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APMP KEYCOMPARISON REPORT

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APMP-Key Comparison of Local realization of ITS-90 above silver point using radiation thermometers as transfer standards, APMP-T-K5-97

Final Report

Report
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Contents

1. Introduction

National Research Laboratory of Metrology in Japan (NRLM), now National Metrology Institute of Japan (NMIJ), submitted a proposal of the APMP key and supplementary comparison on radiation thermometer scales to the APMP Secretariat on October 2nd in 1996. The purpose was to undertake an RMO comparison of the local realizations of the ITS-90 above the silver point. The draft protocol was discussed on October 8th in 1997 at Beijing while Dr. M. Ballico from NML, Dr. Y. Duan from NIM, Mr. Lin John from CMS, Mr. Moussa from NIS, Ms. Othman from SIRIM, Dr. S. Park from KRISS, Dr. Wang Li from SPRING, Dr. F. Sakuma and Dr. A. Ono from NMIJ were attending. Dr. Ono chaired the meeting. A standard radiation thermometer should be used as a transfer standard between the participating laboratories. This comparison has been qualified as APMP key comparison with the potential effect of entailing documented bilateral agreements as to the equivalents of the local realizations of the ITS-90 in the temperature range from silver point up to 2800 °C in the highest case. The comparison started in November 1997 and ended in February 2000. This report describes the result of this comparison.

2. Organizations

NMIJ acted as a pilot institute. Contact persons are

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3. Participating laboratories and schedules

The participating economy, institutes and the contact parsons are listed in Table 1. The schedule of the key-comparison is listed in Table 2.

4. Comparison scheme

The comparison was performed with transfer standard radiation thermometers supplied by NMIJ. The comparison was carried out in the star scheme rather than the round-robin scheme. The radiation thermometer was hand-carried by one or two of NMIJ's staff and it was compared to the radiation thermometer of each institute by using a radiation source.

The main travel funding was supported by the Agency of Industrial Science and Technology (AIST) in Japan in the project "Research on development and transfer technology of radiation thermometers and standard radiation sources" from April 1996 to December 2000.

5. Instruments

The transfer standard radiation thermometers selected are denoted by Topcon 019 and 181, respectively. The radiation thermometer Topcon 019 was used in the comparison between KRISS and NMIJ and Topcon 181 was used in other comparisons. The thermometer was calibrated before the transfer and after the transfer it was checked by the copper-point blackbody for the stability at each institute, if available. On return to NMIJ, it was recalibrated. No large difference from calibration at NMIJ was found in the check.

Table 3 shows the list of parameters of the radiation thermometers used in the comparison. The central wavelengths of all the radiation thermometers were close to 650 nm. The stability of the transfer standard radiation thermometer before and after the transportation are shown in Appendix A. The radiation thermometer had the enough stability for the comparison of scales.

Parameters of the radiation sources used in the comparison are listed in Table 4. Black bodies were mostly used for the comparison between radiation thermometers. At NIM and ITRI standard lamps were used. The size of the source effect and the ambient temperature effect were corrected for the transfer standard radiation thermometer. In the lamp comparison almost the same method was used as in the CCT key comparison. Temperature range measured in this comparison was from the silver point or 1000°C to at least 1500°C and at the highest 2800°C.

Some uniformity information of the radiation sources are shown in Appendix C. If the uniformity is not good, then the alignment of the radiation thermometers are very important. The nonuniformity of the micron furnace used above 1600°C caused much larger scatter than the land furnace below that temperature in the comparison between SPRING and NMIJ.

Table 5 shows the parameters of the fixed point blackbodies for the comparison. Silver, copper and gold points are used. The purity was all better than five nines. Emissivity was estimated from 0.999 to 0.99995. The scale was calculated by the method of effective wavelength or integral.

6. Results of each institute

Results of each institute compared to NMIJ are shown in the Appendix B.

Following are short notes for each comparison.

6.1 KRISS

This was the first comparison. The first run and the second run agreed very well. The 1085°C point was a little out partly because this was measured after the run from 1000°C to 1800°C and then continued again from 2000°C to 2500°C. Though the agreement was as much as 0.4°C between 1000°C and 1600°C, the agreement at higher temperature was within 1°C. The difference was within the range of the expanded uncertainty (*k* =2).

6.2 NIM

NIM used a vacuum standard lamp for the key comparison. So the temperature range was limited to 1700°C. The first run and the second run agreed very well. The agreement was better than 0.2°C at the silver point and the difference increased as temperature goes up and the difference at 1700°C was about 0.5°C. The difference was within the range of the expanded uncertainty (*k* =2).

6.3 NMC/SPRING

SPRING used two blackbodies. One was a Land furnace used from 1000°C to 1600°C and the other was a Micron furnace used from 1600°C to 2800°C. In case of the Land furnace, the first run and the second run agreed very well. Also the agreement between NMIJ and SPRING was better than 0.2°C and within the expanded uncertainty (k=2). However, in case of the Micron furnace, the measurement results were affected by pyrometer's alignment due to its small aperture, large temperature distribution and changing position by heating. Therefore, a much larger uncertainty was found. The difference between NMIJ and SPRING was within 2°C and within the range of expanded uncertainty (*k* =2).

6.4 KIM LIPI

KIM LIPI also used a Land furnace. Three runs agreed very well. At 1000°C and 1085°C the agreement was better than 0.4°C. At 1300°C the difference increased to 1°C and at 1500V, to 2°C. The difference was within the range of the expanded uncertainty (*k*=2).

6.5 CMS/ITRI

ITRI used a vacuum standard lamp. Two runs agreed well. Below 1200°C the difference was smaller than 0.5 °C. But as temperature increased, the difference increased rapidly and reached 3.5 °C at 1700°C. The difference was within the expanded uncertainty up to 1300°C. However from 1400°C to 1700°C the difference was more than the expanded uncertainty. ITRI reported the correction of their scale later. The corrected result is shown in Appendix F.

6.6 NML/CSIRO

CSIRO used a Thermogage blackbody. The two runs agreed well. The agreement was within 0.5°C in the whole range from 1000°C to 2200°C. The difference was within the expanded uncertainty.

7. Results at each temperature

Appendix D shows the comparison result at each temperature. Some data shown in closed diamonds are interpolated from nearby two temperature data.

8. Reference value calculation

Figures E1 in Appendix E shows the comparison result between KRISS and NMIJ where the first run and second run are averaged. The Approx shows the interpolation curve approximated in the second order equation. The residue is small enough compared to the standard deviation. Similar approximations are made for NIM, SPRING and CSIRO and the results are shown in Figs. E2, E3 and E4. In case of SPRING only the data of the L and blackbody were used. Figure 5 shows the summary of the approximations from 962°C to 1700°C. The average of the four curves plus NMIJ is shown in the thick solid line. This is the APMP reference value and is smaller than 0.1°C in the temperature range below 1700°C.

9. Comparison to the result of CCT key comparison

Five of the seven institutes participating in this comparison also participated in the CCT key comparison (CCT k-5). The five institutes are KRISS, NIM, SPRING, CSIRO and NMIJ. Among these SPRING changed their method of establishing their scales. Therefore it was removed from the difference calculation. The data are shown in Appendix G. The difference between APMP and CCT was about 0.3°C at 1000°C and increased to 0.8°C at 1600°C or 1700°C.

Table Captions

Table 1 List of participating economy, institute and contact person.

Table 2 Schedule of the comparison

Table 3 Summary of parameters of the radiation thermometers used for the APMP comparison.

Table 4 Summary of parameters of the radiation sources used for the APMP comparison

Table 5 Summary of param eters of t he f ixed poi nts used for t he A PMP com parison and t he calculation methods

Table 1 List of participating economy, institute and contact person.

Economy	Institute	Contact person
Japan NM	IJ/AIST	F. Sakuma
Korea K	RISS	S.N. Park
China N	IM	Duan Y.N.
Singapore NMC/SPRI	NG	Wang Li
Indonesia K	IM-LIPI	W. Hidayat
Taiwan CMS/I	TRI	J. Lin
Australia NM	L/CSIRO	M. Ballico

Table 2 Schedule of the comparison

Institute Y	ear and month
KRISS 1997.9.	
NIM 1998.10.	
NMC/SPRING 1999.9.	
Kim LIPI	1999.9.
CMS/ITRI 1999.1	1
NML/CSIRO 2000.2.	

Table 3 Summary of parameters of the radiation thermometers used for the APMP comparison.

Laboratory	Radiation themometer	Target distance	Target size	f-number	Central wavelength	FWHM	Optics
		[mm]	[mm]		[nm]	[nm]	
NMIJ	Topcon 019	500	2	12	650.3	14.7	Lenses
NMIJ	Topcon 181	500	1	12	650.3	14.7	Lenses
NMIJ	Topcon 181	250	0.5	6	650.3	14.7	Lenses
KRISS	KPEP	500	0.8	5	650	10	Lenses
NIM	9305	720	0.75	15	660	11.8	Lenses
NMC/SPRING	IMGC-SP1	505	1	12	655	11	Lenses
KIM LIPI	LP2				650	10	Lenses
ITRI /CMS	LP2	820	1		650	10.8	Lenses
NML/CSIRO	HTSP	600	0.6	10	650	10	Lenses

Table 4 Summary of parameters of the radiation sources used for the APMP comparison

Laboratory	Black body or Lamp	Aperture diameter or Ribbon Width	Cavity or Ribbon material	Temperature range	Windows
		[mm]		[°C]	
KRISS	Thermogage BB	38	graphite	1000～2500	No
NIM	Vacuum Lamp	1.5	tungsten	962～1700	Yes
NMC/SPRING	Land P1600B	50	SiC	1000～1600	No
NMC/SPRING	Micron BB	15	graphite	1000～2800	No
KIM LIPI	Land P1600B	50	SiC	1000～1500	No
CMS/ITRI	Vacuum Lamp	1.5	tungsten	1000～1700	Yes
NML/CSIRO	Thermogage BB	25	graphite	1000～2200	No

Table 5 Summary of parameters of the fixed points used for the APMP comparison and the calculation methods

Laboratory	Fixed point metal	Fixed point purity	Fixed point emissivity	Calculation method	
		[%]	[–]	Effective wavelength	Integral
NLRM	Ag, Cu	99.999	0.999		X
KRISS	Cu	99.999	0.99995		X
NIM	Ag	99.9992	0.99992	X	
NMC/SPRING	Ag, Cu	99.999	0.9999	X	
KIM LIPI	Cu	99.999	0.999		
CMS/ITRI	Cu	99.999	0.999	X	
NML/CSIRO	Au	99.999	0.99995		X

Appendix A : Stability of transfer standard radiation thermometer

A1 Stability in the comparison with KRISS

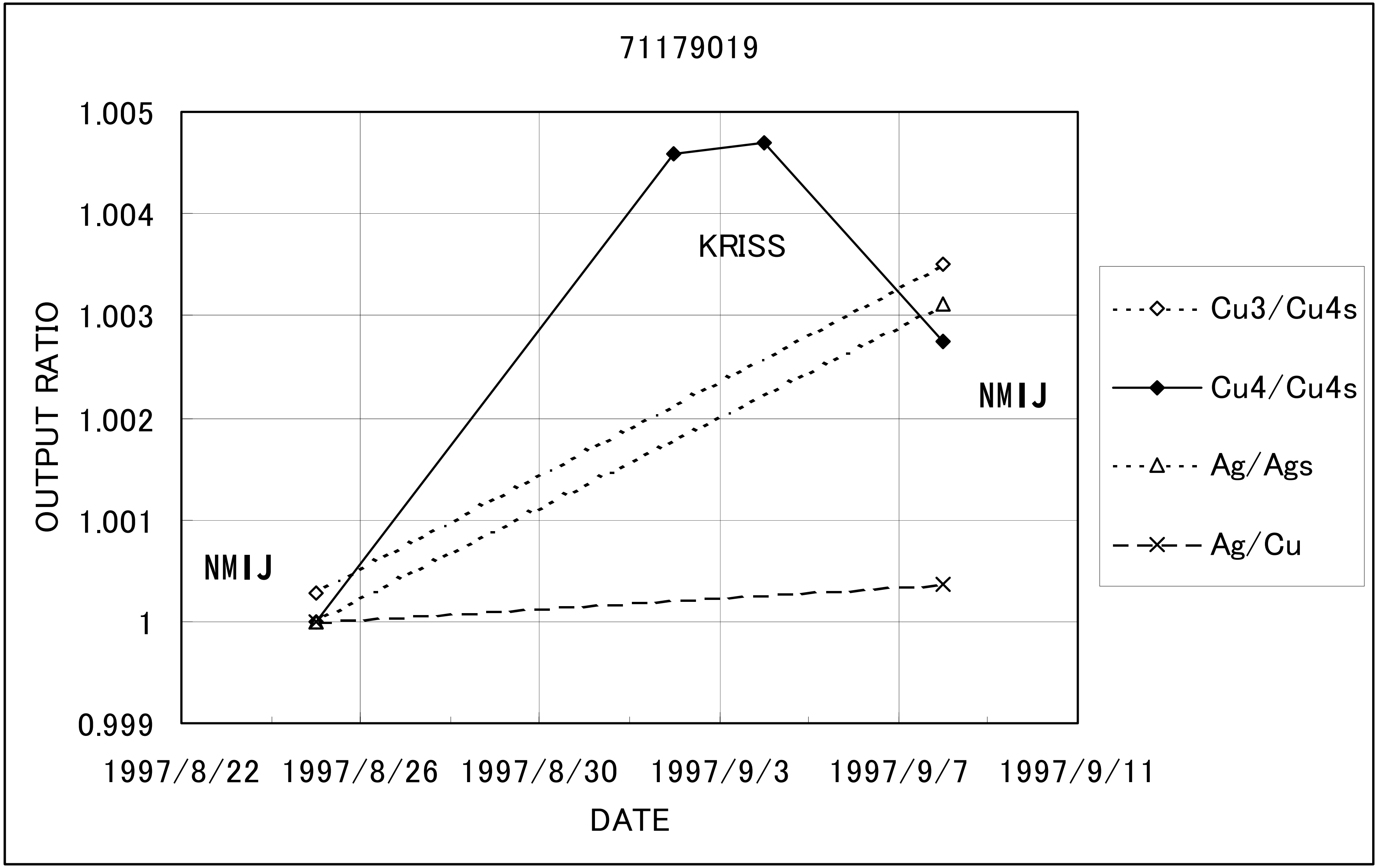
A2 Stability in the comparison with NIM

A3 Stability in the comparison with NMC/SPRING and KIM-LIPI

A4 Stability in the comparison with CMS/ITRI

A5 Stability in the comparison with NML/CSIRO

In the figures the output ratio of the transfer standard radiation thermometer is shown. Small s in the suffix means the output at the start. Different number after Cu means different furnace. Solid line shows that the copper point blackbody was transferred together with the thermometer. Broken line shows that the blackbody was kept at NMIJ. The output change at the last measurement at NMIJ shows the cleaning effect by an air brush.


71179019
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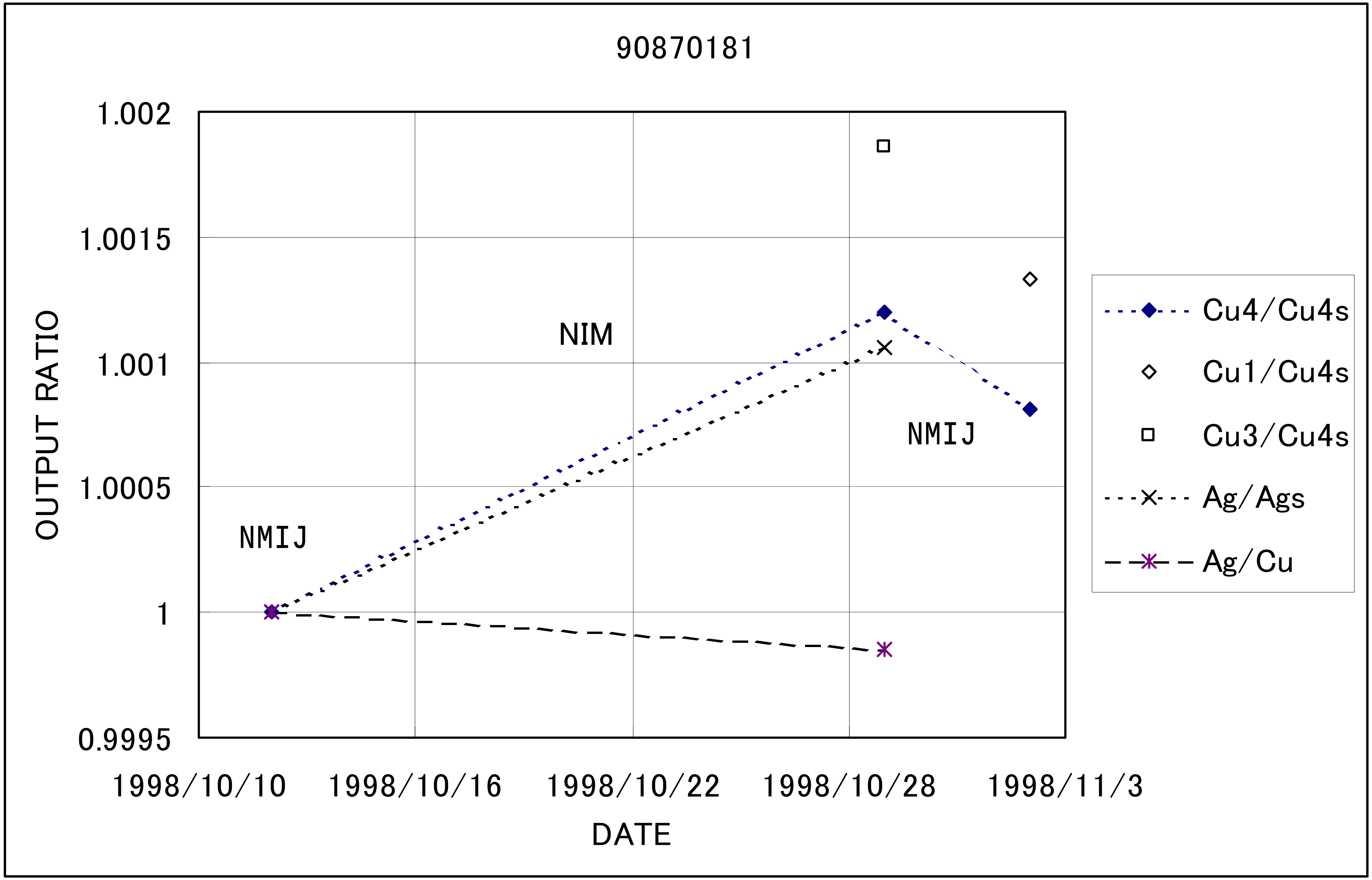
1.004
1.003
1.002
1.001
1
0.999
OUTPUT RATIO
KRISS
NMIJ
NMIJ
1997/8/22
1997/8/26
1997/8/30
1997/9/3
1997/9/7
1997/9/11
DATE
Cu3/Cu4s
Cu4/Cu4s
Ag/Ags
Ag/Cu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1.0015
1.001
1.0005
1
0.9995
OUTPUT RATIO
NIM
NMIJ
NMIJ
1998/10/10
1998/10/16
1998/10/22
1998/10/28
1998/11/3
DATE
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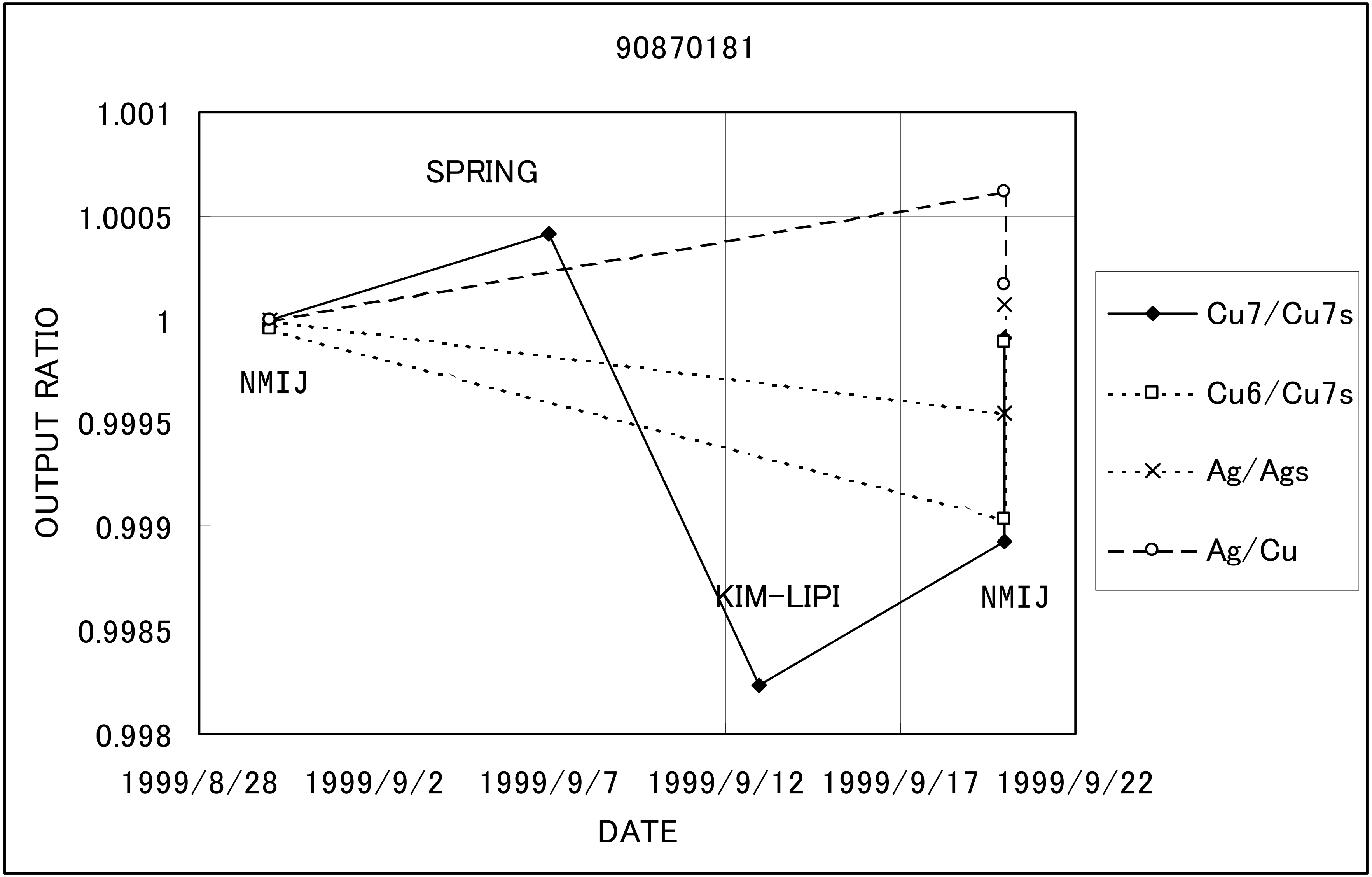
Cu1/Cu4s
Cu3/Cu4s
Ag/Ags
Ag/Cu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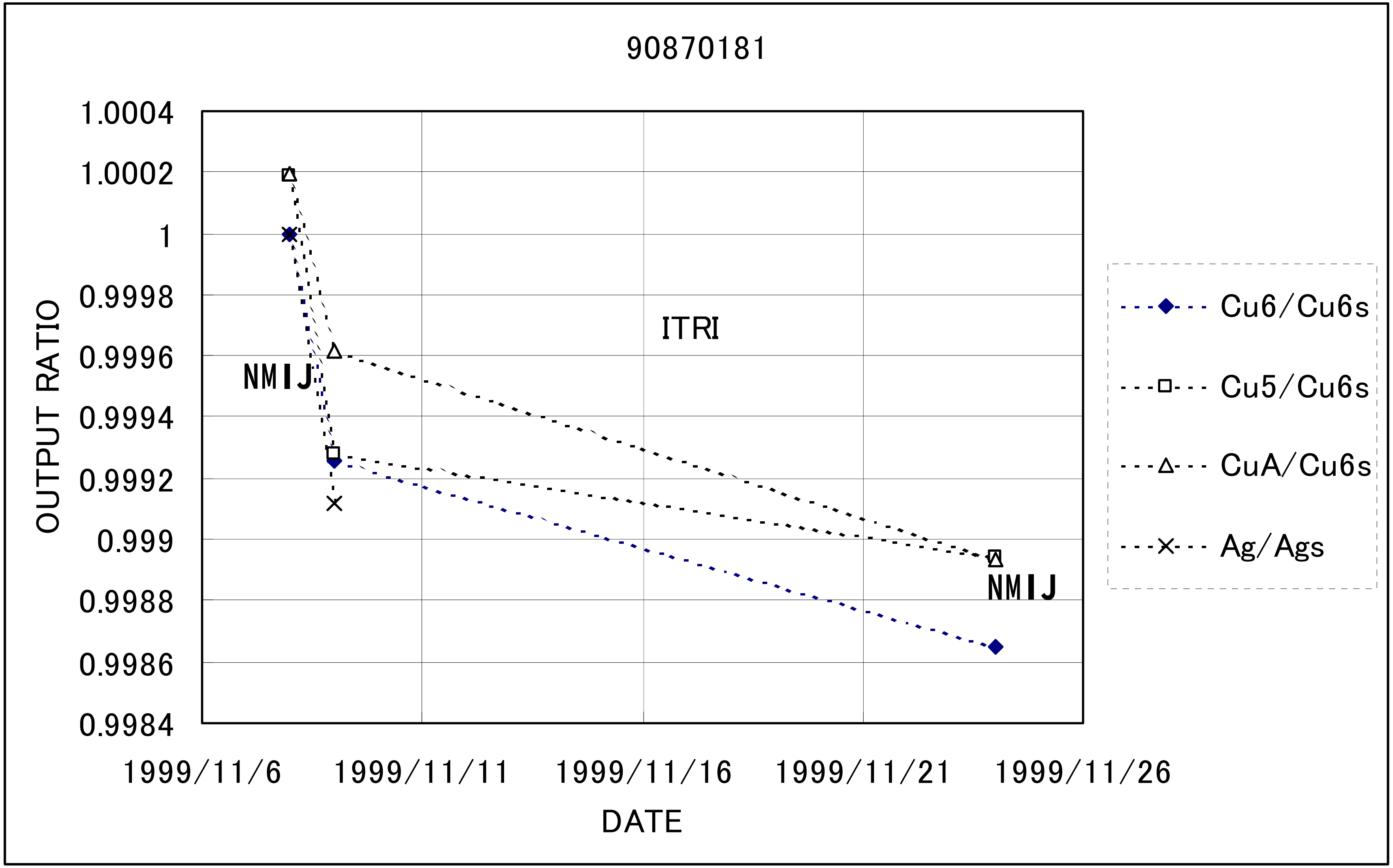
1.0005
1
0.9995
0.999
0.9985
0.998
OUTPUT RATIO
SPRING
NMIJ
KIM-LIPI
NMIJ
1999/8/28
1999/9/2
1999/9/7
1999/9/12
1999/9/17
1999/9/22
DATE
Cu7/Cu7s
Cu6/Cu7s
Ag/Ags
Ag/Cu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0.999
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0.9984
OUTPUT RATIO
NMIJ
ITRI
NMIJ
1999/11/6
1999/11/11
1999/11/16
1999/11/21
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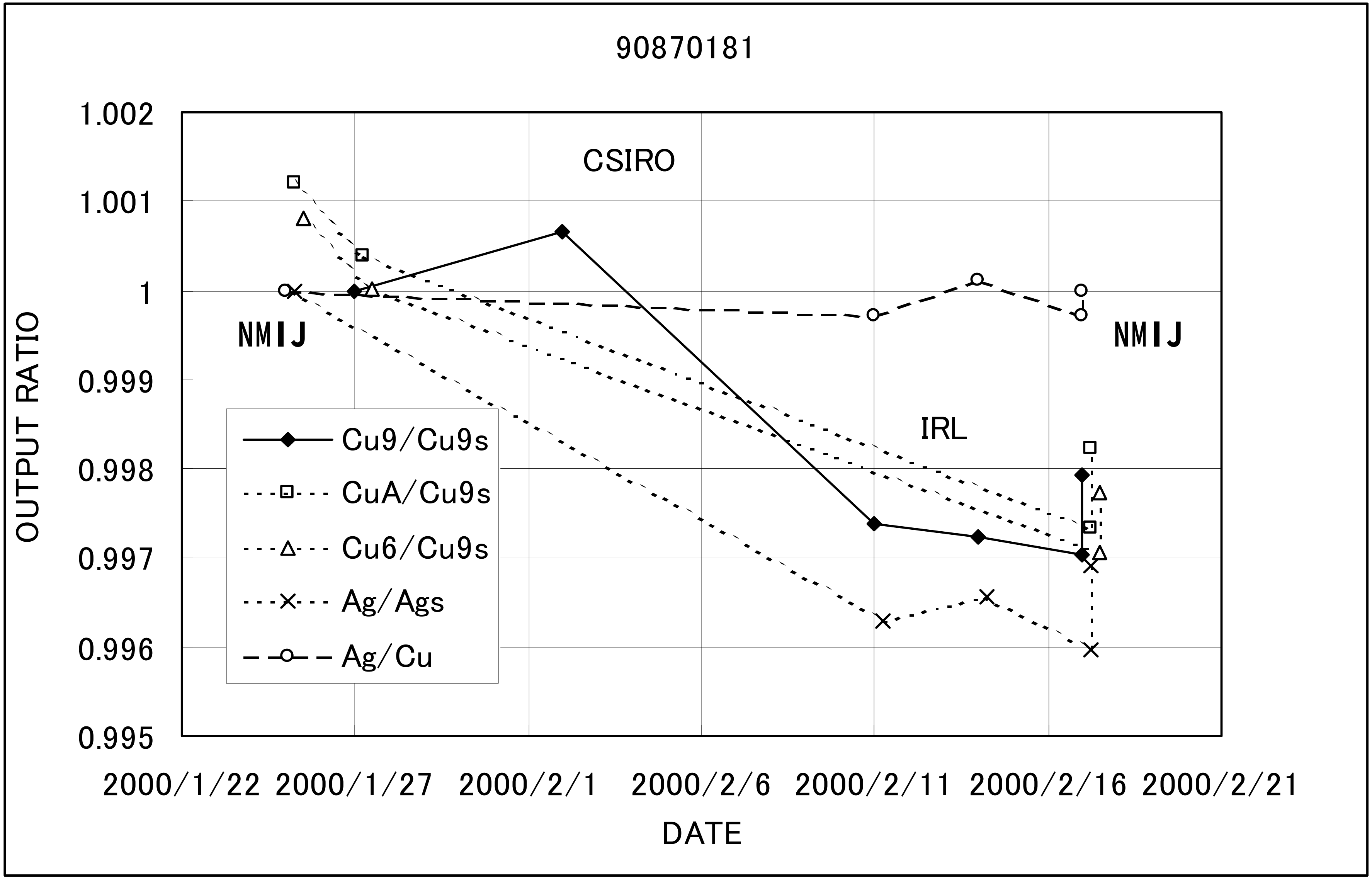
Cu5/Cu6s
CuA/Cu6s
Ag/Ags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0.997
0.996
0.995
OUTPUT RATIO
CSIRO
NMIJ
IRL
NMIJ
Cu9/Cu9s
CuA/Cu9s
Cu6/Cu9s
Ag/Ags
Ag/Cu
2000/1/22
2000/1/27
2000/2/1
2000/2/6
2000/2/11
2000/2/16
2000/2/21
DATE

Appendix B : Results of comparison at each institute

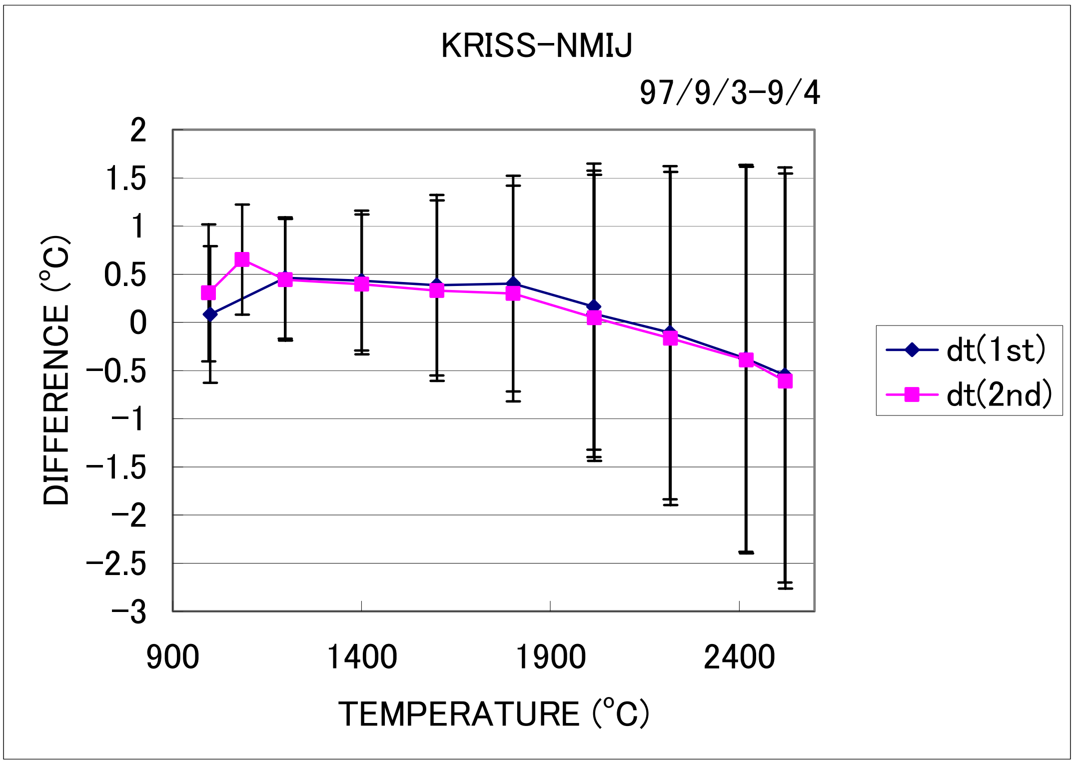
Note: B7a and B8a were added according to the request from Dr. Wang Li who wishes to understand the all result at once.

