APMP INTERCOMPARISON REPORT

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Draft A Version 1.1 on 17 June 2005
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APMP-Supplementary Comparison of Local realization of radiation temperatures from 400 ^{o}C to 2000 ^{o}C using a radiation thermometer as transfer standards, APMP-T-S2-00

Draft B Report (Version 1)

Report
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Revision Note

Draft A1.1 revised on 17 June 2005.

KRISS instrument data change in Table 3 and 4 based on information by Dr. S. N. Park.

Draft A1.2 revised on 11 July 2005.

Appendix D graph change according to the comment from Mr. Z. Yuan.

Draft A1.3 revised on 13 July 2005.

Appendix C missing graphs addition according to the comment from Dr. Wang Li.

Table 3 and 5 change based on information by Dr. Wang Li.

Table 3 and 4 change according to the comment from Dr. M. Ballico

Draft B on 19 July 2005

Table 5 change according to the comment from Dr. Wang Li.

Contents

1. Introduction

National Metrology Institute of Japan (NMIJ) submitted a proposal of the APMP intercomparison on radiation thermometer scales to the APMP Secretariat on October 2nd in 1996. The purpose was to undertake an international comparison of the radiation temperature scales locally realized. The draft protocol was discussed on October 8th in 1997 at Beijing while Dr. Ballico from NML, Mr. 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 PSB, Dr. F. Sakuma and Dr. A. Ono from NMIJ were attending. Dr. Ono chaired the meeting. The conclusion was that a standard radiation thermometer should be used as a transfer standard between the participating laboratories. Two kinds of comparisons have been carried out. One used a 0.65 μm radiation thermometer from 962 °C to 2800 °C and another used a 0.9 μm radiation thermometer from 400 °C to 2000 °C. These comparisons have been qualified as APMP key and supplementary comparison with the potential effect of entailing documented bilateral agreements as to the equivalents of the local realizations of the radiation temperature scales ranging from 400 °C to 2800 °C. The temperature range in which each institute made the comparison was selected by each institute within the temperature range specified for the transfer standard radiation thermometer. The first comparison using a 0.65 μm radiation thermometer has already been reported. This report describes the result of the second comparison using a 0.9 μm radiation thermometer.

2. Organizations

NMIJ acted as a pilot institute. The contact person is

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3. Participating laboratories and schedules

The participating nations/regions, institutes and the contact parsons are listed in Table 1. The schedule and the temperature range of the intercomparison are listed in Table 2.

4. Comparison scheme

The comparison was performed with a standard radiation thermometer supplied by NMIJ. The comparison was carried out in the star 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 one or two blackbody radiation sources.

5. Instruments

The transfer standard radiation thermometers selected are denoted by Topcon 148. The thermometer was fully calibrated before the transfer. On return to NMIJ, it was recalibrated at the four fixed point and spectral responsivity was measured again. No large difference from the pre-calibration at NMIJ was found in the recalibration.

Table 3 shows the list of parameters of the radiation thermometers used in the comparison. The central wavelengths of all the radiation thermometers were within the range from 850 nm to 900 nm. The stability of the transfer radiation thermometer before and after the transportation is 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. Blackbodies and no lamps were used for the comparison between radiation thermometers. The size of the source effect and the ambient temperature effect were corrected for the transfer standard radiation thermometer. Temperature range measured in this comparison was from 600 °C to 1085 °C at least and 400 °C at the lowest or 2000 °C at the highest.

Some uniformity information of the radiation sources are shown in Appendix C. If the uniformity is not good, then the alignments of the radiation thermometers are very important. The uniformity of the heat pipe furnaces was better than 0.1 °C and that of other furnaces used in the comparison were better than 0.4 ^{o}C even at 2000 ^{o}C.

Table 5 shows the parameters of the fixed-point blackbodies for the comparison. Zinc, aluminum, silver and copper 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 interpolation, 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. In the figure the scatter shows the standard combined uncertainty.

6.1 KRISS

The first run and the second run agreed very well in the figure. The reproducibility was better than 0.1 °C below 1200 °C and better than 0.3 °C even at 2000 °C. The objective lens of the Topcon radiation thermometer was cleaned in the second run which showed 0.3 % increase of the signal. This change was corrected for the first day data. The agreement was better than ±0.2 °C below 1600 °C and better than ±0.9 °C at 2000 °C. The difference was within the range of the standard uncertainty (k=1).

