309	1	0.0231	1000000
4	Resolution□V_{X3}	0.050	□V	rectangular	1.732	0.02887	1	0.0289	1000000
5	Contact effect □V_{X4}	0.100	□V	rectangular	1.732	0.05774	1	0.0577	1000000
6	Reference ice point □t_0	0.005	°C	rectangular	1.732	0.00289	5.29	0.0153	1000000
7	Inhomogeneity □U_H	0.000	□V	normal	2	0.00002	1	0.0000	1000000
8	Immersion error □U_{IM}	0.005	°C	rectangular	1.732	0.00289	5.29	0.0153	1000000
9	Reproducibility	0.100	□V	rectangular	1.732	0.05774	1	0.0577	1000000

Combined standard uncertainty	0.09	□V	Un originated from fit	0.06	□V
Effective degrees of freedom	792113		Combined uncertainty with fit	0.1103	□V
Coverage factor	2				
Expended uncertainty	0.221	□V			
Expended uncertainty	0.042	°C			
Round up	0.4	□V			
Equivalent C	0.08	°C			

Note:

1	The uncertainty in the test temperature includes: a. Plateau identification; b. correctness of fixed point value which was defined by a SPRT; c. any possible drift of the fixed point value.
2	Standard deviation of 10 thermocouple emf readings.
3	The nanovoltmeter calibration certificate and stability tracking records showed that the errors of the meter were always within the specification.
4	The least significant digit of the nanovoltmeter was rounded to 0.1□V
5	This uncertainty originated from the contact effect of the scanner, possible drift of zero of the nanovoltmeter and possible influence from ambient parameters and connection leads.
6	The reference ice point uncertainty was estimated based on evaluation of the ice pot.
7	Inhomogeneity =0.009% of reading from NMIA, k=2
8	Immersion error was estimated based on evaluation of the ice pot.
9	Reproducibity = difference between first round and second round test at same conditions

Type R thermocouple calibration at Tin point final DT final Demf

Sensitive coefficient of test TC at 0 °C (□V/C)	5.29		
Sensitive coefficient of test TC at Tin point °C (□V/C)	9.168	0.071	0.653
Reading at Tin point (□V)	1756.89		

No.	Sources of uncertainty	Uncertainty limit [°C/□V]	Units	Probability Distribution	Divisor	Standard uncertainty [u:(°C)]	Sensitivity coefficient [c]	[c* u]	Degrees of freedom
1	Test T (V(t))	0.002	°C	normal	1	0.00238	9.168	0.0218	1000000
2	Repeatability □V_{X1}	0.011	□V	t-distribution	1	0.01100	1	0.0110	9
3	Voltmeter spec □V_{X2}	0.128	□V	rectangular	1.732	0.07381	1	0.0738	1000000
4	Resolution□V_{X3}	0.050	□V	rectangular	1.732	0.02887	1	0.0289	1000000
5	Contact effect □V_{X4}	0.100	□V	rectangular	1.732	0.05774	1	0.0577	1000000
6	Reference ice point □t_0	0.005	°C	rectangular	1.732	0.00289	5.29	0.0153	1000000
7	Inhomogeneity □U_H	0.158	□V	normal	2	0.07906	1	0.0791	1000000
8	Immersion error □U_{IM}	0.100	□V	rectangular	1.732	0.05774	1	0.0577	1000000
9	Reproducibility	0.140	□V	rectangular	1.732	0.08083	1	0.0808	1000000

Combined standard uncertainty	0.16	□V	Un originated from fit	0.10268	□V
Effective degrees of freedom	400592		Combined uncertainty with fit	0.19263	□V
Coverage factor	2				
Expanded uncertainty (U)	0.385	□V			
Expanded uncertainty (U)	0.042	°C			
Round up	0.5	□V			
Equivalent C	0.05	°C			

Type R thermocouple calibration at Zn point

	Value	final DT	final Demf
Sensitive coefficient of test TC at 0 °C (□V/C)	5.29		
Sensitive coefficient of test TC at Zn point °C (□V/C)	10.48	0.126	1.325
Reading at Zn point (□V)	3612.58		

No.	Sources of uncertainty	Uncertainty limit [°C/□V]	Units	Probability Distribution	Divisor	Standard uncertainty [u:(°C)]	Sensitivity coefficient [c]	[c* u]	Degrees of freedom
1	Test T (V(t))	0.004	°C	normal	1	0.00365	10.48	0.0383	1000000
2	Repeatability □V_{X1}	0.012	□V	t-distribution	1	0.01200	1	0.0120	9
3	Voltmeter spec □V_{X2}	0.221	□V	rectangular	1.732	0.12738	1	0.1274	1000000
4	Resolution□V_{X3}	0.050	□V	rectangular	1.732	0.02887	1	0.0289	1000000
5	Contact effect □V_{X4}	0.100	□V	rectangular	1.732	0.05774	1	0.0577	1000000
6	Reference ice point □t_0	0.005	°C	rectangular	1.732	0.00289	5.29	0.0153	1000000
7	Inhomogeneity □U_H	0.325	□V	normal	2	0.16257	1	0.1626	1000000
8	Immersion error □U_{IM}	0.250	□V	rectangular	1.732	0.14434	1	0.1443	1000000
9	Reproducibility	0.134	□V	rectangular	1.732	0.07737	1	0.0774	1000000

Combined standard uncertainty	0.27	□V	Un originated from fit	0.04523	□V
Effective degrees of freedom	1519488		Combined uncertainty with fit	0.27844	□V
Coverage factor	2				
Expanded uncertainty (U)	0.557	□V			
Expanded uncertainty (U)	0.053	°C			
Round up	0.7	□V			
Equivalent C	0.07	°C			

Type R thermocouple calibration at Al point		final DT	final Demf
Sensitive coefficient of test TC at 0 °C (□V/C)	5.29		
Sensitive coefficient of test TC at Al point °C (□V/C)	11.641	0.156	1.811
Reading at Al point (□V)	6278.89		

No.	Sources of uncertainty	Uncertainty limit [°C/□V]	Units	Probability Distribution	Divisor	Standard uncertainty [u:(°C)]	Sensitivity coefficient [c]	[c* u]	Degrees of freedom
1	Test T (V(t))	0.008	°C	normal	1	0.00757	11.641	0.0881	1000000
2	Repeatability □V_{X1}	0.012	□V	t-distribution	1	0.01200	1	0.0120	9
3	Voltmeter spec □V_{X2}	0.354	□V	rectangular	1.732	0.20436	1	0.2044	1000000
4	Resolution⊠ V_{X3}	0.050	□V	rectangular	1.732	0.02887	1	0.0289	1000000
5	Contact effect □V_{X4}	0.100	□V	rectangular	1.732	0.05774	1	0.0577	1000000
6	Reference ice point □t_0	0.005	°C	rectangular	1.732	0.00289	5.29	0.0153	1000000
7	Inhomogeneity □U_H	0.565	□V	Normal	2	0.28255	1	0.2826	1000000
8	Immersion error □U_{IM}	0.545	□V	rectangular	1.732	0.31467	1	0.3147	1000000
9	Reproducibility	0.080	□V	t-distribution	1	0.08006	1	0.0801	2

Combined standard uncertainty	0.49	□V	Un originated from fit	0.139004	□V
Effective degrees of freedom	2785		Combined uncertainty with fit	0.508579	□V
Coverage factor	2				
Expanded uncertainty (U)	1.017	□V			
Expanded uncertainty (U)	0.087	°C			
Round up	1.1	□V			
Equivalent C	0.09	°C			

Note:

1	The uncertainty in the test temperature includes: a. Plateau identification; b. correctness of fixed point value which was defined by a SPRT; c. any possible drift of the fixed point value.
2	Standard deviation of 10 thermocouple emf readings.
3	The nanovoltmeter calibration certificate and stability tracking records showed that the errors of the meter were always within the specification.
4	The least significant digit of the nanovoltmeter was rounded to 0.1□V
5	This uncertainty originated from the contact effect of the scanner, possible drift of zero of the nanovoltmeter and possible influence from ambient parameters and connection leads.
6	The reference ice point uncertainty was estimated based on evaluation of the ice pot.
7	Inhomogeneity =0.009% of reading from NMIA, k=2
8	Immersion error was estimated by taking the maximum difference in correction when the TC was withdrawn from 0cm to 20mm immersion with a step of 10 mm.
9	Reproducibity was estimated by taking the standard deviation of TC emf readings at 3 plateaus.

Type R thermocouple calibration at Ag point

		final DT	final Demf
Sensitive coefficient of test TC at 0 °C (□V/C)	5.29		
Sensitive coefficient of test TC at Ag point °C (□V/C)	13.065	0.139	1.821
Reading at Agpoint (□V)	10005.2		

No.	Sources of uncertainty	Uncertainty limit [°C/□V]	Units	Probability Distribution	Divisor	Standard uncertainty [u:(°C)]	Sensitivity coefficient [c]	[c* u]	Degrees of freedom
1	Test T (V(t))	0.011	°C	normal	1	0.01080	13.065	0.1411	1000000
2	Repeatability □V_{X1}	0.027	□V	t-distribution	1	0.02700	1	0.0270	9
3	Voltmeter spec □V_{X2}	0.700	□V	rectangular	1.732	0.40425	1	0.4042	1000000
4	Resolution□ V_{X3}	0.050	□V	rectangular	1.732	0.02887	1	0.0289	1000000
5	Contact effect □V_{X4}	0.100	□V	rectangular	1.732	0.05774	1	0.0577	1000000
6	Reference ice point □t_0	0.005	°C	rectangular	1.732	0.00289	5.29	0.0153	1000000
7	Inhomogeneity □U_H	0.900	□V	normal	2	0.45023	1	0.4502	1000000
8	Immersion error □U_{IM}	1.210	□V	rectangular	1.732	0.69861	1	0.6986	1000000
9	Reproducibility	0.166	□V	t-distribution	1	0.16600	1	0.1660	3

Combined standard uncertainty	0.95	□V
Effective degrees of freedom	3244	
Coverage factor	2	
Expanded uncertainty (U)	1.907	□V
Expanded uncertainty (U)	0.146	°C
Round up	2.0	□V
Equivalent C	0.15	°C

Un originated from fit	0.050946	□V
Combined uncertainty with fit	0.953613	□V

Uncertainity at 1100°C

1 The extrapolation error at 1100°C is estimated to be 1.36□V (equivalent to 0.1°C)

2 The uncertainty at 1100°C is obtained by combining the uncertainty at Ag point and the extrapolation error and rounded up to 2.5□V.

3 The uncertainty at temperature other than the fixed point temperature and 1100°C is interpolated between the two adjacent fixed points.

Name of Laboratory: SCL, HongKong,

Uncertainty Analysis for Calibration of Type R Thermocouple APMP-02

3. For measurment at 0.01 degree Celsius

Nominal Test Temperature	Measured emf of Test Thermocouple (uV)								Seebeck coefficient	Expanded uncertainty (°C)
	Standard Uncertainty of Components (uV)					Combined standard uncertainty	Coverage factor	Expanded uncertainty		
	Component 1	Component 2	Component 3	Component 4	Component 5					
0.01	0.00	0.01	0.00	0.02	0.10	0.10	2.005	0.20	5.29	0.039

Component 1 : Uncertainty of triple-point-of water cell from internal calibration
Component 2 : Inhomogeneity of test thermocouple provided by pilot laboratory
Component 3 : Type A error of mean reading of test thermocouple
Component 4 : Uncertainty of ice point cell for cold junctions of test thermocouple
Component 5 : Uncertainty of DVM readings for test thermocouple obtained from internal calibrations

Uncertainty Analysis for Calibration of Type R Thermocouple APMP-02

2. For measurments from 100 to 500 degree Celsius

Nominal Test Temperature	Measured emf of Test Thermocouple (uV)											Seebeck coefficient	Expanded uncertainty (°C)
	Standard Uncertainty of Components (uV)								Combined standard uncertainty	Coverage factor	Expanded uncertainty		
	Component 1	Component 2	Component 3	Component 4	Component 5	Component 6	Component 7	Component 8					
100	0.01	0.01	0.00	0.03	0.01	0.02	0.10	0.08	0.13	1.981	0.27	7.48	0.036
200	0.01	0.00	0.01	0.08	0.01	0.02	0.10	0.12	0.18	1.977	0.35	8.84	0.040
300	0.01	0.02	0.01	0.12	0.02	0.02	0.10	0.56	0.58	2.002	1.17	9.74	0.120
400	0.01	0.01	0.01	0.18	0.01	0.02	0.12	0.60	0.64	1.998	1.28	10.37	0.123
500	0.02	0.02	0.01	0.23	0.02	0.02	0.15	0.63	0.69	1.995	1.37	10.88	0.126

Component 1 : Uncertainty of reference SPRT from calibration certificates of SCL
Component 2 : Type A error of mean reading of reference SPRT
Component 3 : Uncertainty of resistance bridge readings for reference SPRT obtained from internal calibrations
Component 4 : Inhomogeneity of test thermocouple provided by pilot laboratory
Component 5 : Type A error of mean reading of test thermocouple
Component 6 : Uncertainty of ice point cell for cold junctions of test thermocouple
Component 7 : Uncertainty of DVM readings for test thermocouple obtained from internal calibrations
Component 8 : Tip temperature difference estimated from internal calibration of temperature uniformity of stirred liquid baths

Uncertainty Analysis for Calibration of Type R Thermocouple APMP-02

1. For measurments at or above 600 degree Celsius

Nominal Test Temperature	Measured emf of Test Thermocouple (uV)														Seebeck coefficient	Expanded uncertainty (°C)
	Standard Uncertainty of Components (uV)											Combined standard uncertainty	Coverage factor	Expanded uncertainty		
	Component 1	Component 2	Component 3	Component 4	Component 5	Component 6	Component 7	Component 8	Component 9	Component 10	Component 11					
600	1.75	1.10	1.14	0.02	0.60	0.02	0.29	0.03	0.02	0.60	2.84	3.80	1.978	7.52	11.37	0.661
700	1.75	1.10	1.18	0.02	0.70	0.02	0.34	0.03	0.02	0.70	2.96	3.94	1.978	7.79	11.83	0.659
800	1.75	1.10	1.23	0.02	0.80	0.02	0.40	0.03	0.02	0.80	3.08	4.09	1.978	8.09	12.31	0.657
900	1.75	1.10	1.28	0.02	0.91	0.02	0.46	0.03	0.02	0.91	5.11	5.82	1.989	11.58	12.78	0.906
1000	1.75	1.10	1.32	0.02	1.02	0.02	0.53	0.03	0.02	1.02	5.29	6.03	1.989	12.00	13.22	0.907
1100	1.75	1.10	1.36	0.05	1.14	0.02	0.59	0.07	0.02	1.14	5.45	6.23	1.989	12.39	13.62	0.909