APMP-Comparison ITS-90 above silver point Appendix B
KRISS Result of measurements Difference from NMIJ
Thermogage blackbody 97/09/03 t(KRISS)-t(NMIJ)

t set	t(KRISS)	s(KRISS)	t(NMIJ)	s(NMIJ)	dt(1st)	s(total)	NE	2s total
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]
1000	999.49	0.33	999.41	0.13	0.08	0.35	0.23	0.71
1200	1198.17	0.27	1197.71	0.16	0.46	0.32	1.46	0.63
1400	1400.29	0.29	1399.86	0.22	0.43	0.36	1.19	0.73
1600	1600.06	0.37	1599.67	0.29	0.39	0.47	0.82	0.94
1800	1801.89	0.42	1801.48	0.37	0.40	0.56	0.72	1.12
2000	2016.11	0.58	2015.95	0.46	0.16	0.74	0.22	1.48
2000	2016.04	0.58	2015.95	0.46	0.09	0.74	0.12	1.48
2200	2216.53	0.65	2216.64	0.57	-0.11	0.86	-0.13	1.73
2400	2417.86	0.73	2418.24	0.69	-0.37	1.00	-0.37	2.01
2500	2520.83	0.77	2521.38	0.75	-0.55	1.08	-0.51	2.15

Thermogage blackbody 97/09/04

t set	t(KRISS)	s(KRISS)	t(NMIJ)	s(NMIJ)	dt(2nd)	s(total)	NE	2s total
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]
1000	995.61	0.33	995.30	0.13	0.31	0.35	0.86	0.71
1085	1084.65	0.25	1083.99	0.14	0.65	0.29	2.28	0.57
1200	1199.18	0.27	1198.74	0.16	0.44	0.32	1.40	0.63
1400	1400.67	0.29	1400.27	0.22	0.39	0.36	1.09	0.73
1600	1600.38	0.37	1600.05	0.29	0.33	0.47	0.70	0.94
1800	1801.96	0.42	1801.66	0.37	0.30	0.56	0.53	1.12
2000	2017.34	0.58	2017.29	0.46	0.05	0.74	0.06	1.48
2200	2217.96	0.65	2218.13	0.57	-0.17	0.86	-0.19	1.73
2400	2419.21	0.73	2419.60	0.69	-0.39	1.00	-0.39	2.01
2500	2521.83	0.77	2522.44	0.75	-0.61	1.08	-0.57	2.15



APMP−Comparison ITS−90 above silver point Appendix B

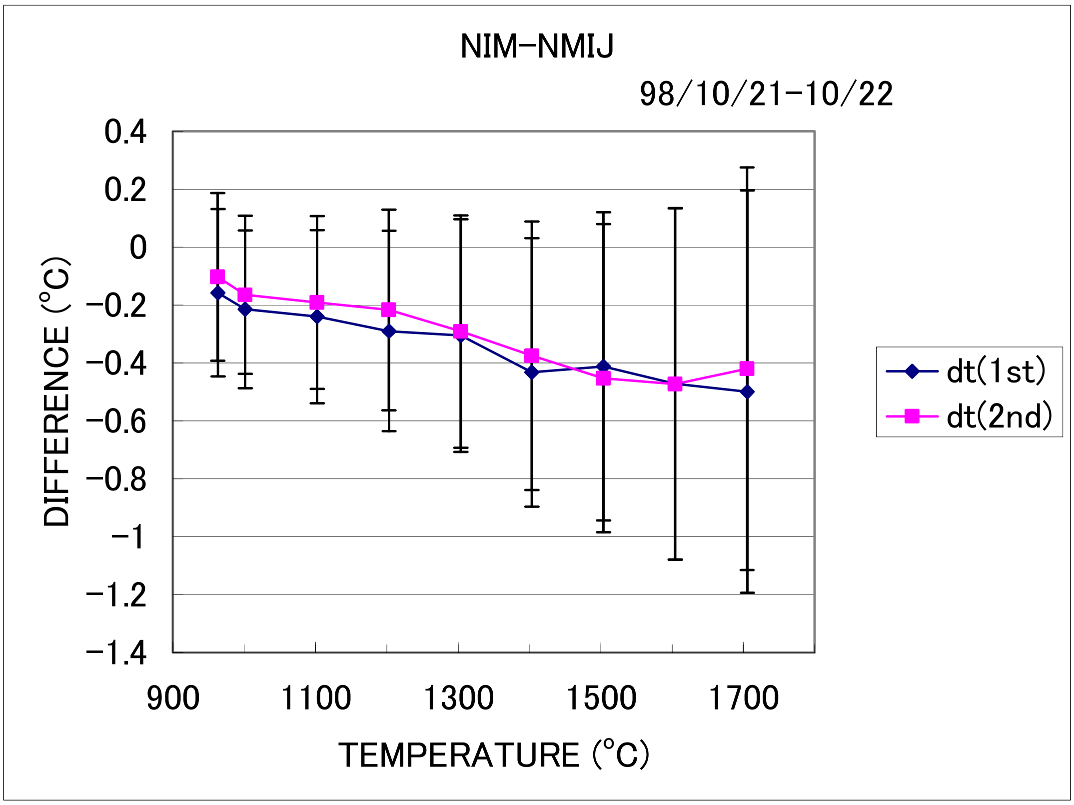
NIM Result of measurements Difference from NMIJ

NIM9304(Lamp) 98/10/20 t(NIM)−t(NMIJ)

t set	t(NIM)	s(NIM)	t(NMIJ)	s(NMIJ)	dt(1st)	s(total)	NE	2s total
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]
962	962.91	0.04	963.07	0.14	−0.16	0.14	−1.09	0.29
1000	1001.17	0.04	1001.39	0.13	−0.21	0.14	−1.57	0.27
1100	1102.21	0.05	1102.45	0.14	−0.24	0.15	−1.61	0.30
1200	1202.49	0.06	1202.78	0.16	−0.29	0.17	−1.67	0.35
1300	1303.19	0.07	1303.50	0.19	−0.31	0.20	−1.52	0.40
1400	1403.02	0.08	1403.45	0.22	−0.43	0.23	−1.86	0.46
1500	1503.21	0.09	1503.63	0.25	−0.41	0.27	−1.55	0.53
1600	1603.94	0.10	1604.41	0.29	−0.47	0.30	−1.55	0.61
1700	1704.78	0.12	1705.28	0.33	−0.50	0.35	−1.44	0.70

NIM9304(Lamp) '98/10/21

t set	t(NIM)	s(NIM)	t(NMIJ)	s(NMIJ)	dt(2nd)	s(total)	NE	2s total
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]
962	962.73	0.04	962.84	0.14	−0.10	0.14	−0.71	0.29
1000	1001.15	0.04	1001.32	0.13	−0.16	0.14	−1.21	0.27
1100	1102.19	0.05	1102.38	0.14	−0.19	0.15	−1.28	0.30
1200	1202.43	0.06	1202.65	0.16	−0.22	0.17	−1.25	0.35
1300	1303.18	0.07	1303.48	0.19	−0.29	0.20	−1.45	0.40
1400	1402.99	0.08	1403.37	0.22	−0.38	0.23	−1.62	0.46
1500	1503.24	0.09	1503.69	0.25	−0.45	0.27	−1.70	0.53
1600	1603.95	0.10	1604.43	0.29	−0.47	0.30	−1.56	0.61
1700	1704.73	0.12	1705.15	0.33	−0.42	0.35	−1.21	0.70

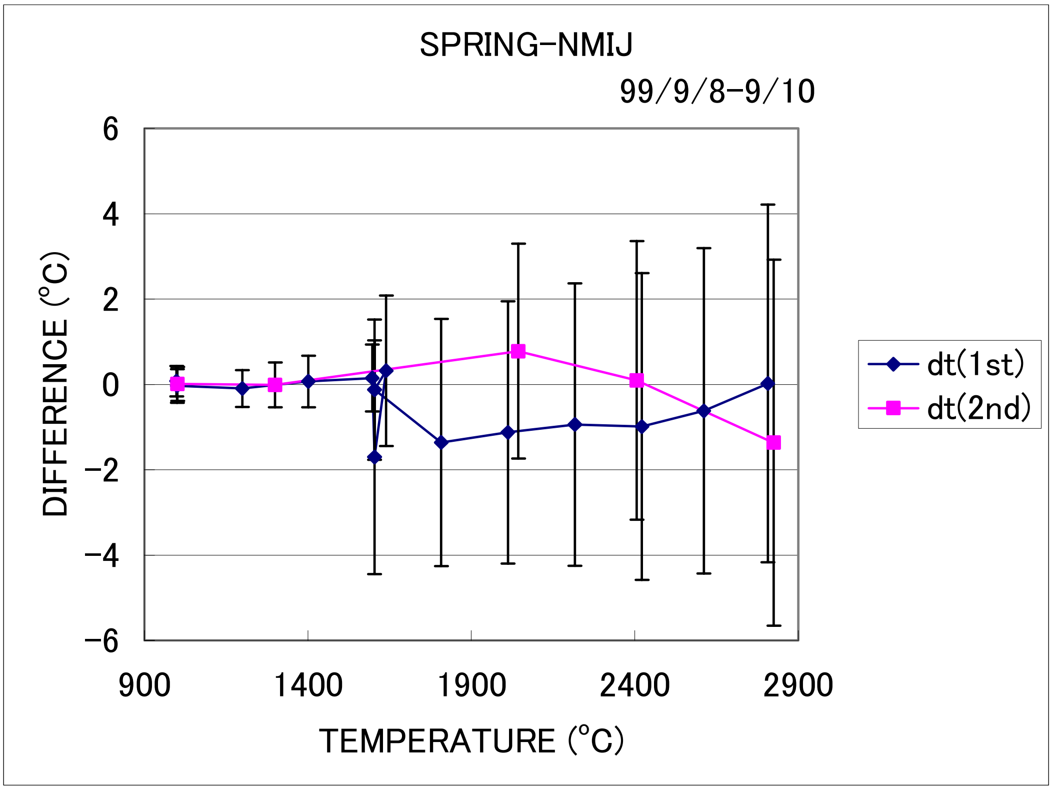


APMP−Comparison ITS−90 above silver point　　Appendix B　　Revised
SPRING Result of measurements　　Difference from NMIJ　　2001/12/19
Blackbody 99/09/8−9/9　　t(SPRING)−t(NMIJ)

t set	t(SPRING)	s(SPRING)	t(NMIJ)	s(NMIJ)	dt(1st)	s(total)	NE	2s total
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]
1000	998.85	0.12	998.77	0.13	0.08	0.18	0.45	0.36
1000	1000.50	0.15	1000.53	0.13	−0.03	0.20	−0.18	0.39
1200	1199.28	0.14	1199.37	0.16	−0.09	0.22	−0.43	0.43
1400	1401.52	0.21	1401.45	0.22	0.07	0.30	0.23	0.61
1600	1596.46	0.27	1596.30	0.29	0.15	0.39	0.39	0.78
1600	1602.43	1.34	1604.13	0.29	−1.70	1.37	−1.24	2.74
1600	1639.97	0.83	1639.65	0.30	0.32	0.88	0.37	1.76
1600	1603.86	0.77	1603.99	0.29	−0.12	0.82	−0.15	1.64
1800	1806.67	1.40	1808.02	0.37	−1.36	1.45	−0.94	2.90
2000	2010.46	1.46	2011.59	0.47	−1.12	1.54	−0.73	3.08
2200	2216.22	1.55	2217.16	0.58	−0.94	1.65	−0.57	3.31
2400	2421.29	1.65	2422.27	0.70	−0.99	1.80	−0.55	3.59
2600	2611.00	1.72	2611.61	0.83	−0.62	1.91	−0.32	3.81
2800	2807.09	1.86	2807.06	0.97	0.03	2.09	0.01	4.19

Blackbody 99/09/10

t set	t(SPRING)	s(SPRING)	t(NMIJ)	s(NMIJ)	dt(2nd)	s(total)	NE	2s total
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]
1000	1000.70	0.15	1000.68	0.13	0.01	0.20	0.07	0.40
1300	1299.83	0.18	1299.84	0.19	−0.01	0.26	−0.04	0.52
2000	2044.37	1.16	2043.59	0.48	0.78	1.26	0.62	2.52
2400	2406.67	1.48	2406.57	0.69	0.10	1.63	0.06	3.26
2800	2823.96	1.91	2825.32	0.98	−1.36	2.15	−0.63	4.29



APMP-Comparison ITS-90 above silver point Appendix B
KIM LIPI Result of measurements Difference from NMIJ
Land blackbody 99/9/14 t(KIM LIPI)-t(NMIJ)

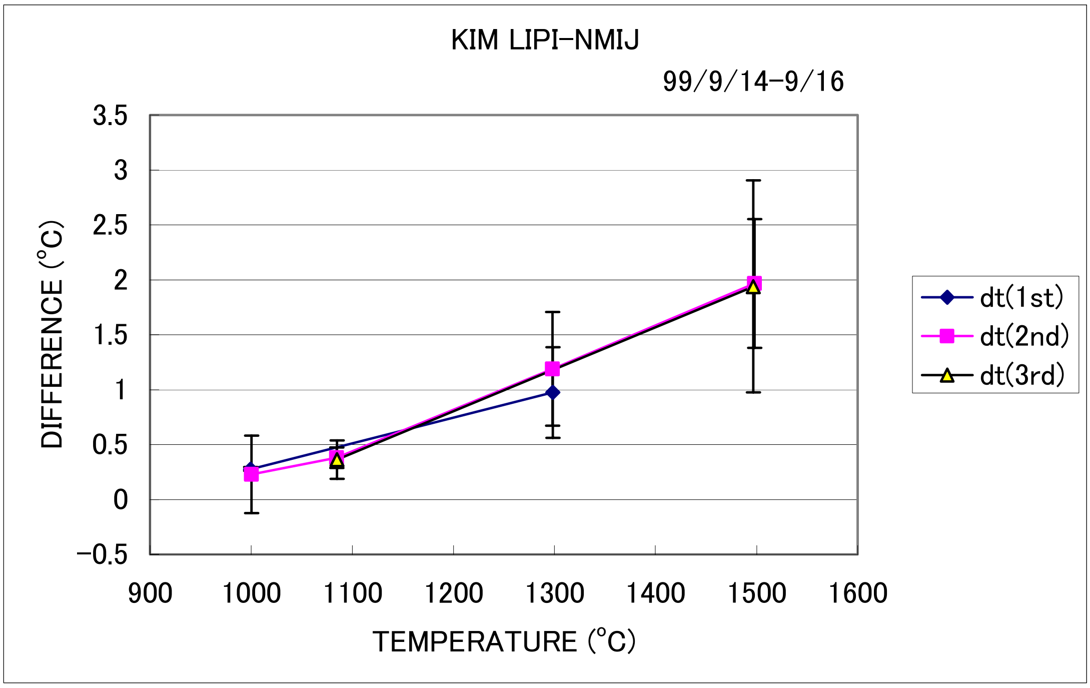
t set	t(KIM LIPI)	s(KIM LIPI)	t(NMIJ)	s(NMIJ)	dt(1st)	s(total)	NE
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	
1000	999.67	0.92	999.39	0.13	0.28	0.93	0.30
1300	1299.29	1.03	1298.32	0.19	0.97	1.05	0.93

Land blackbody '99/9/15

t set	t(KIM LIPI)	s(KIM LIPI)	t(NMIJ)	s(NMIJ)	dt(2nd)	s(total)	NE
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	
1000	1000.45	0.92	1000.22	0.13	0.23	0.93	0.25
1085	1084.97	0.92	1084.59	0.14	0.38	0.93	0.41
1300	1299.30	1.04	1298.11	0.19	1.19	1.05	1.13
1500	1499.83	1.32	1497.86	0.25	1.97	1.34	1.46

Land blackbody '99/9/16

t set	t(KIM LIPI)	s(KIM LIPI)	t(NMIJ)	s(NMIJ)	dt(3rd)	s(total)	NE
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	
1085	1085.15	0.92	1084.79	0.14	0.36	0.93	0.39
1500	1498.85	1.32	1496.91	0.25	1.94	1.34	1.44

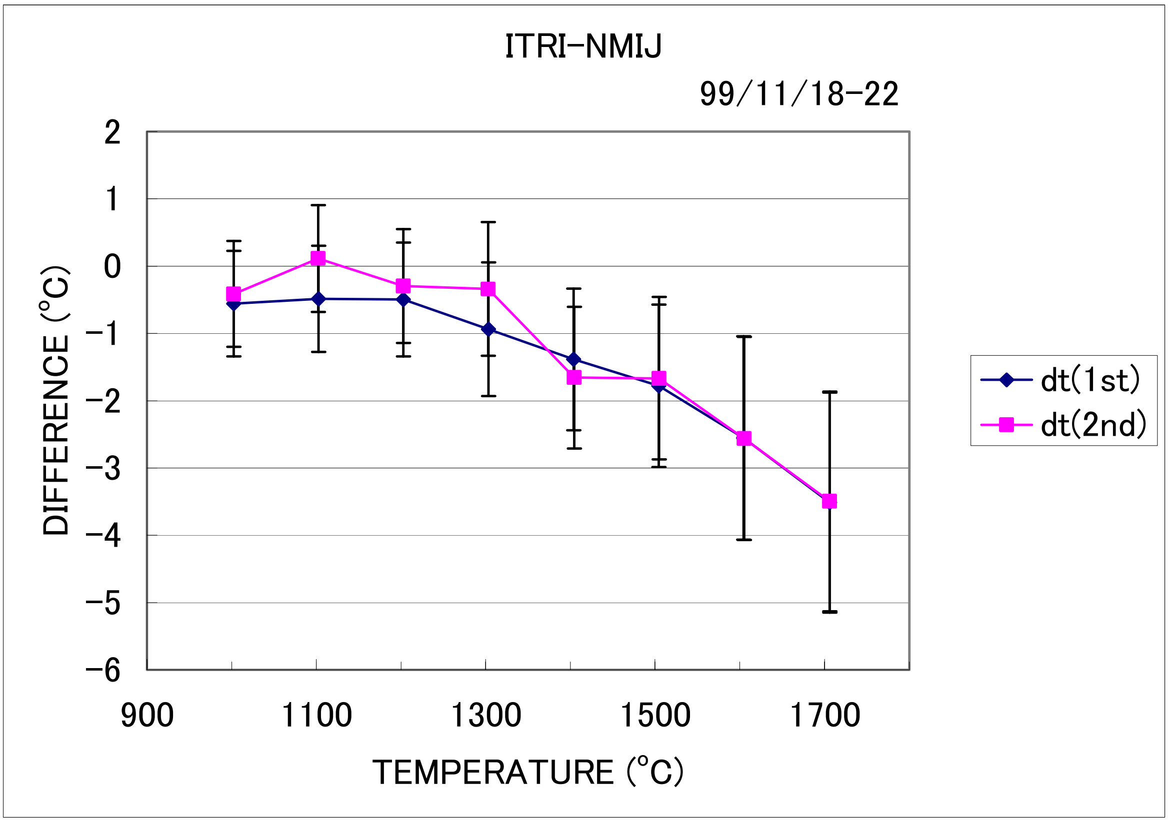


APMP-Comparison ITS-90 above silver point Appendix B
ITRI Result of measurements Difference from NMIJ
C833 lamp 99/11/18-19 t(ITRI)-t(NMIJ)

t set	t(ITRI)	s(ITRI)	t(NMIJ)	s(NMIJ)	dt(1st)	s(total)	NE	2s total
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]
1000	1001.85	0.37	1002.41	0.13	-0.56	0.39	-1.42	0.78
1100	1102.04	0.37	1102.52	0.14	-0.48	0.40	-1.22	0.79
1200	1201.98	0.39	1202.48	0.16	-0.50	0.42	-1.17	0.84
1300	1302.14	0.46	1303.08	0.19	-0.94	0.50	-1.88	0.99
1400	1402.29	0.48	1403.67	0.22	-1.38	0.53	-2.63	1.05
1500	1502.29	0.55	1504.07	0.25	-1.78	0.60	-2.95	1.21
1600	1601.9	0.70	1604.45	0.29	-2.55	0.76	-3.37	1.51
1700	1702.35	0.75	1705.87	0.33	-3.52	0.82	-4.30	1.64

C833 lamp 99/11/19,22

t set	t(ITRI)	s(ITRI)	t(NMIJ)	s(NMIJ)	dt(2nd)	s(total)	NE	2s total
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]
1000	1001.85	0.37	1002.26	0.13	-0.41	0.39	-1.05	0.78
1100	1102.25	0.37	1102.14	0.14	0.11	0.40	0.29	0.79
1200	1202.36	0.39	1202.65	0.16	-0.29	0.42	-0.70	0.84
1300	1302.49	0.46	1302.83	0.19	-0.34	0.50	-0.68	0.99
1400	1402.63	0.48	1404.29	0.22	-1.66	0.53	-3.14	1.05
1500	1502.77	0.55	1504.44	0.25	-1.67	0.60	-2.76	1.21
1600	1602.59	0.70	1605.15	0.29	-2.56	0.76	-3.38	1.51
1700	1702.35	0.75	1705.85	0.33	-3.50	0.82	-4.28	1.64

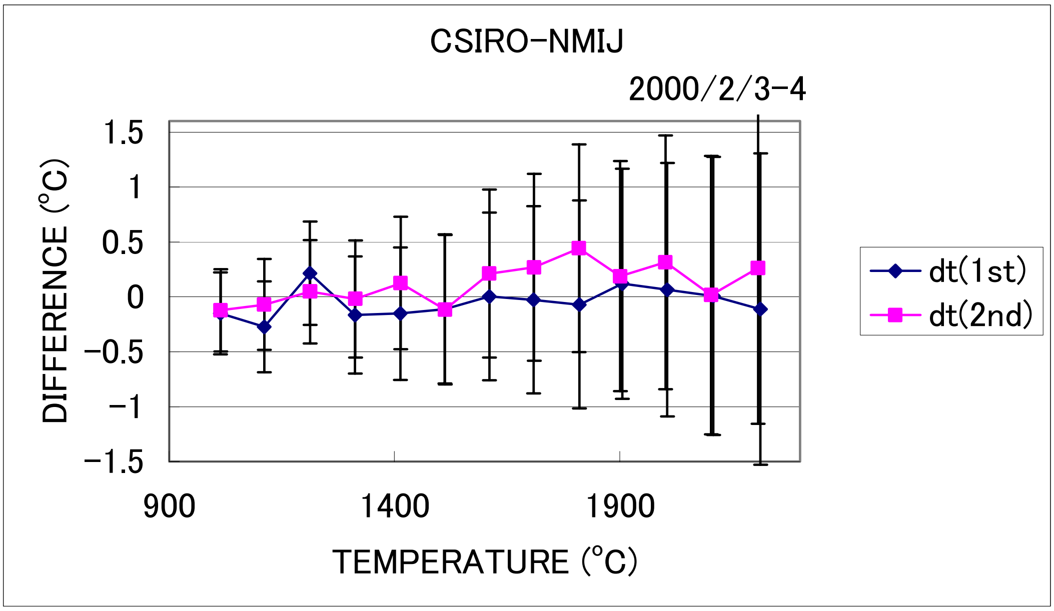


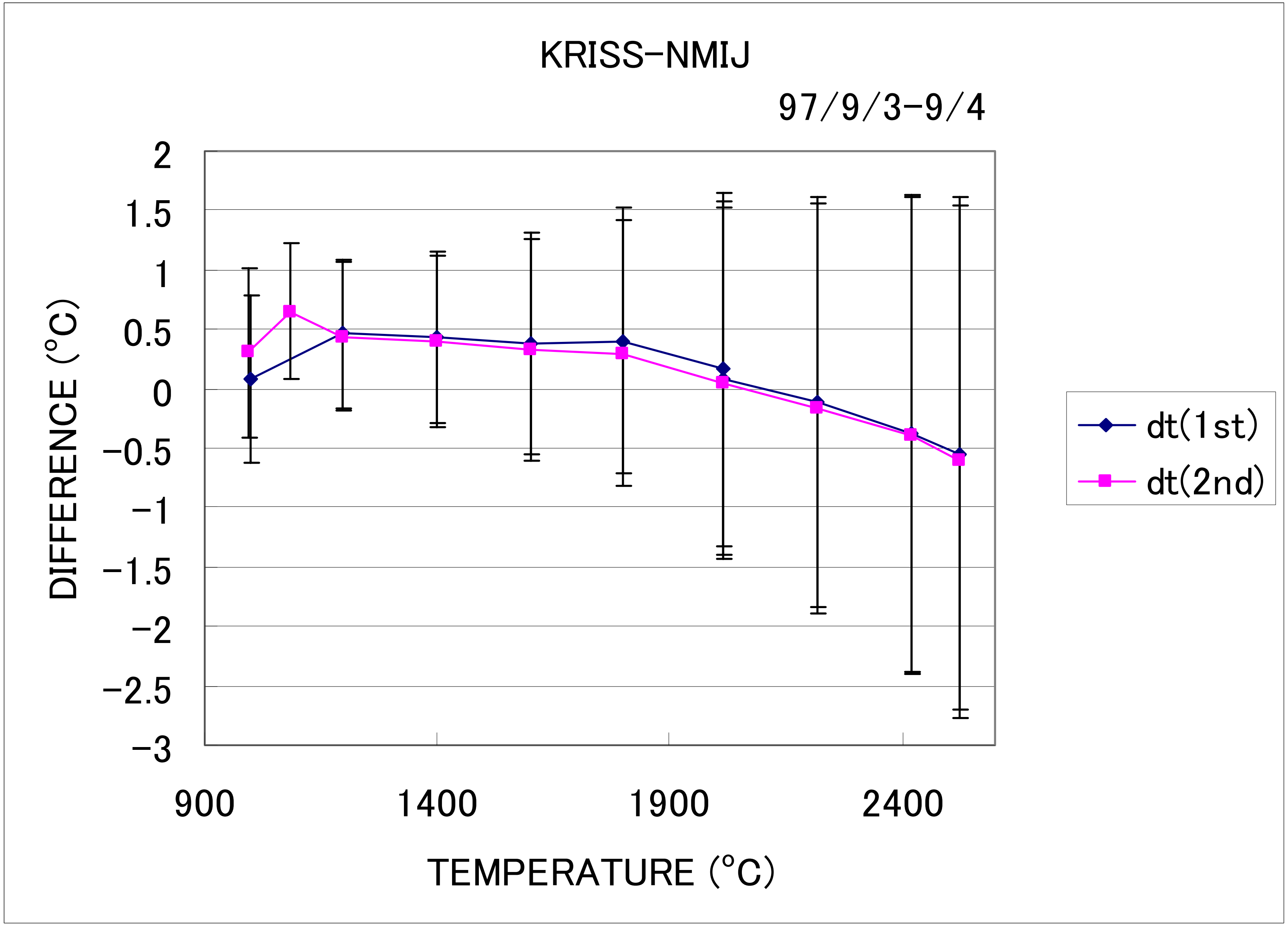
APMP-Comparison ITS-90 above silver point Appendix B
CSIRO Result of measurements Difference from NMIJ
Thermogage blackbody 2000/2/3 t(CSIRO)-t(NMIJ)

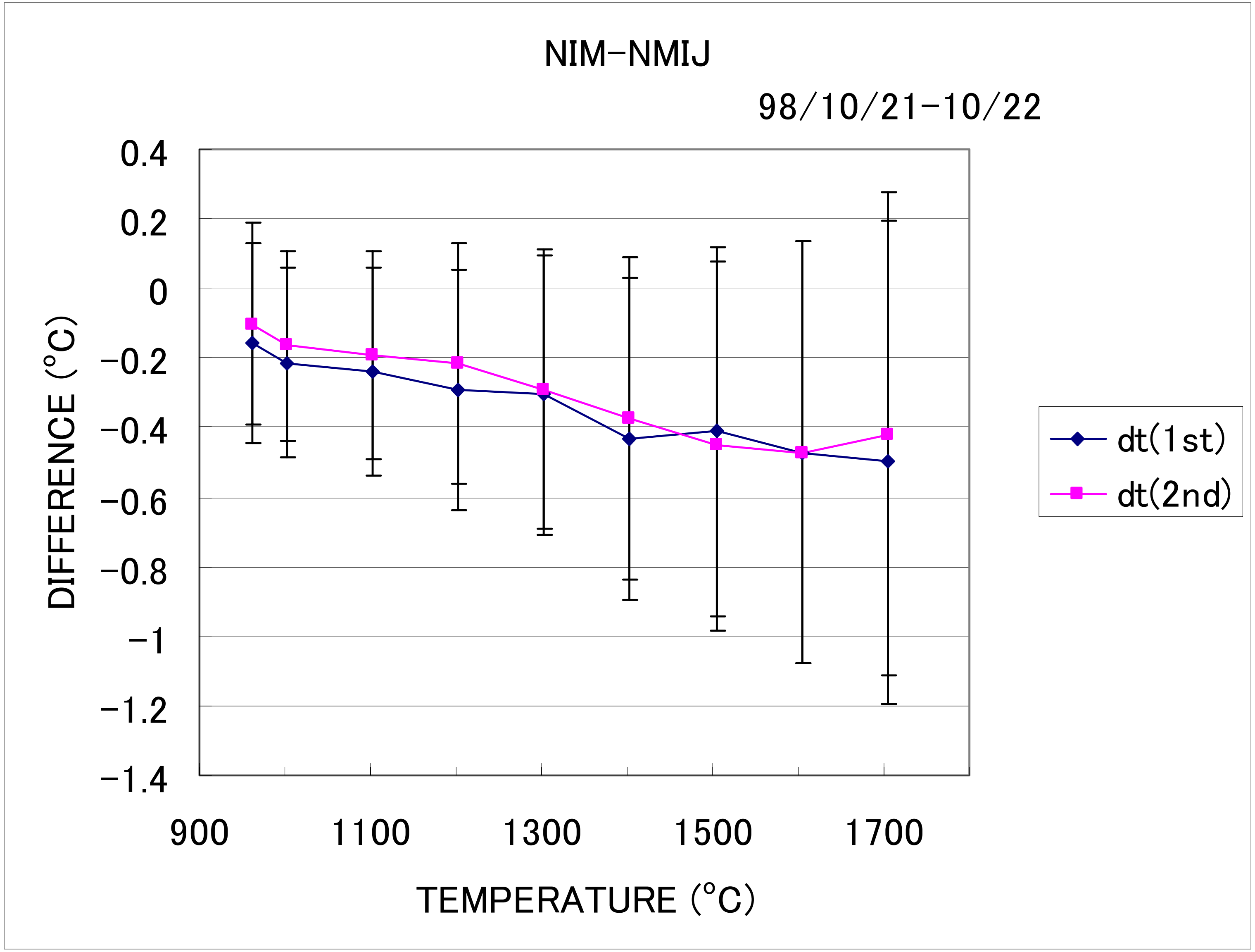
t set	t(CSIRO)	s(CSIRO)	t(NMIJ)	s(NMIJ)	dt(1st)	s(total)	NE	2s total
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]
1000	1013.25	0.11	1013.40	0.15	-0.15	0.19	-0.80	0.37
1100	1110.31	0.13	1110.58	0.16	-0.27	0.21	-1.32	0.41
1200	1212.02	0.14	1211.80	0.19	0.21	0.24	0.91	0.47
1300	1312.32	0.15	1312.48	0.22	-0.17	0.27	-0.62	0.53
1400	1412.96	0.17	1413.11	0.25	-0.15	0.30	-0.51	0.60
1500	1511.14	0.18	1511.25	0.29	-0.11	0.34	-0.32	0.68
1600	1610.61	0.20	1610.61	0.33	0.00	0.38	0.01	0.76
1700	1708.54	0.21	1708.56	0.37	-0.03	0.43	-0.06	0.85
1800	1810.18	0.23	1810.25	0.42	-0.07	0.47	-0.15	0.95
1900	1905.49	0.24	1905.37	0.47	0.12	0.52	0.23	1.05
2000	2005.19	0.25	2005.13	0.52	0.06	0.58	0.11	1.15
2100	2107.82	0.27	2107.81	0.57	0.01	0.63	0.01	1.27
2200	2212.24	0.32	2212.35	0.63	-0.11	0.71	-0.16	1.42

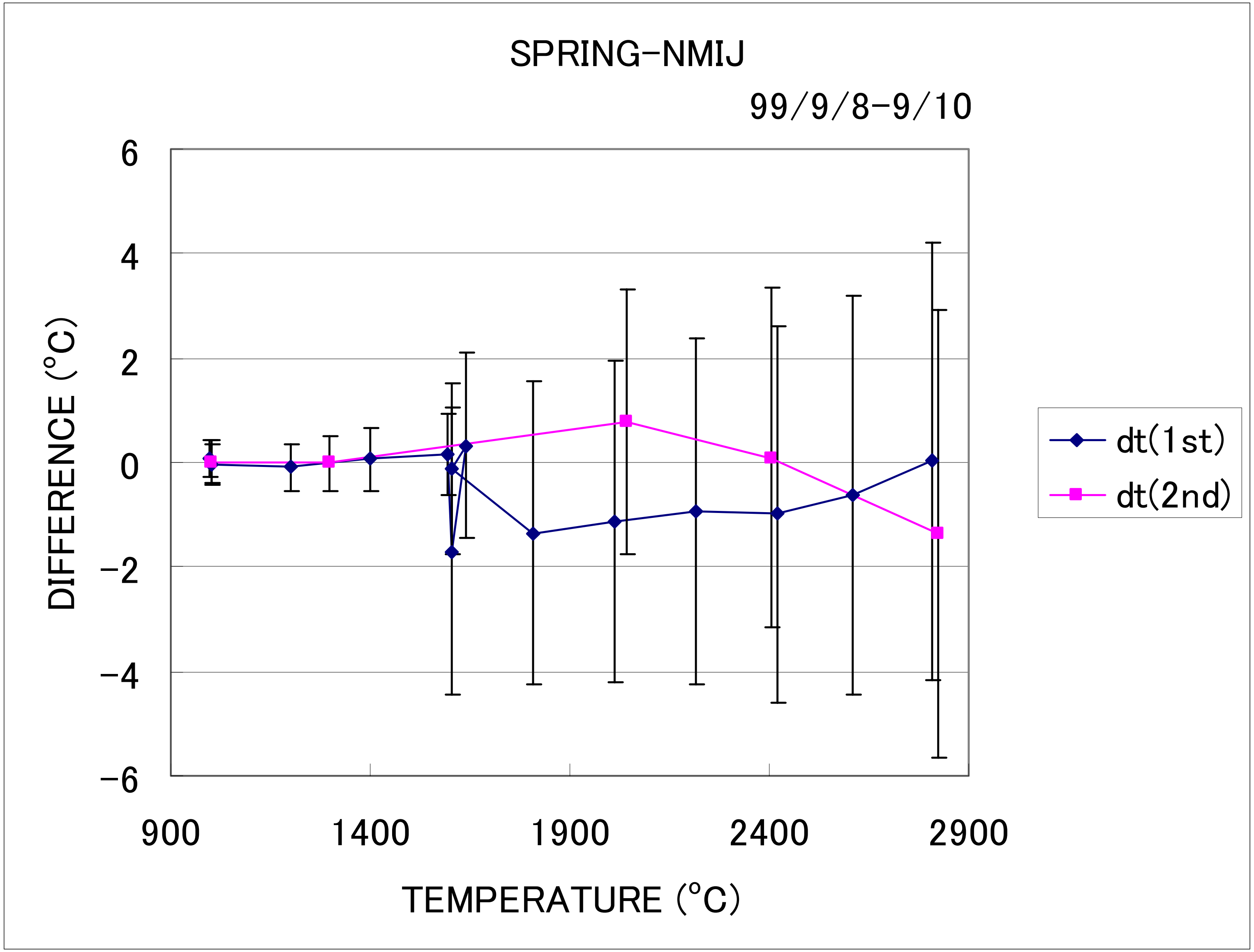
Thermogage blackbody 2000/2/4

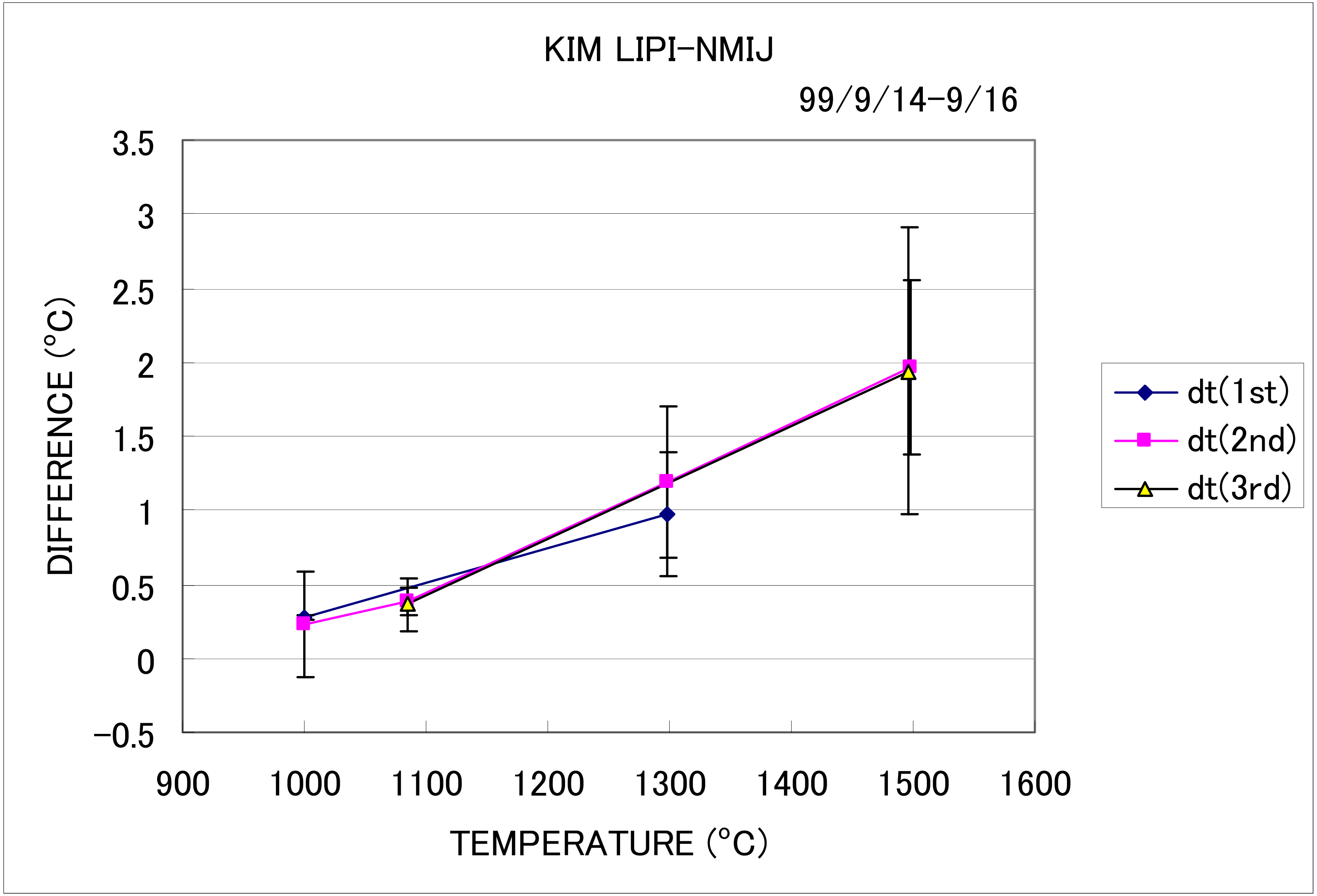
t set	t(CSIRO)	s(CSIRO)	t(NMIJ)	s(NMIJ)	dt(2nd)	s(total)	NE	2s total
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]
1000	1014.00	0.11	1014.12	0.15	-0.12	0.19	-0.66	0.37
1100	1110.61	0.13	1110.68	0.16	-0.07	0.21	-0.34	0.41
1200	1212.56	0.14	1212.51	0.19	0.05	0.24	0.20	0.47
1300	1312.93	0.15	1312.95	0.22	-0.02	0.27	-0.07	0.53
1400	1413.41	0.17	1413.29	0.25	0.13	0.30	0.42	0.60
1500	1512.07	0.18	1512.19	0.29	-0.12	0.34	-0.34	0.68
1600	1610.96	0.20	1610.74	0.33	0.21	0.38	0.55	0.76
1700	1709.84	0.21	1709.57	0.37	0.27	0.43	0.63	0.85
1800	1810.10	0.23	1809.65	0.42	0.44	0.47	0.93	0.95
1900	1900.81	0.24	1900.62	0.47	0.19	0.52	0.36	1.05
2000	2001.37	0.25	2001.05	0.52	0.32	0.58	0.55	1.15
2100	2102.29	0.27	2102.27	0.57	0.01	0.63	0.02	1.27
2200	2206.99	0.32	2206.72	0.63	0.26	0.71	0.37	1.42