6.2 NML/CSIRO

CSIRO used heat pipe blackbodies of Na and Cs. The two runs agreed very well, better than 0.1 °C. The agreement was within 0.2 °C in the range from 500 °C to 1000 °C and reached 0.35 °C at 1085 °C. The difference was within the expanded uncertainty. The drift of the calibration of CSIRO radiation thermometer in three months including the comparison period amounted to be 0.3 °C to 0.8 °C in this temperature range. So the average of pre and post comparison calibrations was used for the CSIRO scale.

6.3 NMC/SPRING

NMC used two blackbodies. One was a Land furnace used from 1000 °C to 1600 °C and the other was a Na heat pipe furnace used from 400 °C to 1000 °C. The reproducibility of the differences of two runs was better than 0.1 °C except for 1600 °C which amounted to 0.3 °C. Also the agreement between NMIJ and NMC was better than 0.3 °C except for the data at 1600 °C in the first run. The difference was within the standard uncertainty.

6.4 NIM

NIM used two blackbodies. One was a furnace used from 1000 °C to 1600 °C and the other was a furnace used from 400 °C to 800 °C. The first run and the second run agreed better than 0.1 °C except for 400 °C and 1000 °C. The agreement was about or better than 0.2 °C from 600 °C to 1400 °C. The difference at 1400 °C in the first run amounted to 0.5 °C. The difference was within the range of the standard uncertainty (k=1) except for the data at 400 °C which was better than the expanded uncertainty (k=2).

7. Results at each temperature

Appendix D shows the comparison result at each temperature. The scatter show the expanded uncertainty of k=2.

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 fourth-order polynomials. The residue is small enough compared to the standard deviation. Figure E2 shows the result for CSIRO. Quadratic polynomials are used for this result. In case of NMC in

Fig. E3 the data of the Land blackbody were used above 1000 °C where quadratic polynomials were applied. On the other hand a heat-pipe furnace was used below 1000 °C where cubic polynomials were applied. Figure E4 shows the result for NIM where quadratic polynomials were applied. Figure E5 shows the summary of the approximations from 600 °C to 1085 °C. The average of the four curves is shown in the thick solid line. This is the APMP average value and is smaller than 0.1 °C in this temperature range. The differences of the five institutes from the APMP average are shown in Fig. E6. In the figure closed marks of KRISS, NMC and NIM are measured data whereas open marks are interpolated data. All the differences are within 0.25 °C from the average and also within the standard uncertainty which each institute claims.

Table Captions

Table 1 List of participating nation or region, institute and contact person.

Nation or Region	Institute	Contact person
Korea	KRISS	S.N. Park
Australia	NML/CSIRO	M. Ballico
Singapore	NMC/SPRING	L. Wang
China	NIM	Z. Yuan
Japan	NMIJ/AIST	F. Sakuma

Table 2 Schedule and temperature range of the comparison

Institute	Year and month	Temperature range
KRISS	2000.10	600°C to 2000°C
NML/CSIRO	2000.11-12	400°C to 1085°C
NMC/SPRING	2001.12	400°C to 1600°C
NIM	2003.9	400°C to 1400°C

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 148	500	3.8	12	904	83	Lenses
KRISS	KPEP	500	0.8	10	850	10	Lenses
NIM	RT9301	840	4.6	15	901	32	Lenses
NMC/SPRING	NML MTSP	500	2	10.4	900	100	Lenses
	IMGC SP1	500	1	12	900	10	Lenses
NML/CSIRO	MTSP	600	2	10	850	10	Lenses

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

Laboratory	Blackbody	Aperture diameter	Cavity	Temperature range	Windows
		[mm]		[°C]	
KRISS	Thermogage BB	38	graphite	600～2500	No
NML/CSIRO	Cs Heatpipe		Cs Heatpipe	400～700	No
	Na Heatpipe		Na Heatpipe	700～1081	No
NMC/SPRING	Carbolite CTF12-100-550	40	Thermacore	400～1000	No
	Land P1600B	50	SiC	1000～1600	No
NIM	BF1000	45	Oxidized inconel	200～1000	No
	BF1400	50	SiC	1000～1400	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		
		[%]	[-]	Inter-polation	Effective wavelength	Integral
NMIJ/AIST	Zn, Al, Ag, Cu	99.999	0.999	X		X
KRISS	Cu	99.999	0.99995			X
NML/CSIRO	Zn, Al, Ag, Cu	99.999	0.99995	X	X	
NMC/ SPRING	Zn, Al, Ag, Cu	99.999	0.9999	X	X	
NIM	Zn, Al, Ag, Cu	99.9992	0.99992	X		