Component 1 Uncertainty of reference thermocouple (including interpolation error) obtained from calibration certificates of NPL and SCL
Component 2 Inhomogeneity of reference thermocouple estimated from internal calibrations.
Component 3 Drift of reference thermocouple estimated from internal calibrations.
Component 4 Type A error of mean reading of reference thermocouple
Component 5 Uncertainty of DVM readings for reference thermocouple obtained from internal calibrations
Component 6 Uncertainty of ice point cell for cold junctions of reference thermocouple
Component 7 Inhomogeneity of test thermocouple provided by pilot laboratory
Component 8 Type A error of mean reading of test thermocouple
Component 9 Uncertainty of ice point cell for cold junctions of test thermocouple
Component 10 Uncertainty of DVM readings for test thermocouple obtained from internal calibrations
Component 11 Tip temperature difference estimated from internal calibration of temperature uniformity of furnace

Name of Laboratory : SIRIM, Malaysia

UNCERTAINTY EVALUATION/ANALYSIS

Cal. point	1		Test temperature	Ice-point	
Avg Reading (Ref)	0.00	°C	No. of reading		
Avg Reading (UUT)	-1E-07	uV	No. of reading	35	
StDev (UUT)	0.05	uV	Sensitivity	0.185	°C / uV

Symbol	Sources of Uncertainty	Dist.	Type	Value (±)	Unit	Divisor	v_i	Sensitivity coefficient	u_i
U_1	Repeated observation	Normal	A	0.009	uV	1	34	1	0.009
U_2	Cal. Of Std Ref Thermometer	Normal	B	0.025	°C	2	1.00E+10	5.5	0.069
U_3	Cal. Of DVM HP3458A	Normal	B	0.630	uV	2	1.00E+10	1	0.315
U_4	DVM HP3458A resolution	Rect	B	0.100	uV	1.73	1.00E+10	1	0.058
U_8	Ice-point (UUT)	Rect	B	0.005	°C	1.73	1.00E+10	5.4	0.016
U_{10}	Drift of DVM HP3458A	Rect	B	0.330	uV	1.73	1.00E+10	1	0.191
U_{11}	Inhomogeinity	Normal	B	0.000	uV	2	1.00E+10	1	0.000

$u_{combined}$		0.379
Effective degree of freedom		1.29E+08
	k	**2**
Expanded Uncertainty		**0.8**
	or	**0.14**

Cal. point	2		Test temperature	100.60	°C
Avg Reading (Ref)	100.60	°C	No. of reading	63	
Avg Reading (UUT)	650.9	uV	No. of reading	35	
StDev (UUT)	0.1	uV	Sensitivity	0.133	°C / uV

Symbol	Sources of Uncertainty	Dist.	Type	Value (±)	Unit	Divisor	v_i	Sensitivity coefficient	u_i
U_1	Repeated observation	Normal	A	0.017	uV	1	3.50E+01	1	0.017
U_2	Cal. Of Std Ref TC	Normal	B	0.500	°C	2	1.00E+10	7.35	1.838
U_3	Cal. Of DVM HP3458A	Normal	B	0.630	uV	2	1.00E+10	1	0.315
U_4	DVM HP3458A resolution	Rect	B	0.100	uV	1.73	1.00E+10	1	0.058
U_5	Axial Uniformity of furnace	Rect	B	0.100	°C	1.73	1.00E+10	7.5	0.434
U_6	Radial Uniformity of furnace	Rect	B	0.200	°C	1.73	1.00E+10	7.5	0.867
U_7	Ice-point (Std Ref TC)	Rect	B	0.005	°C	1.73	1.00E+10	7.35	0.021
U_8	Ice-point (UUT)	Rect	B	0.005	°C	1.73	1.00E+10	7.50	0.022
U_9	Drift of Std Ref TC	Rect	B	0.200	°C	1.73	1.00E+10	7.35	0.850
U_{10}	Drift of DVM HP3458A	Rect	B	0.330	uV	1.73	1.00E+10	1	0.191
U_{11}	Inhomogeinity	Normal	B	0.052	uV	2	1.00E+10	1	0.026

$u_{combined}$		2.276
Effective degree of freedom		7.48E+09
	k	**2**
Expanded Uncertainty		**4.6**

Cal. point	4		Test temperature	300.53	°C
Avg Reading (Ref)	300.53	°C	No. of reading	68	
Avg Reading (UUT)	2404.6	uV	No. of reading	32	
StDev (UUT)	0.1	uV	Sensitivity	0.103	°C / uV

Symbol	Sources of Uncertainty	Dist.	Type	Value (±)	Unit	Divisor	v_i	Sensitivity coefficient	u_i
U_1	Repeated observation	Normal	A	0.018	uV	1	32	1	0.018
U_2	Cal. Of Std Ref TC	Normal	B	0.500	°C	2	1.00E+10	9.15	2.288
U_3	Cal. Of DVM HP3458A	Normal	B	0.630	uV	2	1.00E+10	1	0.315
U_4	DVM HP3458A resolution	Rect	B	0.100	uV	1.73	1.00E+10	1	0.058
U_5	Axial Uniformity of furnace	Rect	B	0.100	°C	1.73	1.00E+10	9.7	0.561
U_6	Radial Uniformity of furnace	Rect	B	0.200	°C	1.73	1.00E+10	9.7	1.121
U_7	Ice-point (Std Ref TC)	Rect	B	0.005	°C	1.73	1.00E+10	9.15	0.026
U_8	Ice-point (UUT)	Rect	B	0.005	°C	1.73	1.00E+10	9.7	0.028
U_9	Drift of Std Ref TC	Rect	B	0.200	°C	1.73	1.00E+10	9.15	1.058
U_{10}	Drift of DVM HP3458A	Rect	B	0.330	uV	1.73	1.00E+10	1	0.191
U_{11}	Inhomogeinity	Normal	B	0.192	uV	2	1.00E+10	1	0.096

$u_{combined}$		2.841
Effective degree of freedom		1.07E+10
	k	**2**
Expanded Uncertainty		**5.7**
	or	**0.59**

Cal. point	5		Test temperature	400.41	°C
Avg Reading (Ref)	400.41	°C	No. of reading	82	
Avg Reading (UUT)	3412.1	uV	No. of reading	41	
StDev (UUT)	0.1	uV	Sensitivity	0.096	°C / uV

Symbol	Sources of Uncertainty	Dist.	Type	Value (±)	Unit	Divisor	v_i	Sensitivity coefficient	u_i
U_1	Repeated observation	Normal	A	0.016	uV	1	41	1	0.016
U_2	Cal. Of Std Ref TC	Normal	B	0.500	°C	2	1.00E+10	9.55	2.388
U_3	Cal. Of DVM HP3458A	Normal	B	0.630	uV	2	1.00E+10	1	0.315
U_4	DVM HP3458A resolution	Rect	B	0.100	uV	1.73	1.00E+10	1	0.058
U_5	Axial Uniformity of furnace	Rect	B	0.100	°C	1.73	1.00E+10	10.4	0.601
U_6	Radial Uniformity of furnace	Rect	B	0.200	°C	1.73	1.00E+10	10.4	1.202
U_7	Ice-point (Std Ref TC)	Rect	B	0.005	°C	1.73	1.00E+10	9.55	0.028
U_8	Ice-point (UUT)	Rect	B	0.005	°C	1.73	1.00E+10	10.4	0.030
U_9	Drift of Std Ref TC	Rect	B	0.200	°C	1.73	1.00E+10	9.55	1.104
U_{10}	Drift of DVM HP3458A	Rect	B	0.330	uV	1.73	1.00E+10	1	0.191
U_{11}	Inhomogeinity	Normal	B	0.273	uV	2	1.00E+10	1	0.136

$u_{combined}$		2.981
Effective degree of freedom		1.56E+10
	k	**2**
Expanded Uncertainty		**6.0**

Cal. point	6		Test temperature	500.21	°C
Avg Reading (Ref)	500.21	°C	No. of reading	82	
Avg Reading (UUT)	4474.7	uV	No. of reading	41	
StDev (UUT)	0.1	uV	Sensitivity	0.092	°C / uV

Symbol	Sources of Uncertainty	Dist.	Type	Value (±)	Unit	Divisor	v_i	Sensitivity coefficient	u_i
U_1	Repeated observation	Normal	A	0.016	uV	1	41	1	0.016
U_2	Cal. Of Std Ref TC	Normal	B	0.500	°C	2	1.00E+10	9.9	2.475
U_3	Cal. Of DVM HP3458A	Normal	B	0.630	uV	2	1.00E+10	1	0.315
U_4	DVM HP3458A resolution	Rect	B	0.100	uV	1.73	1.00E+10	1	0.058
U_5	Axial Uniformity of furnace	Rect	B	0.100	°C	1.73	1.00E+10	10.85	0.627
U_6	Radial Uniformity of furnace	Rect	B	0.200	°C	1.73	1.00E+10	10.85	1.254
U_7	Ice-point (Std Ref TC)	Rect	B	0.005	°C	1.73	1.00E+10	9.9	0.029
U_8	Ice-point (UUT)	Rect	B	0.005	°C	1.73	1.00E+10	10.85	0.031
U_9	Drift of Std Ref TC	Rect	B	0.200	°C	1.73	1.00E+10	9.9	1.145
U_{10}	Drift of DVM HP3458A	Rect	B	0.330	uV	1.73	1.00E+10	1	0.191
U_{11}	Inhomogeinity	Normal	B	0.358	uV	2	1.00E+10	1	0.179

$u_{combined}$		3.094
Effective degree of freedom		1.63E+10
	k	**2**
Expanded Uncertainty		**6.2**
	or	**0.57**

Cal. point	7		Test temperature	599.99	°C
Avg Reading (Ref)	599.99	°C	No. of reading	64	
Avg Reading (UUT)	5585.2	uV	No. of reading	32	
StDev (UUT)	0.1	uV	Sensitivity	0.088	°C / uV

Symbol	Sources of Uncertainty	Dist.	Type	Value (±)	Unit	Divisor	v_i	Sensitivity coefficient	u_i
U_1	Repeated observation	Normal	A	0.018	uV	1	32	1	0.018
U_2	Cal. Of Std Ref TC	Normal	B	0.300	°C	2	1.00E+10	10.2	1.530
U_3	Cal. Of DVM HP3458A	Normal	B	0.630	uV	2	1.00E+10	1	0.315
U_4	DVM HP3458A resolution	Rect	B	0.100	uV	1.73	1.00E+10	1	0.058
U_5	Axial Uniformity of furnace	Rect	B	0.100	°C	1.73	1.00E+10	11.35	0.656
U_6	Radial Uniformity of furnace	Rect	B	0.200	°C	1.73	1.00E+10	11.35	1.312
U_7	Ice-point (Std Ref TC)	Rect	B	0.005	°C	1.73	1.00E+10	10.2	0.029
U_8	Ice-point (UUT)	Rect	B	0.005	°C	1.73	1.00E+10	11.35	0.033
U_9	Drift of Std Ref TC	Rect	B	0.200	°C	1.73	1.00E+10	10.2	1.179
U_{10}	Drift of DVM HP3458A	Rect	B	0.330	uV	1.73	1.00E+10	1	0.191
U_{11}	Inhomogeinity	Normal	B	0.447	uV	2	1.00E+10	1	0.223

$u_{combined}$		2.465
Effective degree of freedom		8.98E+09
	k	**2**
Expanded Uncertainty		**4.9**
	or	**0.43**

Cal. point	8	Test temperature	700.97	°C
Avg Reading (Ref)	700.97 °C	No. of reading	48	
Avg Reading (UUT)	6757.4 uV	No. of reading	29	
StDev (UUT)	0.11 uV	Sensitivity	0.085	°C / uV

Symbol	Sources of Uncertainty	Dist.	Type	Value (±)	Unit	Divisor	v_i	Sensitivity coefficient	u_i
U_1	Repeated observation	Normal	A	0.020	uV	1	29	1	0.020
U_2	Cal. Of Std Ref TC	Normal	B	0.300	°C	2	1.00E+10	10.55	1.583
U_3	Cal. Of DVM HP3458A	Normal	B	0.630	uV	2	1.00E+10	1	0.315
U_4	DVM HP3458A resolution	Rect	B	0.100	uV	1.73	1.00E+10	1	0.058
U_5	Axial Uniformity of furnace	Rect	B	0.200	°C	1.73	1.00E+10	11.8	1.364
U_6	Radial Uniformity of furnace	Rect	B	0.200	°C	1.73	1.00E+10	11.8	1.364
U_7	Ice-point (Std Ref TC)	Rect	B	0.005	°C	1.73	1.00E+10	10.55	0.030
U_8	Ice-point (UUT)	Rect	B	0.005	°C	1.73	1.00E+10	11.8	0.034
U_9	Drift of Std Ref TC	Rect	B	0.200	°C	1.73	1.00E+10	10.55	1.220
U_{10}	Drift of DVM HP3458A	Rect	B	0.330	uV	1.73	1.00E+10	1	0.191
U_{11}	Inhomogeinity	Normal	B	0.541	uV	2	1.00E+10	1	0.270

$u_{combined}$		2.816
Effective degree of freedom		8.33E+09
	k	**2**
Expanded Uncertainty		**5.6**
	or	**0.48**

Cal. point	9	Test temperature	799.14	°C
Avg Reading (Ref)	799.14 °C	No. of reading	62	
Avg Reading (UUT)	7944.1 uV	No. of reading	31	
StDev (UUT)	0.43 uV	Sensitivity	0.081	°C / uV

Symbol	Sources of Uncertainty	Dist.	Type	Value (±)	Unit	Divisor	v_i	Sensitivity coefficient	u_i
U_1	Repeated observation	Normal	A	0.077	uV	1	31	1	0.077
U_2	Cal. Of Std Ref TC	Normal	B	0.300	°C	2	1.00E+10	10.9	1.635
U_3	Cal. Of DVM HP3458A	Normal	B	0.630	uV	2	1.00E+10	1	0.315
U_4	DVM HP3458A resolution	Rect	B	0.100	uV	1.73	1.00E+10	1	0.058
U_5	Axial Uniformity of furnace	Rect	B	0.200	°C	1.73	1.00E+10	12.3	1.422
U_6	Radial Uniformity of furnace	Rect	B	0.200	°C	1.73	1.00E+10	12.3	1.422
U_7	Ice-point (Std Ref TC)	Rect	B	0.005	°C	1.73	1.00E+10	10.9	0.032
U_8	Ice-point (UUT)	Rect	B	0.005	°C	1.73	1.00E+10	12.3	0.036
U_9	Drift of Std Ref TC	Rect	B	0.200	°C	1.73	1.00E+10	10.9	1.260
U_{10}	Drift of DVM HP3458A	Rect	B	0.330	uV	1.73	1.00E+10	1	0.191
U_{11}	Inhomogeinity	Normal	B	0.636	uV	2	1.00E+10	1	0.318