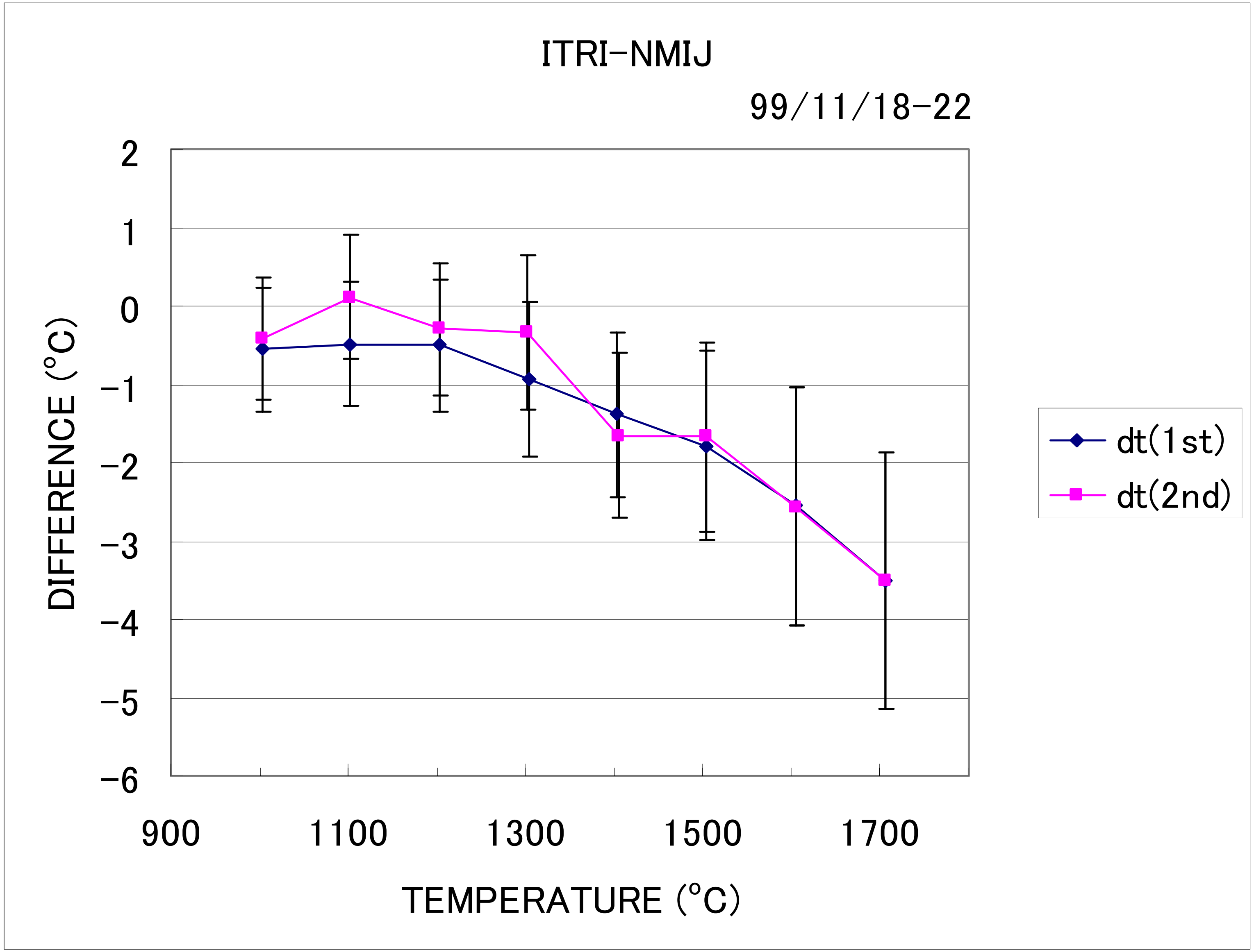


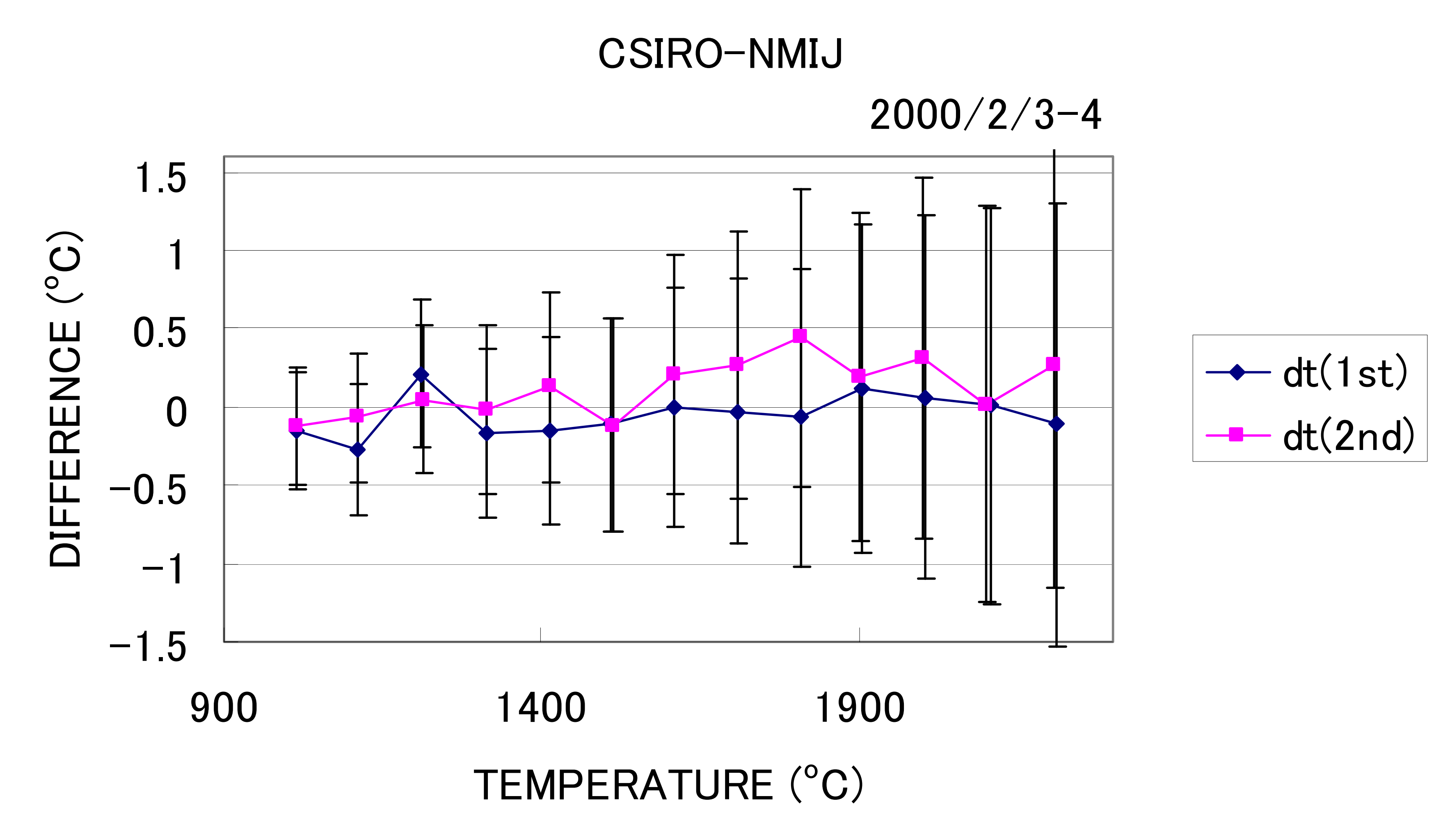

KRISS-NMIJ
97/9/3-9/4
DIFFERENCE (°C)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
900
1400
1900
2400
TEMPERATURE (°C)
dt(1st)
dt(2nd)

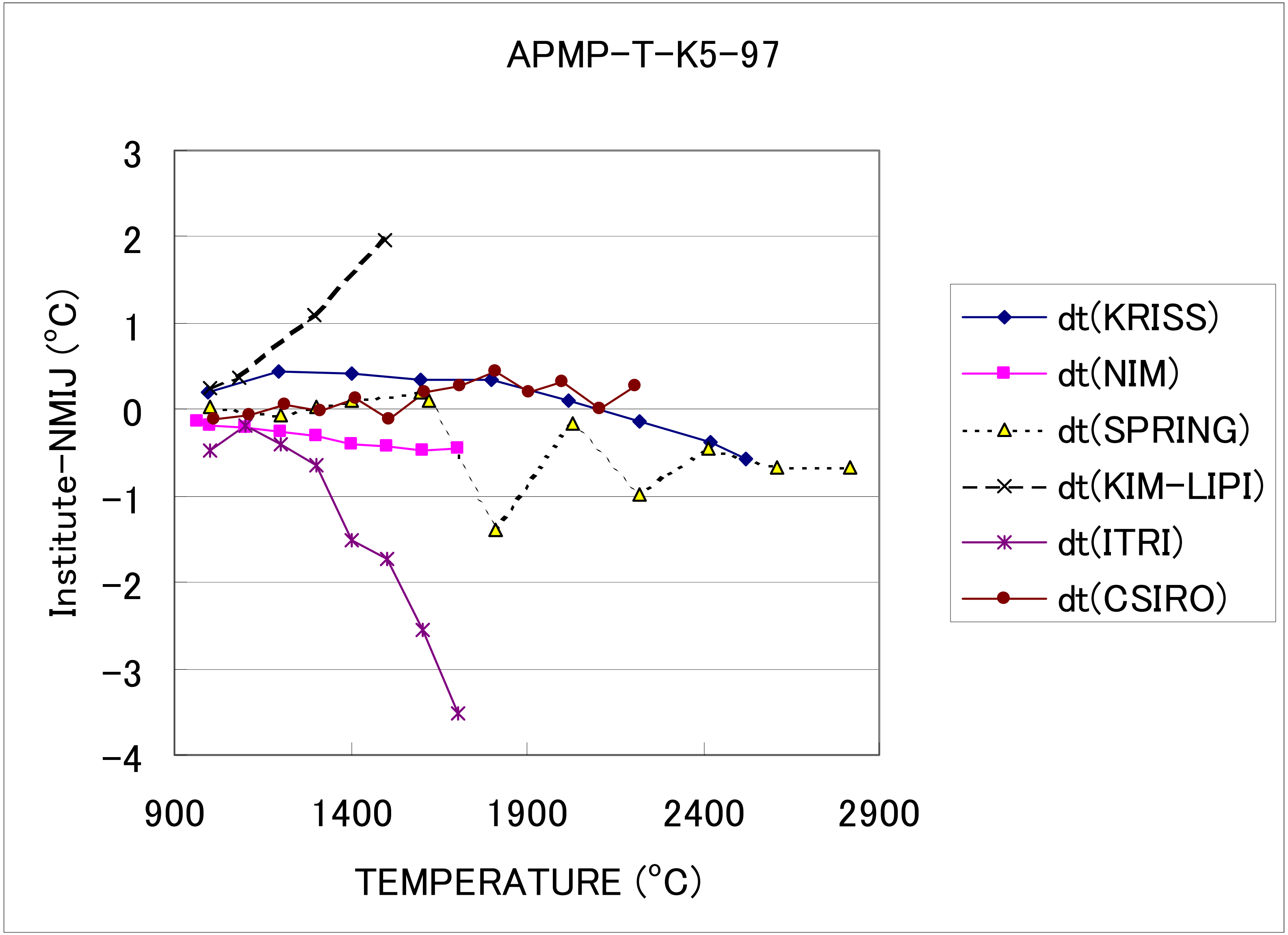

NIM-NMIJ
98/10/21-10/22
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
DIFFERENCE (°C)
900
1100
1300
1500
1700
TEMPERATURE (°C)
dt(1st)
dt(2nd)

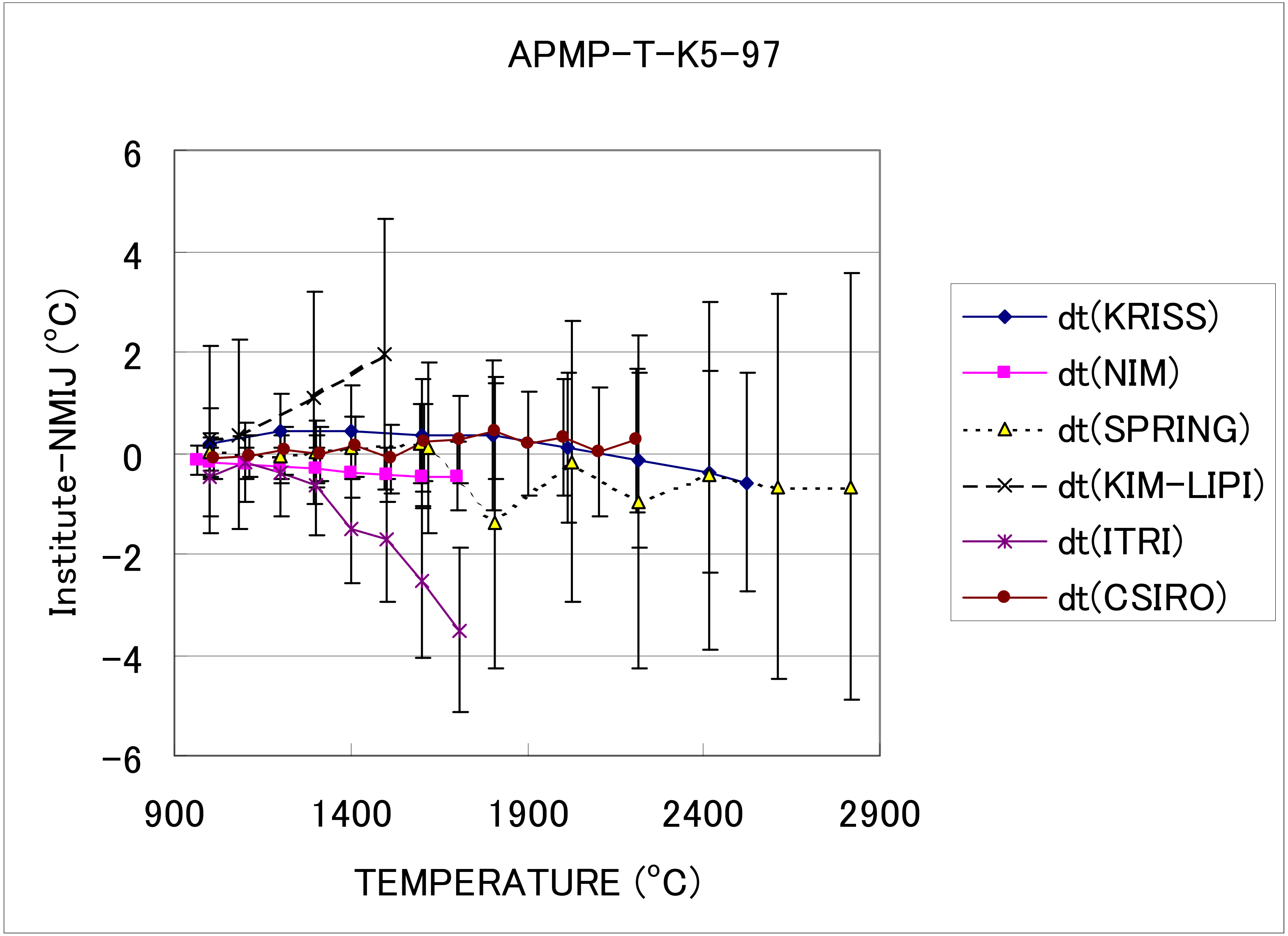

SPRING-NMIJ
99/9/8-9/10
6
4
2
0
−2
−4
−6
DIFFERENCE (°C)
900
1400
1900
2400
2900
TEMPERATURE (°C)
dt(1st)
dt(2nd)


KIM LIPI-NMIJ
99/9/14-9/16
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
DIFFERENCE (°C)
900
1000
1100
1200
1300
1400
1500
1600
TEMPERATURE (°C)
dt(1st)
dt(2nd)
dt(3rd)


ITRI-NMIJ
99/11/18-22
2
1
0
−1
−2
−3
−4
−5
−6
DIFFERENCE (°C)
900
1100
1300
1500
1700
TEMPERATURE (°C)
dt(1st)
dt(2nd)


CSIRO-NMIJ
2000/2/3-4
DIFFERENCE (°C)
1.5
1
0.5
0
-0.5
-1
-1.5
900
1400
1900
TEMPERATURE (°C)
dt(1st)
dt(2nd)


APMP-T-K5-97
3
2
1
0
−1
−2
−3
−4
Institute−NMIJ (°C)
900
1400
1900
2400
2900
TEMPERATURE (°C)
dt(KRISS)
dt(NIM)
dt(SPRING)
dt(KIM−LIPI)
dt(ITRI)
dt(CSIRO)


APMP-T-K5-97
6
4
2
0
−2
−4
−6
Institute−NMIJ (°C)
900
1400
1900
2400
2900
TEMPERATURE (°C)
dt(KRISS)
dt(NIM)
dt(SPRING)
dt(KIM-LIPI)
dt(ITRI)
dt(CSIRO)

Appendix C : Uniformity of radiation source

C1 Horizontal uniformity of Thermogage blackbody at KRISS at 700 C, 1200 C and 2000 C

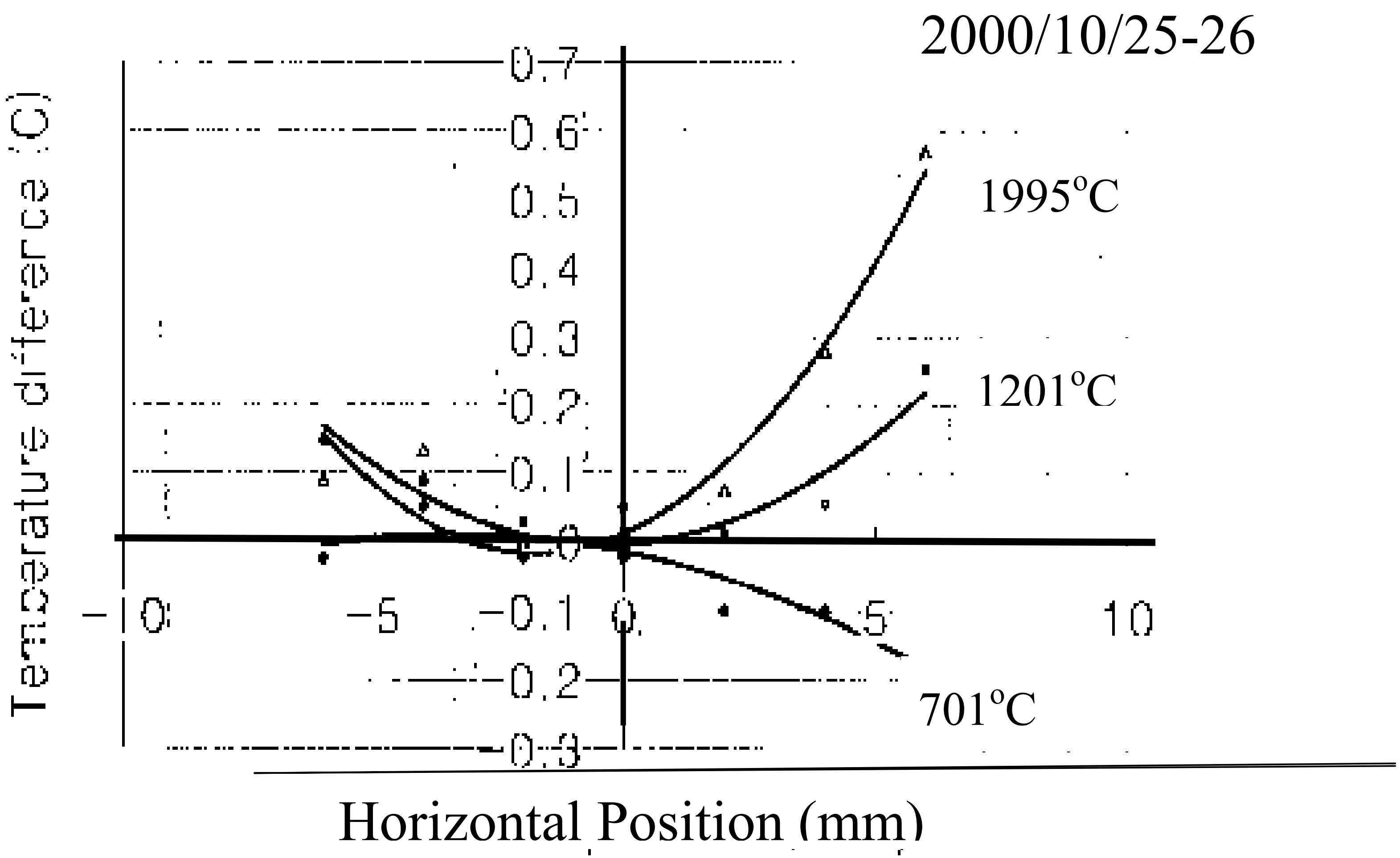
C2 Horizontal uniformity of Micron Blackbody at NMC/SPRING at 1600 C

C3 Vertical uniformity of Micron Blackbody at NMC/SPRING at 1600 C

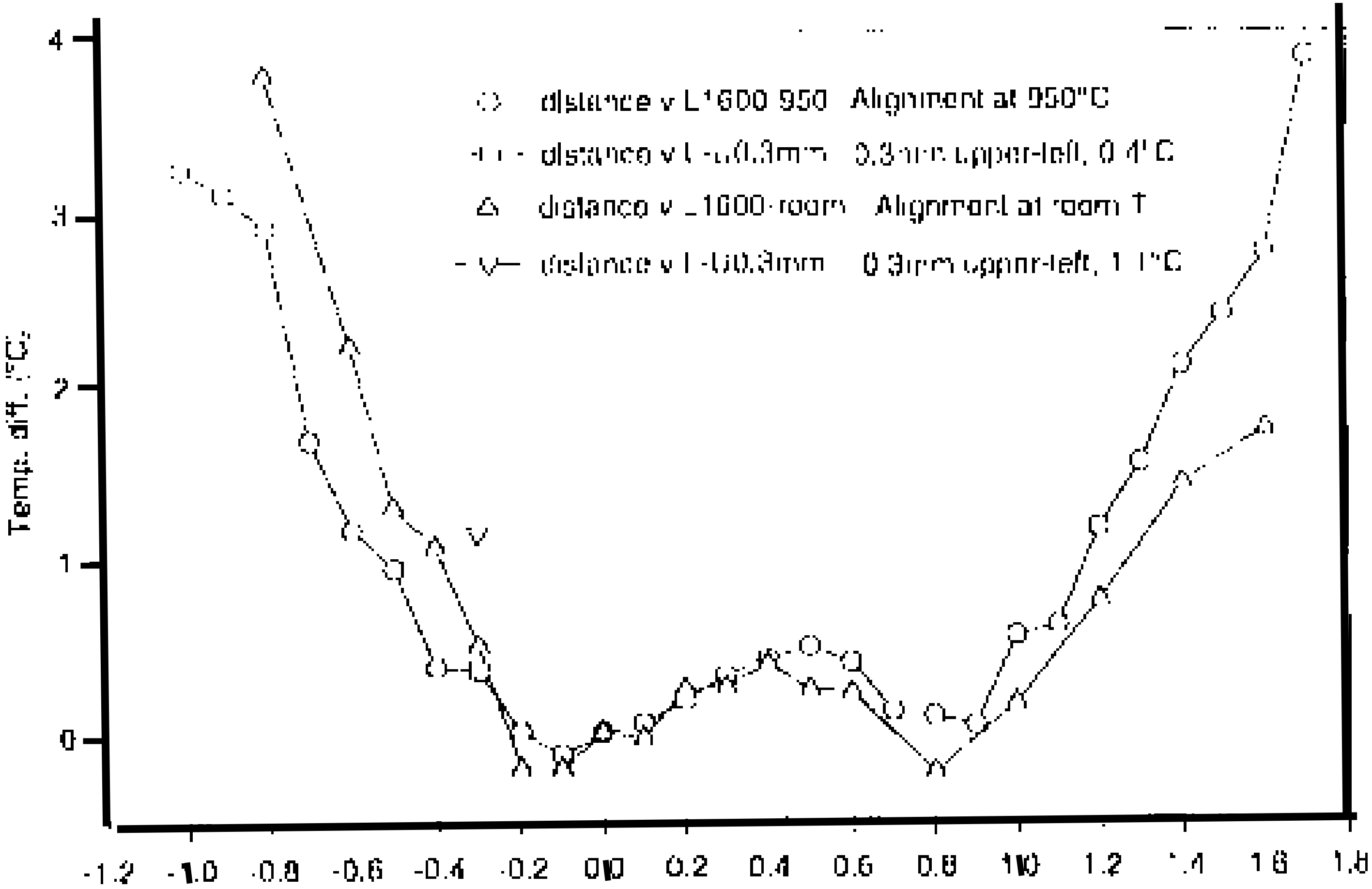
C4 Horizontal uniformity of Micron Blackbody at NMC/SPRING at 2800 C

C5 Vertical uniformity of Micron Blackbody at NMC/SPRING at 2800 C

Uniformity of Thermogage furnace

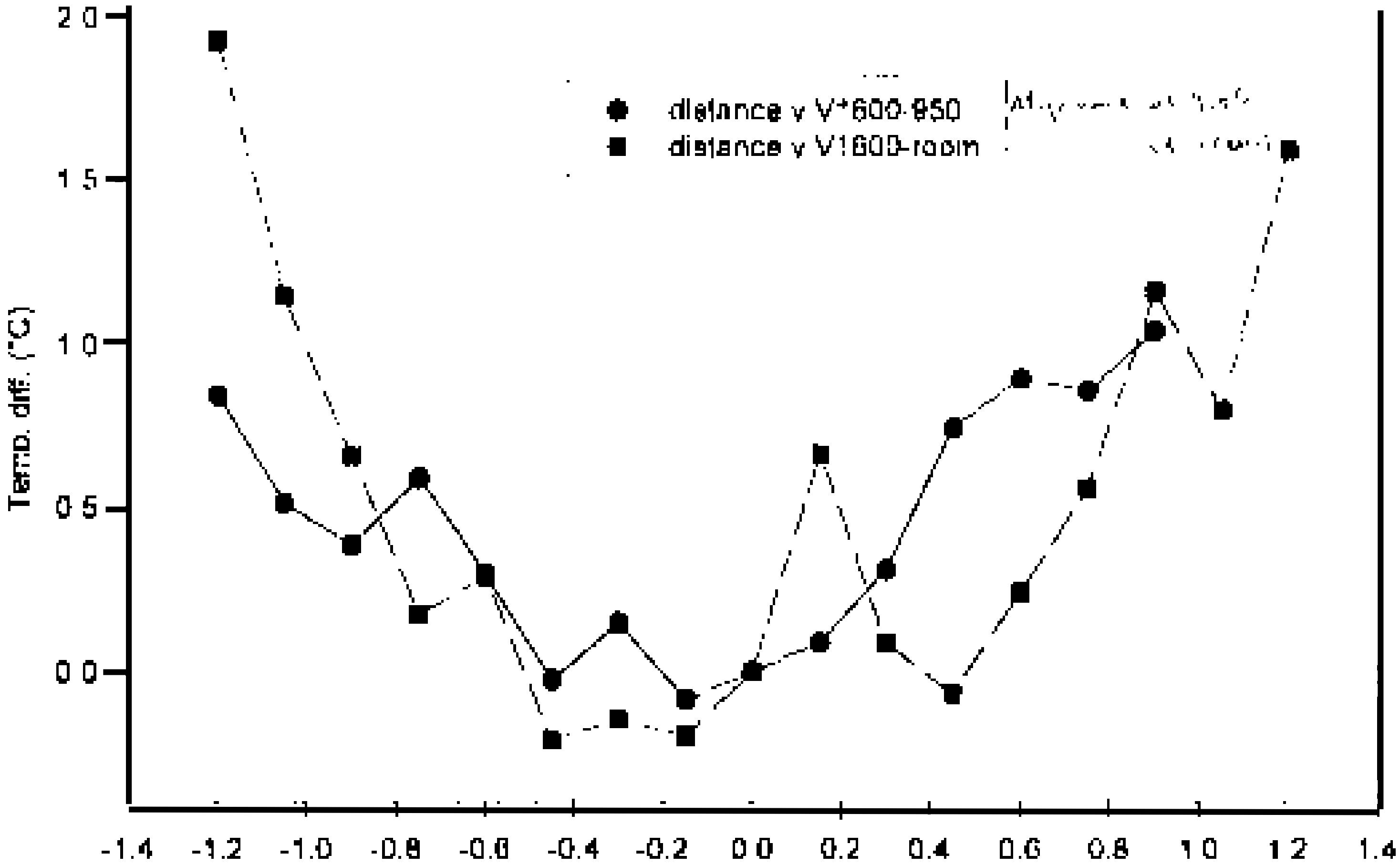


Micron bottom uniformity at 1600^{o}C (Horizontal)



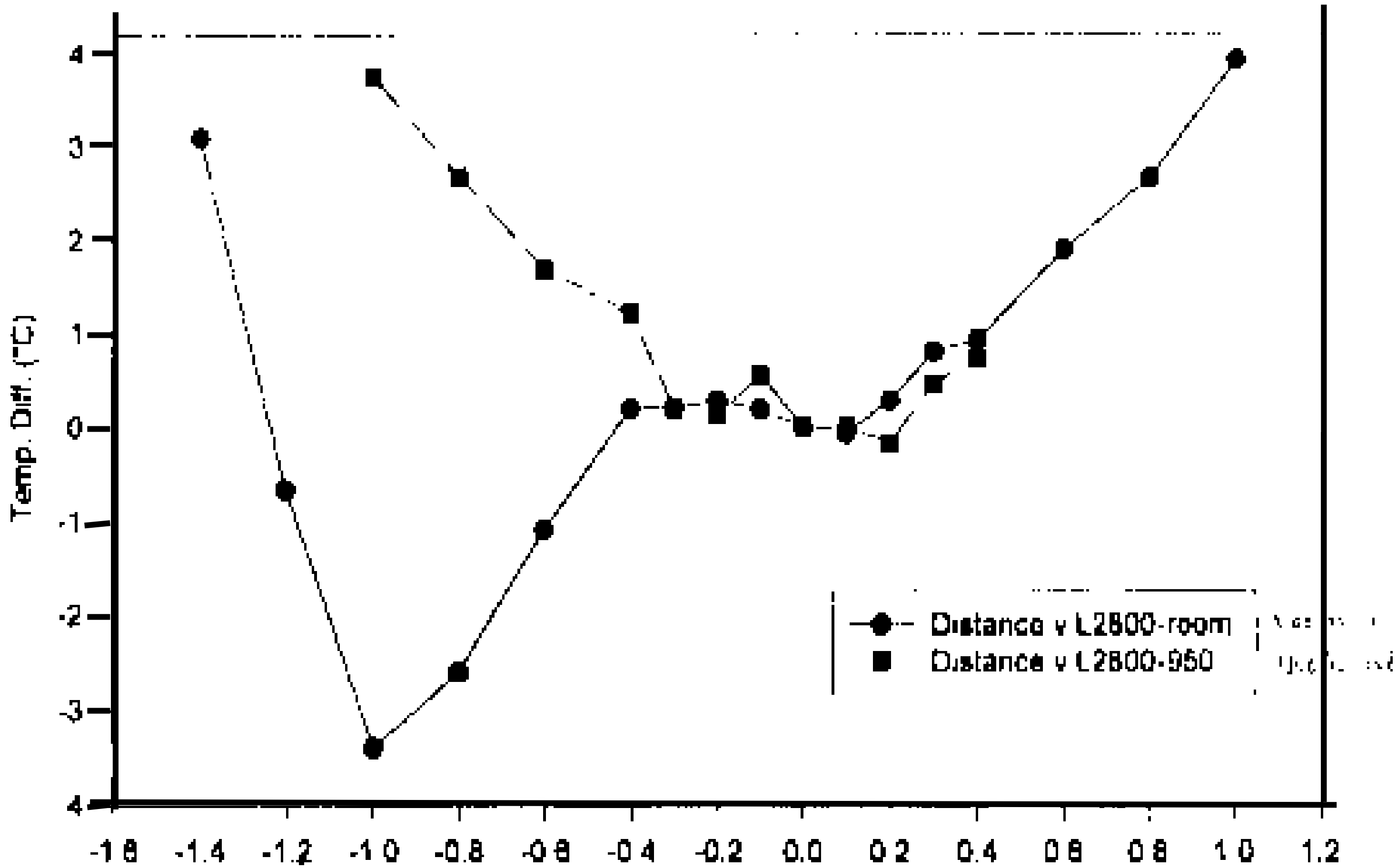
Position (mm), - is left, + is right

Micron bottom uniformity at 1600°C (Vertical)



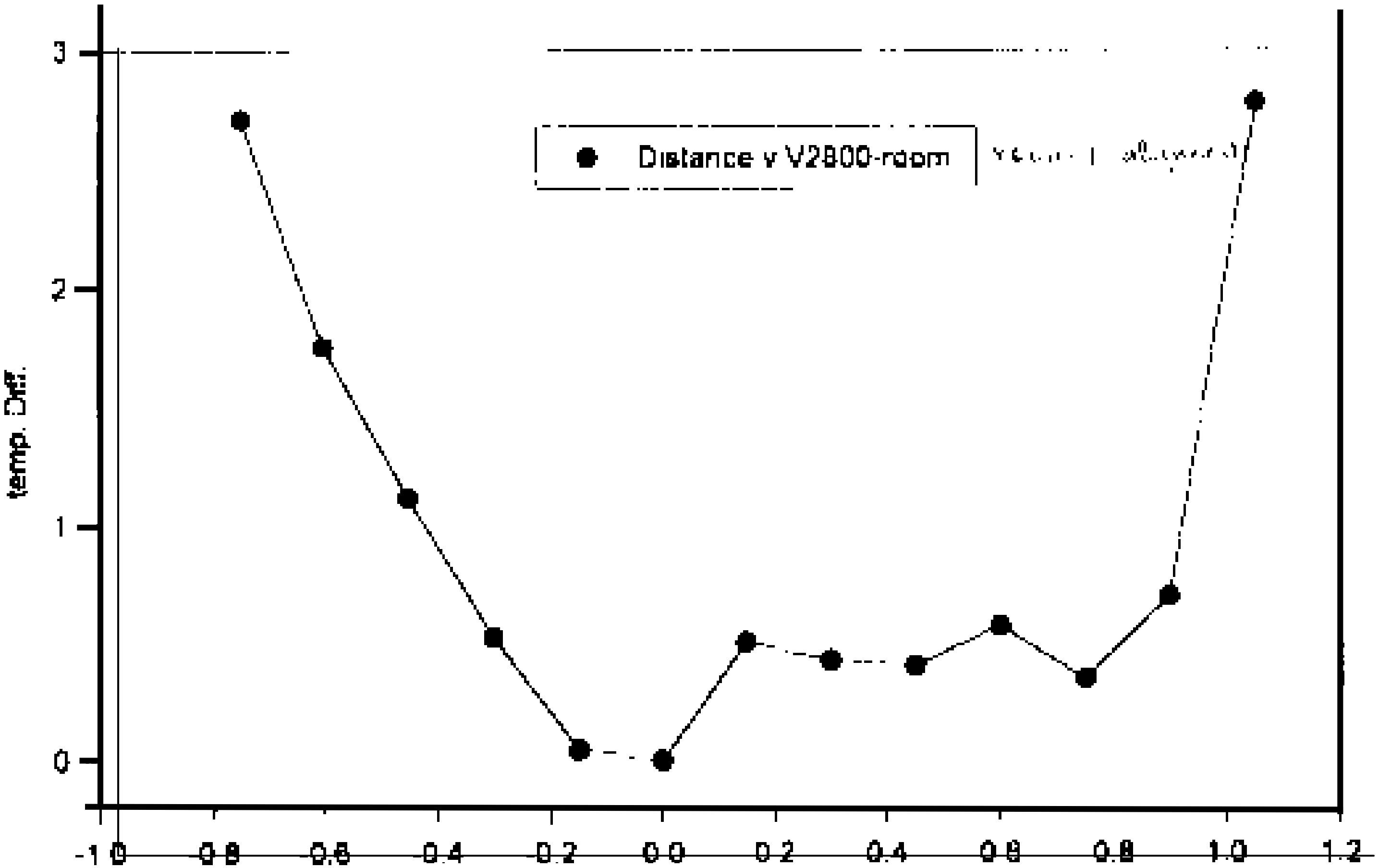
Position (mm), - is higher, + is lower

Micron bottom uniformity at 2800^{o}C (Horizontal)