Table 6 Difference of each institute form APMP Average (°C)

t (°C)	KRISS	CSIRO	NMC	NIM	NMIJ
600	0.03	0.02	-0.09	0.09	-0.04
700	0.00	-0.02	-0.01	0.04	-0.02
800	-0.02	-0.01	0.05	0.02	-0.04
900	-0.01	0.06	0.10	-0.08	-0.07
1000	0.01	0.12	0.08	-0.13	-0.09
1085	-0.01	0.22	0.02	-0.12	-0.12

Appendix A : Stability of transfer radiation thermometer

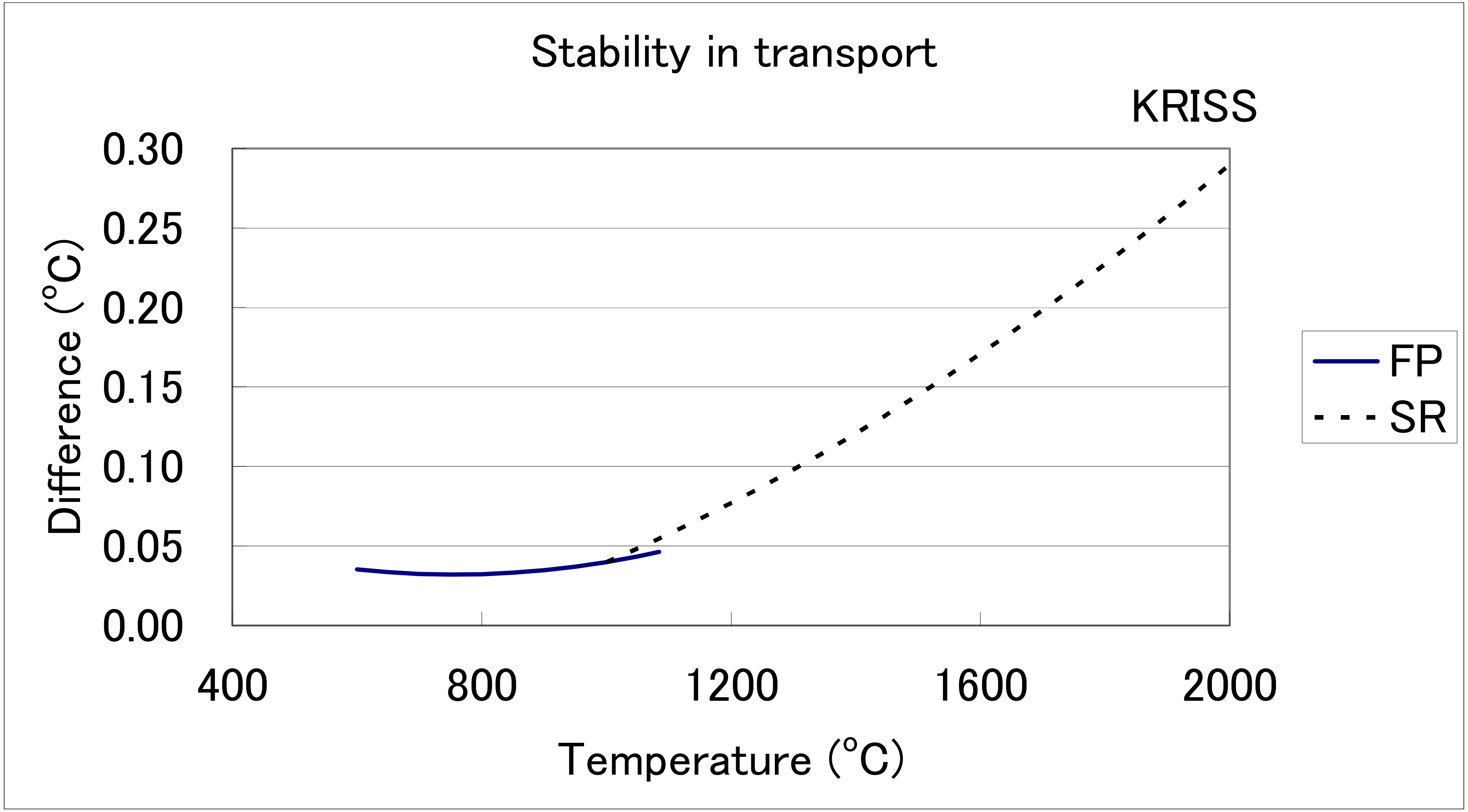
A1 Stability in the comparison with KRISS