$u_{combined}$		2.925
Effective degree of freedom		6.36E+07
	k	**2**
Expanded Uncertainty		**5.8**
	or	**0.47**

Cal. point	10	Test temperature	900.50	°C
Avg Reading (Ref)	900.50 °C	No. of reading	65	
Avg Reading (UUT)	9215.8 uV	No. of reading	32	
StDev (UUT)	1.26 uV	Sensitivity	0.078	°C / uV

Symbol	Sources of Uncertainty	Dist.	Type	Value (±)	Unit	Divisor	v_i	Sensitivity coefficient	u_i
U_1	Repeated observation	Normal	A	0.223	uV	1	32	1	0.223
U_2	Cal. Of Std Ref TC	Normal	B	0.300	°C	2	1.00E+10	11.25	1.688
U_3	Cal. Of DVM HP3458A	Normal	B	0.630	uV	2	1.00E+10	1	0.315
U_4	DVM HP3458A resolution	Rect	B	0.100	uV	1.73	1.00E+10	1	0.058
U_5	Axial Uniformity of furnace	Rect	B	0.200	°C	1.73	1.00E+10	12.8	1.480
U_6	Radial Uniformity of furnace	Rect	B	0.300	°C	1.73	1.00E+10	12.8	2.220
U_7	Ice-point (Std Ref TC)	Rect	B	0.005	°C	1.73	1.00E+10	11.25	0.033
U_8	Ice-point (UUT)	Rect	B	0.005	°C	1.73	1.00E+10	12.8	0.037
U_9	Drift of Std Ref TC	Rect	B	0.200	°C	1.73	1.00E+10	11.25	1.301
U_{10}	Drift of DVM HP3458A	Rect	B	0.330	uV	1.73	1.00E+10	1	0.191
U_{11}	Inhomogeinity	Normal	B	0.737	uV	2	1.00E+10	1	0.369

$u_{combined}$		3.462
Effective degree of freedom		1.87E+06
	k	**2**
Expanded Uncertainty		**6.9**
	or	**0.54**

Cal. point	11	Test temperature	999.27	°C
Avg Reading (Ref)	999.27 °C	No. of reading	59	
Avg Reading (UUT)	10500.1 uV	No. of reading	34	
StDev (UUT)	1.54 uV	Sensitivity	0.074	°C / uV

Symbol	Sources of Uncertainty	Dist.	Type	Value (±)	Unit	Divisor	v_i	Sensitivity coefficient	u_i
U_1	Repeated observation	Normal	A	0.264	uV	1	34	1	0.264
U_2	Cal. Of Std Ref TC	Normal	B	0.300	°C	2	1.00E+10	11.55	1.733
U_3	Cal. Of DVM HP3458A	Normal	B	0.630	uV	2	1.00E+10	1	0.315
U_4	DVM HP3458A resolution	Rect	B	0.100	uV	1.73	1.00E+10	1	0.058
U_5	Axial Uniformity of furnace	Rect	B	0.200	°C	1.73	1.00E+10	13.2	1.526
U_6	Radial Uniformity of furnace	Rect	B	0.400	°C	1.73	1.00E+10	13.2	3.052
U_7	Ice-point (Std Ref TC)	Rect	B	0.005	°C	1.73	1.00E+10	11.55	0.033
U_8	Ice-point (UUT)	Rect	B	0.005	°C	1.73	1.00E+10	13.2	0.038
U_9	Drift of Std Ref TC	Rect	B	0.200	°C	1.73	1.00E+10	11.55	1.335
U_{10}	Drift of DVM HP3458A	Rect	B	0.330	uV	1.73	1.00E+10	1	0.191
U_{11}	Inhomogeinity	Normal	B	0.840	uV	2	1.00E+10	1	0.420

$u_{combined}$		4.101
Effective degree of freedom		1.98E+06
	k	**2**
Expanded Uncertainty		**8.2**
	or	**0.61**

Name of Laboratory : CMS- Taiwan

Sn (Tin)

Quantity	Sumbol	Estimation	Standard Uncertainty	Probability Distribution	Sensitivity	Degrees of freedom	Contribution
Mean emf of the tested TC (mV)	$\overline{V}_x$	1756.84	0.013	Normal	1	29	0.013
Calibration of DVM (mV)	dV_{c1}	0	0.35	Rectangular	1	8	0.35
Drift of DVM (mV)	dV_{c2}	0	0.5773503	Rectangular	1	8	0.57735027
Resolution of DVM (mV)	dV_{c3}	0	0.03	Rectangular	1	8	0.03
Amient parameter and connections (mV)	dV_R	0	0.026	Rectangular	1	8	0.026
Extension cable (mV)	dV_L	0	0	Rectangular	1	8	0
Inhomogeneity of TC (mV)	dV_H	0	0.1405472	Rectangular	1	8	0.1405472
Ice point (mV)	dt_{0S}	0.004	0.047	Normal	1	29	0.047
Determination of the fixed-point (mV)	dtD	0	0.012	Retangular	1	8	0.012
Temperature distribution within the cell	dtF	0	0.015	Retangular	1	8	0.015
EMF of the TC being calibrated (mV)	Vx	1756.84				1359833	0.69263327

Zn(Zinc)

Quantity	Sumbol	Estimation	Standard Uncertainty	Probability Distribution	Sensitivity	Degrees of freedom	Contribution
Mean emf of the tested TC (mV)	$\overline{V}_x$	3612.81	0.028	Normal	1	29	0.028
Calibration of DVM (mV)	dV_{c1}	0	0.35	Rectangular	1	8	0.35
Drift of DVM (mV)	dV_{c2}	0	0.5773503	Rectangular	1	8	0.57735027
Resolution of DVM (mV)	dV_{c3}	0	0.03	Rectangular	1	8	0.03
Amient parameter and connections (mV)	dV_R	0	0.026	Rectangular	1	8	0.026
Extension cable (mV)	dV_L	0	0	Rectangular	1	8	0
Inhomogeneity of TC (mV)	dV_H	0	0.2890248	Rectangular	1	8	0.2890248
Ice point (°C)	dt_{0S}	0.004	0.047	Normal	1	29	0.047
Determination of the fixed-point (mV)	dtD	0	0.026	Retangular	1	8	0.026
Temperature distribution within the cell	dtF	0	0.102	Retangular	1	8	0.102
EMF of the TC being calibrated (mV)	Vx	3612.81				1621319	0.74446872

Al (Aluminum)

Quantity	Sumbol	Estimation	Standard Uncertainty	Probability Distribution	Sensitivity	Degrees of freedom	Contribution
Mean emf of the tested TC (mV)	$\overline{V}_x$	6274.58	0.045	Normal	1	29	0.045
Calibration of DVM (mV)	dV_{c1}	0	0.35	Rectangular	1	8	0.35
Drift of DVM (mV)	dV_{c2}	0	0.5773503	Rectangular	1	8	0.57735027
Resolution of DVM (mV)	dV_{c3}	0	0.03	Rectangular	1	8	0.03
Amient parameter and connections (mV)	dV_R	0	0.026	Rectangular	1	8	0.026
Extension cable (mV)	dV_L	0	0	Rectangular	1	8	0
Inhomogeneity of TC (mV)	dV_H	0	0.5019664	Rectangular	1	8	0.5019664
Ice point (°C)	dt_{0S}	0.004	0.047	Normal	1	29	0.047
Determination of the fixed-point (mV)	dtD	0	0.038	Retangular	1	8	0.038
Temperature distribution within the cell	dtF	0	0.021	Retangular	1	8	0.021
EMF of the TC being calibrated (mV)	Vx	6274.58				1643852	0.84467366

Ag (Silver)

Quantity	Sumbol	Estimation	Standard Uncertainty	Probability Distribution	Sensitivity	Degrees of freedom	Contribution
Mean emf of the tested TC (mV)	$\overline{V}_x$	10003.16	0.023	Normal	1	29	0.023
Calibration of DVM (mV)	dV_{c1}	0	0.35	Rectangular	1	8	0.35
Drift of DVM (mV)	dV_{c2}	0	0.5773503	Rectangular	1	8	0.57735027
Resolution of DVM (mV)	dV_{c3}	0	0.03	Rectangular	1	8	0.03
Amient parameter and connections (mV)	dV_R	0	0.026	Rectangular	1	8	0.026
Extension cable (mV)	dV_L	0	0	Rectangular	1	8	0
Inhomogeneity of TC (mV)	dV_H	0	0.8002528	Rectangular	1	8	0.8002528
Ice point (°C)	dt_{0S}	0.004	0.047	Normal	1	29	0.047
Determination of the fixed-point (°C)	dtD	0	0.017	Retangular	1	8	0.017
Temperature distribution within the cell	dtF	0	0.089	Retangular	1	8	0.089
EMF of the TC being calibrated (mV)	Vx	10003.16				6903202	1.0527264

For others by using curve fitting

Temperature (°C)	0	100	200	300	400	500	600	700	800	900	1000	1100
Temperature (mV)	0	647.4	1468.6	2400.6	3407.7	4471.3	5583.5	6742.7	7949.84	9204.9	10506	11850
Um (mV)	0.678	0.678	0.678	0.678	0.678	0.678	0.678	0.678	0.67795	0.678	0.678	0.678
Inhomogeneity of TC (mV)	0	0.0518	0.1175	0.192	0.2726	0.3577	0.4467	0.5394	0.63599	0.7364	0.8405	0.948
Uapp (mV)	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95
RFU (mV) (<1064.18 (°C))	0.1323	0.187	0.2211	0.2435	0.2594	0.2721	0.2839	0.2958	0.3078	0.3196	0.3308	0.341
RFU (mV) (<=1100(°C); >1064.18)	0	0	0	0	0	0	0	0	0	0	0	1.363
Uex(uV)	0	0	0	0	0	0	0	0	0	0	1.33	1.33
EXU (mV) (0~961.78(°C)) (95%&k=1.96)	4.0547	4.0642	4.076	4.0918	4.1131	4.1412	4.1773	4.2222	4.27682	4.3415	0	0
EXU (mV) (961.78~1100(°C)) (95%&k=1.	0	0	0	0	0	0	0	0	0	0	5.1286	5.81
EXU (°C) (0~961.78(°C)) (95%&	0.7665	0.5434	0.4609	0.4202	0.3965	0.3804	0.3678	0.3569	0.34737	0.3396	0	0
EXU (°C) (961.78~1100(°C)) (95%&k=1.9	0	0	0	0	0	0	0	0	0	0	0.3876	0.426

Note:

1. CSU: Combined Standard Uncertainty
2. EU: Expanded Uncertainty
3. Um: The combined uncertainty includes the calibration , drift, and resolution of DVM, and amient parameter, connections, and ice point
4. Uapp: Uncertainty of the approximation of the deviation function
5. RFU: Uncertainty of reference function from NIST Monograph 175
6. Uex: Uncertainty of the extrapolation from 961.78 °C to 1100 °C
7. EXU: expanded uncertainty by curve fitting

Name of Laboratory : NPLI, INDIA

Temperature = 0°C

UNCERTAINTY BUDGET

Source of Uncertainty	Estimate of Quantity	Probability Distribution	Divisor	Standard Uncertainty	Sensitivity Coefficien	Uncertainty Contribution	Degrees freedom
Uncert.of Std used for calibration,Ub1	0.003000	Normal	2	0.0015	1.0000	0.0015	∞
Uncert. due to Furnace StabilityUb2.	0.00000	Rectangular	1.732	0.0000	0.0833	0.0000	∞
Uncert. due to DVM/BridgeUb3	0.0000000	Normal	3	0.0000	10.0000	0.0000	∞
in Std.Ub4	0.00000	Rectangular	1.732	0.0000	1.0000	0.0000	∞
inhomogeneity of TC	0.00016	Normal	2	0.0001	0.2000	0.0000	∞
Ub6	0.90000	Normal	2	0.4500	0.2000	0.0900	∞
Untof ref jnt Ub7	0.01000	Rectangular	1.732	0.0058	1.0000	0.0058	∞
Stab ice point Ub8	0.00000	Normal	2	0.0000	1.0000	0.0000	∞
Curve fitting Ub9	0.00250	Rectangular	1.732	0.0014	0.2000	0.0003	∞
Round Off Ub10	0.05000	Rectangular	1.732	0.0289	0.2000	0.0058	∞
Type A Std.Uas	0.00092	Normal	3.16228	0.0003	1.0000	0.0003	8
Type A UT,Uau	0.05676	Normal	3.16228	0.0180	0.2000	0.0036	8
Uncertainty, Uc.						0.0905	∞
							∞

Final Result = **1.590** ± **0.90** **Micro volt**

0.18091 DEG C

Temperature = 100°C

UNCERTAINTY BUDGET

Source of Uncertainty	Estimate of Quantity	Probability Distribution	Divisor	Standard Uncertainty	Sensitivity Coefficient	Uncertainty Contribution	Degrees freedom
Uncert.of Std used for calibration,Ub1	0.002500	Normal	2	0.001250	1.000000	0.001250	∞
Uncert. due to Furnace StabilityUb2.	2.00000	Rectangular	1.732	1.1547344	0.12500	0.144342	∞
Uncert. due to DVM/BridgeUb3	0.0000010	Normal	3	0.00000033	10.0000000	0.00000333	∞
Uncert. due to Drift in Std.Ub4	0.00330	Rectangular	1.732	0.001905	1	0.001905	∞
Uncert. Due to inhomogeneity of TC Ub5	0.05940	Normal	2	0.0297000	0.12500	0.003713	∞
Uncert.due to DVM Ub6	0.90000	Normal	2	0.4500000	0.1250000	0.056250	∞
Untof ref jnt Ub7	0.01000	Rectangular	1.732	0.00577367	1	0.005774	∞
Stab ice point Ub8	0.00300	Normal	2	0.0015	1	0.001500	∞
Curve fitting Ub9	-0.02100	Rectangular	1.732	-0.0121247	0.12500	-0.001516	∞
Round Off Ub10	0.05000	Rectangular	1.732	0.02886836	0.12500	0.003609	∞
Type A Std.Uas	0.00007	Normal	3.1622777	2.108E-05	1	0.000021	8
Type A UT,Uau	0.05164	Normal	3.1622777	0.01632993	0.12500	0.002041	8
Combined Uncertainty, Uc.						0.155154	∞
							∞