Position (mm), - is left, + is right

Micron bottom uniformity at 2800°C (Vertical)

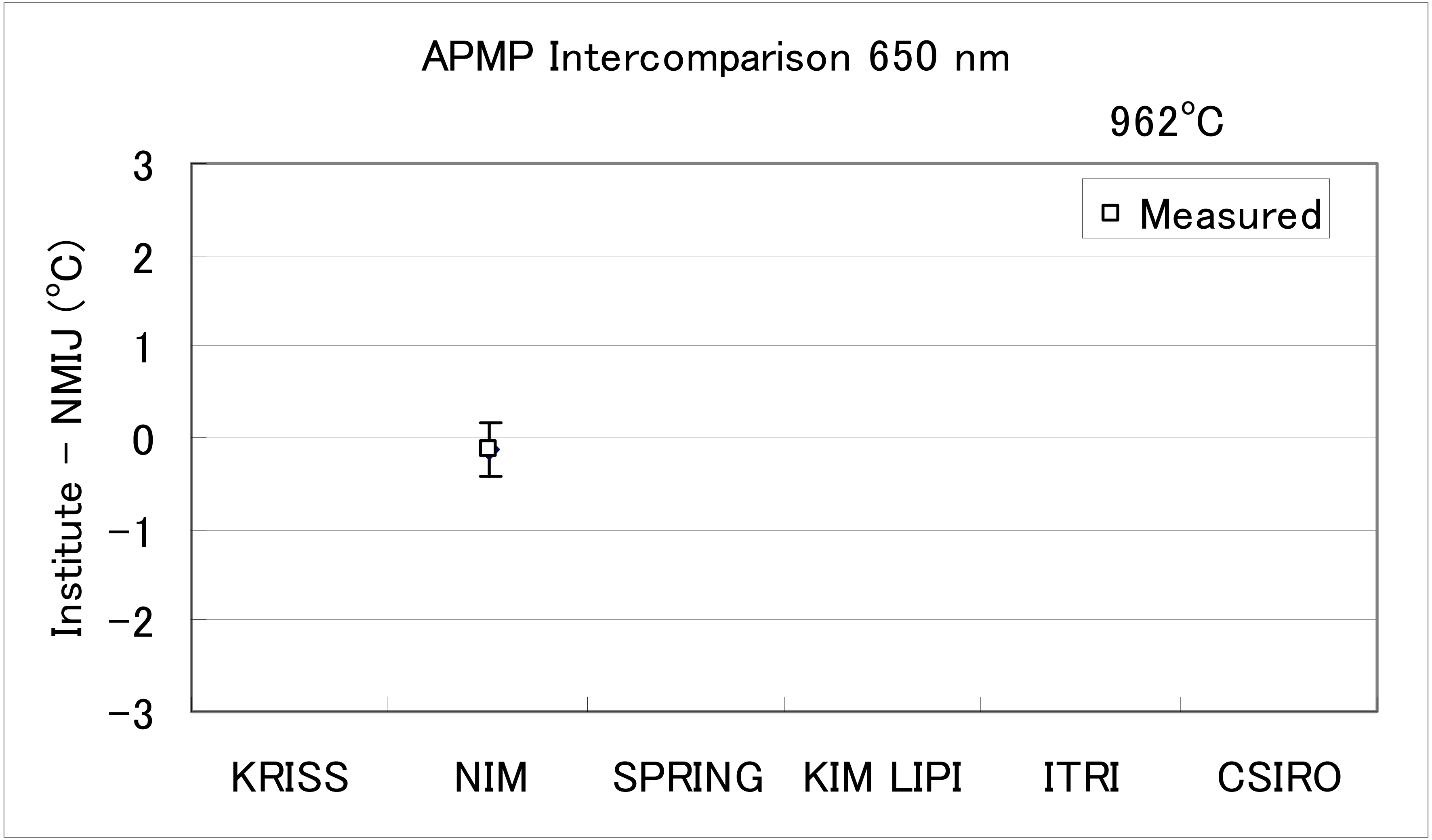


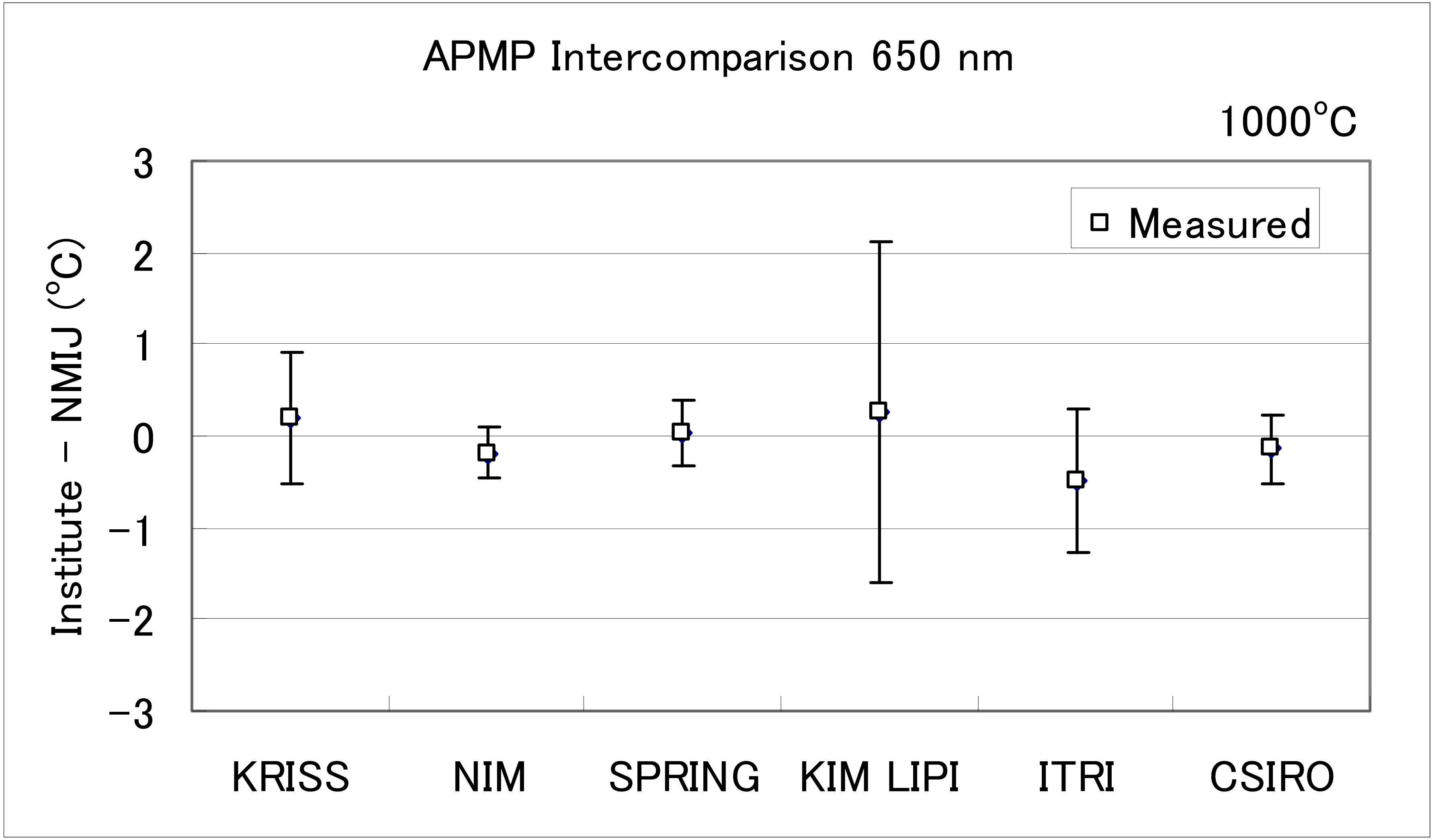
Position (mm), - is h igher, + is l ower

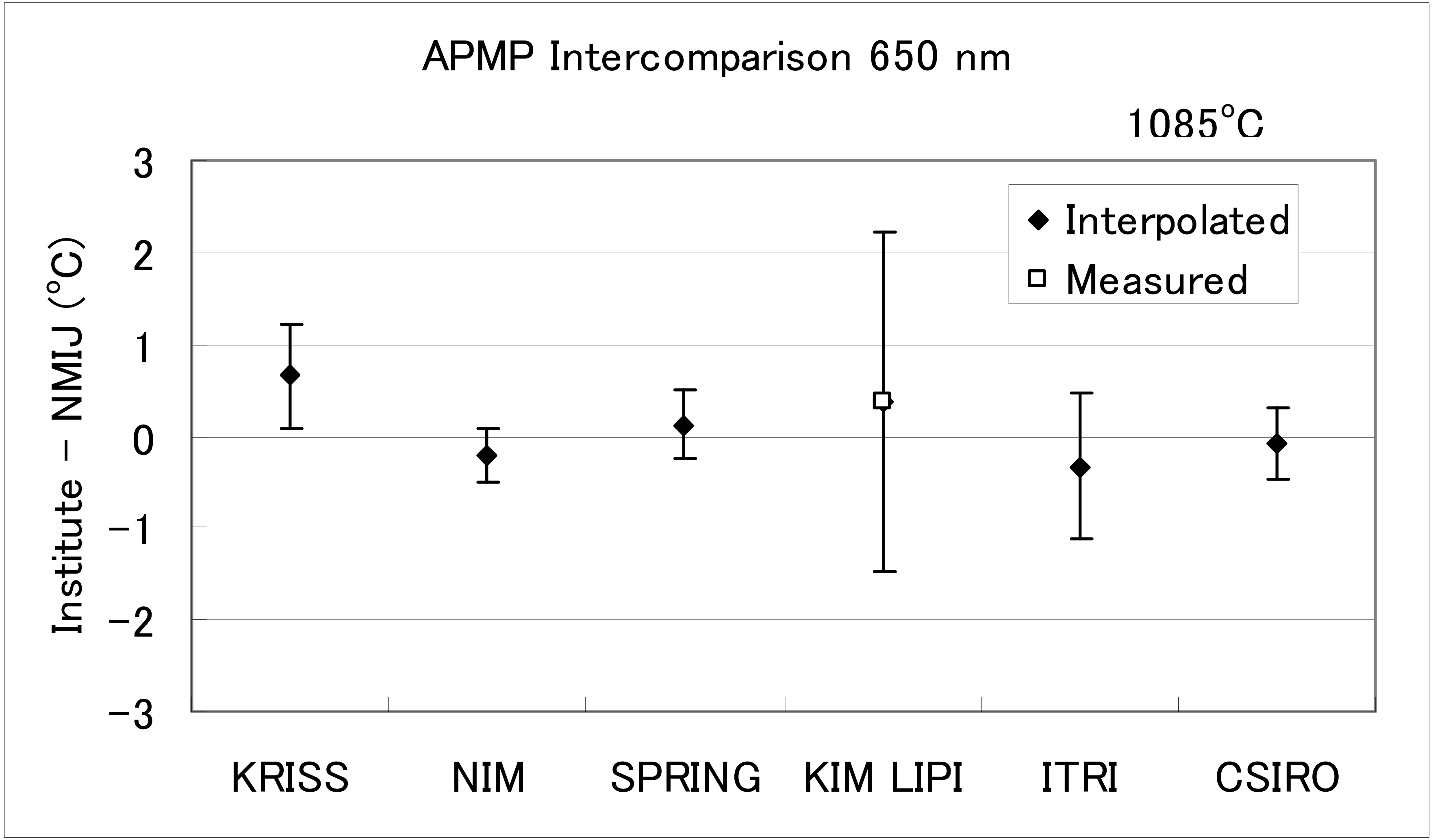
Appendix D : Result of comparison at each temperature

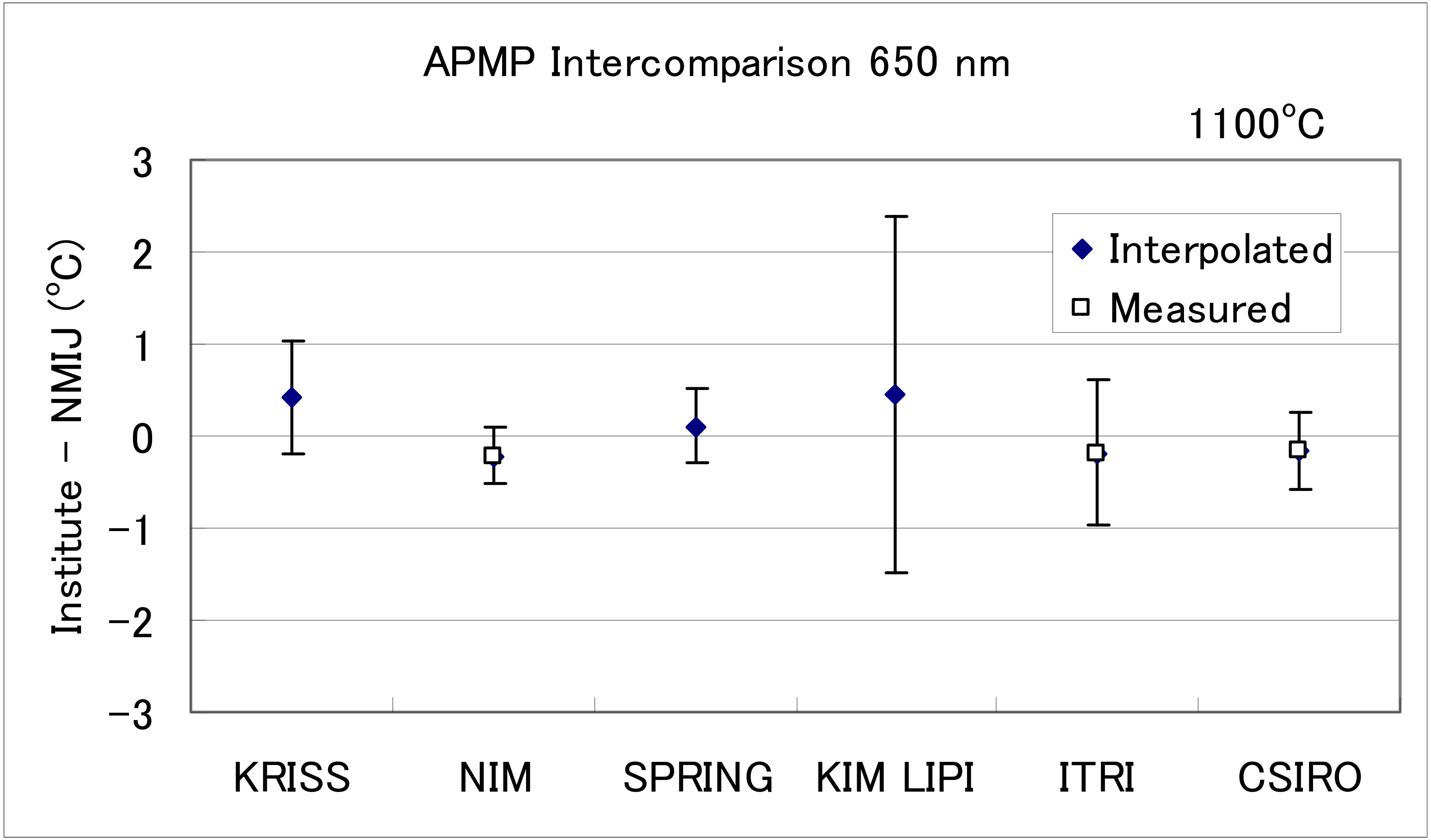
D1 Result at 962 C
D2 Result at 1000 C
D3 Result at 1085 C
D4 Result at 1100 C
D5 Result at 1200 C
D6 Result at 1300C
D7 Result at 1400 C
D8 Result at 1500 C
D9 Result at 1600 C
D10 Result at 1700 C
D11 Result at 1800 C
D12 Result at 1900 C
D13 Result at 2000 C
D14 Result at 2100 C
D15 Result at 2200 C
D16 Result at 2400 C
D17 Result at 2500 C
D18 Result at 2600 C
D19 Result at 2800 C

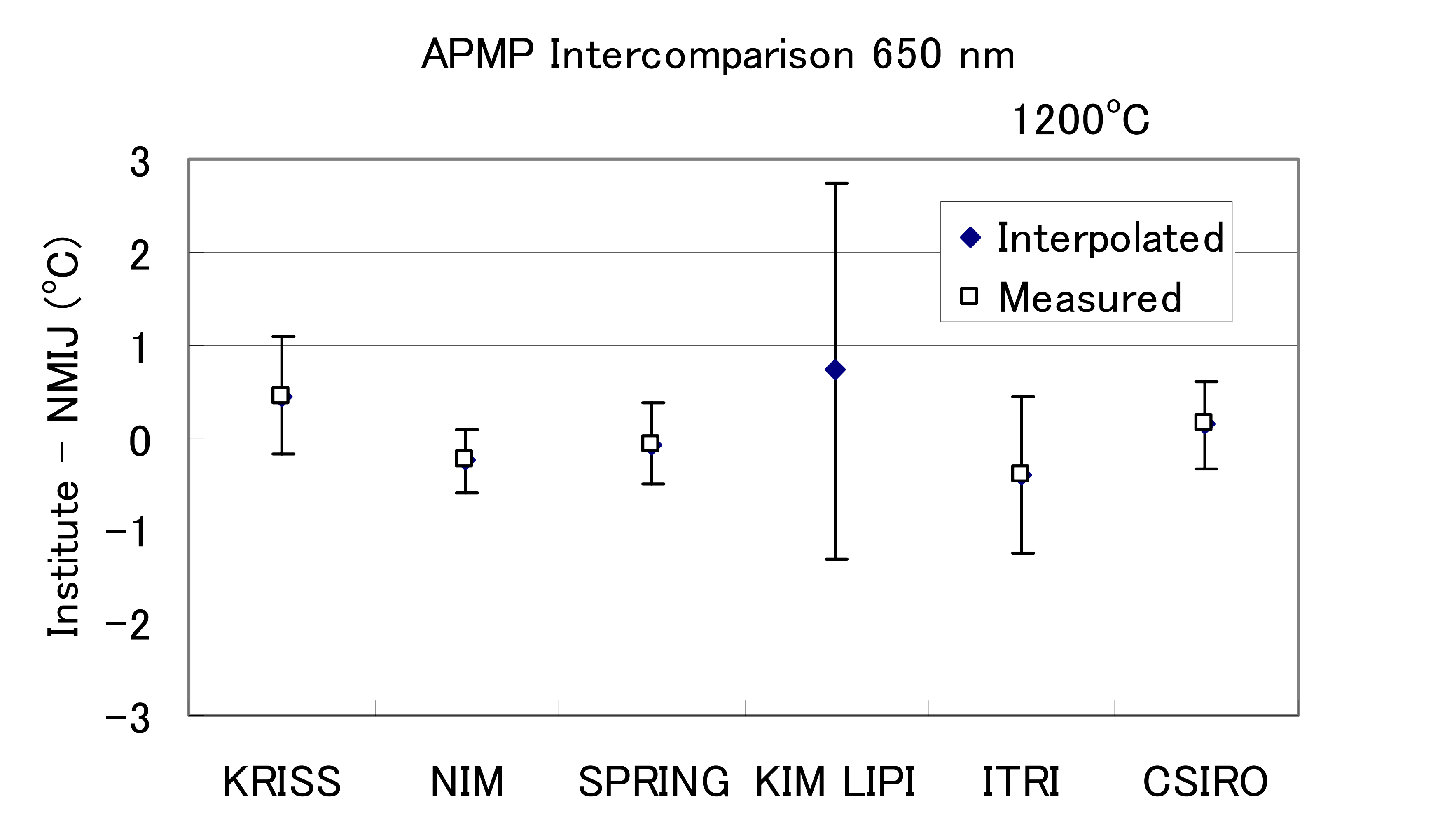
Note that in the figure open square was the measured result and closed diamond was the interpolated result.

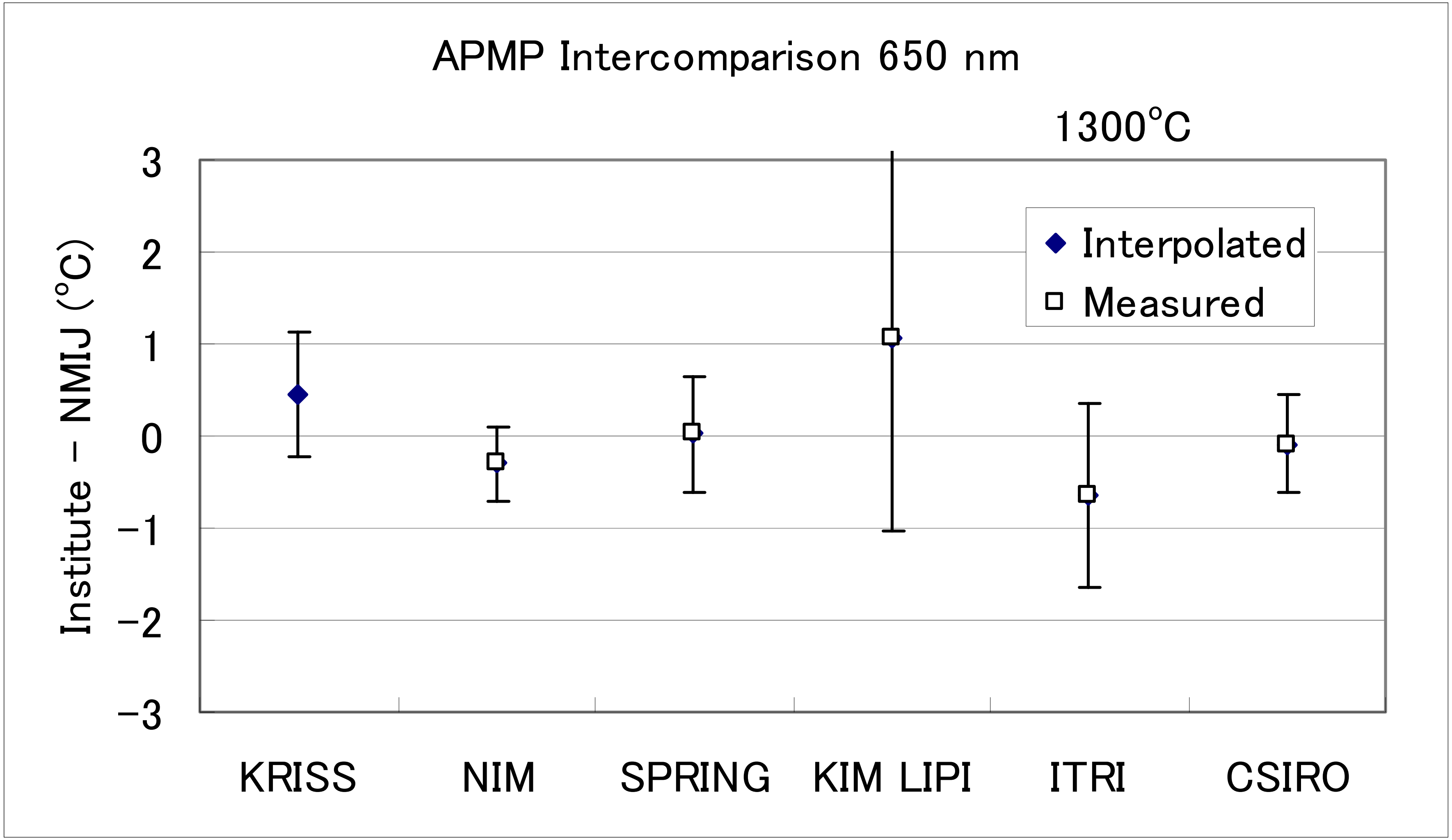

APMP Intercomparison 650 nm
962°C
Measured
Institute - NMIJ (°C)
3
2
1
0
−1
−2
−3
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO

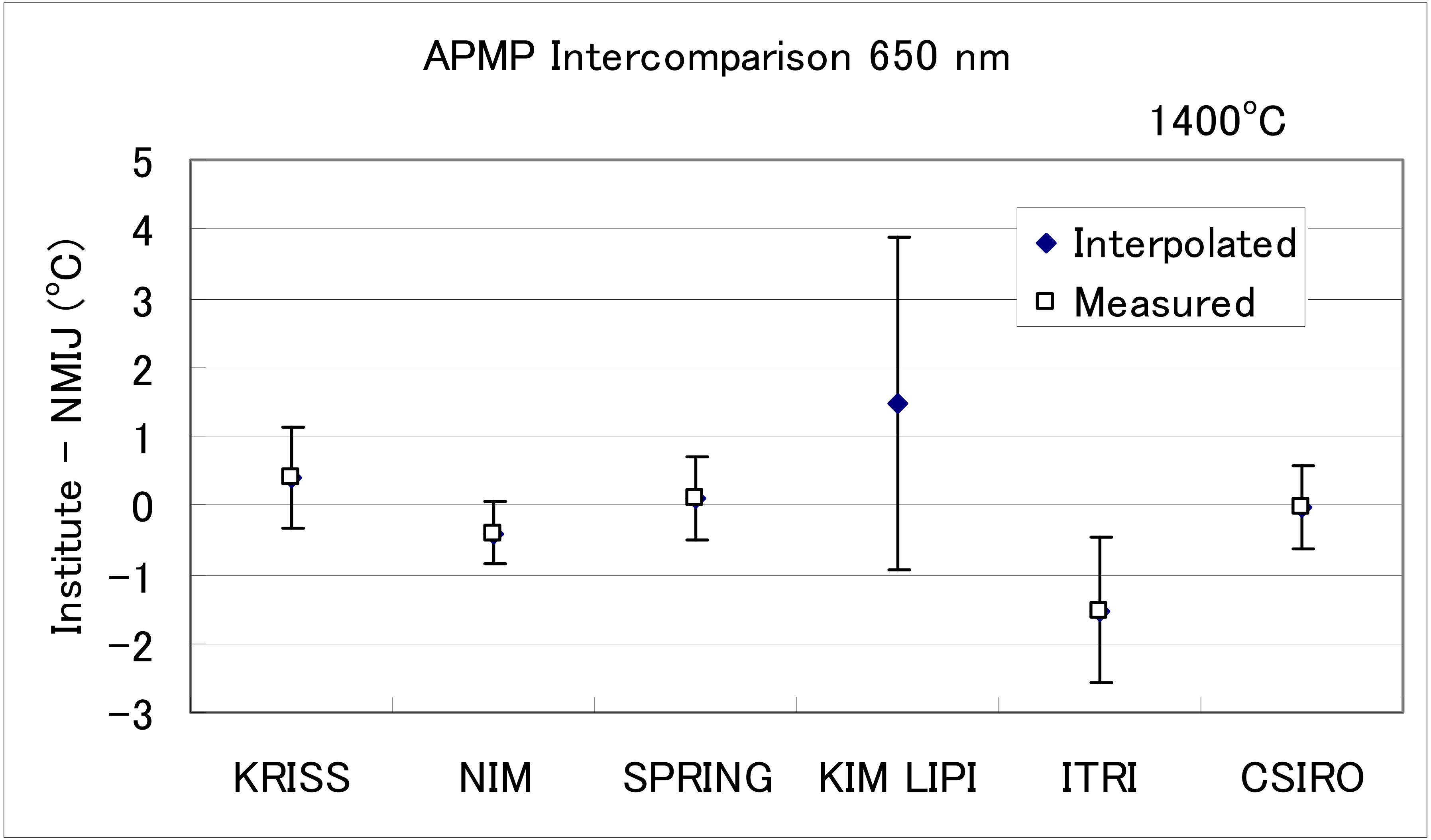

APMP Intercomparison 650 nm
1000°C
Measured
Institute − NMIJ (°C)
3
2
1
0
−1
−2
−3
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO

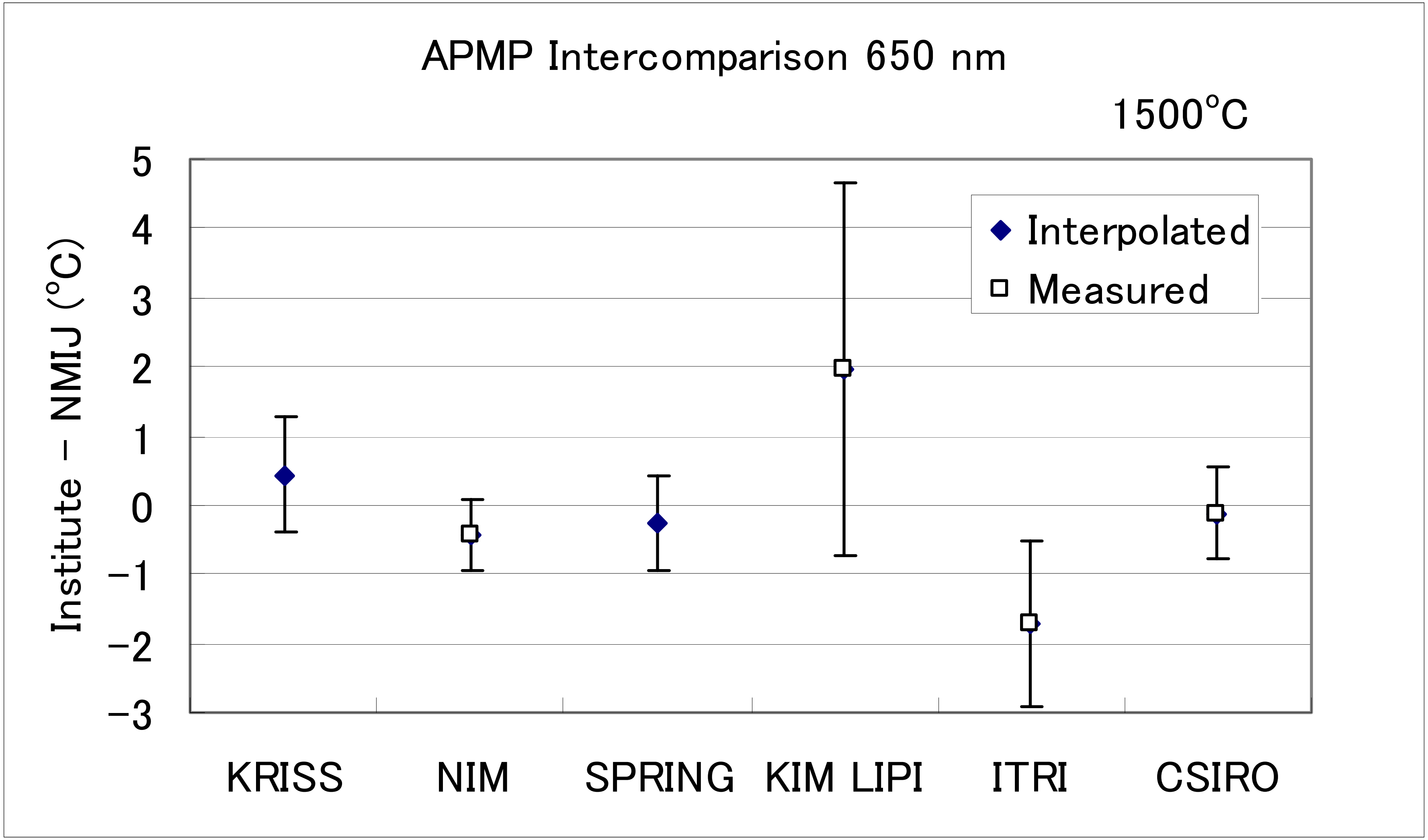

APMP Intercomparison 650 nm
1085°C
Interpolated
Measured
Institute – NMIJ (°C)
3
2
1
0
−1
−2
−3
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO

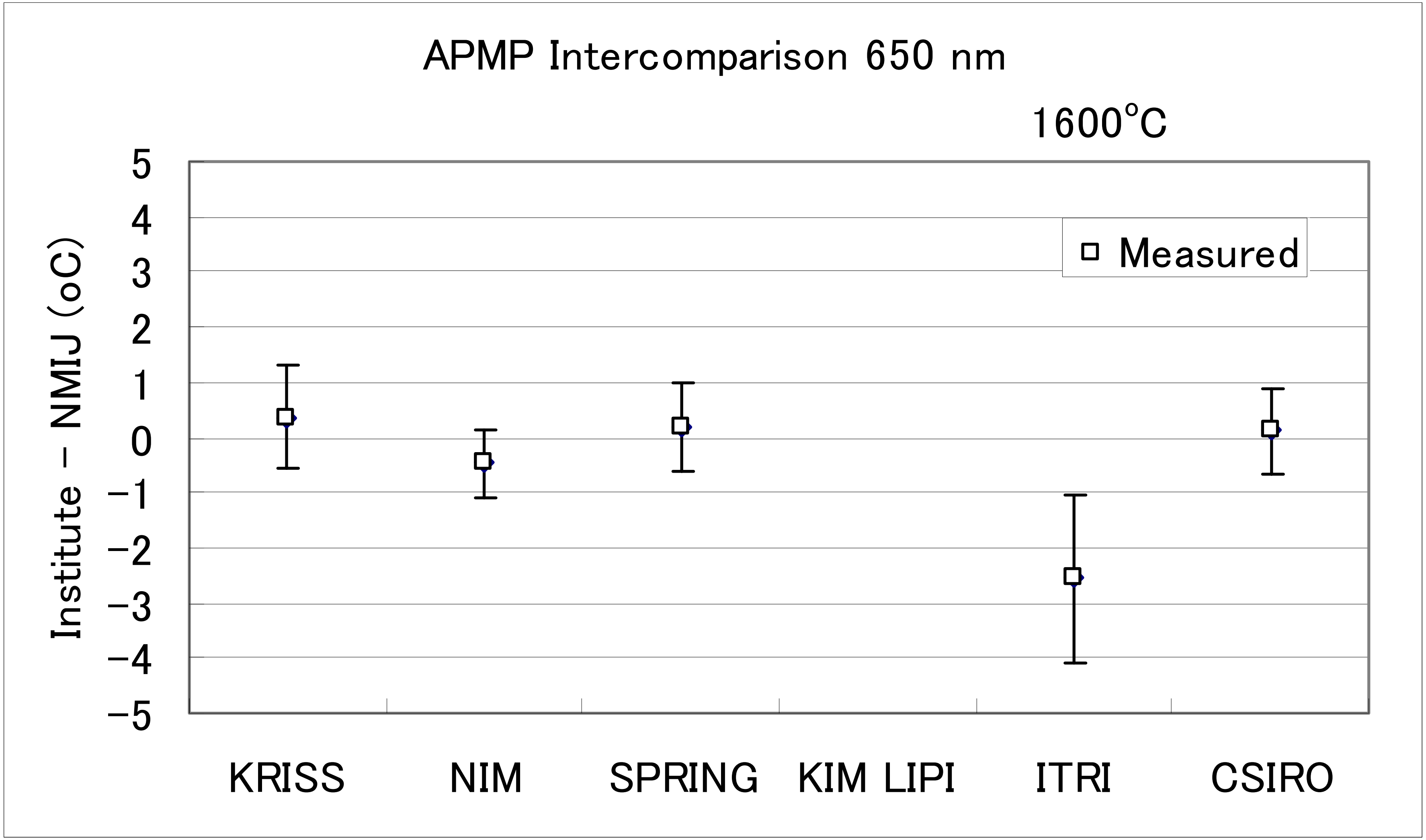

APMP Intercomparison 650 nm
1100°C
Institute − NMIJ (°C)
3
2
1
0
−1
−2
−3
Interpolated
Measured
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO

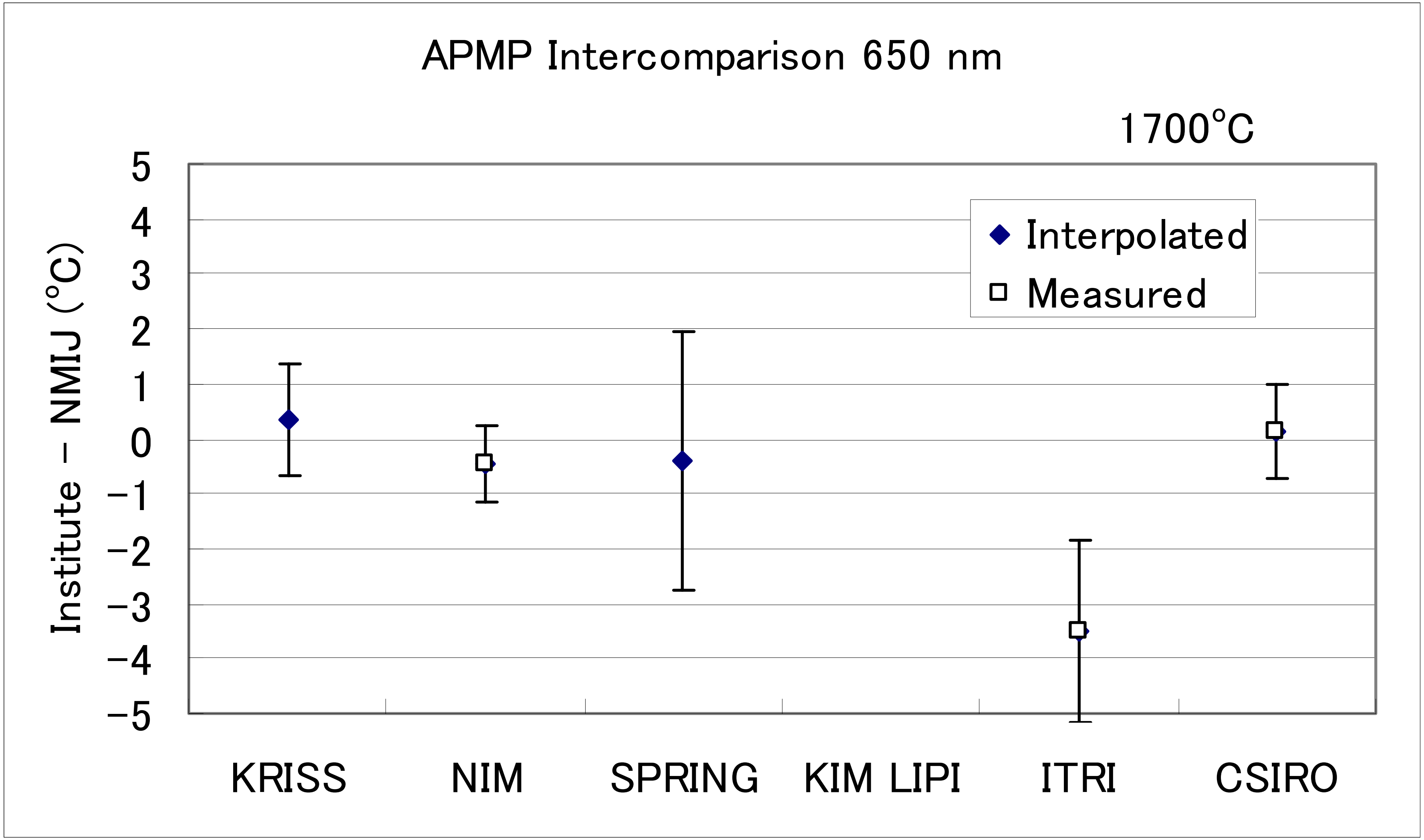

APMP Intercomparison 650 nm
1200°C
Interpolated
Measured
Institute – NMIJ (°C)
3
2
1
0
−1
−2
−3
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO

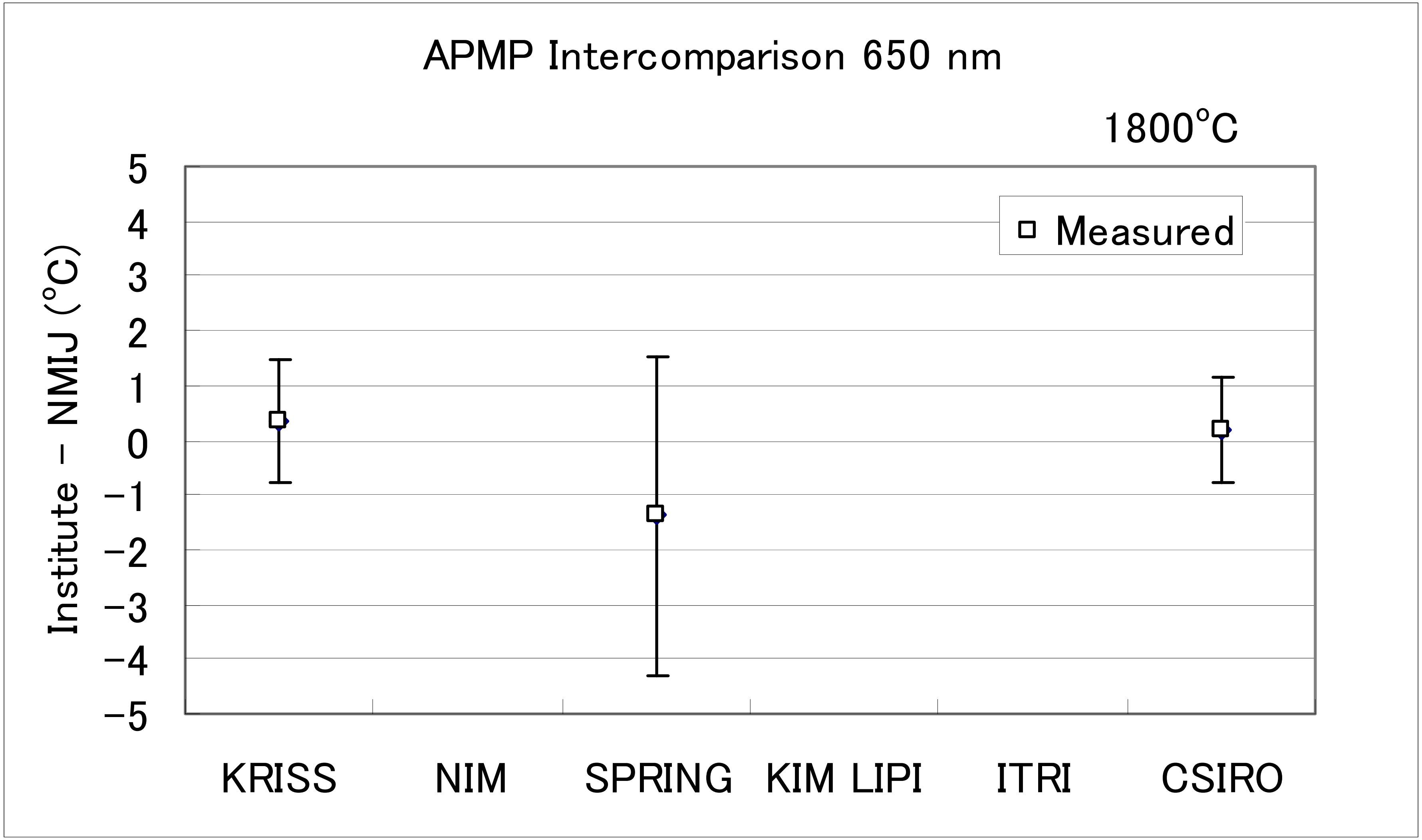

APMP Intercomparison 650 nm
1300°C
Interpolated
Measured
Institute – NMIJ (°C)
3
2
1
0
−1
−2
−3
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO

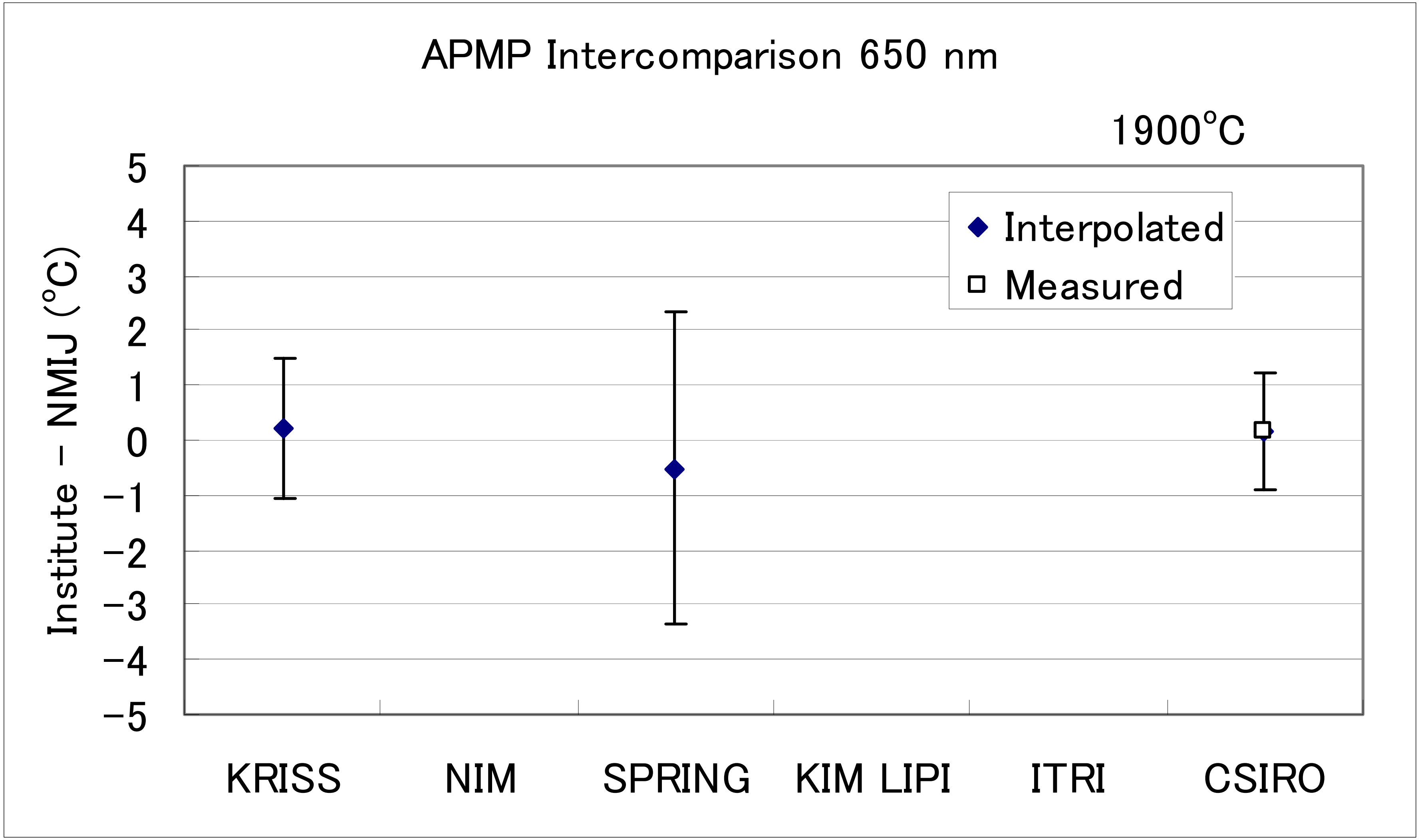

APMP Intercomparison 650 nm
1400°C
Interpolated
Measured
Institute − NMIJ (°C)
5
4
3
2
1
0
−1
−2
−3
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO

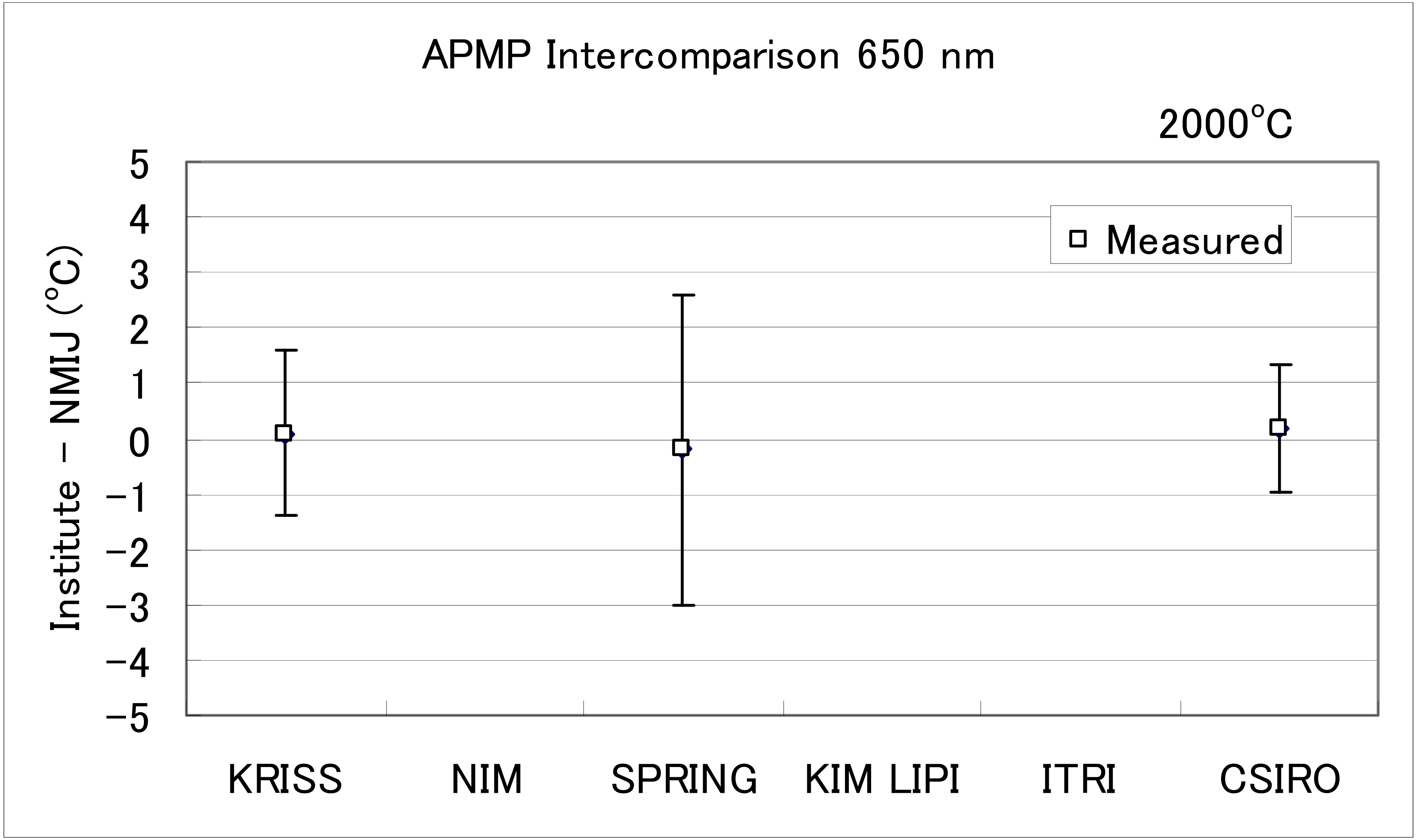

APMP Intercomparison 650 nm
1500°C
Institute − NMIJ (°C)
5
4
3
2
1
0
−1
−2
−3
Interpolated
Measured
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO

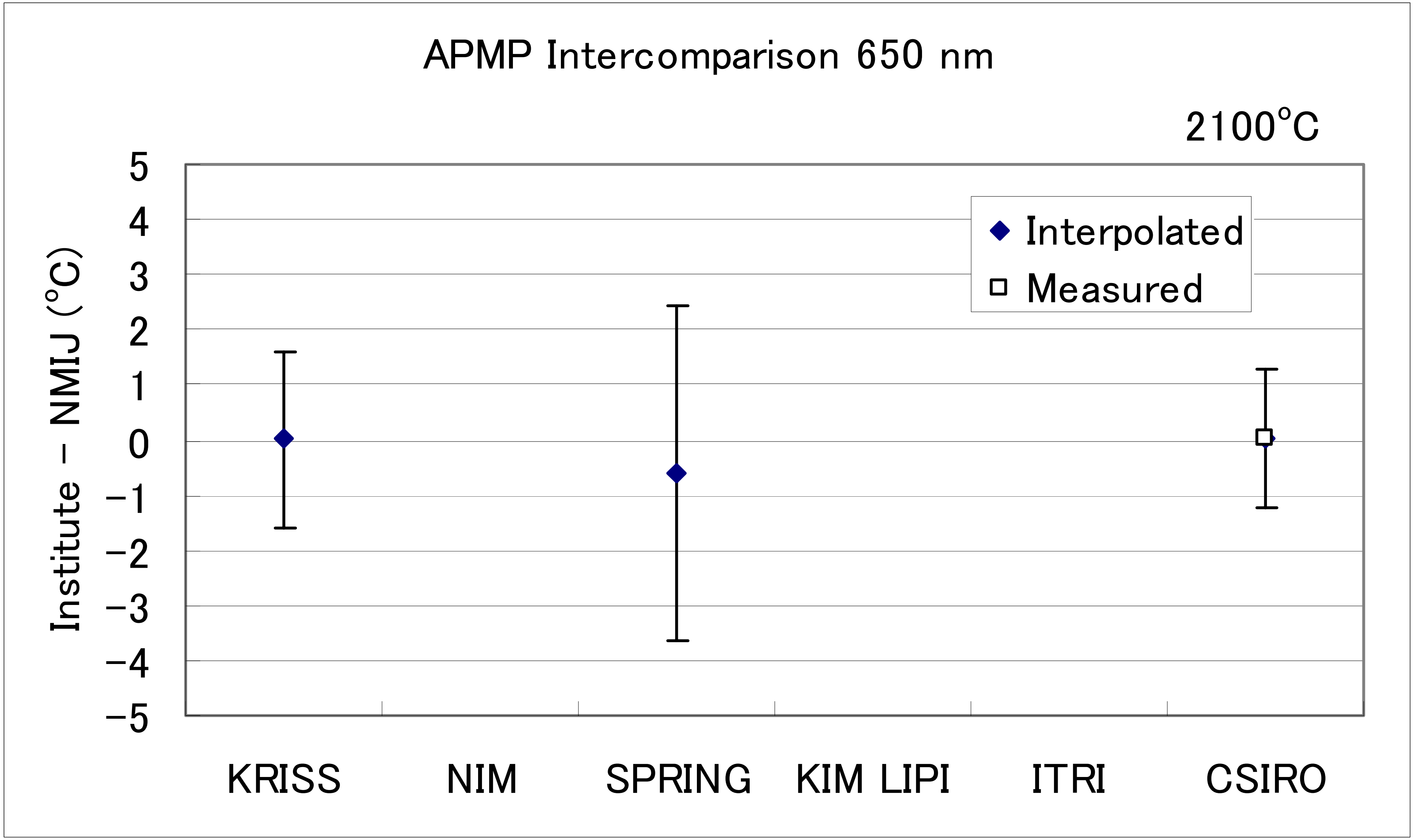

APMP Intercomparison 650 nm
1600°C
Measured
Institute - NMIJ (oC)
5
4
3
2
1
0
−1
−2
−3
−4
−5
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO

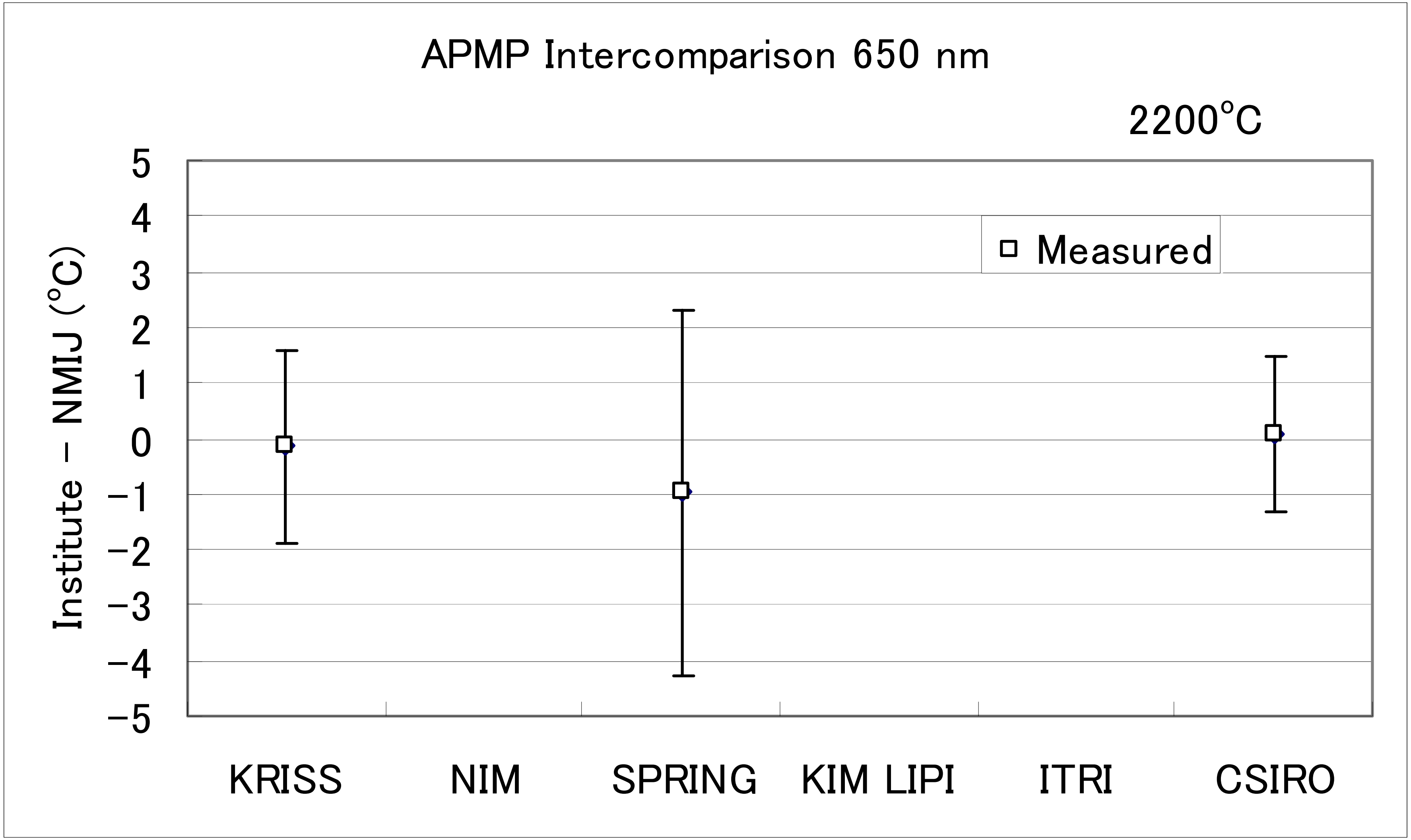

APMP Intercomparison 650 nm
1700°C
Interpolated
Measured
Institute − NMIJ (°C)
5
4
3
2
1
0
−1
−2
−3
−4
−5
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO

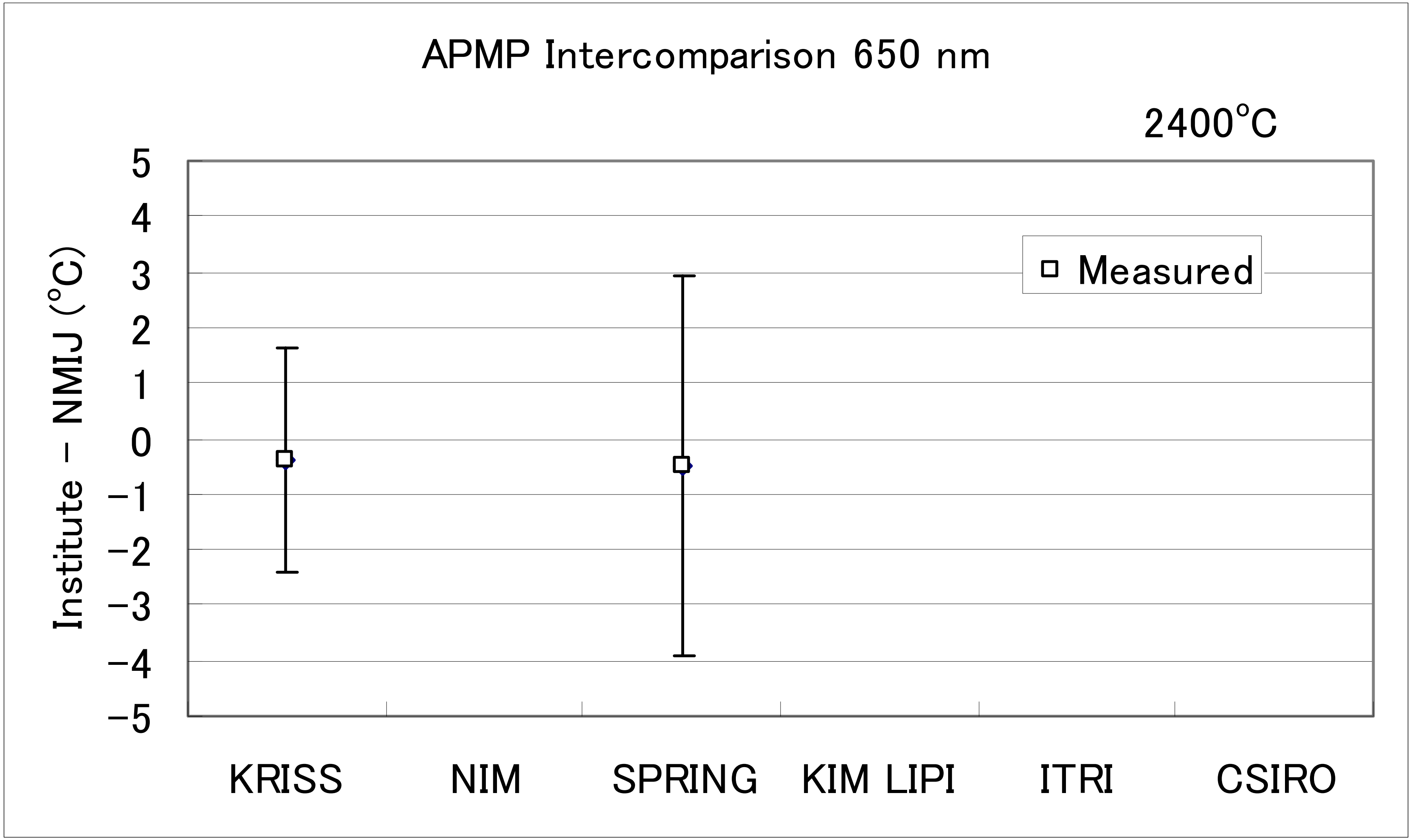

APMP Intercomparison 650 nm
1800°C
Measured
Institute − NMIJ (°C)
5
4
3
2
1
0
−1
−2
−3
−4
−5
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO

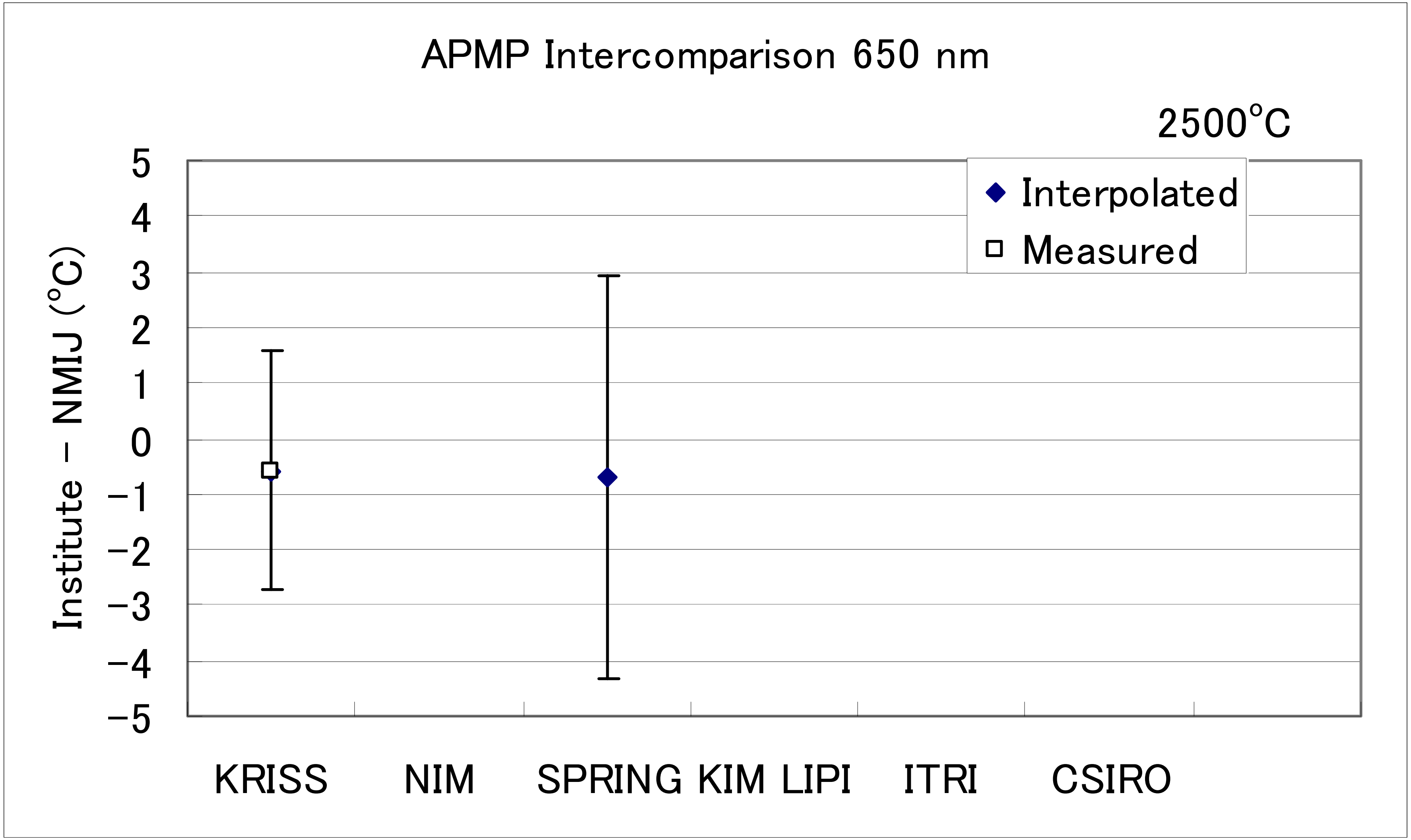

APMP Intercomparison 650 nm
1900°C
Interpolated
Measured
Institute − NMIJ (°C)
5
4
3
2
1
0
−1
−2
−3
−4
−5
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO

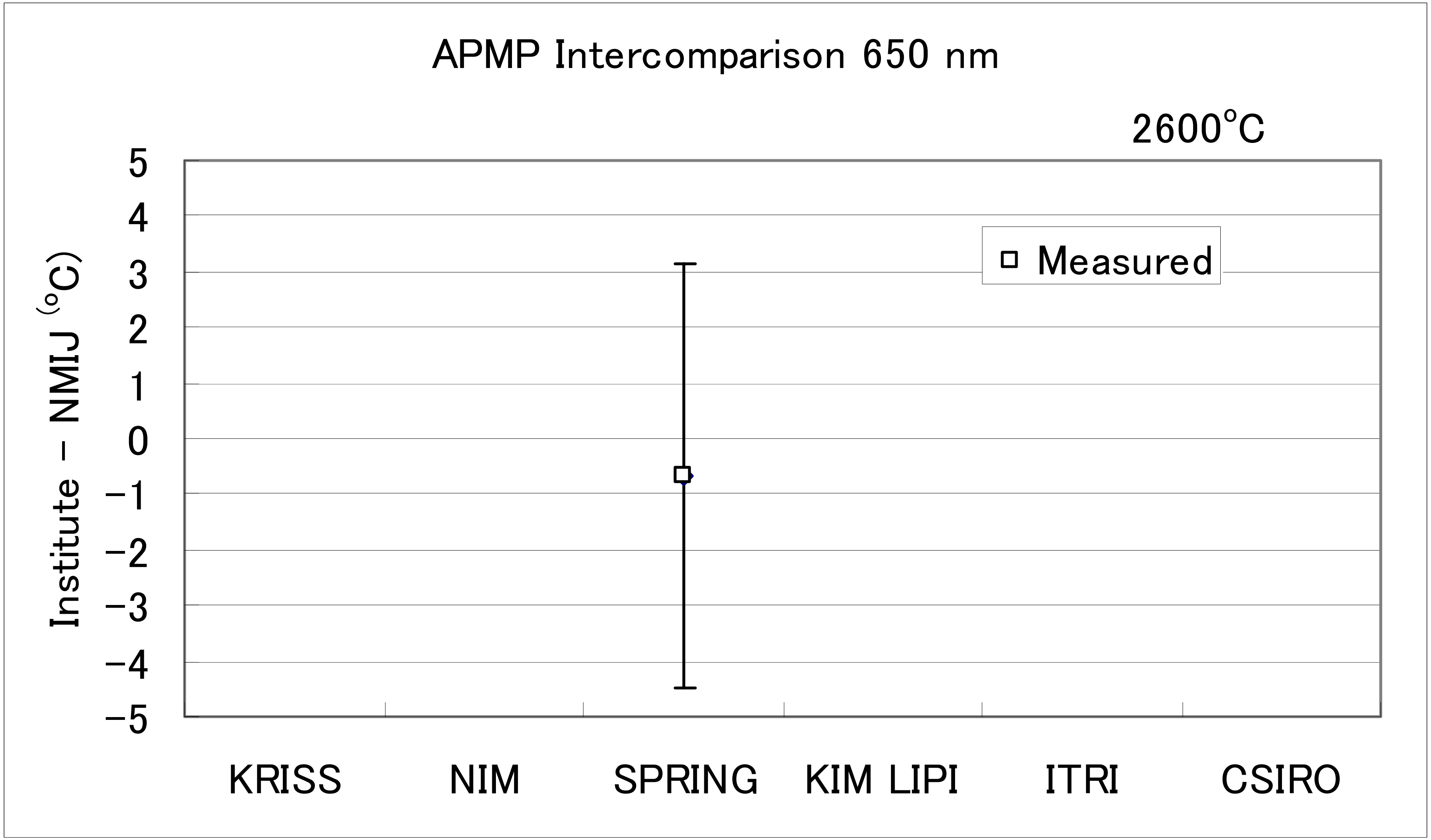

APMP Intercomparison 650 nm
2000°C
Measured
Institute − NMIJ (°C)
5
4
3
2
1
0
−1
−2
−3
−4
−5
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO

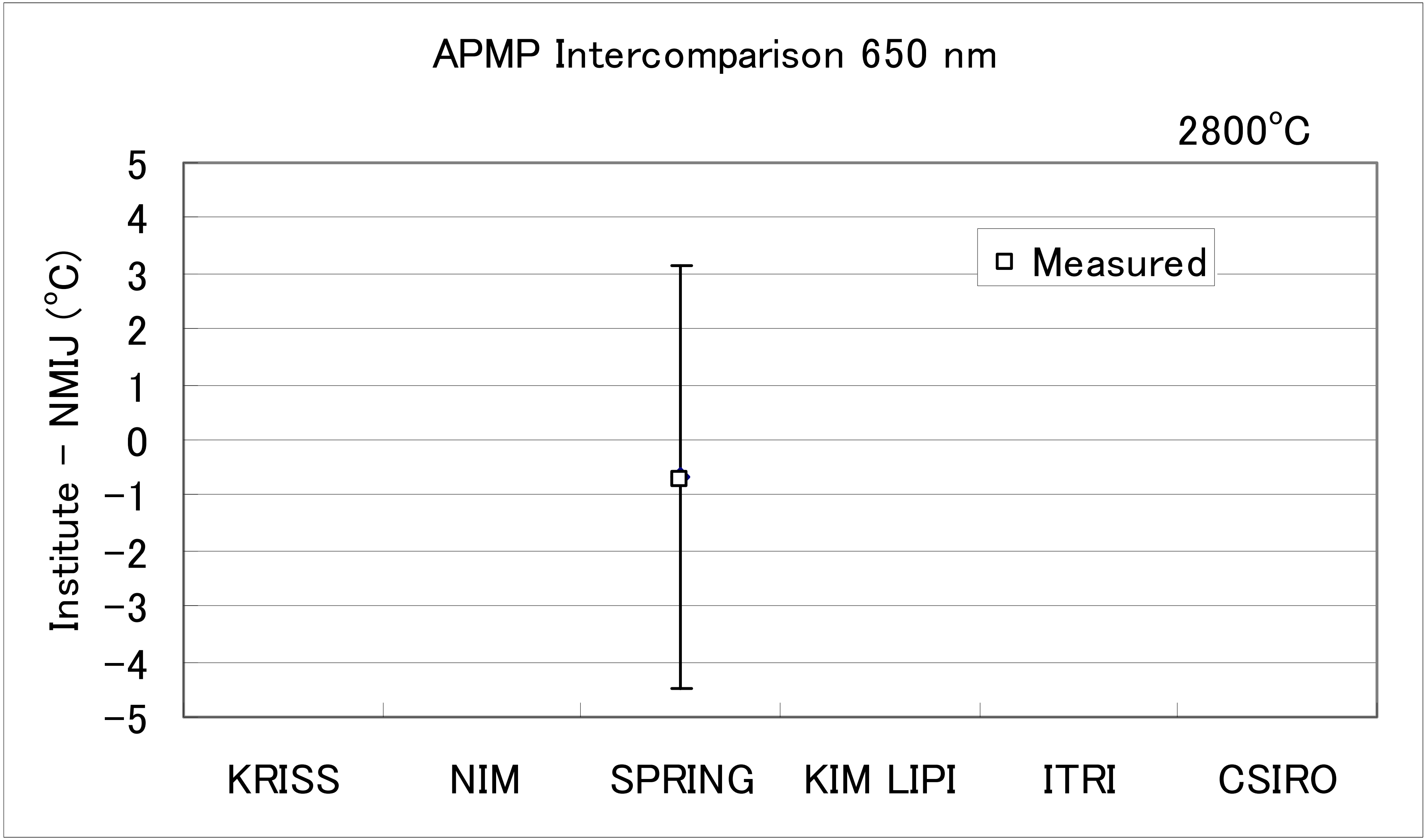

APMP Intercomparison 650 nm
2100°C
Interpolated
Measured
Institute − NMIJ (°C)
5
4
3
2
1
0
−1
−2
−3
−4
−5
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO


APMP Intercomparison 650 nm
2200°C
Measured
Institute - NMIJ (°C)
5
4
3
2
1
0
−1
−2
−3
−4
−5
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO


APMP Intercomparison 650 nm
2400°C
Measured
Institute - NMIJ (°C)
5
4
3
2
1
0
−1
−2
−3
−4
−5
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO


APMP Intercomparison 650 nm
2500°C
Interpolated
Measured
Institute – NMIJ (°C)
5
4
3
2
1
0
−1
−2
−3
−4
−5
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO


APMP Intercomparison 650 nm
2600°C
Measured
Institute – NMIJ (°C)
5
4
3
2
1
0
−1
−2
−3
−4
−5
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO


APMP Intercomparison 650 nm
2800°C
Measured
Institute - NMIJ (°C)
5
4
3
2
1
0
−1
−2
−3
−4
−5
KRISS
NIM
SPRING
KIM LIPI
ITRI
CSIRO

Appendix E : Calculation of the APMP Key Comparison reference value

E1 Difference between KRISS and NMIJ

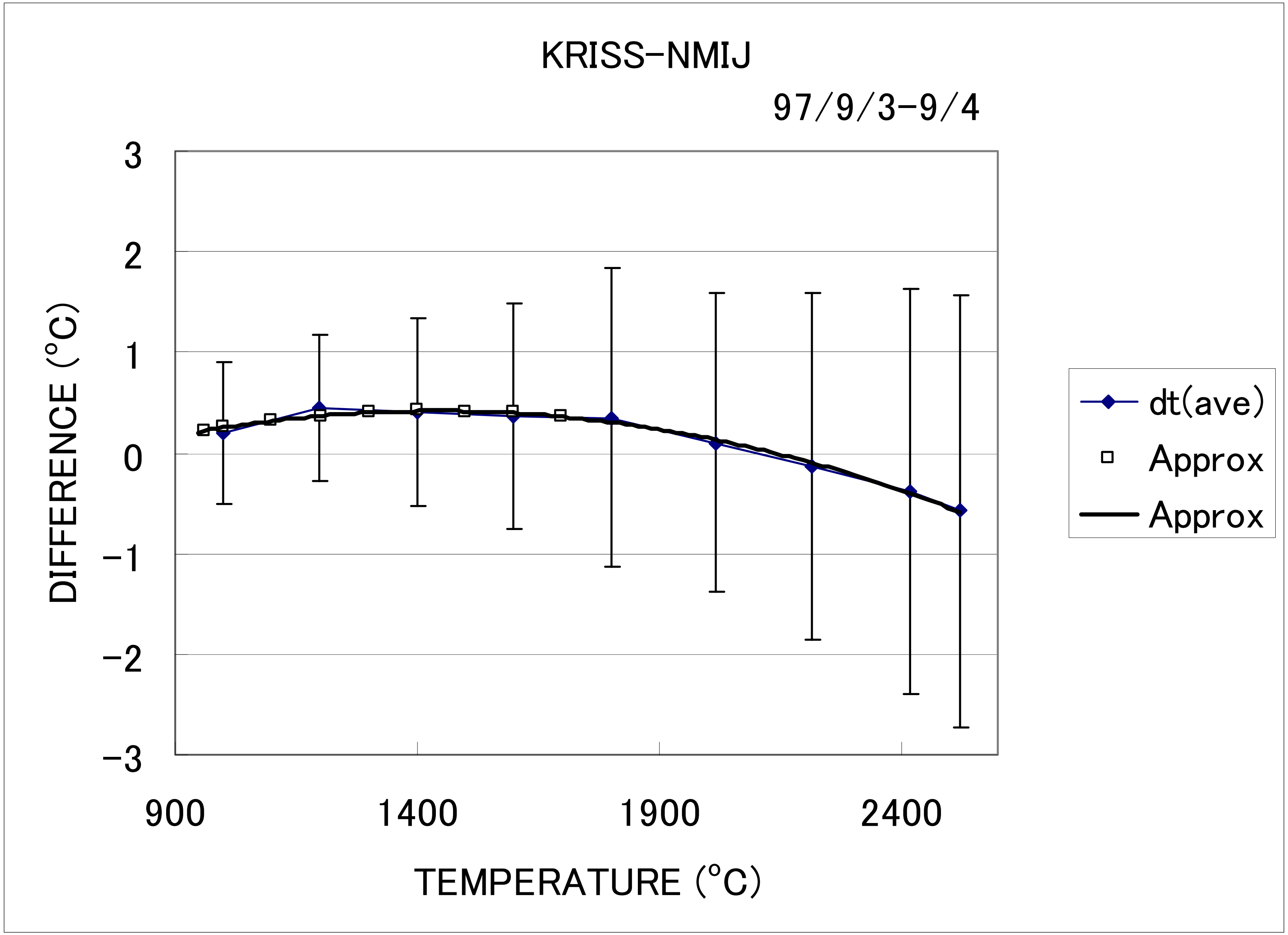
E2 Differ ence between NIM and NMIJ

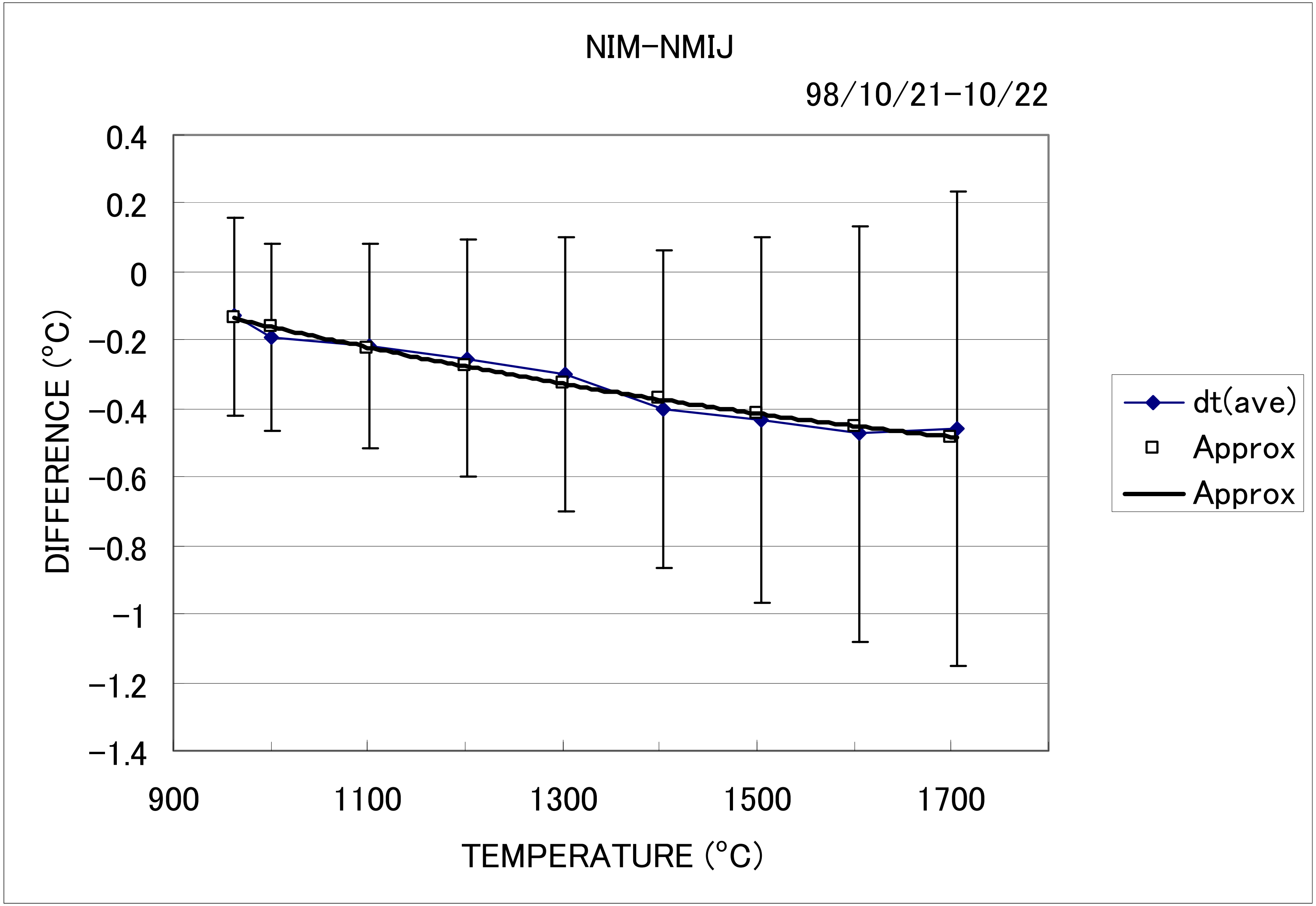
E3 Differ ence between NMC/SPRING and NMIJ

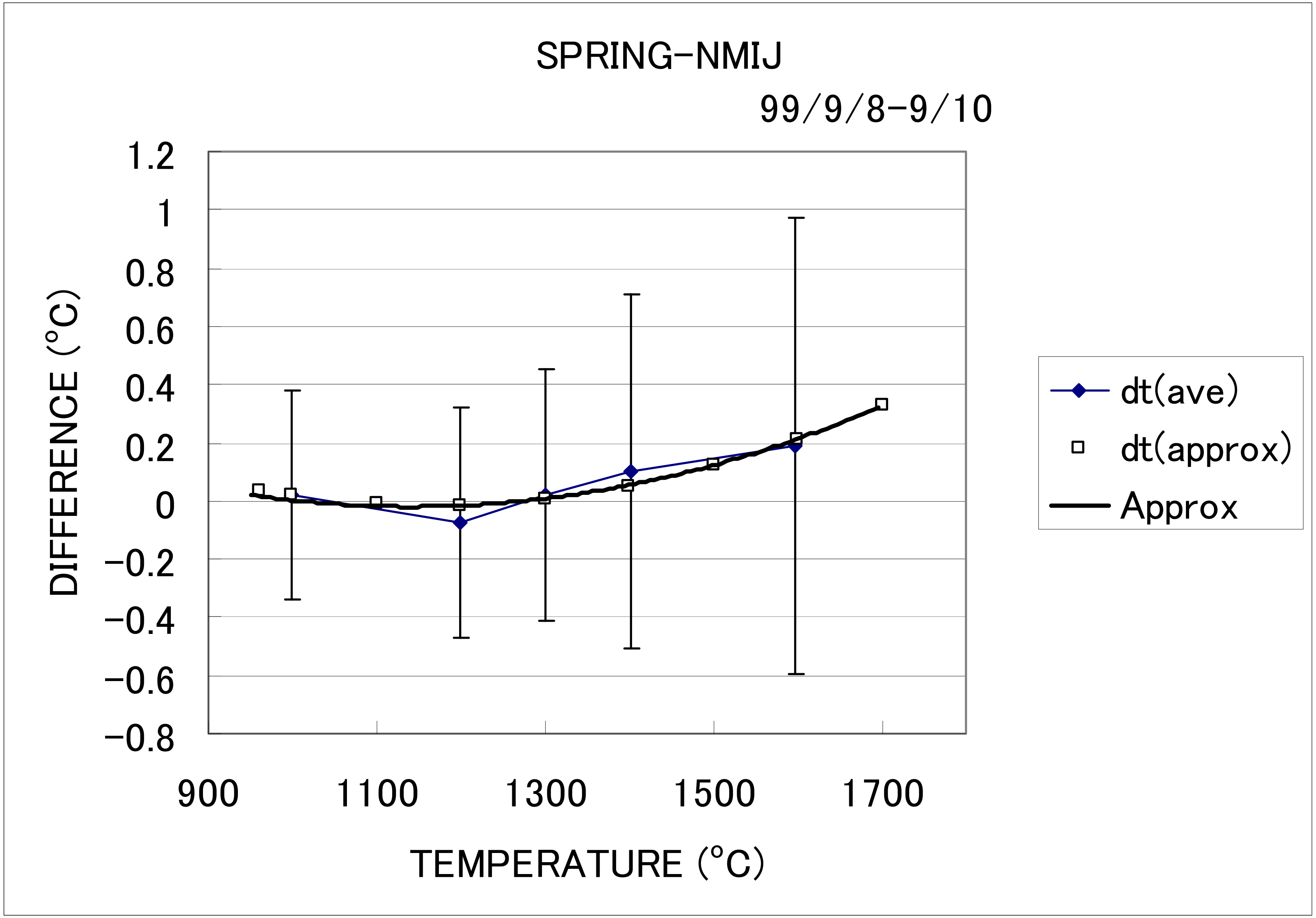
E4 Difference between NML/CSIRO and NMIJ

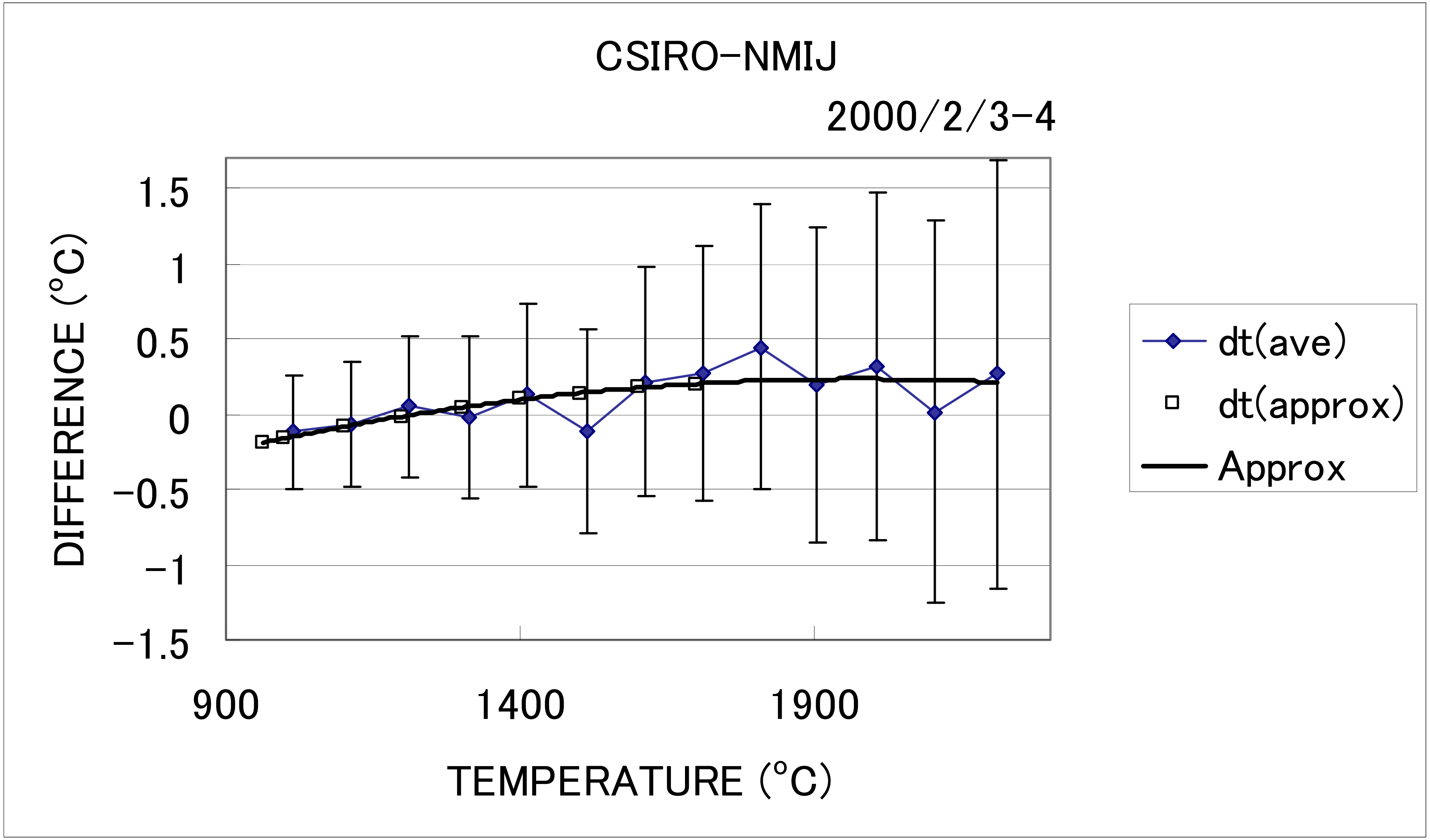
E5 Average of the difference

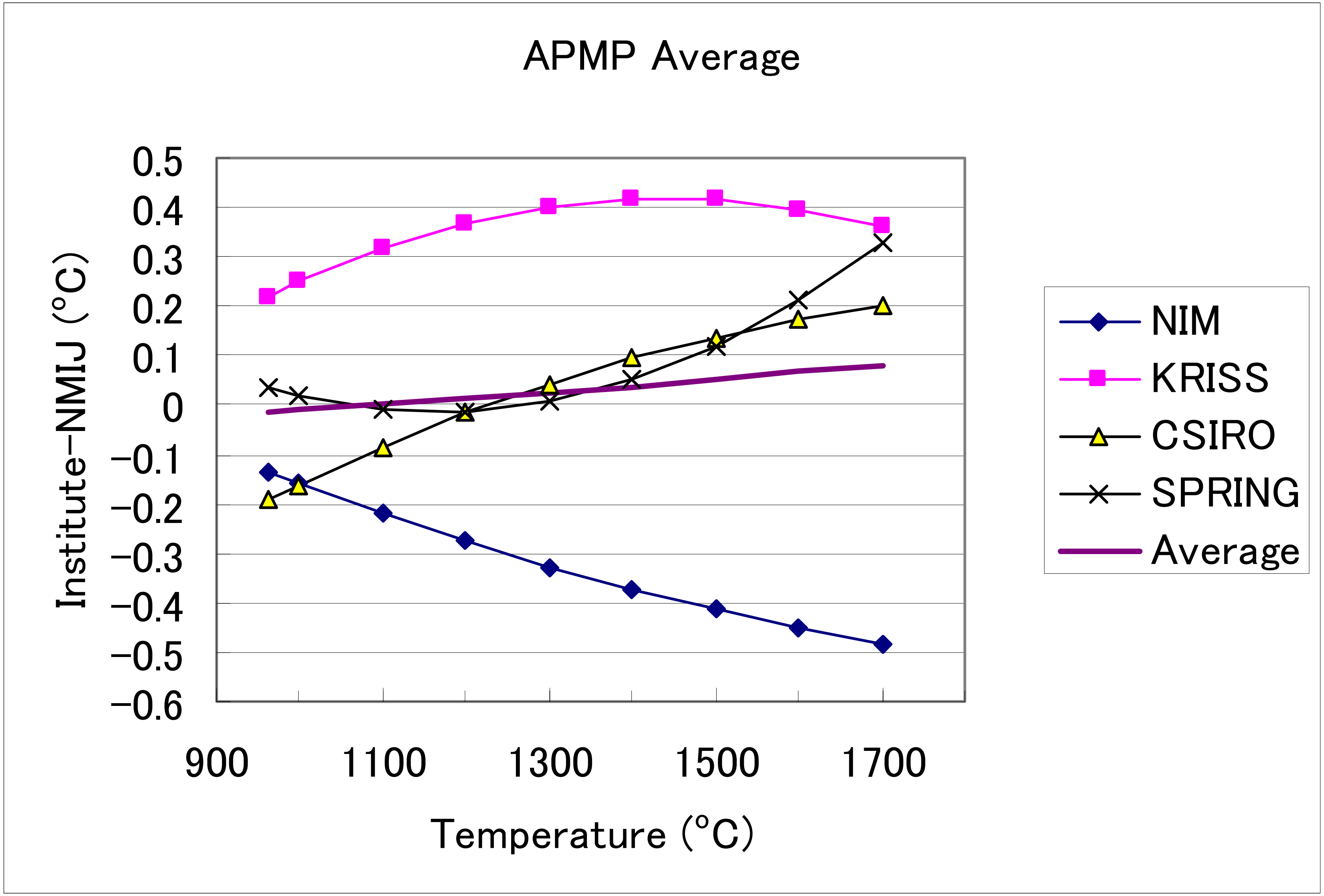
Note that the average was taken among five institutes including NMIJ whose data was zero in the figure.


KRISS-NMIJ
97/9/3-9/4
3
2
1
0
−1
−2
−3
DIFFERENCE (°C)
900
1400
1900
2400
TEMPERATURE (°C)
dt(ave)
Approx
Approx


NIM-NMIJ
98/10/21-10/22
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
−1.2
−1.4
DIFFERENCE (°C)
900
1100
1300
1500
1700
TEMPERATURE (°C)
dt(ave)
Approx
Approx


SPRING-NMIJ
99/9/8-9/10
1.2
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
DIFFERENCE (°C)
900
1100
1300
1500
1700
TEMPERATURE (°C)
dt(ave)
dt(approx)
Approx


CSIRO-NMIJ
2000/2/3-4
DIFFERENCE (°C)
1.5
1
0.5
0
−0.5
−1
−1.5
900
1400
1900
TEMPERATURE (°C)
dt(ave)
dt(approx)
Approx


APMP Average
Institute−NMIJ (°C)
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5
−0.6
900
1100
1300
1500
1700
Temperature (°C)
NIM
KRISS
CSIRO
SPRING
Average

Appendix F : Corrected results of comparison at CMS/ITRI

In October 2001 ITRI reported that ITRI had made a simple mistake in the scale calibration. Value of 0.014833 was used instead of 0.014388 for the second radiation constant, c_2. Therefore the correction was negligible around 1085 ^{o}C but increases to 1.6 ^{o}C at 1700 ^{o}C. After the correction the difference between ITRI and NMIJ became smaller by half and the largest difference was almost 2 ^{o}C at 1700 ^{o}C.

APMP−Comparison ITS−90 above silver point Appendix F

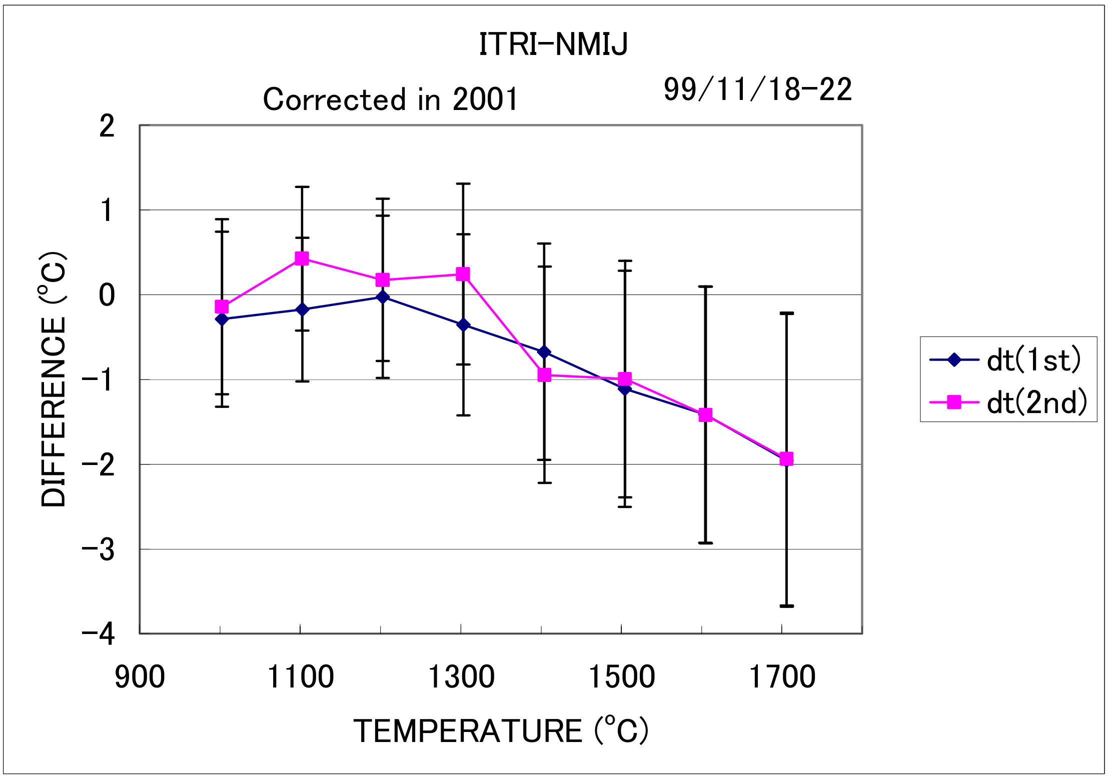
ITRI Result of measurements Difference from NMIJ Ver 2001.10.24

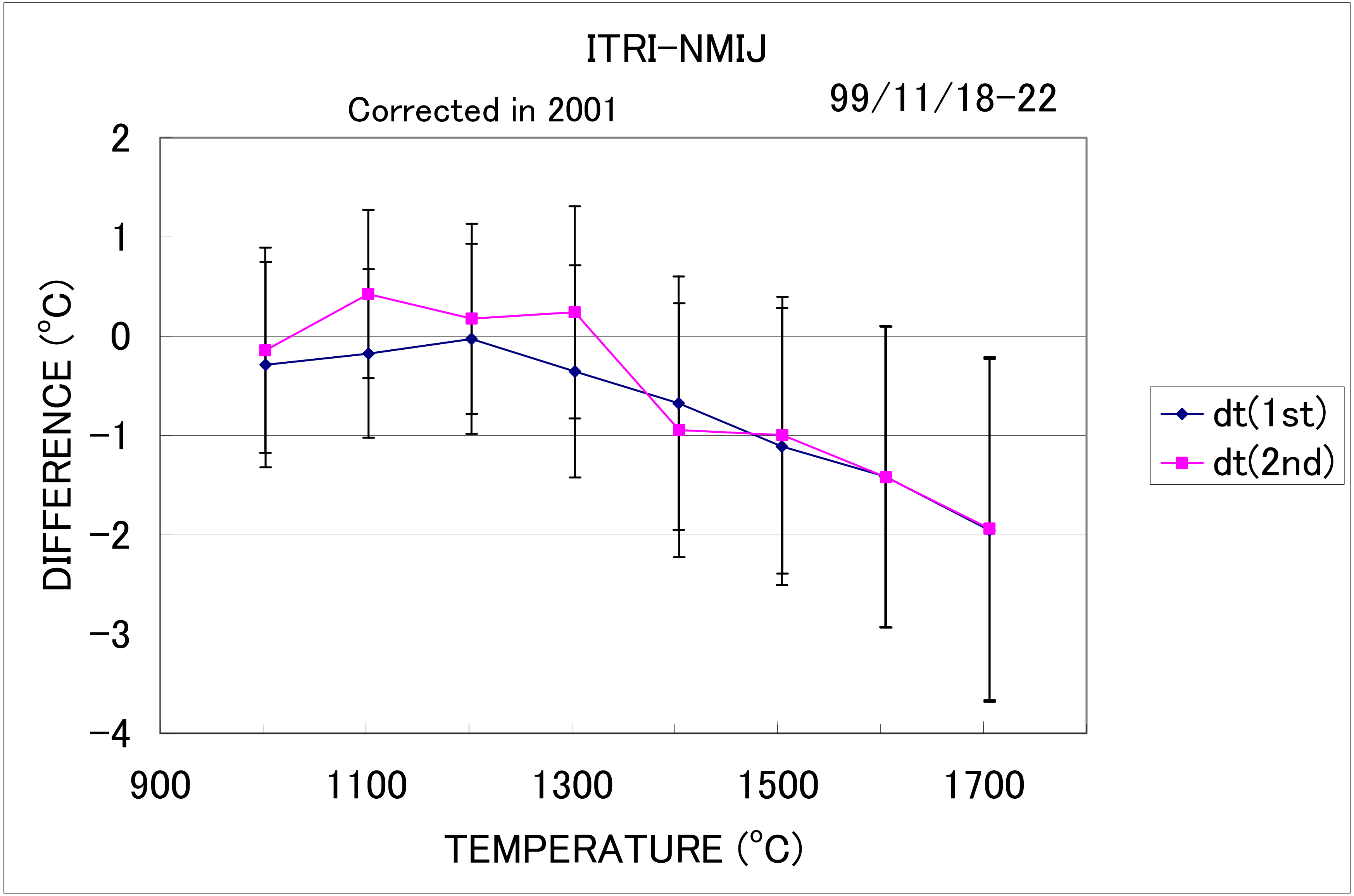
C833 lamp 99/11/18−19 t(ITRI)−t(NMIJ)

t set	t(ITRI)	s(ITRI)	t(NMIJ)	s(NMIJ)	dt(1st)	s(total)	NE	2s total
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]
1000	1002.12	0.50	1002.41	0.13	−0.29	0.52	−0.55	1.03
1100	1102.35	0.40	1102.52	0.14	−0.17	0.42	−0.41	0.85
1200	1202.45	0.45	1202.48	0.16	−0.03	0.48	−0.05	0.96
1300	1302.72	0.50	1303.08	0.19	−0.36	0.53	−0.66	1.07
1400	1403.00	0.60	1403.67	0.22	−0.67	0.64	−1.06	1.28
1500	1502.96	0.65	1504.07	0.25	−1.11	0.70	−1.59	1.39
1600	1603.04	0.70	1604.45	0.29	−1.41	0.76	−1.87	1.51
1700	1703.91	0.80	1705.87	0.33	−1.96	0.86	−2.26	1.73

C833 lamp 99/11/19,22

t set	t(ITRI)	s(ITRI)	t(NMIJ)	s(NMIJ)	dt(2nd)	s(total)	NE	2s total
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]
1000	1002.12	0.50	1002.26	0.13	−0.14	0.52	−0.28	1.03
1100	1102.56	0.40	1102.14	0.14	0.42	0.42	1.00	0.85
1200	1202.83	0.45	1202.65	0.16	0.18	0.48	0.37	0.96
1300	1303.07	0.50	1302.83	0.19	0.24	0.53	0.45	1.07
1400	1403.34	0.60	1404.29	0.22	−0.95	0.64	−1.48	1.28
1500	1503.44	0.65	1504.44	0.25	−1.00	0.70	−1.43	1.39
1600	1603.73	0.70	1605.15	0.29	−1.42	0.76	−1.88	1.51
1700	1703.91	0.80	1705.85	0.33	−1.94	0.86	−2.24	1.73




ITRI-NMIJ
Corrected in 2001
99/11/18-22
2
1
0
−1
−2
−3
−4
DIFFERENCE (°C)
900
1100
1300
1500
1700
TEMPERATURE (°C)
dt(1st)
dt(2nd)

Appendix G : Result of APMP Key Comparison to CCT Key Comparison 5

G1 Difference between KRISS and NMIJ

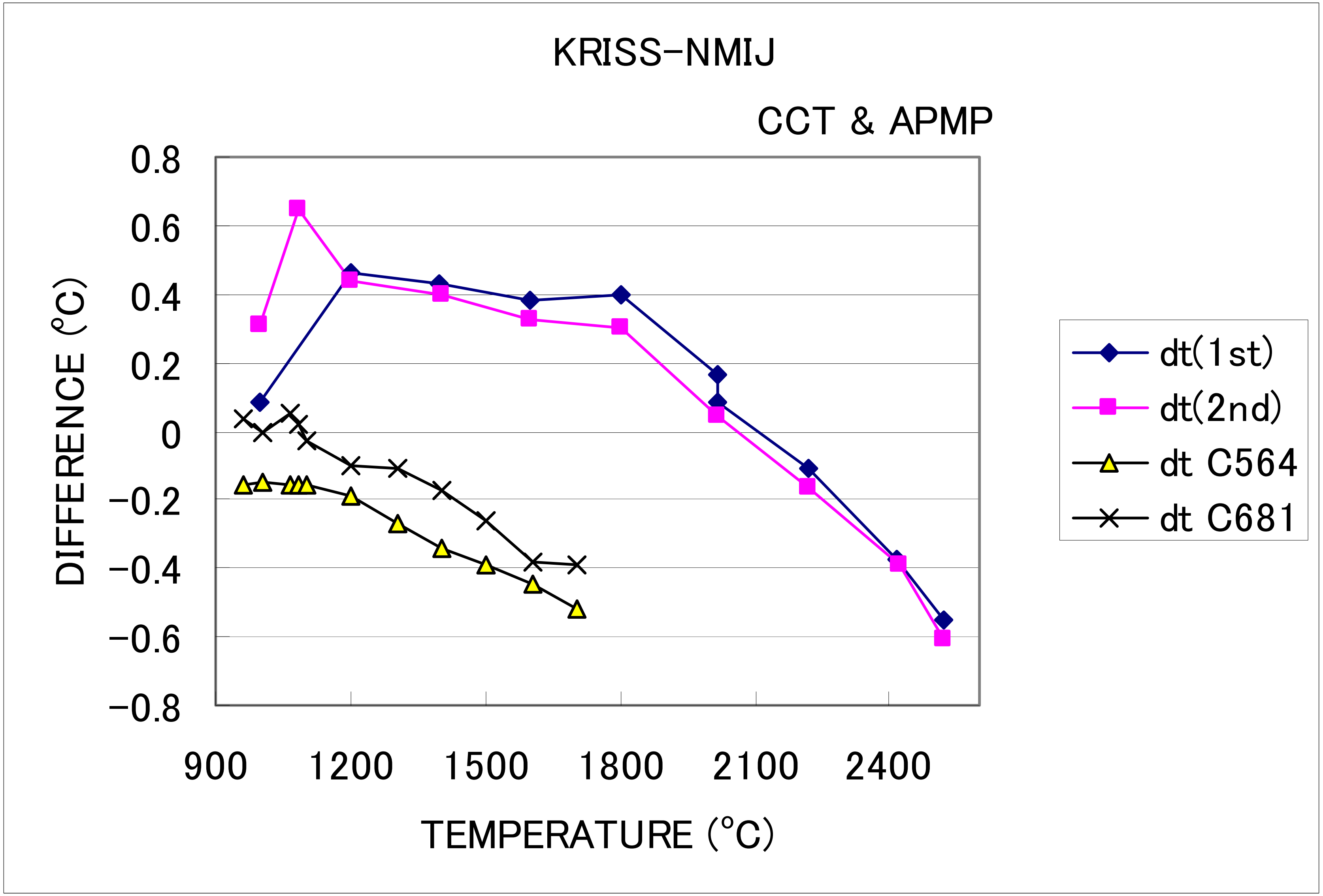
G2 Difference between NIM and NMIJ

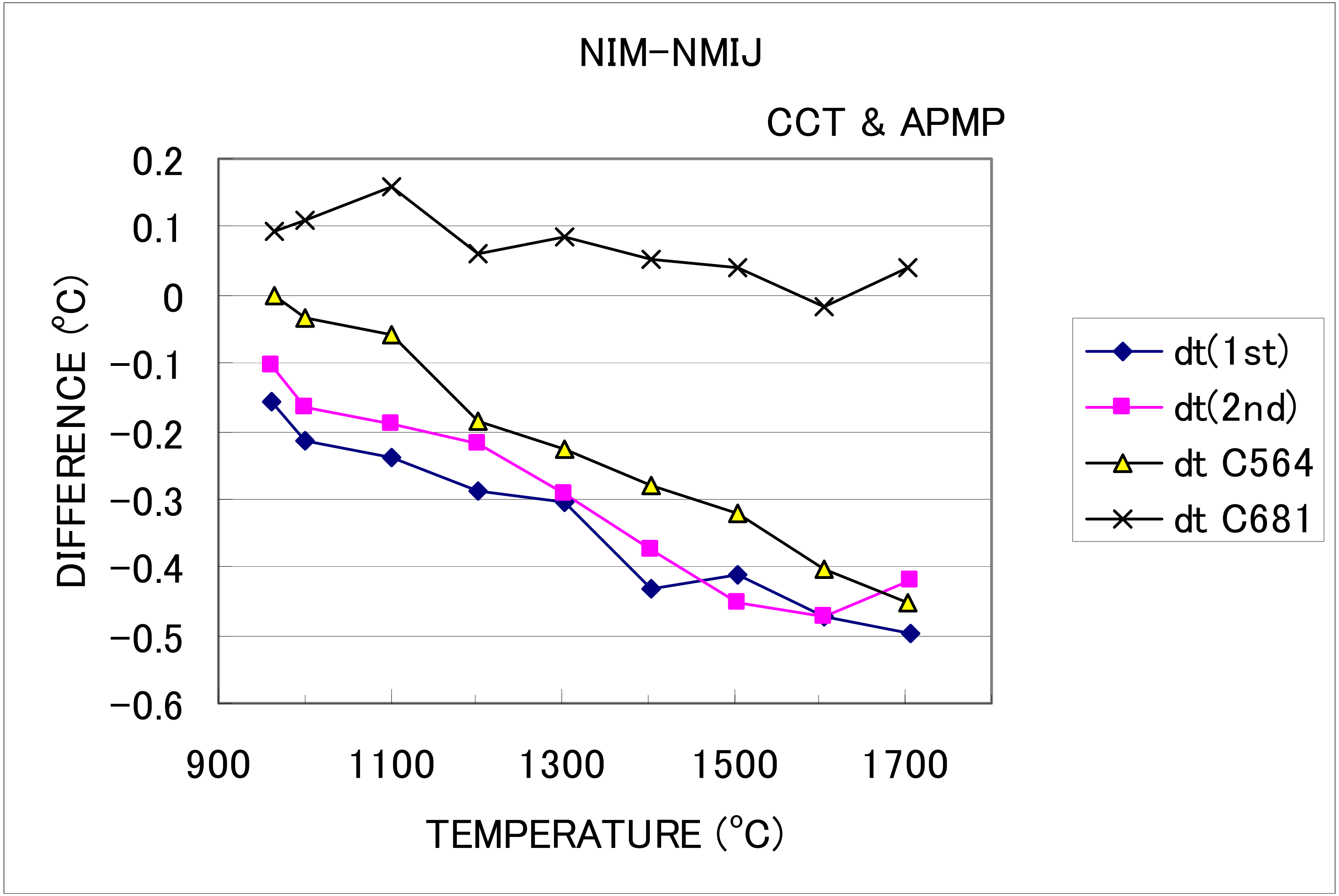
G3 Difference between NMC/SPRING and NMIJ