A2 Stability in the comparison with NML/CSIRO

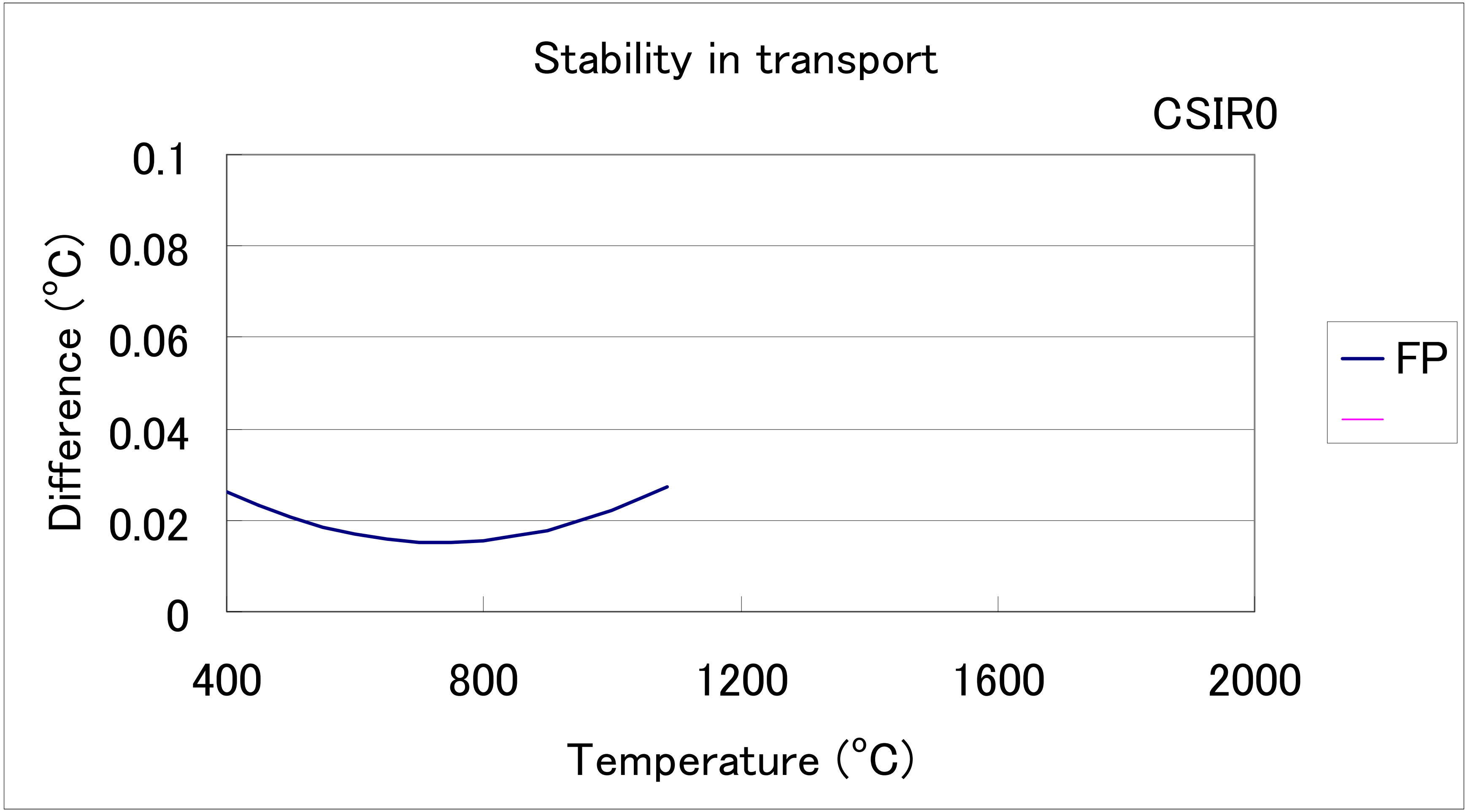
A3 Stability in the comparison with NMC/SPRING