Final Result = **593.940** ± **2.482461** **Micro volts**

0.31031 DEG C

Temperature = 200°C

UNCERTAINTY BUDGET

Source of Uncertainty	Estimate of Quantity	Probability Distribution	Divisor	Standard Uncertainty	Sensitivity Coefficient	Uncertainty Contribution	Degrees of freedom
Uncert.of Std used for calibration,Ub1	0.002500	Normal	2	0.001250	1.000000	0.001250	∞
Uncert. due to Furnace StabilityUb2.	2.00000	Rectangular	1.732	1.1547344	0.12500	0.144342	∞
Uncert. due to DVM/BridgeUb3	0.0000010	Normal	3	0.00000033	10.0000000	0.00000333	∞
Uncert. due to Drift in Std.Ub4	0.00120	Rectangular	1.732	0.000693	1	0.000693	∞
Uncert. Due to inhomogeneity of TC Ub5	0.14630	Normal	2	0.0731500	0.12500	0.009144	∞
Uncert.due to DVM Ub6	0.90000	Normal	2	0.4500000	0.1250000	0.056250	∞
Unt of ref jnt Ub7	0.01000	Rectangular	1.732	0.00577367	1	0.005774	∞
Stab ice point Ub8	0.00300	Normal	2	0.0015	1	0.001500	∞
Curve fitting Ub9	0.10500	Rectangular	1.732	0.06062356	0.12500	0.007578	∞
Round Off Ub10	0.05000	Rectangular	1.732	0.02886836	0.12500	0.003609	∞
Type A Std.Uas	0.00004	Normal	3.1622777	1.3332E-05	1	0.000013	8
Type A UT,Uau	0.06749	Normal	3.1622777	0.02134375	0.12500	0.002668	8
Combined Uncertainty, Uc.						0.155555	∞
							∞

Final Result = **1462.670** ± **2.4889** **in Micro volts**

0.31111 **IN DEG C**

Temperature = 300°C

UNCERTAINTY BUDGET

Source of Uncertainty	Estimate of Quantity	Probability Distribution	Divisor	Standard Uncertainty	Sensitivity Coefficient	Uncertainty Contribution	Degrees of freedom
Uncert.of Std used for calibration,Ub1	0.002500	Normal	2	0.001250	1.000000	0.001250	∞
Uncert. due to Furnace StabilityUb2.	2.00000	Rectangular	1.732	1.1547344	0.11111	0.128304	∞
Uncert. due to DVM/BridgeUb3	0.0000010	Normal	3	0.00000033	10.0000000	0.00000333	∞
Uncert. due to Drift in Std.Ub4	0.00250	Rectangular	1.732	0.001443	1	0.001443	∞
Uncert. Due to inhomogeneity of TC Ub5	0.24230	Normal	2	0.1211500	0.11111	0.013461	∞
Uncert.due to DVM Ub6	0.90000	Normal	2	0.4500000	0.1111111	0.050000	∞
Untof ref jnt Ub7	0.01000	Rectangular	1.732	0.005773672	1	0.005774	∞
Stab ice point Ub8	0.00300	Normal	2	0.0015	1	0.001500	∞
Curve fitting Ub9	-0.32400	Rectangular	1.732	-0.18706697	0.11111	-0.020785	∞
Round Off Ub10	0.05000	Rectangular	1.732	0.02886836	0.11111	0.003208	∞
Type A Std.Uas	0.00005	Normal	3.162278	1.52747E-05	1	0.000015	8
Type A UT,Uau	0.13499	Normal	3.162278	0.042687496	0.11111	0.004743	8
Combined Uncertainty, Uc.						0.140168	∞
							∞

Final Result = **2422.940** ± **2.5230** **Micro volts**

0.28034 **DEG C**

UNCERTAINTY BUDGET at 400°C

Source of Uncertainty	Estimate of Quantity	Probability Distribution	Divisor	Standard Uncertainty	Sensitivity Coefficient	Uncertainty Contribution	Degrees of freedom
Uncert.of Std used for calibration,Ub1	0.003500	Normal	2	0.001750	1.000000	0.001750	∞
Uncert. due to Furnace StabilityUb2.	2.00000	Rectangular	1.732	1.1547344	0.10000	0.115473	∞
Uncert. due to DVM/BridgeUb3	0.0000010	Normal	3	0.00000033	10.0000000	0.00000333	∞
Uncert. due to Drift in Std.Ub4	0.00290	Rectangular	1.732	0.001674	1	0.001674	∞
Uncert. Due to inhomogeneity of TC Ub5	0.34411	Normal	2	0.1720550	0.10000	0.017206	∞
Uncert.due to DVM	0.90000	Normal	2	0.4500000	0.1000000	0.045000	∞
Untof ref jnt Ub7	0.01000	Rectangular	1.732	0.00577367	1	0.005774	∞
stab ice pointUb8	0.00300	Normal	2	0.0015	1	0.001500	∞
curve fittingUb9	0.65700	Rectangular	1.732	0.37933025	0.10000	0.037933	∞
Rounding offUb10	0.05000	Rectangular	1.732	0.02886836	0.10000	0.002887	∞
Type A Std.Uas	0.00003	Normal	3.1622777	9.9921E-06	1	0.000010	8
Type A UT,Uau	0.07379	Normal	3.1622777	0.02333334	0.10000	0.002333	8
Combined Uncertainty, Uc.						0.130955	∞
							∞

Final Result = **3441.090** ± **2.6191** **in Micro volts**

0.26191 **IN DEG C**

UNCERTAINTY BUDGET at 500°C

Source of Uncertainty	Estimate of Quantity	Probability Distribution	Divisor	Standard Uncertainty	Sensitivity Coefficient	Uncertainty Contribution	Degrees of freedom
Uncert.of Std used for calibration,Ub1	0.005500	Normal	2	0.002750	1.000000	0.002750	∞
Uncert. due to Furnace StabilityUb2.	2.00000	Rectangular	1.732	1.1547344	0.09091	0.104976	∞
Uncert. due to DVM/BridgeUb3	0.0000010	Normal	3	0.00000033	10.0000000	0.00000333	∞
Uncert. due to Drift in Std.Ub4	0.00010	Rectangular	1.732	0.000058	1	0.000058	∞
Uncert. Due to inhomogeneity of TC Ub5	0.45158	Normal	2	0.2257900	0.09091	0.020526	∞
Uncert.due to DVM Ub6	0.90000	Normal	2	0.4500000	0.0909091	0.040909	∞
Untof ref jnt Ub7	0.01000	Rectangular	1.732	0.00577367	1	0.005774	∞
Stab ice point Ub8	0.00300	Normal	2	0.0015	1	0.001500	∞
Curve fitting Ub9	-0.93500	Rectangular	1.732	-0.5398383	0.09091	-0.049076	∞
Round Off Ub10	0.05000	Rectangular	1.732	0.02886836	0.09091	0.002624	∞
Type A Std.Uas	0.00003	Normal	3.1622777	1E-05	1	0.000010	8
Type A UT,Uau	0.08756	Normal	3.1622777	0.02768875	0.09091	0.002517	8
Combined Uncertainty, Uc.						0.124819	∞
							∞

Final Result = **4515.790** ± **2.7460** **Micro volts**

0.24964 **DEG C**

UNCERTAINTY BUDGET at 600°C

Source of Uncertainty	Estimate of Quantity	Probability Distribution	Divisor	Standard Uncertainty	Sensitivity Coefficient	Uncertainty Contribution,	Degrees of freedom
Uncert.of Std used for calibration,Ub1	0.005500	Normal	2	0.002750	1.000000	0.002750	∞
Uncert. due to Furnace StabilityUb2.	2.00000	Rectangular	1.732	1.1547344	0.08333	0.096228	∞
Uncert. due to DVM/BridgeUb3	0.0000010	Normal	3	0.00000033	10.0000000	0.00000333	∞
Uncert. due to Drift in Std.Ub4	0.00010	Rectangular	1.732	0.000058	1	0.000058	∞
Uncert. Due to inhomogeneity of TC Ub5	0.56423	Normal	2	0.2821150	0.08333	0.023510	∞
Uncert.due to DVM Ub6	0.90000	Normal	2	0.4500000	0.0833333	0.037500	∞
Untof ref jnt Ub7	0.01000	Rectangular	1.732	0.00577367	1	0.005774	∞
Stab ice point Ub8	0.00300	Normal	2	0.0015	1	0.001500	∞
Curve fitting Ub9	0.89600	Rectangular	1.732	0.51732102	0.08333	0.043110	∞
Round Off Ub10	0.05000	Rectangular	1.732	0.02886836	0.08333	0.002406	∞
Type A Std.Uas	0.00005	Normal	3.162278	1.6326E-05	1	0.000016	8
Type A UT,Uau	0.06325	Normal	3.162278	0.02000002	0.08333	0.001667	8
Combined Uncertainty, Uc.						0.114582	∞
							∞

Final Result = 5642.280 ± 2.7500 in Micro volts

0.22916 IN DEG C

UNCERTAINTY BUDGET at 700°C

Source of Uncertainty	Estimate of Quantity	Probability Distribution	Divisor	Standard Uncertainty	Sensitivity Coefficient	Uncertainty Contribution	Degrees of freedom
Uncert.of Std used for calibration,Ub1	1.000000	Normal	2	0.500000	1.000000	0.500000	∞
Uncert. due to Furnace StabilityUb2.	2.00000	Rectangular	1.732	1.1547344	0.08333	0.096228	∞
Uncert. due to DVM/BridgeUb3	0.0000000	Normal	3	0.00000000	10.0000000	0.00000000	∞
Uncert. due to Drift in Std.Ub4	0.00000	Rectangular	1.732	0.000000	1	0.000000	∞
Uncert. Due to inhomogeneity of TC Ub5	0.68150	Normal	2	0.3407500	0.08333	0.028396	∞
Uncert.due to DVM Ub6	0.90000	Normal	2	0.4500000	0.0833333	0.037500	∞
Untof ref jnt Ub7	0.01000	Rectangular	1.732	0.005773672	1	0.005774	∞
Stab ice point Ub8	0.00300	Normal	2	0.0015	1	0.001500	∞
Curve fitting Ub9	-0.60400	Rectangular	1.732	-0.34872979	0.08333	-0.029061	∞
Round Off Ub10	0.05000	Rectangular	1.732	0.02886836	0.08333	0.002406	∞
Type A Std.Uas	0.08233	Normal	3.162278	0.026034227	1	0.026034	8
Type A UT,Uau	0.06667	Normal	3.162278	0.021081857	0.08333	0.001757	8
Combined Uncertainty, Uc.						0.512217	∞
							∞

Final Result = 6814.800 ± 12.2932 Micro volts

1.02443 DEG C

UNCERTAINTY BUDGET at 800°C

Source of Uncertainty	Estimate of Quantity	Probability Distribution	Divisor	Standard Uncertainty	Sensitivity Coefficient	Uncertainty Contribution	Degrees of freedom
Uncert.of Std used for calibration,Ub1	1.000000	Normal	2	0.500000	1.000000	0.500000	∞
Uncert. due to Furnace StabilityUb2.	2.00000	Rectangular	1.732	1.1547344	0.08333	0.096228	∞
Uncert. due to DVM/BridgeUb3	0.0000000	Normal	3	0.00000000	10.0000	0.00000000	∞
Uncert. due to Drift in Std.Ub4	0.00000	Rectangular	1.732	0.000000	1.0000	0.000000	∞
Uncert. Due to inhomogeneity of TC Ub5	0.80387	Normal	2	0.4019350	0.0833	0.033495	∞
Uncert.due to DVM Ub6	0.90000	Normal	2	0.4500000	0.0833	0.037500	∞
Untof ref jnt Ub7	0.01000	Rectangular	1.732	0.005773672	1	0.005774	∞
Stab ice point Ub8	0.00300	Normal	2	0.0015	1	0.001500	∞
Curve fitting Ub9	0.30600	Rectangular	1.732	0.176674365	0.08333	0.014723	∞
Round Off Ub10	0.05000	Rectangular	1.732	0.02886836	0.08333	0.002406	∞
Type A Std.Uas	0.09189	Normal	3.16228	0.029059299	1	0.029059	8
Type A UT,Uau	0.20575	Normal	3.16228	0.065064054	0.08333	0.005422	8
Combined Uncertainty, Uc.						0.511939	∞
							∞

Final Result = 8038.67 ± 12.2865 Micro volts

1.02388 DEG C

UNCERTAINTY BUDGET at 900°C

Source of Uncertainty	Estimate of Quantity	Probability Distribution	Divisor	Standard Uncertainty	Sensitivity Coefficient	Uncertainty Contribution	Degrees of freedom
Uncert.of Std used for calibration,Ub1	1.000000	Normal	2	0.500000	1.000000	0.500000	∞
Uncert. due to Furnace StabilityUb2.	2.00000	Rectangular	1.732	1.1547344	0.07692	0.088826	∞
Uncert. due to DVM/BridgeUb3	0.0000000	Normal	3	0.00000000	10.0000000	0.00000000	∞
Uncert. due to Drift in Std.Ub4	0.00000	Rectangular	1.732	0.000000	1	0.000000	∞
Uncert. Due to inhomogeneity of TC Ub5	0.93108	Normal	2	0.4655400	0.07692	0.035811	∞
Uncert.due to DVM Ub6	0.90000	Normal	2	0.4500000	0.0769231	0.034615	∞
Untof ref jnt Ub7	0.01000	Rectangular	1.732	0.0057737	1	0.005774	∞
Stab ice point Ub8	0.00300	Normal	2	0.0015	1	0.001500	∞
Curve fitting Ub9	-0.10200	Rectangular	1.732	-0.0588915	0.07692	-0.004530	∞
Round Off Ub10	0.05000	Rectangular	1.732	0.0288684	0.07692	0.002221	∞
Type A Std.Uas	0.19692	Normal	3.16227766	0.0622718	1	0.062272	8
Type A UT,Uau	0.18409	Normal	3.16227766	0.0582142	0.07692	0.004478	8
Combined Uncertainty, Uc.						0.510367	∞
							∞