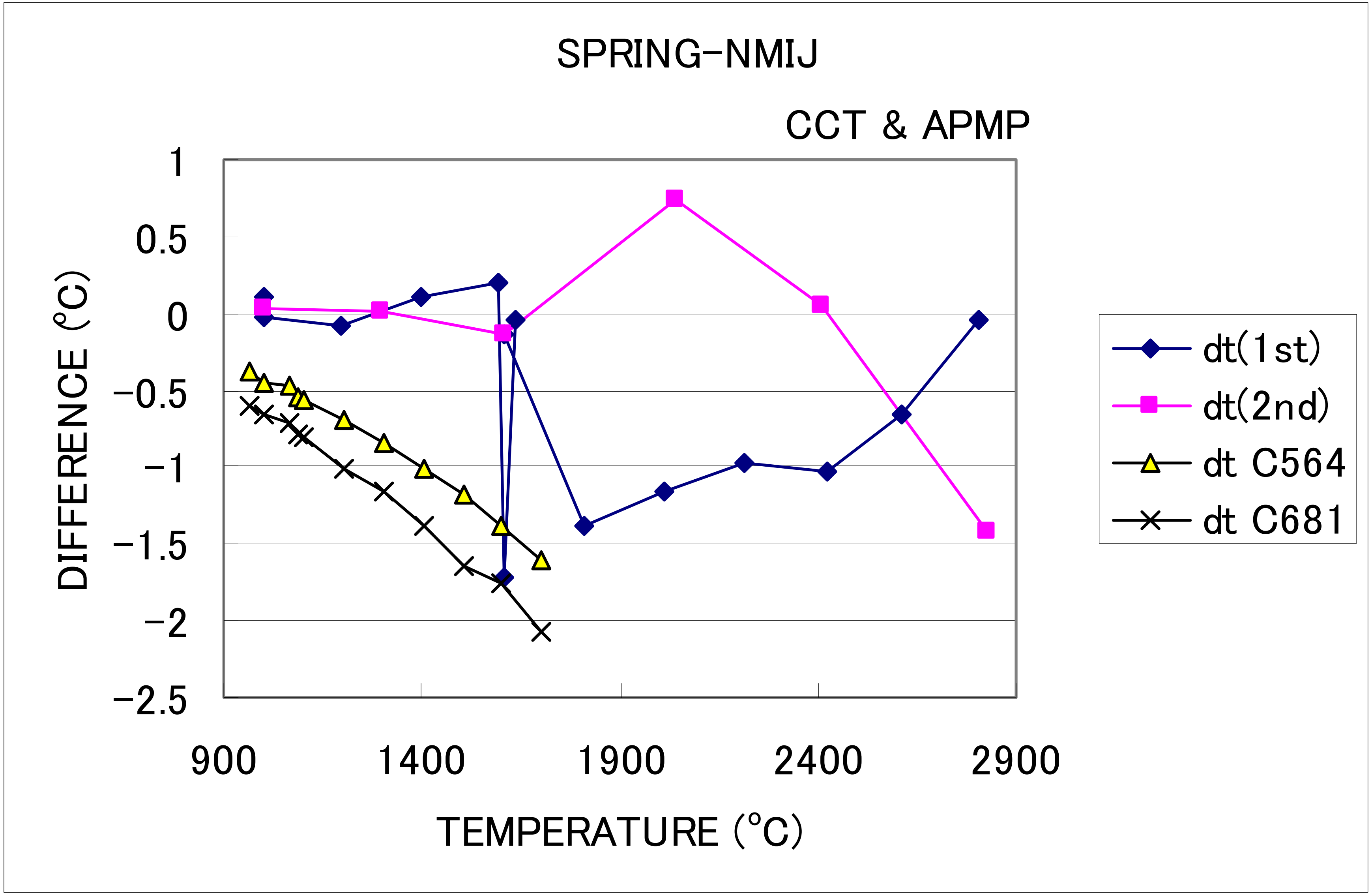
G4 Difference between NML/CSIRO and NMIJ

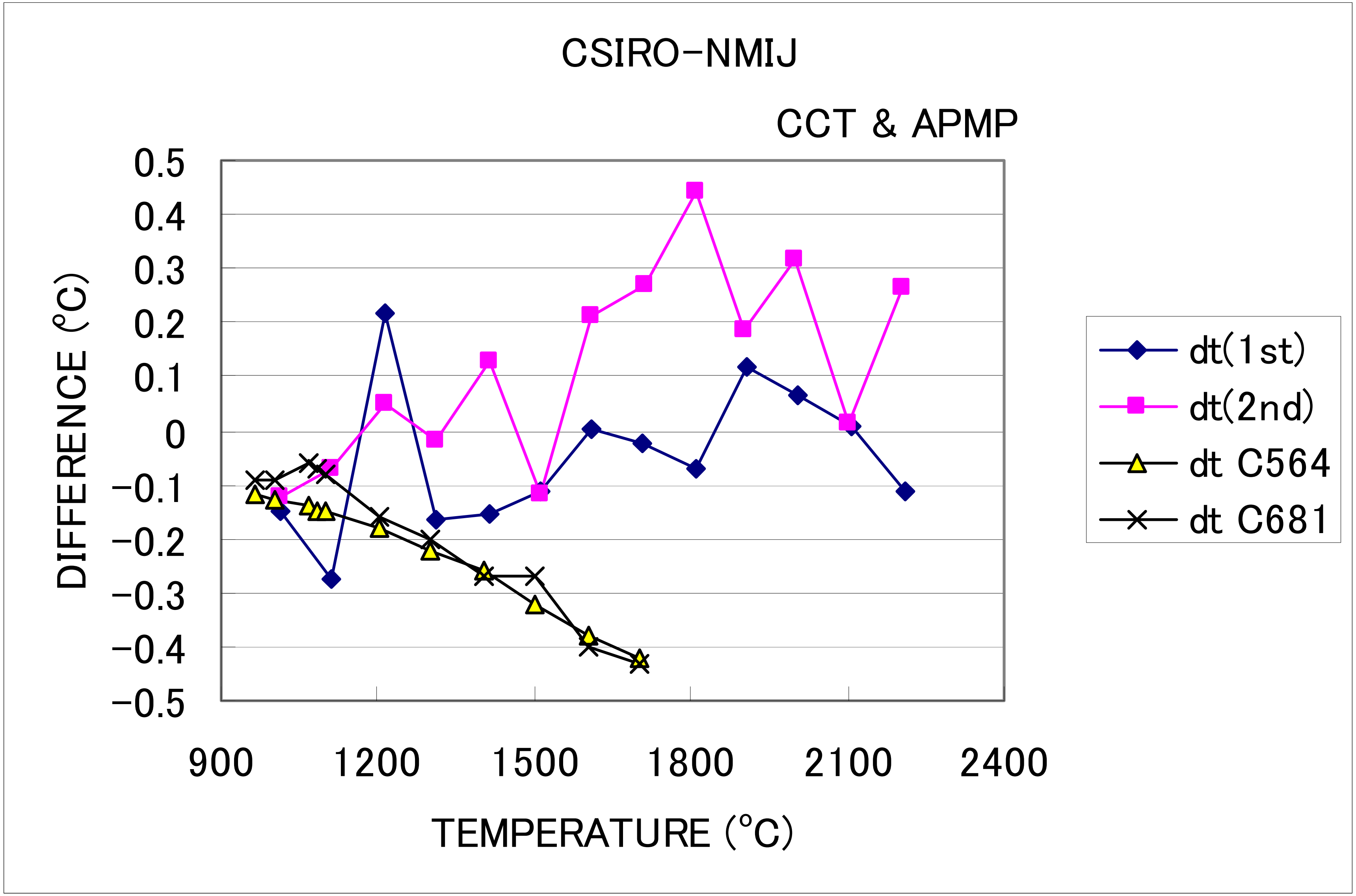
G5 Difference between APMP difference and CCT difference

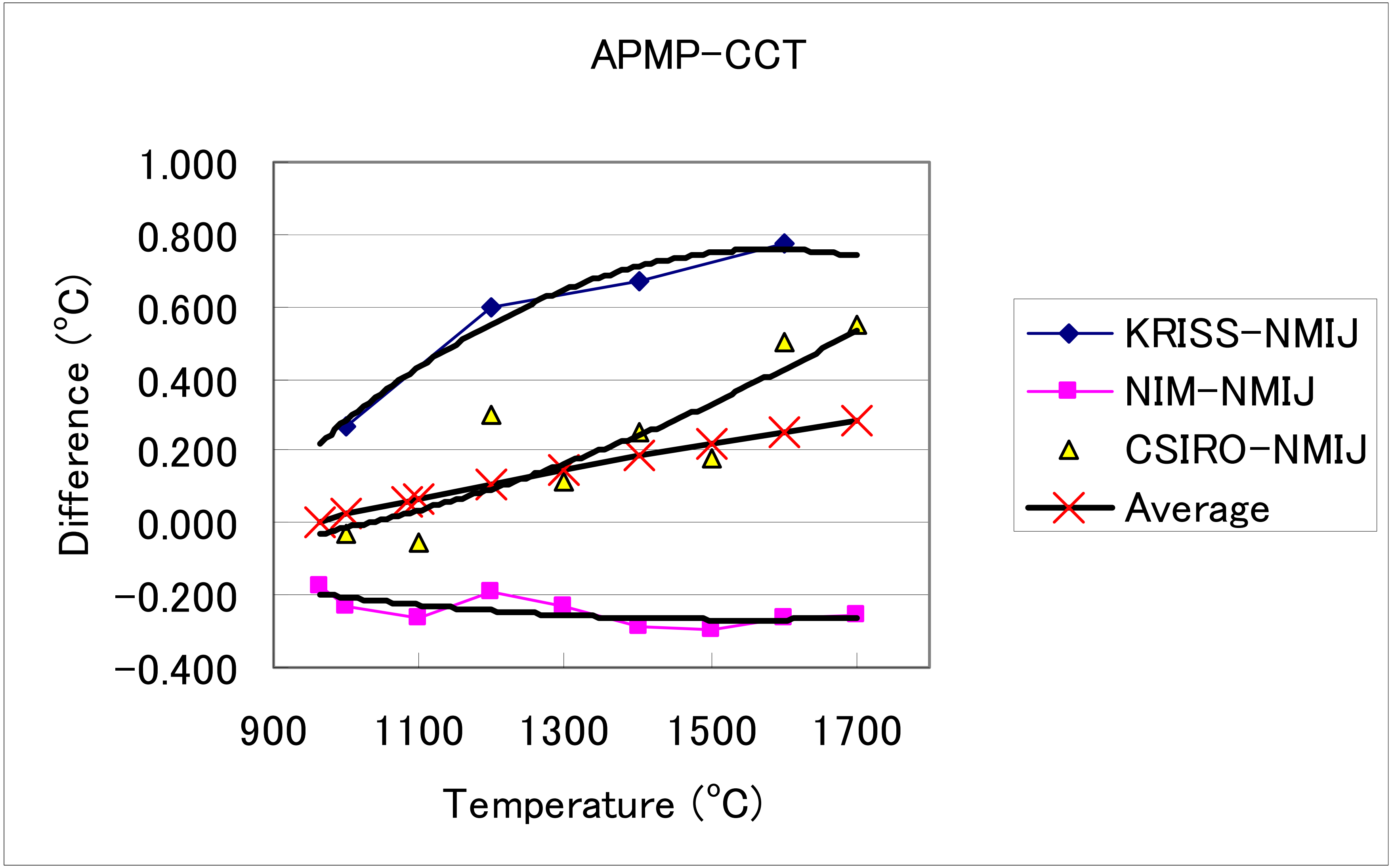
Note that the average was taken among four institutes including NMIJ whose data was zero in the figure and excluding SPRING whose scale was completely different between CCT comparison and APMP comparison.


KRISS-NMIJ
CCT & APMP
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
DIFFERENCE (°C)
900
1200
1500
1800
2100
2400
TEMPERATURE (°C)
dt(1st)
dt(2nd)
dt C564
dt C681


NIM-NMIJ
CCT & APMP
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
DIFFERENCE (°C)
900
1100
1300
1500
1700
TEMPERATURE (°C)
dt(1st)
dt(2nd)
dt C564
dt C681


SPRING-NMIJ
CCT & APMP
1
0.5
0
−0.5
−1
−1.5
−2
−2.5
DIFFERENCE (°C)
900
1400
1900
2400
2900
TEMPERATURE (°C)
dt(1st)
dt(2nd)
dt C564
dt C681


CSIRO–NMIJ
CCT & APMP
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5
DIFFERENCE (°C)
900
1200
1500
1800
2100
2400
TEMPERATURE (°C)
dt(1st)
dt(2nd)
dt C564
dt C681


APMP-CCT
1.000
0.800
0.600
0.400
0.200
0.000
−0.200
−0.400
Difference (°C)
900
1100
1300
1500
1700
Temperature (°C)
KRISS−NMIJ
NIM−NMIJ
CSIRO−NMIJ
Average

APMP-Key Comparison Protocol for Radiation Temperature Scale

1998.10.5

NRLM

1. Purpose of the Key Comparison of Radiation Thermometer

To provide a technical basis for establishing the equivalence of national/territorial measurement standards in the Asia-Pacific region maintaining a link to the CCT key comparison.

2. Temperature range and Wavelength

960ºC to 2800ºC; defined by ITS-90

Radiance temperature at 0.65 μm

3. Transfer Instrument

The transfer instrument is a transportable radiation thermometer with an operational wavelength of 0.65 μm which will be provided by the pilot laboratory (NRLM). The target size is 1 to 2 mm in diameter at a distance of 50 cm. The output is a dc voltage. The spectral responsivity, non-linearity and size-of-source effect are measured by NRLM.

4. Type of Comparison

The interlaboratory comparison will be made in the way of star scheme where the transfer instrument goes back to the pilot laboratory each time. The reason why we do not take a round-robin type is a lack of good long-term stability with the transfer instrument compared with a strip lamp.

5. Transportation of the Transfer Instrument

The transfer instrument should be hand-carried because it is a fragile optical instrument. Two types of transportation are envisaged:

[Type A]

An NRLM radiation thermometrist takes the transfer instrument with him (hand-carrying) to a participating lab, stay there for a week to assist in operation of the transfer instrument and bring it back to NRLM after comparison.

[Type B]

A radiation thermometrist of a participating lab picks up the transfer instrument at NRLM and takes it with him/her (hand-carrying) to a participating lab. It is suggested for the radiation thermometrist to stay at NRLM for a few days if he/she is not familiar with the operation of the transfer instrument. It is required for the participating laboratory to return the transfer instrument to NRLM by hand-carrying within six months.

6. What to Be Done by Participating Labs.

① To prepare and submit to the Program Coordinator an uncertainty budget of the comparison covering all of major uncertainty sources resulting from the participating laboratory. The submission of the uncertainty budget should be before the comparison.

② To prepare two voltmeters; one for the output of the transfer instrument and the other for monitoring the temperature of the transfer instrument.

③ To calibrate the transfer instrument at selected temperatures through a blackbody furnace on the basis of the primary standards of the participating laboratory.

④ To report the calibration results to the Program Coordinator.

7. Questionnaire

The Program Coordinator will send a questionnaire and revised protocol to potential participating laboratories in 1998.

8. Anticipated Comparison Period

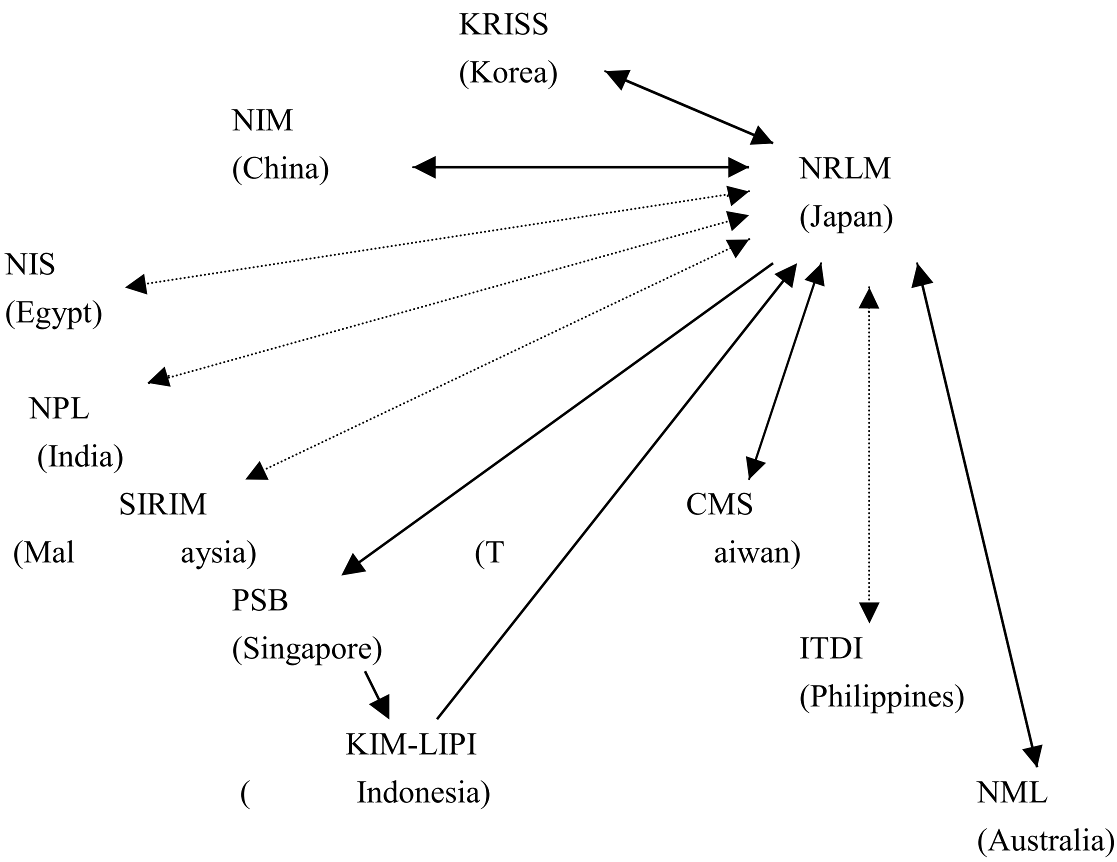
From April 1998 until March 2000.

9. Contact persons

Dr. Akira Ono	Dr. Fumihiro Sakuma
ono@nrlm.go.jp	fsakuma@nrlm.go.jp
Tel 81-298-54-4111	Tel 81-298-54-4031
Fax 81-298-54-4007	Fax 81-298-54-4010
Department Head	Head of Thermal Measurement Section

Thermophysical Metrology Department
National Research Laboratory of Metrology
1-1-4 Umezono, Tukuba City, Ibaraki 305-8563, Japan

Transfer Instrument Transportation Scheme
(Draft ver. 1)



[Type A] transportation of transfer instrument
(The travel funds are available from NRLM)
[Type B] or some other scheme

APMP Intercomparison Details for Radiation Temperature Scale

In principle, a blackbody is used for comparison.

1. Measuring temperature point
Use possible points in below.

In case the range extends above 2000°C,
962, 1000, 1085, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2600, 2800

In case the range is limited to 2000°C,
962, 1000, 1085, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000

2. The measurement is repeated five to seven times at each temperature to see the repeatability of measurement.
Each institute and NRLM radiation thermometers alternately see the blackbody.

3. Measuring distance 50 cm to 80 cm for high temperature blackbody
(for blackbody above 2000°C)
corresponding to the target size of 1 to 1.5 mm diameter
40 cm to 60 cm for medium temperature (below 2000°C)
corresponding to the target size of about 1 mm diameter

4. The total measurement is repeated again on a different day

5. Measurement of the radiance distribution of the blackbody
horizontal and if possible vertical

6. NRLM radiation thermometer has two outputs, one for silicon photodiode and the other for ambient temperature output. Therefore two digital voltmeters are necessary. It would be helpful if the digital voltmeters are connected to a computer and data acquisition can be made automatically.

7. Unc ertainty ta bles o f the c alibration of the radiation the rmometers use d in the comparison will be exchanged before the measurement starts.

8. The corrections to be made for the transfer radiation thermometer are
a. ambient temperature correction
b. size of source effect
c. distance effect
d. wavelength, if necessary

9. Copper point calibration of the NR LM radiation thermometer is made just before the comparison and, if necessary and possible, also after it.

10. What we request for NRLM radiation thermometer at each institute is
AC 100 V power source (also for Copper point blackbody)
two digital voltmeter: one good and the other so so
one tripod or stage for the comparison

11. Specifications of NRLM Transfer standard radiation thermometer

1. Center wavelength	650 nm
2. Band width	10 nm to 15 nm
3. T emperature range	960°C to 2800°C
4. Measuring Distance	200 mm to infinity
5. Focal length	f=80 mm
6. Field angle	0.1 °
7. Size of source effect	<1%
8. Resolution	<0.1°C at 960°C
9. Detector	S1336-5BK
10. Ambient temperature detector	IC temperature sensor
11. Feedback resister of Amp.	100 MΩ, 10 MΩ, 1 MΩ, 100kΩ
12. Power source	AC 100 V ± 10%, 50/60 Hz
13. Temperature coefficient	less than ±0.24%/°C
14. Size	320 mm (L), 80 mm (W), 160 mm (H)
15. Screw for tripod	1/4 inch

Questionnaires

1. Blackbody

1.1 Temperature range

1.2 Aperture diameter

1.3 Distance from the bottom to the aperture

1.4 Temperature stability (in 10 minutes)

1.5 Temperature distribution

1.6 Cavity material

1.7 Window

1.8 Warm-up time

1.9 Manufacturer

1.10 Emissivity

2. Radiation thermometer

2.1 Temperature range

2.2 Measuring distance from the objective

2.3 Target size

2.4 Aperture ratio (target size/distance)

2.5 Calibration method

2.6 Uncertainty of scale (Table)

2.7 Wavelength center and band width

2.8 Resolution

2.9 Size of Source effect

2.10 Detector

2.11 Feedback resistance for amplifier

2.12 Linearity

2.13 Telescope for alignment

2.14 Stability

2.15 Manufacturer

3. Others

3.1 Schedule

3.2 Comparison tools (stage, tripod, etc.)

3.3 Power source (for example, 100V AC 50Hz)

3.4 Room temperature

3.5 Contact person (affiliation, tel, fax, e-mail)

3.6 Uncertainty table

(Temperature, Uncertainty of radiation thermometer, stability of bb, uniformity of bb, emissivity correction of bb, correction of SSE, ambient temperature correction)

February 13, 2009

Addendum to the final report of APMP-T-K5-1997

APMP Comparison of local realizations of the ITS-90 above the silver point using radiation thermometers as transfer standards

Linking the final results of APMP-T-K5-1997 to the KCRV of the CCT-K5

based on
- the draft B report APMP-T-K5-1997 of March 2003
- the draft B report CCT K5 of May 2005
- the addendum to draft B report K5 of April 2008
- the final report K5.1 of May 2008

Prepared by
Fumihiro Sakuma
National Metrology Institute of Japan

1. Introduction

In the CCT Key Comparison 5 (CCT KC5) standard lamps were transferred to check the agreement of radiation temperature scales between 962 °C and 1700 °C. On the other side in the APMP Temperature key Comparison 5 (APMP-T-K5-1997) radiation thermometers were transferred to check the agreement of radiation temperature scales between 962 °C and 2800 °C at the highest. Five institutes joined both comparisons. Among them four institutes (NMIJ, NIM, KRISS and CSIRO) were selected as the linking institutes between the two comparisons. In the APMP comparison, the scale difference from the NMIJ was measured. Here the differences of the seven APMP participating institutes from the Key Comparison Reference Value (KCRV) of the CCT comparison were calculated. In this calculation it is supposed that the average of the four institutes agree in the CCT and APMP comparisons.

Because the comparison and the report have taken a long time to complete, many institutes have changed their names. Therefore Table 1 shows the names of the participating institutes in 2009 and 1999.

2. Calculation method

2.1 Calculation of the difference

For each temperature T_j (j=1 to 11) between 962 °C and 1700 °C, if the institute has the data at T_j, then the data are employed. If not, the data interpolated by using the quadratic equation are employed.

In the CCT Key Comparison, the participating institute k reported the temperature as $T_k^{\mathrm{CCT}}(T_j)$. Its difference from the KCRV $T_{\mathrm{KCRV}}(T_j)$ is expressed as $dT_k^{\mathrm{CCT}}(T_j)$.

$$dT_k^{CCT}(T_j) \equiv T_k^{CCT}(T_j) - T_{KCRV}(T_j) \tag{1}$$

The four linking institute average of the difference is expressed as $dT_{Ave}^{\mathrm{CCT}}(T_j)$.

$$\begin{aligned} dT_{Ave}^{CCT}(T_j) &\equiv \frac{1}{4}\sum_{k=1}^{4} dT_k^{CCT}(T_j) \\ &= \frac{1}{4}\sum_{k=1}^{4} T_k^{CCT}(T_j) - T_{KCRV}(T_j) \end{aligned} \tag{2}$$

In the APMP Key Comparison, the temperature of the participating institute k (k=1 to 7) and that of the pilot institute are expressed as $T_k^{\mathrm{APMP}}(T_j)$ and $T_{Pilot}^{\mathrm{APMP}}(T_j)$, respectively. The difference between the two temperature is $dT_k^{\mathrm{APMP}}(T_j)$.

$$dT_k^{APMP}(T_j) \equiv T_k^{APMP}(T_j) - T_{Pilot}^{APMP}(T_j) \tag{3}$$

The four linking institute average of the difference is expressed as $dT_{Ave}^{\mathrm{APMP}}(T_j)$.

$$\begin{aligned} dT_{Ave}^{APMP}(T_j) &\equiv \frac{1}{4}\sum_{k=1}^{4} dT_k^{APMP}(T_j) \\ &= \frac{1}{4}\sum_{k=1}^{4} T_k^{APMP}(T_j) - T_{Pilot}^{APMP}(T_j) \end{aligned} \tag{4}$$

The difference between the two averages in eqs. (2) and (4) is expessed as $\Delta(T_j)$.

$$\Delta(T_j) \equiv dT_{Ave}^{APMP}(T_j) - dT_{Ave}^{CCT}(T_j)$$
$$= \frac{1}{4}\sum_{k=1}^{4} T_k^{APMP}(T_j) - \frac{1}{4}\sum_{k=1}^{4} T_k^{CCT}(T_j) + T_{KCRV}(T_j) - T_{Pilot}^{APMP}(T_j)$$
(5)

Because the link was established by the average of the four linking institutes, the following equation applies.

$$\frac{1}{4}\sum_{k} T_k^{APMP}(T_j) = \frac{1}{4}\sum_{k} T_k^{CCT}(T_j) \quad (6)$$

Therefore the eq. (5) becomes

$$\Delta(T_j) = T_{KCRV}(T_j) - T_{Pilot}^{APMP}(T_j) \quad . \quad (7)$$

The difference of the APMP participant from the KCRV, $dT_k(T_j)$ (k=1 to 7) is expressed as follows.

$$dT_k(T_j) = T_k^{APMP}(T_j) - T_{KCRV}(T_j)$$
$$= dT_k^{APMP}(T_j) - \Delta(T_j) \quad (8)$$

2.2 Calculation of the uncertainty

Following factors of uncertainties are considered.

A. Uncertainty in APMP comparison
B. Uncertainty in linking APMP KC and CCT KC
C. Uncertainty of KCRV

Below each factor is described in detail.

2.2.1 Uncertainty in APMP comparison

This uncertainty is composed of the uncertainty u_k of the participant k and u_p of the pilot p. In principle two runs were carried out at each temperature T_j. The number of the run is expressed by m. The scatter in two runs is also included in this uncertainty

$$u_{1k}(T_j)^2 = \sum_m \left[u_{1k\,m}^{APMP}(T_j)^2 + u_{p\,m}^{APMP}(T_j)^2 \right] / \sum_m 1 + stdev^2(dT_{k\,m}^{APMP}(T_j)) / \sum_m 1$$
(9)

2.2.2 Uncertainty in linking

The difference between the differences of eq.(1) and eq(3) is expressed as $\Delta_k(T_j)$.

$$\Delta_k(T_j) \equiv dT_k^{APMP}(T_j) - dT_k^{CCT}(T_j) \quad (10)$$

Then the difference $\Delta(T_j)$ is expressed as follows.

$$\Delta(T_j) = \frac{1}{4}\sum_k (dT_k^{APMP}(T_j) - dT_k^{CCT}(T_j))$$
$$= \frac{1}{4}\sum_k \Delta_k(T_j) \quad (11)$$

The difference $\Delta(T_j)$ is the average of the four differences $\Delta_k(T_j)$. Therefore the standard deviation of the difference $\Delta_k(T_j)$ is the uncertainty in the linking.

$$u_2(T_j) = \frac{1}{\sqrt{4}} stdev(\Delta_k(T_j)) \quad k \in \{1,2,3,4\} \quad (12)$$

2.2.3 Uncertainty of KCRV

The four linking institutes participated in the loop 1 in the CCT KC5. Two lamps, C564 and C681, were used. The uncertainty of the KCRV is square-averaged.

$$u_3(T_j) \equiv \sqrt{\left\{u^{C564}(T_j)^2 + u^{C681}(T_j)^2\right\}/2} \qquad (13)$$

2.2.4 Combined standard uncertainty

$$u_k(T_j) = \sqrt{u_{1k}(T_j)^2 + u_2(T_j)^2 + u_3(T_j)^2} \quad k \in \{1,2,3,4,5,6,7\} \qquad (14)$$

3. Comment of each institute about linking CCT and APMP key comparisons
3.1 NMIA
In the view of NMIA, the ITS-90 scale realised in the CCT-K5 is equivalent to the ITS-90 scale realised in the APMP-K5 and any systematic scale errors are likely to be similar in the two realisations.
In APMP-K5 and CCT-K5, both the comparison measurements and the calibration of the transfer pyrometers was performed by Dr Ballico. APMP-K5 was performed using the transfer pyrometer HTSP, whereas the CCT-K5 was performed using the transfer pyrometer APEP-2.
Both pyrometers were constructed by NMIA and share the same design features of:
* A multi-cavity interference filter near to 650nm, with approximately a 10nm bandwidth.
* A Hamamatsu 1010BQ silicon photodiode
* Virtual-earth high linearity current to voltage amplifier
* A Lyot-stop (a stop near the detector imaged onto a virtual stop on the main objective lens)
* A simple optical system involving an objective lens, a target aperture , a collimating lens, Lyot-stop,interference filter and a windowed silicon photodiode.
* A 1:1 magnification of the aperture by the objective lens.
* A shutter system which automatically takes a zero for each measurement.
* A HP3458A precision voltmeter for measuring the amplified detector signal.

Differences between the pyrometers are:
* The HTSP has a 0.8mm target, whereas the APEP-2 had a 0.5mm target.
* The HTSP has a 50mm diameter objective , whereas the APEP-2 had a 100mm diameter objective
* The HTSP uses an additional 650nm interference filter to suppress out-of-band transmission, whereas the APEP-2 used a coloured glass pre-filter.
* The HTSP focal length is 500mm whereas the APEP-2 had a 300mm focal length

The calibration of the two pyrometers was performed using the same equipment and facilities:
* Same fixed point reference (Au point blackbody cavity Au-95). The same furnace, based on a Na heatpipe was used. The Au-95 gold-point blackbody is regularly compared to a second gold-point blackbody Au-2, with differences between the radiance temperatures always found less than 10mK.
* Same relative spectral responsivity apparatus: The pyrometer was focused onto the exit slit of a 1m McPherson single monochromator. A three element reflection trap was used as the reference detector. Coloured glass pre-filters were used to improve the measurement of out-of-band leakage. Multi-line Ne discharge lamp was used for wavelength calibration. A similar bandwidth and wavelength interval was used for both the filter bandpass regions and out-of-band measurements.
* Same linearity apparatus: A system based on using a beamsplitter to superimpose images of strip lamp filaments, together with shutters to make linearity measurements over a "doubling step", which was then performed many times to build up a linearity assessment over a wide signal range.
* Same SOSE apparatus: A system based on perspex screens with blackened metal disks, illuminated by a QTH lamp.
* Same integral calculation method for converting the radiance ratio to the reference temperature to an equivalent source temperature.

3.2 KRISS

KRISS took part in the CCT-K5 and the APMP-K5 by using the same transfer pyrometer and by same staff, Dr. Seung-Nam Park. Any systematic errors among both comparisons are likely to be similar.

3.3 NIM

In the comparisons of the CCT-K5 and the APMP-K5, the scale of ITS-90 at NIM were realized in same way (same procedure, same pyrometer, and by same person, Mr.YUAN Zundong). Of course, in the CCT-K5 the t90 was assigned to the transfer lamps of the CCT-K5, and in the APMP-K5 the t90 realized at NIM was assigned to the NIM's lamp. The uncertainties and systematic errors among the CCT-K5 and the APMP-5 are similar.

3.4 NMIJ

The radiation thermometer used for both comparisons was the same at NMIJ. It was calibrated according to ITS-90 by using the copper-point blackbody, the spectral responsivity measurement and the nonlinearity measurement by the same staff, Dr. F. Sakuma. Except for the difference of the radiation sources, the uncertainties and systematic errors among the CCT-KC5 and the APMP-TK5 were similar.

3.5 NMC

NMC has a large deviation from the KCRV in the CCT K5. This is likely due to the drift of the interference filters of the radiation thermometer after the calibration at NMIA (then NML), Australia (NMC was unable to measure the spectral responsivity at that time). NMC changed its realization method in the APMP K5 by using a new reference radiation thermometer and NMC's own spectral responsivity measurement facility. This explains the different results in the two comparisons.

4. Youden plot

Figure 9 shows the Youden plot of the temperature difference from the KCRV in CCT KC5 and APMP TK5 comparisons for the four linking institutes. KRISS lies upper, NIM lies lower left, NMIA lies near center and NMIJ lies right. All institutes were within ±0.5 °C in the whole temperature range from 1000 °C to 1700 °C. The agreement was better at lower temperatures.