Final Result = 9310.750 ± 13.2695 Micro volts

1.02073 DEG C

UNCERTAINTY BUDGET at 1000°C

Source of Uncertainty	Estimate of Quantity	Probability Distribution	Divisor	Standard Uncertainty	Sensitivity Coefficient	Uncertainty Contribution	Degrees of freedom
Uncert.of Std used for calibration,Ub1	1.000000	Normal	2	0.500000	1.000000	0.500000	∞
Uncert. due to Furnace StabilityUb2.	2.00000	Rectangular	1.732	1.1547344	0.07692	0.088826	∞
Uncert. due to DVM/BridgeUb3	0.0000000	Normal	3	0.00000000	10.0000000	0.00000000	∞
Uncert. due to Drift in Std.Ub4	0.00000	Rectangular	1.732	0.000000	1	0.000000	∞
Uncert. Due to inhomogeneity of TC Ub5	1.06275	Normal	2	0.5313750	0.07692	0.040875	∞
Uncert.due to DVM Ub6	0.90000	Normal	2	0.4500000	0.0769231	0.034615	∞
Untof ref jnt Ub7	0.01000	Rectangular	1.732	0.005773672	1	0.005774	∞
Stab ice point Ub8	0.00300	Normal	2	0.0015	1	0.001500	∞
Curve fitting Ub9	0.02000	Rectangular	1.732	0.011547344	0.07692	0.000888	∞
Round Off Ub10	0.05000	Rectangular	1.732	0.02886836	0.07692	0.002221	∞
Type A Std.Uas	0.32592	Normal	3.162278	0.10306417	1	0.103064	8
Type A UT,Uau	0.25386	Normal	3.162278	0.080277292	0.07692	0.006175	8
Combined Uncertainty, Uc.						0.533914	∞
							∞

Final Result =		**10627.50**	±	**13.8818**	**Micro volts**
				1.06783	**DEG C**

UNCERTAINTY BUDGET at 1100°C

Source of Uncertainty	Estimate of Quantity	Probability Distribution	Divisor	Standard Uncertainty	Sensitivity Coefficient	Uncertainty Contribution	Degrees of freedom
Uncert.of Std used for calibration,Ub1	1.000000	Normal	2	0.500000	1.000000	0.500000	∞
Uncert. due to Furnace StabilityUb2.	2.00000	Rectangular	1.732	1.1547344	0.07692	0.088826	∞
Uncert. due to DVM/BridgeUb3	0.0000000	Normal	3	0.00000000	10.0000000	0.00000000	∞
Uncert. due to Drift in Std.Ub4	0.00000	Rectangular	1.732	0.000000	1	0.000000	∞
Uncert. Due to inhomogeneity of TC Ub5	1.19818	Normal	2	0.5990900	0.07692	0.046084	∞
Uncert.due to DVM Ub6	0.90000	Normal	2	0.4500000	0.0769231	0.034615	∞
Untof ref jnt Ub7	0.01000	Rectangular	1.732	0.00577367	1	0.005774	∞
Stab ice point Ub8	0.00300	Normal	2	0.0015	1	0.001500	∞
Curve fitting Ub9	0.00000	Rectangular	1.732	0	0.07692	0.000000	∞
Round Off Ub10	0.05000	Rectangular	1.732	0.02886836	0.07692	0.002221	∞
Type A Std.Uas	0.24585	Normal	3.162278	0.07774602	1	0.077746	8
Type A UT,Uau	0.14757	Normal	3.162278	0.04666671	0.07692	0.003590	8
Combined Uncertainty, Uc.						0.511176	∞
							∞

Final Result =		**11981.78**	±	**13.2906**	**Micro volts**
				1.02235	**DEG C**

Name of Laboratory : NIMT, Thailand

Calibration record No.TL-05-049

Type R APMP-11 (from 0 to 500° C) Page......of......Pag

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sensitivity coef. (ci)	Standard uncertainty (°C)	Deg. of freedom
A	Repeatibility of STD / SPRT (oC)	0.00069	Normal	1	1.00	0.0007	6
B	Calibration of Indicator of STD (ohm)	0.0003	Normal	2	10.00	0.0015	∞
B	Drift of Indicator(ohm)	0.001	Rec.	SQRT(3)	10.00	0.0058	∞
B	Resolution of Indicator (oC)	0.001	Rec.	2SQRT(3)	1.00	0.0003	∞
B	Calibration of STD (oC)	0.004	Normal	2	1.00	0.0020	∞
B	Drift of STD (oC)	0.002	Rec.	SQRT(3)	1.00	0.0012	∞
B	Non-uniformity of temp. enclosure(oC)	0.005	Rec.	SQRT(3)	1.00	0.0029	∞
B	Intability of temp. enclosure(oC)	0.002	Rec.	SQRT(3)	1.00	0.0012	∞
-	Combinded standard uncertainty		normal			0.0072	> 200
-	Expanded uncertainty		normal (k=...)			0.0143	2.00

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sensitivity coef. (ci)	Standard uncertainty (uV)	Deg. of freedom
A	Indication of UUC(u V)	0.00715	Normal	1	1.00	0.00715	6
B	Calibration of voltmeter (u V)	0.13	Normal	2	1.00	0.06500	∞
B	Long term drift of voltmeter (u V)	1.00	Rec.	SQRT(3)	1.00	0.57735	∞
B	Resolution of voltmeter (u V)	0.01	Rec.	2SQRT(3)	1.00	0.002887	∞
B	Inhomogeneity of UUC 0.012% of E (u V)	0.00012	Rec.	SQRT(3)	1.00	0.00007	∞
B	Hysteresis of UUC 0.01% of E (u V)	0.00010	Rec.	SQRT(3)	1.00	0.000	∞
B	Instability of ref. temperature (oC)	0.03	Rec	SQRT(3)	5.4	0.09399	∞
B	Non-Uniformity of ref.temperature (oC)	0.03	Rec	SQRT(3)	5.4	0.09399	∞
B	Deviation of calibration temperature(oC)	0.0143	Normal	2	5.4	0.03881	∞
B	Correction due to electrical contact (u V)	1.0	Rec.	SQRT(3)	1.00	0.57735	∞
B	Correction due to interpolation data (u V)	1.0	Rec.	SQRT(3)	1.00	0.5774	∞
-	Combinded standard uncertainty		normal			1.01166	> 200
-	Expanded uncertainty (mV)		normal (k=...)			2.02332	2.00

Expanded uncertainty(oC) = 0.37 Calibration Point (oC) = 0.00

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sensitivity coef. (ci)	Standard uncertainty (°C)	Deg. of freedom
A	Repeatibility of STD / SPRT (oC)	0.000364	Normal	1	1.00	0.0004	6
B	Calibration of Indicator (ohm)	0.00003	Normal	2	10.00	0.0002	∞
B	Drift of Indicator(ohm)	0.001	Rec.	SQRT(3)	10.00	0.0058	∞
B	Resolution of Indicator (oC)	0.001	Rec.	2SQRT(3)	1.00	0.0003	∞
B	Calibration of STD (oC)	0.004	Normal	2	1.00	0.0020	∞
B	Drift of STD (oC)	0.002	Rec.	SQRT(3)	1.00	0.0012	∞
B	Non-uniformity of temp. enclosure(oC)	0.010	Rec.	SQRT(3)	1.00	0.0058	∞
B	Intability of temp. enclosure(oC)	0.009	Rec.	SQRT(3)	1.00	0.0052	∞
-	Combinded standard uncertainty		normal			0.0100	> 200
-	Expanded uncertainty		normal (k=...)			0.0199	2.00

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sensitivity coef. (ci)	Standard uncertainty (uV)	Deg. of freedom
A	Indication of UUC(u V)	0.00782	Normal	1	1.00	0.00782	6
B	Calibration of voltmeter (u V)	0.13	Normal	2	1.00	0.0650	∞
B	Long term drift of voltmeter (u V)	1.00	Rec.	SQRT(3)	1.00	0.5774	∞
B	Resolution of voltmeter (u V)	0.01	Rec.	2SQRT(3)	1.00	0.0029	∞
B	Inhomogeneity of UUC 0.012% of E (u V)	0.08	Rec.	SQRT(3)	1.00	0.0449	∞
	Instability of scaned temperature (oC)						
	Non-uniformity of scaned temperature (oC)						
B	Hysteresis of UUC 0.01% of E (u V)	0.06	Rec.	SQRT(3)	1.00	0.0375	∞
B	Instability of ref. temperature (oC)	0.03	Rec	SQRT(3)	5.4	0.0940	∞
B	Non-Uniformity of ref.temperature (oC)	0.03	Rec	SQRT(3)	5.4	0.0940	∞
B	Deviation of calibration temperature(oC)	0.020	Normal	2	7.4	0.0736	∞
B	Correction due to electrical contact (u V)	1.00	Rec.	SQRT(3)	1.00	0.5774	∞
B	Correction due to interpolation data (u V)	1.00	Rec.	SQRT(3)	1.00	0.5774	∞
-	Combinded standard uncertainty		normal			1.01529	> 200
-	Expanded uncertainty (mV)		normal (k=...)			2.03057	2.00

Expanded uncertainty(oC) = 0.27 Calibration Point (oC) = 100.00

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sensitivity coef. (ci)	Standard uncertainty (oC)	Deg. of freedom
A	Repeatability of STD / SPRT (oC)	0.000335	Normal	1	1.00	0.0003	6
B	Calibration of Indicator (ohm)	0.0003	Normal	2	10.00	0.0015	∞
B	Drift of Indicator(ohm)	0.001	Rec.	SQRT(3)	10.00	0.0058	∞
B	Resolution of Indicator (oC)	0.001	Rec.	2SQRT(3)	1.00	0.0003	∞
B	Calibration of STD (oC)	0.004	Normal	2	1.00	0.0020	∞
B	Drift of STD (oC)	0.002	Rec.	SQRT(3)	1.00	0.0012	∞
B	Non-uniformity of temp. enclosure(oC)	0.020	Rec.	SQRT(3)	1.00	0.0115	∞
B	Intability of temp. enclosure(oC)	0.015	Rec.	SQRT(3)	1.00	0.0087	∞
-	Combinded standard uncertainty		normal			0.0158	> 200
-	Expanded uncertainty		normal (k=...)			0.0316	2.00

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sensitivity coef. (ci)	Standard uncertainty (uV)	Deg. of freedom
A	Indication of UUC(u V)	0.00598	Normal	1	1.00	0.00598	6
B	Calibration of voltmeter (u V)	0.13	Normal	2	1.00	0.06500	∞
B	Long term drift of voltmeter (u V)	1.00	Rec.	SQRT(3)	1.00	0.57735	∞
B	Resolution of voltmeter (u V)	0.01	Rec.	2SQRT(3)	1.00	0.002887	∞
B	Inhomogeneity of UUC 0.012% of E (u V)	0.18	Rec.	SQRT(3)	1.00	0.10191	∞
B	Hysteresis of UUC 0.01% of E (u V)	0.15	Rec.	SQRT(3)	1.00	0.08492	∞
B	Instability of ref. temperature (oC)	0.03	Rec	SQRT(3)	5.4	0.09399	∞
B	Non-Uniformity of ref.temperature (oC)	0.03	Rec	SQRT(3)	5.4	0.09399	∞
B	Deviation of calibration temperature(oC)	0.0316	Normal	2	8.8	0.13880	∞
B	Correction due to electrical contact (u V)	1.000	Rec.	SQRT(3)	1.00	0.57735	∞
B	Correction due to interpolation data (u V)	1.000	Rec.	SQRT(3)	1.00	0.5774	∞
-	Combinded standard uncertainty		normal			1.02898	> 200
-	Expanded uncertainty (mV)		normal (k=...)			2.05796	2.00

Expanded uncertainty(°C) = 0.23 Calibration Point (oC) = 200.00

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sensitivity coef. (ci)	Standard uncertainty (^oC)	Deg. of freedom
A	Repeatability of STD / SPRT (oC)	0.000279	Normal	1	1.00	0.0003	6
B	Calibration of Indicator (ohm)	0.0003	Normal	2	10.00	0.0015	∞
B	Drift of Indicator(ohm)	0.001	Rec.	SQRT(3)	10.00	0.0058	∞
B	Resolution of Indicator (oC)	0.001	Rec.	2SQRT(3)	1.00	0.0003	∞
B	Calibration of STD (oC)	0.004	Normal	2	1.00	0.0020	∞
B	Drift of STD (oC)	0.002	Rec.	SQRT(3)	1.00	0.0012	∞
B	Non-uniformity of temp. enclosure(oC)	0.020	Rec.	SQRT(3)	1.00	0.0115	∞
B	Intability of temp. enclosure(oC)	0.015	Rec.	SQRT(3)	1.00	0.0087	∞
-	Combinded standard uncertainty		normal			0.016	> 200
-	Expanded uncertainty		normal (k=...)			0.032	2.00

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sensitivity coef. (ci)	Standard uncertainty (uV)	Deg. of freedom
A	Indication of UUC(uV)	0.00001	Normal	1	1.00	0.00001	6
B	Calibration of voltmeter (uV)	0.13	Normal	2	1.00	0.06500	∞
B	Long term drift of voltmeter (uV)	1.00	Rec.	SQRT(3)	1.00	0.57735	∞
B	Resolution of voltmeter(uV)	0.01	Rec.	2SQRT(3)	1.00	0.002887	∞
B	Inhomogeneity of UUC 0.012% of E (uV)	0.29	Rec.	SQRT(3)	1.00	0.17	∞
B	Hysteresis of UUC 0.01% of E (uV)	0.24	Rec.	SQRT(3)	1.00	0.14	∞
B	Instability of ref. temperature (oC)	0.03	Rec	SQRT(3)	5.4	0.09399	∞
B	Non-Uniformity of ref.temperature (oC)	0.03	Rec	SQRT(3)	5.4	0.09399	∞
B	Deviation of calibration temperature(oC)	0.0316	Normal	2	9.7	0.15321	∞
B	Correction due to electrical contact (uV)	1.0	Rec.	SQRT(3)	1.00	0.57735	∞
B	Correction due to interpolation data (uV)	1.0	Rec.	SQRT(3)	1.00	0.5774	∞
-	Combinded standard uncertainty		normal			1.05	> 200
-	Expanded uncertainty (mV)		normal (k=...)			2.09	2.00