Table 1 Name of participating institute

Year, A.D.	2009	1999
Rep. of Korea	KRISS	KRISS
China	NIM	NIM
Australia	NMIA	NML/CSIRO
Japan	NMIJ/AIST	NRLM
Singapore	NMC-A*STAR	NMC/SPRING
Chinese Taipei	CMS/ITRI	CMS/ITRI
Indonesia	KIM-LIPI	KIM-LIPI

Average of two runs *dt* and uncertainty u_1 of the APMP key comparison

Table 2 APMP T-K5-97 Result (KRISS-NMIJ)

t set	dt(ave)	Diff	m	uk	up	stdev/rt(m	u1	u2	u3	u
[° C]	[° C]	[° C]		[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]
962	0.22							0.11	0.08	
1000	0.19	0.23	2	0.33	0.13	0.11	0.37	0.12	0.09	0.40
1064	0.30							0.14	0.08	
1085	0.31							0.14	0.08	
1100	0.32							0.16	0.08	
1200	0.45	−0.02	2	0.27	0.16	0.01	0.32	0.20	0.07	0.38
1300	0.40							0.20	0.07	
1400	0.41	−0.04	2	0.29	0.22	0.02	0.36	0.24	0.07	0.44
1500	0.41							0.25	0.07	
1600	0.36	−0.06	2	0.37	0.29	0.03	0.47	0.28	0.07	0.55
1700	0.36							0.30	0.05	

Table 3 APMP T-K5-97 Result (NIM-NMIJ)

t set	dt(ave)	Diff	m	uk	up	stdev(dt)	u1	u2	u3	u
[° C]	[° C]	[° C]		[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]
962	−0.13	0.05	2	0.04	0.14	0.03	0.15	0.11	0.08	0.20
1000	−0.19	0.05	2	0.04	0.13	0.02	0.14	0.12	0.09	0.20
1064	−0.20						0.00	0.14	0.08	
1085	−0.21							0.14	0.08	
1100	−0.22	0.05	2	0.05	0.14	0.02	0.15	0.16	0.08	0.24
1200	−0.25	0.07	2	0.06	0.16	0.04	0.18	0.20	0.07	0.27
1300	−0.30	0.01	2	0.07	0.19	0.01	0.20	0.20	0.07	0.29
1400	−0.40	0.06	2	0.08	0.22	0.03	0.23	0.24	0.07	0.34
1500	−0.43	−0.04	2	0.09	0.25	0.02	0.27	0.25	0.07	0.37
1600	−0.47	0.00	2	0.10	0.29	0.00	0.30	0.28	0.07	0.42
1700	−0.46	0.08	2	0.12	0.33	0.04	0.35	0.30	0.05	0.46

Table 4 APMP T-K5-97 Result (CSIRO-NMIJ)

t set	dt(ave)	Diff	m	uk	up	stdev/rt(m	u1	u2	u3	u
[° C]	[° C]	[° C]		[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]
962	−0.19							0.11	0.08	
1000	−0.12	0.03	2	0.11	0.15	0.01	0.19	0.12	0.09	0.24
1064	−0.11							0.14	0.08	
1085	−0.10							0.14	0.08	
1100	−0.07	0.20	2	0.13	0.16	0.10	0.23	0.16	0.08	0.29
1200	0.05	−0.17	2	0.14	0.19	0.08	0.25	0.20	0.07	0.32
1300	−0.02	0.15	2	0.15	0.22	0.07	0.28	0.20	0.07	0.35
1400	0.13	0.28	2	0.17	0.25	0.14	0.33	0.24	0.07	0.42
1500	−0.12	−0.01	2	0.18	0.29	0.00	0.34	0.25	0.07	0.43
1600	0.21	0.21	2	0.20	0.33	0.10	0.40	0.28	0.07	0.49
1700	0.27	0.29	2	0.21	0.37	0.15	0.45	0.30	0.05	0.54

Table 5 APMP T-K5-97 Result (NMC-NMIJ)

t set	dt(ave)	Stdev	m	uk	up	stdev/rt(m	u1	u2	u3	u
[° C]	[° C]	[° C]		[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]
1000	0.04		3	0.12	0.13	0.03	0.18	0.12	0.09	0.23
1200	-0.07		1	0.14	0.16		0.22	0.20	0.07	0.30
1300	0.02		1	0.25	0.19		0.31	0.20	0.07	0.38
1400	0.10		1	0.21	0.22		0.30	0.24	0.07	0.39
1600	0.19		1	0.27	0.29		0.39	0.28	0.07	0.49

Table 6 APMP T-K5-97 Result (KIM-LIPI-NMIJ)

t set	dtAve	Diff		uk	up	stdev/rt(m	u1	u2	u3	u
[° C]	[° C]	[° C]		[° C]			[° C]	[° C]	[° C]	[° C]
1000	0.25	-0.05	2	0.92	0.13	0.02	0.93	0.12	0.09	0.94
1085	0.37	-0.02	2	0.92	0.14	0.01	0.93	0.14	0.09	0.95
1300	1.08	0.21	2	1.03	0.19	0.11	1.06	0.20	0.07	1.08
1500	1.95	-0.03	2	1.32	0.25	0.01	1.34	0.25	0.07	1.37

Table 7 APMP T-K5-97 Result (ITRI-NMIJ) (Revised)

t set	dtAve	Diff	m	uk	up	stdev/rt(m	u1	u2	u3	u
[° C]	[° C]	[° C]		[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]
1000	-0.21	0.14	2	0.37	0.13	0.07	0.40	0.12	0.09	0.42
1100	0.13	0.60	2	0.37	0.14	0.30	0.50	0.16	0.08	0.53
1200	0.07	0.20	2	0.39	0.16	0.10	0.43	0.20	0.07	0.48
1300	-0.06	0.60	2	0.46	0.19	0.30	0.58	0.20	0.07	0.62
1400	-0.81	-0.27	2	0.48	0.22	0.14	0.54	0.24	0.07	0.60
1500	-1.05	0.11	2	0.55	0.25	0.06	0.61	0.25	0.07	0.66
1600	-1.42	-0.01	2	0.70	0.29	0.00	0.76	0.28	0.07	0.81
1700	-1.95	0.02	2	0.75	0.33	0.01	0.82	0.30	0.05	0.87

Table 8 APMP T-K5-97 Result (ITRI-NMIJ) (Original)

t set	dtAve	Diff	m	uk	up	stdev/rt(m	u1	u2	u3	u
[° C]	[° C]	[° C]		[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]
1000	-0.48	0.14	2	0.37	0.13	0.07	0.40	0.12	0.09	0.42
1100	-0.18	0.60	2	0.37	0.14	0.30	0.50	0.16	0.08	0.53
1200	-0.40	0.20	2	0.39	0.16	0.10	0.43	0.20	0.07	0.48
1300	-0.64	0.60	2	0.46	0.19	0.30	0.58	0.20	0.07	0.62
1400	-1.52	-0.27	2	0.48	0.22	0.14	0.54	0.24	0.07	0.60
1500	-1.72	0.11	2	0.55	0.25	0.06	0.61	0.25	0.07	0.66
1600	-2.56	-0.01	2	0.70	0.29	0.00	0.76	0.28	0.07	0.81
1700	-3.51	0.02	2	0.75	0.33	0.01	0.82	0.30	0.05	0.87

Table 9 Comparison between CCT key comparison and APMP key comparison among four linking institutes

CCT KC5 Eq(1) Eq(2)

t set	CSIRO	KRISS	NIM	NRLM	Average
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]
961	−0.10	−0.05	0.06	0.01	−0.02
1000	−0.06	−0.02	0.09	0.05	0.02
1064	−0.04	0.01	0.10	0.06	0.03
1084	−0.01	0.03	0.10	0.10	0.05
1100	−0.01	0.01	0.16	0.10	0.06
1200	−0.03	0.00	0.09	0.15	0.05
1300	0.00	0.02	0.14	0.21	0.09
1400	0.05	0.06	0.20	0.31	0.15
1500	0.06	0.03	0.21	0.35	0.16
1600	0.05	0.03	0.24	0.44	0.19
1700	0.03	0.00	0.25	0.46	0.18

APMP T K5 Eq(3) Eq(4)

t set	KRISS	NIM	CSIRO	NMIJ	Average
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]
962	0.22	−0.13	−0.19	0.00	−0.03
1000	0.19	−0.19	−0.12	0.00	−0.03
1064	0.30	−0.20	−0.11	0.00	0.00
1085	0.31	−0.21	−0.10	0.00	0.00
1100	0.32	−0.22	−0.07	0.00	0.01
1200	0.45	−0.25	0.05	0.00	0.06
1300	0.40	−0.30	−0.02	0.00	0.02
1400	0.41	−0.40	0.13	0.00	0.03
1500	0.41	−0.43	−0.12	0.00	−0.03
1600	0.36	−0.47	0.21	0.00	0.02
1700	0.36	−0.46	0.27	0.00	0.04

dt(apmp−cct) Eq(10) Eq(5) Eq(12)

t set	KRISS	NIM	CSIRO	NMIJ	Average	Stdev	Stdev/rt3
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]
962	0.27	−0.18	−0.10	−0.01	−0.01	0.20	0.11
1000	0.22	−0.28	−0.07	−0.05	−0.05	0.20	0.12
1064	0.29	−0.30	−0.07	−0.06	−0.04	0.24	0.14
1085	0.28	−0.31	−0.08	−0.10	−0.05	0.25	0.14
1100	0.31	−0.37	−0.06	−0.10	−0.06	0.28	0.16
1200	0.45	−0.34	0.07	−0.15	0.01	0.34	0.20
1300	0.38	−0.44	−0.02	−0.21	−0.07	0.35	0.20
1400	0.36	−0.60	0.08	−0.31	−0.12	0.42	0.24
1500	0.39	−0.65	−0.17	−0.35	−0.20	0.43	0.25
1600	0.33	−0.71	0.16	−0.44	−0.17	0.49	0.28
1700	0.36	−0.71	0.24	−0.46	−0.14	0.52	0.30

Table 10 Difference of four linking institutes from CCT KCRV

Difference from KCRV Eq(8)

t set	KRISS	NIM	CSIRO	NMIJ
[° C]	[° C]	[° C]	[° C]	[° C]
962	0.23	−0.12	−0.19	0.01
1000	0.24	−0.14	−0.08	0.05
1064	0.33	−0.16	−0.08	0.04
1085	0.36	−0.16	−0.04	0.05
1100	0.37	−0.16	−0.01	0.06
1200	0.44	−0.26	0.04	−0.01
1300	0.47	−0.23	0.05	0.07
1400	0.53	−0.29	0.24	0.12
1500	0.61	−0.24	0.08	0.20
1600	0.52	−0.31	0.38	0.17
1700	0.50	−0.32	0.41	0.14

u Eq(14)

t set	KRISS	NIM	CSIRO	NMIJ
[° C]	[° C]	[° C]	[° C]	[° C]
962		0.20		0.20
1000	0.40	0.20	0.24	0.21
1064				
1085				
1100		0.24	0.29	0.25
1200	0.38	0.27	0.33	0.28
1300		0.29	0.35	0.31
1400	0.44	0.35	0.42	0.36
1500		0.37	0.43	0.39
1600	0.55	0.42	0.49	0.44
1700		0.46	0.54	0.48

U=2u

t set	KRISS	NIM	CSIRO	NMIJ
[° C]	[° C]	[° C]	[° C]	[° C]
962		0.41		0.40
1000	0.80	0.41	0.48	0.43
1064				
1085				
1100		0.47	0.59	0.49
1200	0.76	0.55	0.65	0.56
1300		0.59	0.70	0.61
1400	0.89	0.69	0.84	0.72
1500		0.75	0.86	0.78
1600	1.10	0.84	0.98	0.88
1700		0.93	1.09	0.96

Table 11 Difference of three other institutes from CCT KCRV

dtAPMP Eq(3)

t set	NMC	KIM-LIPI	ITRI (re)	ITRI
[° C]	[° C]	[° C]	[° C]	[° C]
962				
1000	0.04	0.25	−0.21	−0.48
1064				
1085		0.37		
1100			0.13	−0.18
1200	−0.07		0.07	−0.40
1300	0.02	1.08	−0.06	−0.64
1400	0.10		−0.81	−1.52
1500		1.95	−1.05	−1.72
1600	0.19		−1.42	−2.56
1700			−1.95	−3.51

dt (to CCTKCRV) Eq(8)

t set	NMC	KIM-LIPI	ITRI(re)	ITRI
[° C]	[° C]	[° C]	[° C]	[° C]
962				
1000	0.08	0.30	−0.17	−0.44
1064				
1085		0.42		
1100			0.18	−0.13
1200	−0.08		0.06	−0.41
1300	0.09	1.15	0.02	−0.56
1400	0.22		−0.69	−1.40
1500		2.15	−0.86	−1.53
1600	0.36		−1.25	−2.39
1700			−1.80	−3.36

u Eq(14)

t set	NMC	KIM-LIPI	ITRI(re)	ITRI
[° C]	[° C]	[° C]	[° C]	[° C]
962				
1000	0.30	0.92	0.53	0.53
1064				
1085		0.92		
1100			0.72	0.72
1200	0.30		0.50	0.50
1300	0.38	1.06	0.78	0.78
1400	0.40		0.65	0.65
1500		1.32	0.64	0.64
1600	0.49		0.71	0.71
1700			0.79	0.79

U=2u

t set	NMC	KIM-LIPI	ITRI(re)	ITRI
[° C]	[° C]	[° C]	[° C]	[° C]
962				
1000	0.59	1.84	1.07	1.07
1064				
1085		1.84		
1100			1.45	1.45
1200	0.60		0.99	0.99
1300	0.76	2.11	1.57	1.57
1400	0.79		1.31	1.31
1500		2.64	1.28	1.28
1600	0.98		1.42	1.42
1700			1.58	1.58

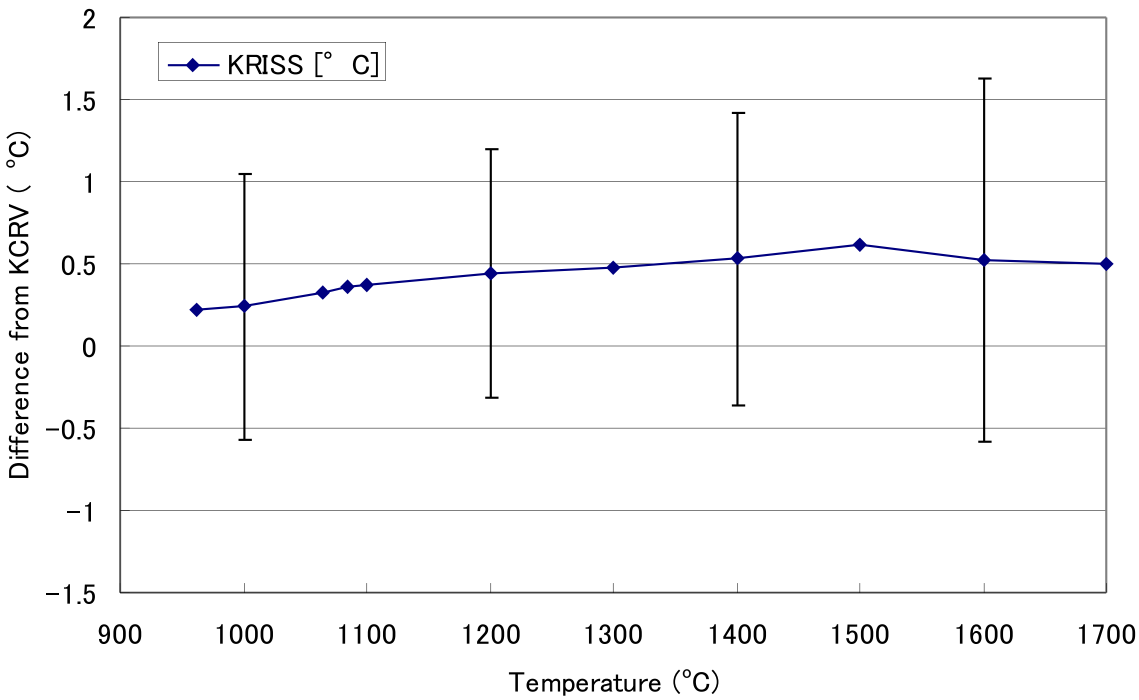


Fig. 1 Difference of KRISS from the KCRV

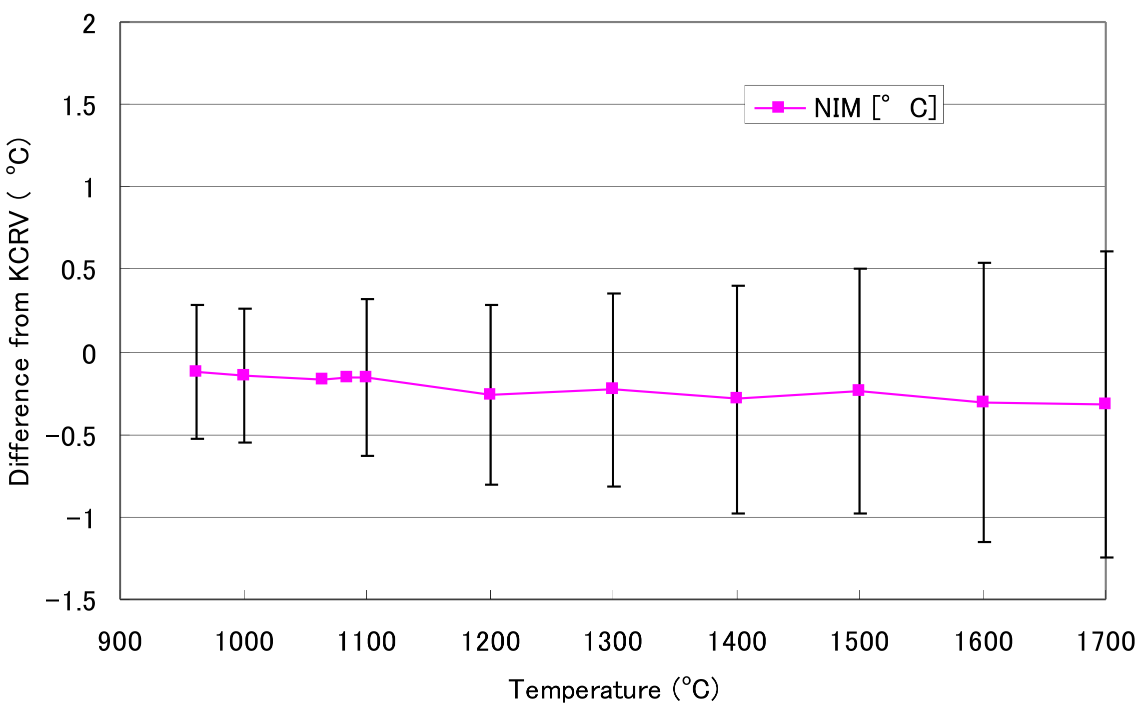


Fig. 2 Difference of NIM from the KCRV

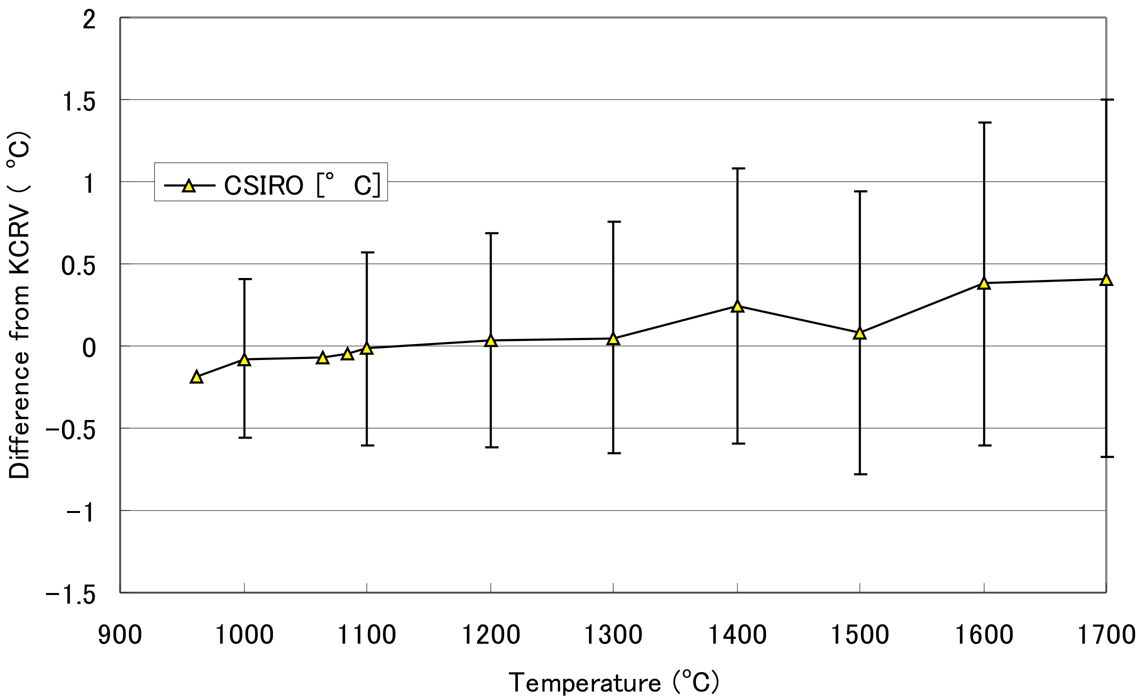


Fig. 3 Difference of CSIRO from the KCRV

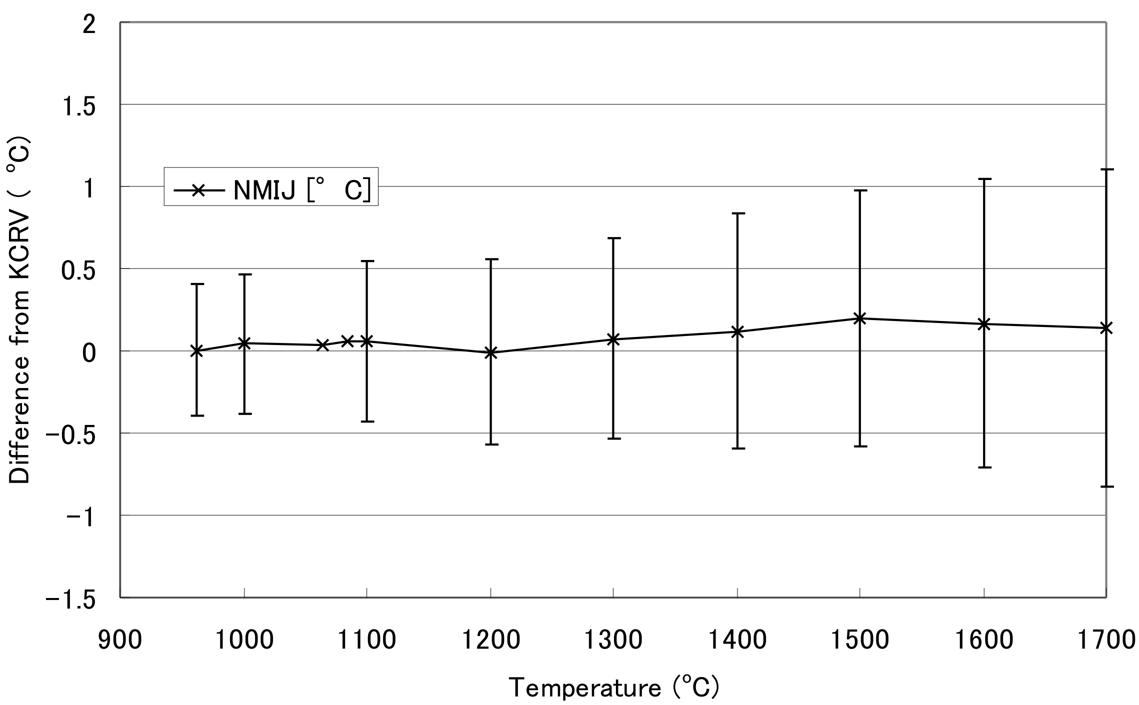


Fig. 4 Difference of NMIJ from the KCRV

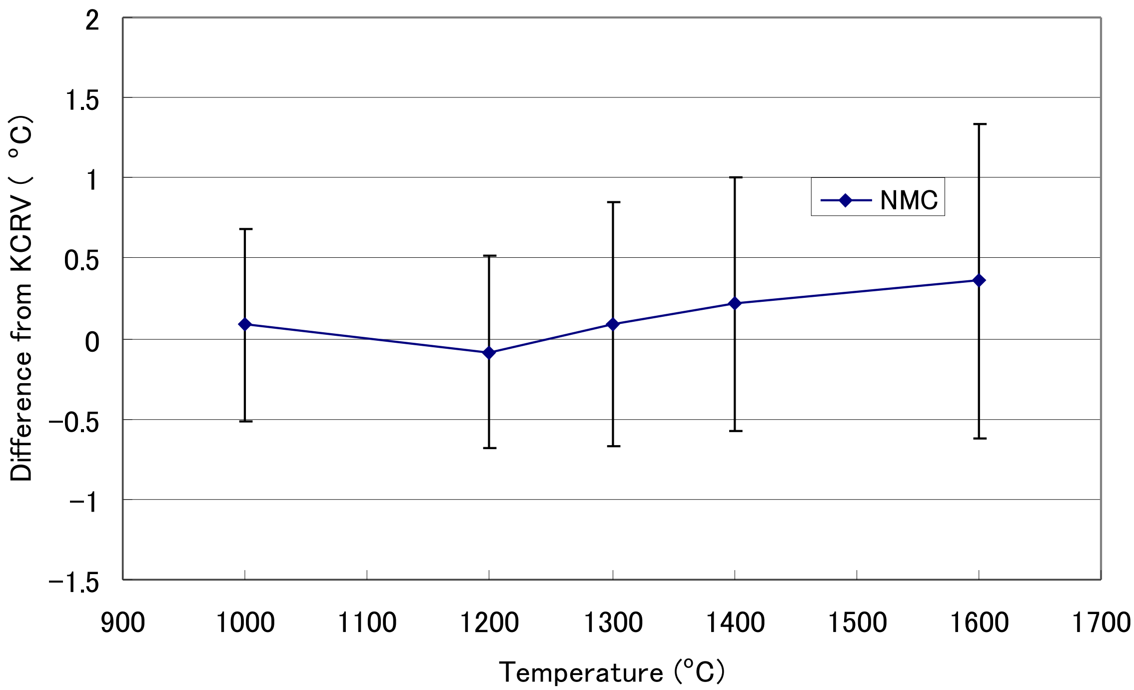


Fig. 5 Difference of NMC from the KCRV

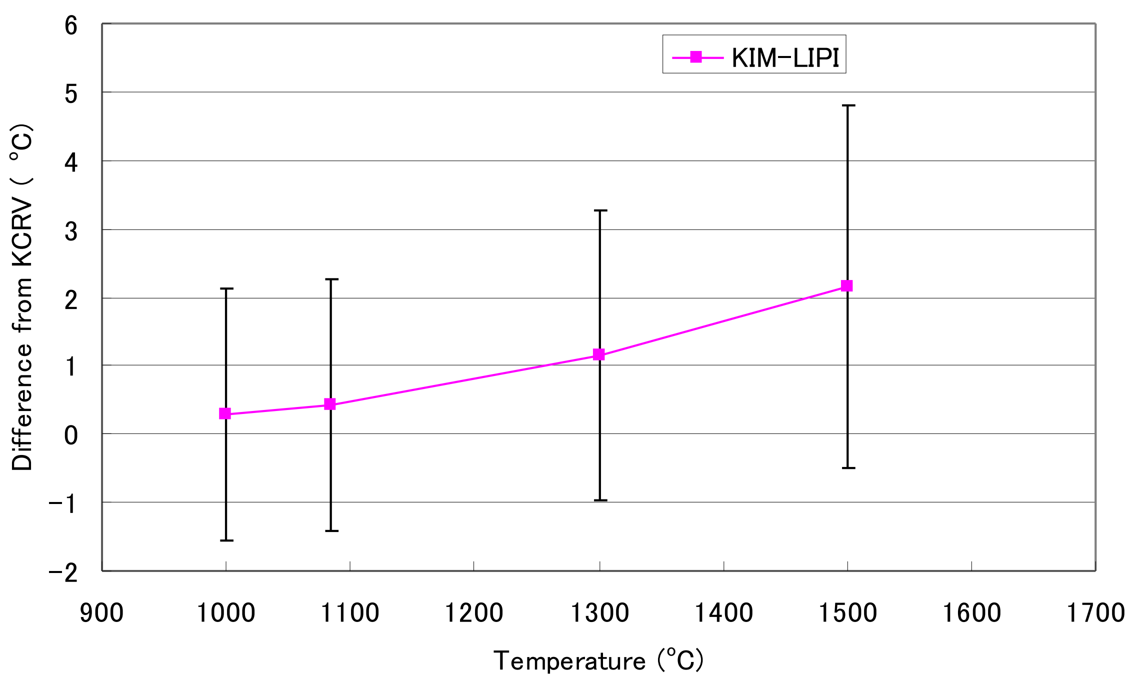


Fig. 6 Difference of KIM-LIPI from the KCRV

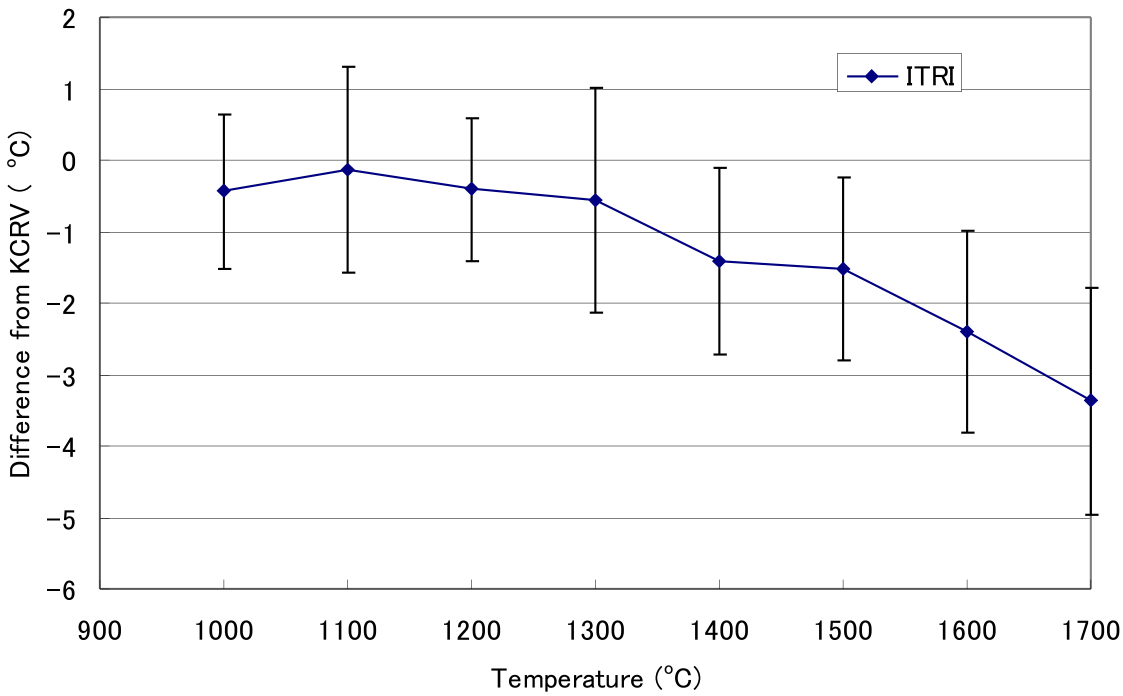


Fig. 7 Difference of ITRI from the KCRV

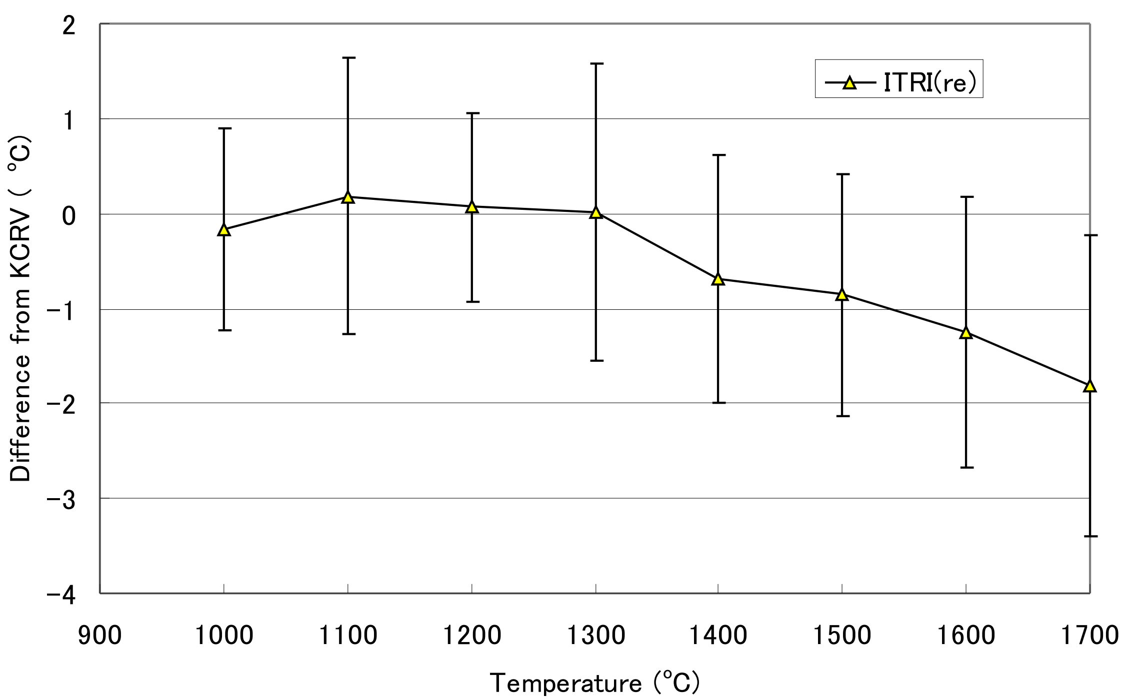
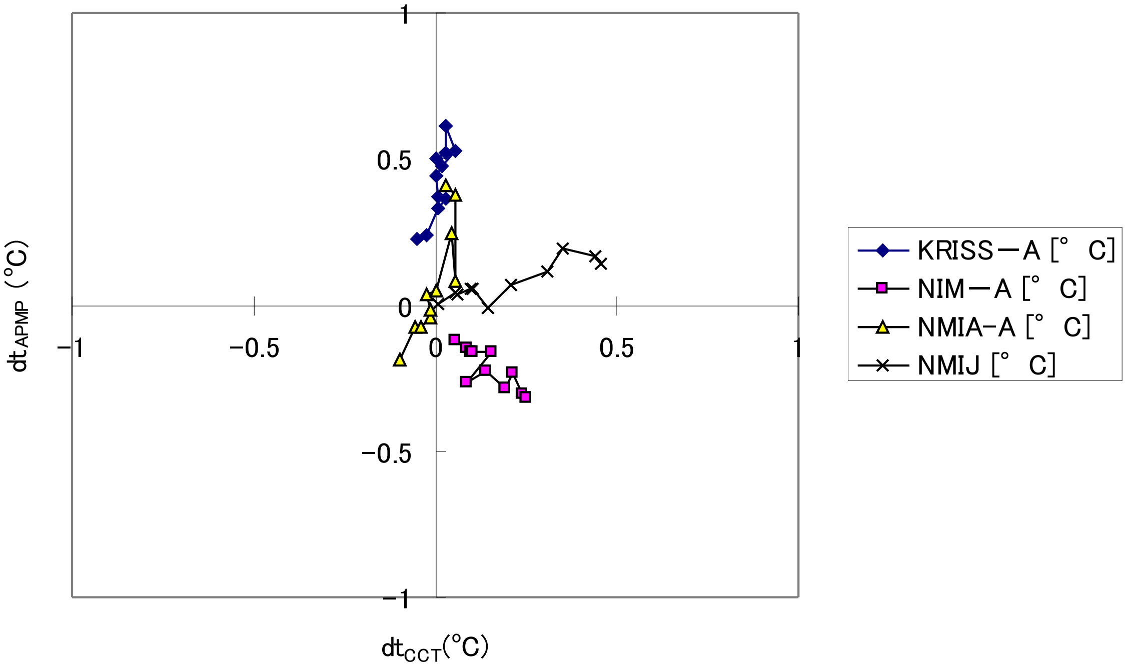


Fig. 8 Difference of ITRI (Revised) from the KCRV

Fig. 9 Youden plot of the difference from the KCRV in CCT KC5 and in APMP TK5 comparisons



That is all