Expanded uncertainty(oC) = 0.22 Calibration Point (oC) = 300.00

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sensitivity coef. (ci)	Standard uncertainty (^oC)	Deg. of freedom
A	Repeatability of STD / SPRT (oC)	0.000748	Normal	1	1.00	0.0007	6
B	Calibration of Indicator (ohm)	0.0003	Normal	2	10.00	0.0015	∞
B	Drift of Indicator(ohm)	0.001	Rec.	SQRT(3)	10.00	0.0058	∞
B	Resolution of Indicator (oC)	0.001	Rec.	2SQRT(3)	1.00	0.0003	∞
B	Calibration of STD (oC)	0.004	Normal	2	1.00	0.0020	∞
B	Drift of STD (oC)	0.010	Rec.	SQRT(3)	1.00	0.0058	∞
B	Non-uniformity of temp. enclosure(oC)	0.020	Rec.	SQRT(3)	1.00	0.0115	∞
B	Intability of temp. enclosure(oC)	0.015	Rec.	SQRT(3)	1.00	0.0087	∞
-	Combinded standard uncertainty		normal			0.0168	> 200
-	Expanded uncertainty		normal (k=...)			0.0336	2.00

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sensitivity coef. (ci)	Standard uncertainty (uV)	Deg. of freedom
A	Indication of UUC(uV)	0.014	Normal	1	1.00	0.01379	6
B	Calibration of voltmeter (uV)	0.130	Normal	2	1.00	0.06500	∞
B	Long term drift of voltmeter (uV)	1.000	Rec.	SQRT(3)	1.00	0.57735	∞
B	Resolution of voltmeter (uV)	0.010	Rec.	2SQRT(3)	1.00	0.002887	∞
B	Inhomogeneity of UUC 0.012% of E (uV)	0.409	Rec.	SQRT(3)	1.00	0.23627	∞
B	Hysteresis of UUC 0.01% of E (uV)	0.341	Rec.	SQRT(3)	1.00	0.19689	∞
B	Instability of ref. temperature (oC)	0.03	Rec	SQRT(3)	5.4	0.09399	∞
B	Non-Uniformity of ref.temperature (oC)	0.03	Rec	SQRT(3)	5.4	0.09399	∞
B	Deviation of calibration temperature(oC)	0.0336	Normal	2	10.3	0.17371	∞
B	Correction due to electrical contact (uV)	1.0	Rec.	SQRT(3)	1.00	0.57735	∞
B	Correction due to interpolation data (uV)	1.0	Rec.	SQRT(3)	1.00	0.5774	∞
-	Combinded standard uncertainty		normal			1.07091	> 200
-	Expanded uncertainty (mV)		normal (k=...)			2.14182	2.00

Expanded uncertainty(oC) = 0.21 Calibration Point (oC) = 400.00

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sensitivity coef. (ci)	Standard uncertainty (°C)	Deg. of freedom
A	Repeatibility of STD / SPRT (oC)	0.000194	Normal	1	1.00	0.0002	6
B	Calibration of Indicator (ohm)	0.0003	Normal	2	10.00	0.0015	∞
B	Drift of Indicator(ohm)	0.001	Rec.	SQRT(3)	10.00	0.0058	∞
B	Resolution of Indicator (oC)	0.001	Rec.	2SQRT(3)	1.00	0.0003	∞
B	Calibration of STD (oC)	0.004	Normal	2	1.00	0.0020	∞
B	Drift of STD (oC)	0.010	Rec.	SQRT(3)	1.00	0.0058	∞
B	Non-uniformity of temp. enclosure(oC)	0.020	Rec.	SQRT(3)	1.00	0.0115	∞
B	Intability of temp. enclosure(oC)	0.015	Rec.	SQRT(3)	1.00	0.0087	∞
-	Combinded standard uncertainty		normal			0.0168	> 200
-	Expanded uncertainty		normal (k=...)			0.0335	2.00

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sensitivity coef. (ci)	Standard uncertainty (uV)	Deg. of freedom
A	Indication of UUC(uV)	0.013	Normal	1	1.00	0.01280	6
B	Calibration of voltmeter(uV)	0.13	Normal	2	1.00	0.06500	∞
B	Long term drift of voltmeter (uV)	1.00	Rec.	SQRT(3)	1.00	0.57735	∞
B	Resolution of voltmeter (uV)	0.01	Rec.	2SQRT(3)	1.00	0.002887	∞
B	Inhomogeneity of UUC 0.012% of E (uV)	0.54	Rec.	SQRT(3)	1.00	0.309949	∞
B	Hysteresis of UUC 0.01% of E (uV)	0.45	Rec.	SQRT(3)	1.00	0.2583	∞
B	Instability of ref. temperature (oC)	0.03	Rec	SQRT(3)	5.4	0.09399	∞
B	Non-Uniformity of ref.temperature (oC)	0.03	Rec	SQRT(3)	5.4	0.09399	∞
B	Deviation of calibration temperature(oC)	0.0335	Normal	2	10.9	0.18219	∞
B	Correction due to electrical contact (uV)	1.0	Rec.	SQRT(3)	1.00	0.57735	∞
B	Correction due to interpolation data (uV)	1.0	Rec.	SQRT(3)	1.00	0.5774	∞
-	Combinded standard uncertainty		normal			1.10365	> 200
-	Expanded uncertainty (mV)		normal (k=...)			2.20730	2.00

Expanded uncertainty(oC) = 0.20 Calibration Point (oC) = 500.00

Check by ....

Uncertainty from 600 to 1100° C

Calibration record No.TL-05-049

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Type R

APMP-11

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sen. coef. (c_i)	Standard uncertainty (°C)	Deg. of freedom
A	Repeatibility of STD (uV)	0.05	Normal	1	0.098	0.0052	6
A	Repeatibility of STD (mV)	0.00	Normal	1	0.098	0.0000	6
B	Calibration of Indicator (uV)	0.13	Normal	2	0.098	0.0064	∞
B	Drift of Indicator(uV)	1.00	Rec.	SQRT(3)	0.098	0.0566	∞
B	Resolution of Indicator (uV)	0.00	Rec.	2SQRT(3)	1.0	0.000289	∞
B	Calibration of STD (°C)	0.30	Normal	2	1.0	0.1500	∞
B	Drift of STD (uV)	1.00	Rec.	SQRT(3)	0.098	0.0566	∞
B	Inhomogeneity of STD = 0.03% E(u	1.68	Rec.	SQRT(3)	0.098	0.0951	∞
B	Intability of temp. enclosure(°C)	0.10	Rec.	SQRT(3)	1.0	0.0577	∞
B	Drift & uniformity of temp. enclosu	0.20	Rec.	SQRT(3)	1.0	0.1155	∞
B	stability of ref. junction(°C)	0.03	Rec.	SQRT(3)	1.0	0.0173	∞
B	uniformity of ref.junction (°C)	0.03	Rec.	SQRT(3)	1.0	0.0173	∞
-	Combinded standard uncertainty		normal			0.2351	> 200
-	Expanded uncertainty		normal (k=...)			0.4703	2.00

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sen. coef. (c_i)	Standard uncertainty (uV)	Deg. of freedom
A	Indication of UUC(uV)	0.06	Normal	1	1.00	0.05898	6
B	Calibration of Indicator (uV)	0.13	Normal	2	1.00	0.06500	∞
B	Drift of Indicator(uV)	1.00	Rec.	SQRT(3)	1.00	0.57735	∞
B	Resolution of Indicator (uV)	0.01	Rec.	2SQRT(3)	1.00	0.002887	∞
B	Inhomogeneity of UUC 0.012% of E (uV)	0.67	Rec.	SQRT(3)	1.00	0.38778	∞
B	Hysteresis of UUC 0.01% of E (uV)	0.56	Rec.	SQRT(3)	1.00	0.32315	∞
B	Instability of ref. junction (°C)	0.03	Rec	SQRT(3)	5.4	0.09353	∞
B	Non-Uniformity of ref.junction (°C)	0.03	Rec	SQRT(3)	5.4	0.09353	∞
B	Deviation of calibration temperature(°C)	0.47	Normal	2	11.3	2.66478	∞
B	Correction due to electrical contact (uV)	2.00	Rec.	SQRT(3)	1.00	1.15470	∞
B	Correction due to interpolation data (uV)	1.00	Rec.	SQRT(3)	1.00	0.5774	∞
-	Combinded standard uncertainty		normal			3.06285	> 200
-	Expanded uncertainty (uV)		normal (k=...)			6.1257	2.00

Expanded uncertainty(°C) = 0.54 Calibration Point (°C) = 600

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sen. coef. (c_i)	Standard uncertainty (°C)	Deg. of freedom
A	Repeatibility of STD (uV)	0.02	Normal	1	0.095	0.0023	6
A	Repeatibility of STD (mV)	0.00	Normal	1	0.095	0.0000	6
B	Calibration of Indicator (uV)	0.13	Normal	2	0.095	0.0062	∞
B	Drift of Indicator(uV)	1.00	Rec.	SQRT(3)	0.095	0.0549	∞
B	Resolution of Indicator (uV)	0.01	Rec.	2SQRT(3)	1.0	0.002887	∞
B	Calibration of STD (°C)	0.30	Normal	2	1.0	0.1500	∞
B	Drift of STD (uV)	1.00	Rec.	SQRT(3)	0.095	0.0549	∞
B	Inhomogeneity of STD = 0.03% E(u	2.02	Rec.	SQRT(3)	0.095	0.1111	∞
B	Intability of temp. enclosure(°C)	0.10	Rec.	SQRT(3)	1.0	0.0577	∞
B	Drift& uniformity of temp. enclosure(°C)	0.20	Rec.	SQRT(3)	1.0	0.1155	∞
B	stability of ref. junction (°C)	0.03	Rec.	SQRT(3)	1.0	0.0173	∞
B	uniformity of ref.junction (°C)	0.03	Rec.	SQRT(3)	1.0	0.0173	∞
-	Combinded standard uncertainty		normal			0.2412	> 200
-	Expanded uncertainty		normal (k=...)			0.4825	2.00

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sen. coef. (c_i)	Standard uncertainty (uV)	Deg. of freedom
A	Indication of UUC(uV)	0.02	Normal	1	1.00	0.01924	6
B	Calibration of Indicator (uV)	0.13	Normal	2	1.00	0.06500	∞
B	Drift of Indicator(uV)	1.00	Rec.	SQRT(3)	1.00	0.57735	∞
B	Resolution of Indicator (uV)	0.01	Rec.	2SQRT(3)	1.00	0.002887	∞
B	Inhomogeneity of UUC 0.012% of E (uV)	0.81	Rec.	SQRT(3)	1.00	0.46756	∞
B	Hysteresis of UUC 0.01% of E (uV)	0.67	Rec.	SQRT(3)	1.00	0.38963	∞
B	Instability of ref. junction (°C)	0.03	Rec	SQRT(3)	5.4	0.09353	∞
B	Non-Uniformity of ref.junction (°C)	0.03	Rec	SQRT(3)	5.4	0.09353	∞
B	Deviation of calibration temperature(°C)	0.48	Normal	2	11.8	2.84818	∞
B	Correction due to electrical contact (uV)	2.00	Rec.	SQRT(3)	1.00	1.15470	∞
B	Correction due to interpolation data (uV)	1.00	Rec.	SQRT(3)	1.00	0.5774	∞
-	Combinded standard uncertainty		normal			3.24109	> 200
-	Expanded uncertainty (uV)		normal (k=...)			6.48218	2.00

Expanded uncertainty(°C) = 0.55 Calibration Point (°C) = 700

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sen. coef. (c_i)	Standard uncertainty (°C)	Deg. of freedom
A	Repeatibility of STD (uV)	0.06	Normal	1	0.092	0.0053	6
A	Repeatibility of STD (mV)	0.00	Normal	1	0.092	0.0000	6
B	Calibration of Indicator (uV)	0.13	Normal	2	0.092	0.0060	∞
B	Drift of Indicator(uV)	1.00	Rec.	SQRT(3)	0.092	0.0532	∞
B	Resolution of Indicator (uV)	0.01	Rec.	2SQRT(3)	1.0	0.002887	∞
B	Calibration of STD (°C)	0.30	Normal	2	1.0	0.1500	∞
B	Drift of STD (uV)	1.00	Rec.	SQRT(3)	0.092	0.0532	∞
B	Inhomogeneity of STD = 0.03%E(u	2.38	Rec.	SQRT(3)	0.092	0.1268	∞
B	Intability of temp. enclosure(°C)	0.15	Rec.	SQRT(3)	1.0	0.0866	∞
B	Drift& uniformity of temp. enclosure(°C)	0.30	Rec.	SQRT(3)	1.0	0.1732	∞
B	stability of ref. junction (°C)	0.03	Rec.	SQRT(3)	1.0	0.0173	∞
B	uniformity of ref.junction (°C)	0.03	Rec.	SQRT(3)	1.0	0.0173	∞
-	Combinded standard uncertainty		normal			0.2871	> 200
-	Expanded uncertainty		normal (k=...)			0.5741	2.00

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sen. coef. (c_i)	Standard uncertainty (uV)	Deg. of freedom
A	Indication of UUC(uV)	0.06	Normal	1	1.00	0.06160	6
B	Calibration of Indicator (uV)	0.13	Normal	2	1.00	0.06500	∞
B	Drift of Indicator(uV)	1.00	Rec.	SQRT(3)	1.00	0.57735	∞
B	Resolution of Indicator (uV)	0.01	Rec.	2SQRT(3)	1.00	0.002887	∞
B	Inhomogeneity of UUC 0.012% of E (uV)	0.95	Rec.	SQRT(3)	1.00	0.55107	∞
B	Hysteresis of UUC 0.01% of E (uV)	0.80	Rec.	SQRT(3)	1.00	0.45923	∞
B	Instability of ref. junction (°C)	0.03	Rec	SQRT(3)	5.4	0.09353	∞
B	Non-Uniformity of ref.junction (°C)	0.03	Rec	SQRT(3)	5.4	0.09353	∞
B	Deviation of calibration temperature(°C)	0.57	Normal	2	12.3	3.52754	∞
B	Correction due to electrical contact (uV)	2.00	Rec.	SQRT(3)	1.00	1.15470	∞
B	Correction due to interpolation data (uV)	1.00	Rec.	SQRT(3)	1.00	0.5774	∞
-	Combinded standard uncertainty		normal			3.87087	> 200
-	Expanded uncertainty (mV)		normal (k=...)			7.74174	2.00
	Expanded uncertainty(°C) =	0.63			Calibration Point (°C) =		800

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sen. coef. (c_i)	Standard uncertainty (°C)	Deg. of freedom
A	Repeatibility of STD (uV)	0.03	Normal	1	0.089	0.0023	6
A	Repeatibility of STD (mV)	0.00	Normal	1	0.089	0.0000	6
B	Calibration of Indicator (uV)	0.13	Normal	2	0.089	0.0058	∞
B	Drift of Indicator(uV)	1.00	Rec.	SQRT(3)	0.089	0.0516	∞
B	Resolution of Indicator (uV)	0.01	Rec.	2SQRT(3)	1.0	0.002887	∞
B	Calibration of STD (°C)	0.30	Normal	2	1.0	0.1500	∞
B	Drift of STD (uV)	1.00	Rec.	SQRT(3)	0.089	0.0516	∞
B	Inhomogeneity of STD = 0.03% E(u	2.76	Rec.	SQRT(3)	0.089	0.1423	∞
B	Intability of temp. enclosure(°C)	0.30	Rec.	SQRT(3)	1.0	0.1732	∞
B	Drift& uniformity of temp. enclosure(°C)	0.15	Rec.	SQRT(3)	1.0	0.0866	∞
B	stability of ref. junction (°C)	0.03	Rec.	SQRT(3)	1.0	0.0173	∞
B	uniformity of ref.junction (°C)	0.03	Rec.	SQRT(3)	1.0	0.0173	∞
-	Combinded standard uncertainty		normal			0.2936	> 200
-	Expanded uncertainty		normal (k=...)			0.587	2.00

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sen. coef. (c_i)	Standard uncertainty (uV)	Deg. of freedom
A	Indication of UUC(uV)	0.03	Normal	1	1.00	0.02780	6
B	Calibration of Indicator (uV)	0.13	Normal	2	1.00	0.06500	∞
B	Drift of Indicator(uV)	1.00	Rec.	SQRT(3)	1.00	0.57735	∞
B	Resolution of Indicator (uV)	0.01	Rec.	2SQRT(3)	1.00	0.002887	∞
B	Inhomogeneity of UUC 0.012% of E (uV)	1.10	Rec.	SQRT(3)	1.00	0.63795	∞
		0.00					
		0.00					
B	Hysteresis of UUC 0.01% of E (uV)	0.92	Rec.	SQRT(3)	1.00	0.53163	∞
B	Instability of ref. junction (°C)	0.03	Rec	SQRT(3)	5.4	0.09353	∞
B	Non-Uniformity of ref.junction (°C)	0.03	Rec	SQRT(3)	5.4	0.09353	∞
B	Deviation of calibration temperature(°C)	0.59	Normal	2	12.8	3.74751	∞
B	Correction due to electrical contact (uV)	2.00	Rec.	SQRT(3)	1.00	1.15470	∞
B	Correction due to interpolation data (uV)	1.00	Rec.	SQRT(3)	1.00	0.5774	∞
-	Combinded standard uncertainty		normal			4.09341	> 200
-	Expanded uncertainty (uV)		normal (k=...)			8.18681	2.00
	Expanded uncertainty(°C) =	0.64			Calibration Point (°C) =		900

Type	Source of uncertainty	Uncertaint y value	Probability distributio n	Divisor	Sen. coef. (c_i)	Standard uncertaint y	Deg. of freedom
A	Repeatibility of STD (uV)	0.10	Normal	1	0.087	0.0084	6
A	Repeatibility of STD (mV)	0.00	Normal	1	0.087	0.0000	6
B	Calibration of Indicator (uV)	0.13	Normal	2	0.087	0.0056	∞
B	Drift of Indicator(uV)	1.00	Rec.	SQRT(3)	0.087	0.0501	∞
B	Resolution of Indicator (uV)	0.01	Rec.	2SQRT(3)	1.0	0.0029	∞
B	Calibration of STD (°C)	0.30	Normal	2	1.0	0.1500	∞
B	Drift of STD (uV)	1.00	Rec.	SQRT(3)	0.087	0.0501	∞
B	Inhomogeneity of STD = 0.03% E(u	3.15	Rec.	SQRT(3)	0.087	0.1579	∞
B	Intability of temp. enclosure(°C)	0.15	Rec.	SQRT(3)	1.0	0.0866	∞
B	Drift& uniformity of temp. enclosure(°C)	0.30	Rec.	SQRT(3)	1.0	0.1732	∞
B	stability of ref. temperature (°C)	0.03	Rec.	SQRT(3)	1.0	0.0173	∞
B	uniformity of ref.temperature (°C)	0.03	Rec.	SQRT(3)	1.0	0.0173	∞
-	Combinded standard uncertainty		normal			0.3011	> 200
-	Expanded uncertainty		normal (k=...)			0.6022	2.00

Type	Source of uncertainty	Uncertaint y value	Probability distributio n	Divisor	Sen. coef. (c_i)	Standard uncertaint y (uV)	Deg. of freedom
A	Indication of UUC(uV)	0.13	Normal	1	1.00	0.12657	6
B	Calibration of Indicator (uV)	0.13	Normal	2	1.00	0.06500	∞
B	Drift of Indicator(uV)	1.00	Rec.	SQRT(3)	1.00	0.57735	∞
B	Resolution of Indicator (uV)	0.01	Rec.	2SQRT(3)	1.00	0.002887	∞
B	Inhomogeneity of UUC 0.012% of E (uV)	1.26	Rec.	SQRT(3)	1.00	0.72787	∞
		0.00					
		0.00					
B	Hysteresis of UUC 0.01% of E (uV)	1.05	Rec.	SQRT(3)	1.00	0.60655	∞
B	Instability of ref. junction(°C)	0.03	Rec	SQRT(3)	5.4	0.09353	∞
B	Non-Uniformity of ref.junction (°C)	0.03	Rec	SQRT(3)	5.4	0.09353	∞
B	Deviation of calibration temperature(°C)	0.60	Normal	2	13.2	3.97447	∞
B	Correction due to electrical contact (uV)	2.00	Rec.	SQRT(3)	1.00	1.15470	∞
B	Correction due to interpolation data (uV)	1.00	Rec.	SQRT(3)	1.00	0.5774	∞
-	Combinded standard uncertainty		normal			4.328	> 200
-	Expanded uncertainty (uV)		normal (k=...)			8.656	2.00

Expanded uncertainty(°C) = 0.66 Calibration Point (°C) = 1000

Type	Source of uncertainty	Uncertaint y value	Probability distributio n	Divisor	Sen. coef. (c_i)	Standard uncertaint y	Deg. of freedom
A	Repeatibility of STD (uV)	0.11	Normal	1	0.084	0.0089	6
A	Repeatibility of STD (mV)	0.00	Normal	1	0.084	0.0000	6
B	Calibration of Indicator (uV)	0.13	Normal	2	0.084	0.0055	∞
B	Drift of Indicator(uV)	1.00	Rec.	SQRT(3)	0.084	0.0487	∞
B	Resolution of Indicator (uV)	0.01	Rec.	2SQRT(3)	1.0	0.0029	∞
B	Calibration of STD (°C)	0.30	Normal	2	1.0	0.1500	∞
B	Drift of STD (uV)	1.00	Rec.	SQRT(3)	0.084	0.0487	∞
B	Inhomogeneity of STD = 0.03% E(u	3.55	Rec.	SQRT(3)	0.084	0.1731	∞
B	Intability of temp. enclosure(°C)	0.15	Rec.	SQRT(3)	1.0	0.0866	∞
B	Drift& uniformity of temp. enclosure(°C)	0.30	Rec.	SQRT(3)	1.0	0.1732	∞
B	stability of ref. junction (°C)	0.03	Rec.	SQRT(3)	1.0	0.0173	∞
B	uniformity of ref.junction (°C)	0.03	Rec.	SQRT(3)	1.0	0.0173	∞
-	Combinded standard uncertainty		normal			0.3089	> 200
-	Expanded uncertainty		normal (k=...)			0.6179	2.00

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sen. coef. (c_i)	Standard uncertainty (uV)	Deg. of freedom
A	Indication of UUC(uV)	0.03	Normal	1	1.00	0.02768	6
B	Calibration of Indicator (uV)	0.13	Normal	2	1.00	0.06500	∞
B	Drift of Indicator(uV)	1.00	Rec.	SQRT(3)	1.00	0.57735	∞
B	Resolution of Indicator (uV)	0.01	Rec.	2SQRT(3)	1.00	0.002887	∞
B	Inhomogeneity of UUC 0.012% of E (uV)	1.42	Rec.	SQRT(3)	1.00	0.81998	∞
B	Hysteresis of UUC 0.01% of E (uV)	1.18	Rec.	SQRT(3)	1.00	0.68331	∞
B	Instability of ref. junction (°C)	0.03	Rec	SQRT(3)	5.4	0.09353	∞
B	Non-Uniformity of ref.junction (°C)	0.03	Rec	SQRT(3)	5.4	0.09353	∞
B	Deviation of calibration temperature(°C)	0.62	Normal	2	13.6	4.20146	∞
B	Correction due to electrical contact (uV)	2.00	Rec.	SQRT(3)	1.00	1.15470	∞
B	Correction due to interpolation data (uV)	1.00	Rec.	SQRT(3)	1.00	0.5774	∞
-	Combinded standard uncertainty		normal			4.56224	> 200
-	Expanded uncertainty		normal (k=...)			9.12448	2.00

Expanded uncertainty(°C) = 0.67

Calibration Point (°C) = 1100

Uncertainty for fixed point

Calibration Record No. TL-05-049

Type R

APMP-11

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sensitivity coefficient (cI)	Standard uncertainty (°C)	Degrees of freedom
A	Scatter of fitted curve (uV)	0.009	normal	1	0.110	0.0010	16
B	Inhomogeneity of UUC (uV) =0.012% of E	0.211	rectangular	SQRT(3)	0.110	0.0134	∞
B	Calibration of fixed point cell (oC)	0.001	normal	2	1.0	0.0004	∞
B	Correction due to the calibration of fixed point cell (oC	0.000	rectangular	SQRT(3)	1.0	0.0000	∞
B	Calibration of emf indicator (uV)	0.065	normal	2	0.110	0.0036	∞
B	Voltage correction due to the contact (uV)	1.000	rectangular	SQRT(3)	0.110	0.0635	∞
B	Long term drift of voltmeter (uV)	1.000	rectangular	SQRT(3)	0.110	0.0635	∞
B	Resolution of emf indicator (uV)	0.010	rectangular	2*SQRT(3)	0.110	0.0003	∞
B	Fitting(uV)	1.000	rectangular	SQRT(3)	0.110	0.0317	∞
B	Uniformity of constant temperature ice bath (oC)	0.030	rectangular	SQRT(3)	1.0	0.0173	∞
B	Stability of constant temperature ice bath (oC)	0.030	rectangular	SQRT(3)	1.0	0.0173	∞
-	Combinded standard uncertainty		normal			0.099	> 500
-	Expanded uncertainty		normal (k= ...)			0.199	2.00

Calibration Point, (oC) = 231.939

Calibration Record No. TL-05-049

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sensitivity coefficient (cI)	Standard uncertainty (oC)	Degrees of freedom
A	Scatter of fitted curve (uV)	0.006	normal	1	0.096	0.0006	16
B	Inhomogeneity of UUC (uV)=0.012% of E	0.434	rectangular	SQRT(3)	0.096	0.0239	∞
B	Calibration of fixed point cell (oC)	0.001	normal	2	1.0	0.0007	∞
B	Correction due to the calibration of fixed point cell (oC	0	rectangular	SQRT(3)	1.0	0.0000	∞
B	Calibration of emf indicator (uV)	0.065	normal	2	0.096	0.0031	∞
B	Voltage correction due to the contact (uV)	1.000	rectangular	SQRT(3)	0.096	0.0552	∞
B	Long term drift of voltmeter (uV)	1.000	rectangular	SQRT(3)	0.096	0.0552	∞
B	Resolution of emf indicator (uV)	0.010	rectangular	2*SQRT(3)	0.096	0.0003	∞
B	Fitting(uV)	1.00	rectangular	SQRT(3)	0.096	0.0276	∞
B	Uniformity of constant temperature ice bath (oC)	0.030	rectangular	SQRT(3)	1.0	0.0173	∞
B	Stability of constant temperature ice bath (oC)	0.030	rectangular	SQRT(3)	1.0	0.0173	∞
-	Combinded standard uncertainty		normal			0.090	> 500
-	Expanded uncertainty		normal (k= ...)			0.179	2.00

Calibration Point, (oC) = 419.527

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sensitivity coefficient (cI)	Standard uncertainty (oC)	Degrees of freedom
A	Scatter of fitted curve (uV)	0.011	normal	1	0.086	0.0009	16
B	Inhomogeneity of UUC (uV)	0.753	rectangular	SQRT(3)	0.086	0.0374	∞
B	Calibration of fixed point cell (oC)	0.003	normal	2	1.0	0.0015	∞
B	Correction due to the calibration of fixed point cell (oC	0.000	rectangular	SQRT(3)	1.0	0.0000	∞
B	Calibration of emf indicator (uV)	0.065	normal	2	0.086	0.0028	∞
B	Voltage correction due to the contact (uV)	1.000	rectangular	SQRT(3)	0.086	0.0497	∞
B	Long term drift of voltmeter (uV)	1.000	rectangular	SQRT(3)	0.086	0.0497	∞
B	Resolution of emf indicator (uV)	0.010	rectangular	2*SQRT(3)	0.086	0.0002	∞
B	Fitting(uV)	1.000	rectangular	SQRT(3)	0.086	0.0249	∞
B	Uniformity of constant temperature ice bath (oC)	0.03	rectangular	SQRT(3)	1.0	0.0173	∞
B	Stability of constant temperature ice bath (oC)	0.03	rectangular	SQRT(3)	1.0	0.0173	∞
-	Combinded standard uncertainty		normal			0.087	> 500
-	Expanded uncertainty		normal (k= …)			0.174	2.00

Calibration Point, (oC) = 660.323

Type	Source of uncertainty	Uncertainty value	Probability distribution	Divisor	Sensitivity coefficient (cI)	Standard uncertainty (oC)	Degrees of freedom
A	Scatter of fitted curve (uV)	0.038	normal	1	0.077	0.0029	16
B	Inhomogeneity of UUC (uV)	1.200	rectangular	SQRT(3)	0.077	0.0532	∞
B	Calibration of fixed point cell (oC)	0.004	normal	2	1.0	0.0020	∞
B	Correction due to the calibration of fixed point cell (oC	0.000	rectangular	SQRT(3)	1.0	0.0000	∞
B	Calibration of emf indicator (uV)	0.065	normal	2	0.077	0.0025	∞
B	Voltage correction due to the contact (uV)	1.000	rectangular	SQRT(3)	0.077	0.0443	∞
B	Long term drift of voltmeter (uV)	1.000	rectangular	SQRT(3)	0.077	0.0443	∞
B	Resolution of emf indicator (uV)	0.010	rectangular	2*SQRT(3)	0.077	0.0002	∞
B	Fitting(uV)	5.00	rectangular	SQRT(3)	0.077	0.1107	∞
B	Uniformity of constant temperature ice bath (oC)	0.03	rectangular	SQRT(3)	1.0	0.0173	∞
B	Stability of constant temperature ice bath (oC)	0.03	rectangular	SQRT(3)	1.0	0.0173	∞
-	Combinded standard uncertainty		normal			0.140	> 500
-	Expanded uncertainty		normal (k= …)			0.280	2.00

Calibration Point, (oC) = 961.780

Name of Laboratory: CSIR, South Africa

Impurity: 15-7-1 to 5-4-5 comparisons of ice pts to WTP cells
Ref junction temp: larger than uncert of ice pt temp, since ref junction in 11mm (
Cal of DVM: 8-6-5 cal by CSIR-NML DCLF lab
Spec of DVM: 1-yr spec
Spurious thermal emfs: ch 0-9 of K705 scanner shorted

Cal of SPRT: Tinsley 5187SA vs Sn, Zn, Al freeze points
Drift of SPRT: max[|W(Dec 00) - W(May 03)|, |W(May 03) - W(Apr 05)|]
Stability of Rtp: |Rtp(after) - Rtp(before)| / 2
Cal of bridge: U(k=2) from RBC100 software
Temp diff: data with proc TH\RT-0002

Impurity: T(AL108) - T(TS-004) of 3 SPRTs on freeze, 14 & 18-4-05
Realisation: [T(F=1) - T(F=0.5)] of SPRT on freezes of 2 cells, 14 & 18-4-05
Gas press: 101325 Pa - p(ambient)
Hydrostatic head: no correction applied
Stem conduction: type S & R, 0->20mm from bottom, 27-7-05 freeze of AL108
Reproducibility: melt - freeze of SPRT in 2 cells, 13-18 Apr 2005

Impurity: T(TS-003) - T(Ag36) of 3 T/Cs on freeze, 21 Nov & 5 May 2003
Realisation: [T(S10-75,start) - T(S10-75,end)] on freeze of Ag36, 30-7-05
Stem conduction: type R & S, 0->20mm from bottom, 30-7-05 freeze of Ag36
Reproducibility: type S, freeze - melt in Ag36, 29 to 30-7-05

Impurity: T(Cu) - T(Au) of 3 type S & 1 type B, 19 Nov - 14 Dec 2002
Realisation: [T(F=1) - T(F=0)] of type S on freeze, 6-8-05
Stem conduction: type S, 0->20mm from bottom, 6-8-05 freeze
Reproducibility: type S, freeze - melt, 6-8-05

UUT: type =	R											
Rtp (Ω), Rs (Ω), dRs/dt (K-1):												
t(ref junction), t(a	0	22					0	22				
t (°C), emf (µV),	**0.00**	-0.36	10				**199.90**	1467.95	10			
	Value	Unit	Divisor	Sensitivity	ui(k=1) (µV)	D.o.f.	Value	Unit	Divisor	Sensitivity	ui(k=1) (µV)	D.o.f.
REF STD:												
Fixed pt:												
Chemical impurit	0.002	°C	1.732	5.28961724	**0.006**	500.0						
PRT:												
Cal of std thermom							0.0013	°C	2.000	8.84220712	**0.006**	500.0
Drift of std thermom							0.0006	°C	1.732	8.84220712	**0.003**	500.0
Stability of Rtp							0.0003	°C	1.732	15.6799151	**0.003**	500.0
Uncert of ref temp (WTP or ice pt)							0.0003	°C	2.000	15.6799151	**0.002**	500.0
Cal of meas instrum							1.90E-07	Ω/Ω	2.000	7073.62247	**0.001**	41.0
Spec of meas instrum								Ω/Ω	1.732	7073.62247	**0.000**	500.0
Ref resistor: cal												
Ref resistor: temp coeff							0.2	°C	1.732	0.00707362	**0.001**	500.0
Stem conduction								°C	1.732	8.84220712	**0.000**	500.0
HEAT SOURCE:												
Temp diff betw std & UUT							0.0043	°C	1.732	8.84220712	**0.022**	500.0
UUT:												
TC:												
Thermoelectric in	8.00E-05	V/V	2.000	-122.86104	**-0.005**	500.0	8.00E-05	V/V	2.000	1344.8731	**0.054**	500.0
Uncert of ref tem	0.01	°C	1.732	5.28961724	**0.031**	500.0	0.01	°C	1.732	5.28961724	**0.031**	500.0
Cal of meas. inst	0.02	µV	2.000	1	**0.010**	500.0	0.04	µV	2.000	1	**0.022**	500.0
Spec of meas. in	0.04	µV	1.732	1	**0.023**	500.0	0.11	µV	1.732	1	**0.065**	500.0
Spurious thermal	0.4	µV	1.732	1	**0.231**	500.0	0.4	µV	1.732	1	**0.231**	500.0
Curve fit residual	0.001	°C	1.732	5.28961724	**0.003**	500.0	0.002	°C	1.732	8.84220712	**0.010**	500.0
Compensating wire cold junction												
Stem conduction								°C	1.732	8.84220712	**0.000**	500.0
Repeatability	0.000	°C	1.000	5.28961724	**0.000**	1.0	0.002	°C	1.000	8.84220712	**0.015**	2.0
Reproducibility		µV	1.732	1	**0.000**	500.0		µV	1.732	1	**0.000**	500.0
uc(k=1) (µV):					0.234						0.251	
Eff d.o.f.					531.0						683.1	
t(eff d.o.f.):					2						2	
U(k=2) (µV):					**0.469**						**0.501**	
U(k=2) (°C):					0.089						0.057	

t(ref junction), t(a	0	22					0	22				
t (°C), emf (µV),	**419.72**	3614.71	10				**540.20**	4914.63	10			
	Value	Unit	Divisor	Sensitivity	ui(k=1) (µV)	D.o.f.	Value	Unit	Divisor	Sensitivity	ui(k=1) (µV)	D.o.f.
REF STD:												
Fixed pt:												
Chemical impurit												
PRT:												
Cal of std thermom	0.0012	°C	2.000	10.4813466	**0.006**	500.0	0.0036	°C	2.000	11.0762273	**0.020**	500.0
Drift of std thermom	0.0026	°C	1.732	10.4813466	**0.016**	500.0	0.0024	°C	1.732	11.0762273	**0.015**	500.0
Stability of Rtp	0.0003	°C	1.732	26.9327464	**0.005**	500.0	0.0003	°C	1.732	33.0305627	**0.006**	500.0
Uncert of ref temp (WTP or ice pt)	0.0003	°C	2.000	26.9327464	**0.004**	500.0	0.0003	°C	2.000	33.0305627	**0.005**	500.0
Cal of meas instrum	1.90E-07	Ω/Ω	2.000	12085.6833	**0.001**	41.0	1.90E-07	Ω/Ω	2.000	13315.9006	**0.001**	41.0
Spec of meas instrum	0.00E+00	Ω/Ω	1.732	12085.6833	**0.000**	500.0	0.00E+00	Ω/Ω	1.732	13315.9006	**0.000**	500.0
Ref resistor: cal												
Ref resistor: temp coeff	0.2	°C	1.732	-0.0060428	**-0.001**	500.0	0.2	°C	1.732	-0.006658	**-0.001**	500.0
Stem conduction		°C	1.732	10.4813466	**0.000**	500.0		°C	1.732	11.0762273	**0.000**	500.0
HEAT SOURCE:												
Temp diff betw std & UUT	0.00585	°C	1.732	10.4813466	**0.035**	500.0	0.00585	°C	1.732	11.0762273	**0.037**	500.0
UUT:												
TC:												
Thermoelectric in	8.00E-05	V/V	2.000	3490.45455	**0.140**	500.0	8.00E-05	V/V	2.000	4789.78237	**0.192**	500.0
Uncert of ref tem	0.01	°C	1.732	5.28961724	**0.031**	500.0	0.01	°C	1.732	5.28961724	**0.031**	500.0
Cal of meas. inst	0.08	µV	2.000	1	**0.039**	500.0	0.10	µV	2.000	1	**0.049**	500.0
Spec of meas. in	0.22	µV	1.732	1	**0.127**	500.0	0.29	µV	1.732	1	**0.165**	500.0
Spurious thermal	0.4	µV	1.732	1	**0.231**	500.0	0.4	µV	1.732	1	**0.231**	500.0
Curve fit residual	0.001	°C	1.732	10.4813466	**0.006**	500.0	0	°C	1.732	11.0762273	**0.000**	500.0
Compensating wire cold junction												
Stem conduction		°C	1.732	10.4813466	**0.000**	500.0		°C	1.732	11.0762273	**0.000**	500.0
Repeatability	0.002	°C	1.000	10.4813466	**0.024**	2.0	0.001	°C	1.000	11.0762273	**0.006**	2.0
Reproducibility		µV	1.732	1	**0.000**	500.0		µV	1.732	1	**0.000**	500.0
uc(k=1) (µV):					0.306						0.350	
Eff d.o.f.					1227.1						1524.5	
t(eff d.o.f.):					2						2	
U(k=2) (µV):					**0.612**						**0.701**	
U(k=2) (°C):					0.058						0.063	

t(ref junction), t(a	0	22					0	22				
t (°C), emf (µV),	**660.32**	6279.31	10				**961.78**	10004.47	10			
	Value	Unit	Divisor	Sensitivity	ui(k=1) (µV)	D.o.f.	Value	Unit	Divisor	Sensitivity	ui(k=1) (µV)	D.o.f.
REF STD:												
Fixed pt:												
Chemical impurit	0.003	°C	1.732	11.6412269	**0.018**	7.1	-0.026	°C	1.732	13.0646715	**-0.196**	500.0
PRT:												
Cal of std thermom												
Drift of std thermom												
Stability of Rtp												
Uncert of ref temp (WTP or ice pt)												
Cal of meas instrum												
Spec of meas instrum												
Ref resistor: cal												
Ref resistor: temp coeff												
Stem conduction												
HEAT SOURCE:												
Temp diff betw std & UUT												
UUT:												
TC:												
Thermoelectric in	8.00E-05	V/V	2.000	6154.22558	**0.246**	500.0	8.00E-05	V/V	2.000	9880.57216	**0.395**	500.0
Uncert of ref tem	0.01	°C	1.732	5.28961724	**0.031**	500.0	0.01	°C	1.732	5.28961724	**0.031**	500.0
Cal of meas. inst	0.12	µV	2.000	1	**0.060**	500.0	0.18	µV	2.000	1	**0.090**	500.0
Spec of meas. in	0.35	µV	1.732	1	**0.204**	500.0	0.54	µV	1.732	1	**0.312**	500.0
Spurious thermal	0.4	µV	1.732	1	**0.231**	500.0	0.4	µV	1.732	1	**0.231**	500.0
Curve fit residual	0.006	°C	1.732	11.6412269	**0.040**	500.0	0.019	°C	1.732	13.0646715	**0.143**	500.0
Compensating wire cold junction												
Stem conduction	-0.006	°C	1.732	11.6412269	**-0.037**	0.2	0.018	°C	1.732	13.0646715	**0.132**	0.1
Repeatability	0.06	µV	1.000	1	**0.060**	3.0	0.02	µV	1.000	1	**0.015**	3.0
Reproducibility	0.001	°C	1.732	11.6412269	**0.004**	1781.3	0.004	°C	1.732	13.0646715	**0.030**	500.0
uc(k=1) (µV):					0.409						0.631	
Eff d.o.f.					873.2						27.0	
t(eff d.o.f.):					2						2.11	
U(k=2) (µV):					**0.818**						**1.331**	
U(k=2) (°C):					0.070						0.102	

t(ref junction), t(a	0	22				
t (°C), emf (µV),	**1084.62**	11638.74	10			
	Value	Unit	Divisor	Sensitivity	ui(k=1) (µV)	D.o.f.
REF STD:						
Fixed pt:						
Chemical impurit	0.076	°C	1.732	13.5750462	**0.592**	2.2
PRT:						
Cal of std thermom						
Drift of std thermom						
Stability of Rtp						
Uncert of ref temp (WTP or ice pt)						
Cal of meas instrum						
Spec of meas instrum						
Ref resistor: cal						
Ref resistor: temp coeff						
Stem conduction						
HEAT SOURCE:						
Temp diff betw std & UUT						
UUT:						
TC:						
Thermoelectric in	8.00E-05	V/V	2.000	11517.5692	**0.461**	500.0
Uncert of ref tem	0.01	°C	1.732	5.28961724	**0.031**	500.0
Cal of meas. inst	0.21	µV	2.000	1	**0.103**	500.0
Spec of meas. in	0.62	µV	1.732	1	**0.359**	500.0
Spurious thermal	0.4	µV	1.732	1	**0.231**	500.0
Curve fit residual	0.035	°C	1.732	13.5750462	**0.274**	500.0
Compensating wire cold junction						
Stem conduction	-0.03	°C	1.732	13.5750462	**-0.235**	500.0
Repeatability	0.02	µV	1.000	1	**0.023**	2.0
Reproducibility	0.004	°C	1.732	13.5750462	**0.031**	500.0
uc(k=1) (µV):					1.163	
Eff d.o.f.					33.0	
t(eff d.o.f.):					2.09	
U(k=2) (µV):					**2.431**	
U(k=2) (°C):					0.179	

Calibration of:
Manufacturer:
Model number:
Serial number:
Calibrated for:
Period of calibration:
Certificate number:

Date	Deviation (µV)	Deviation (°C)	U(k=2) (µV)	U(k=2) (°C)
6/Aug/05	-0.280	-0.052	0.09	0.469
25/Jul/05	-3.580	-0.424	0.06	0.501
25/Jul/05	-9.620	-1.001	0.06	0.612
25/Jul/05	-13.620	-1.363	0.06	0.701
27/Jul/05	-16.660	-1.607	0.07	0.818
30/Jul/05	-27.590	-2.426	0.10	1.331
13/Dec/02	-33.570	-2.870	0.26	3.502
6/Aug/05	-34.140	-2.906	0.18	2.431
1/Aug/02	-60.710	-5.106	0.97	13.597