A4 Stability in the comparison with NIM

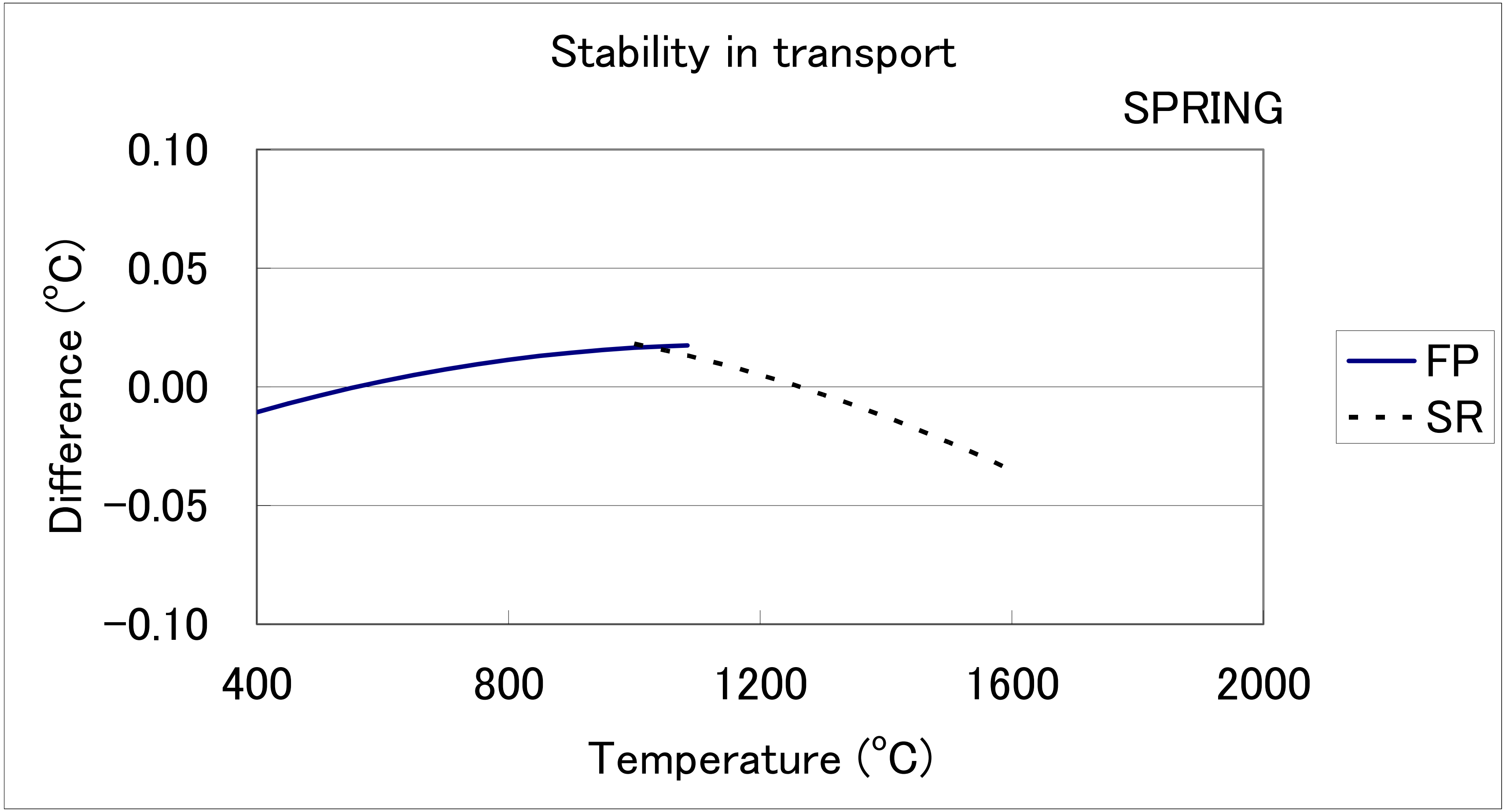
A1 Stability in the comparison with KRISS



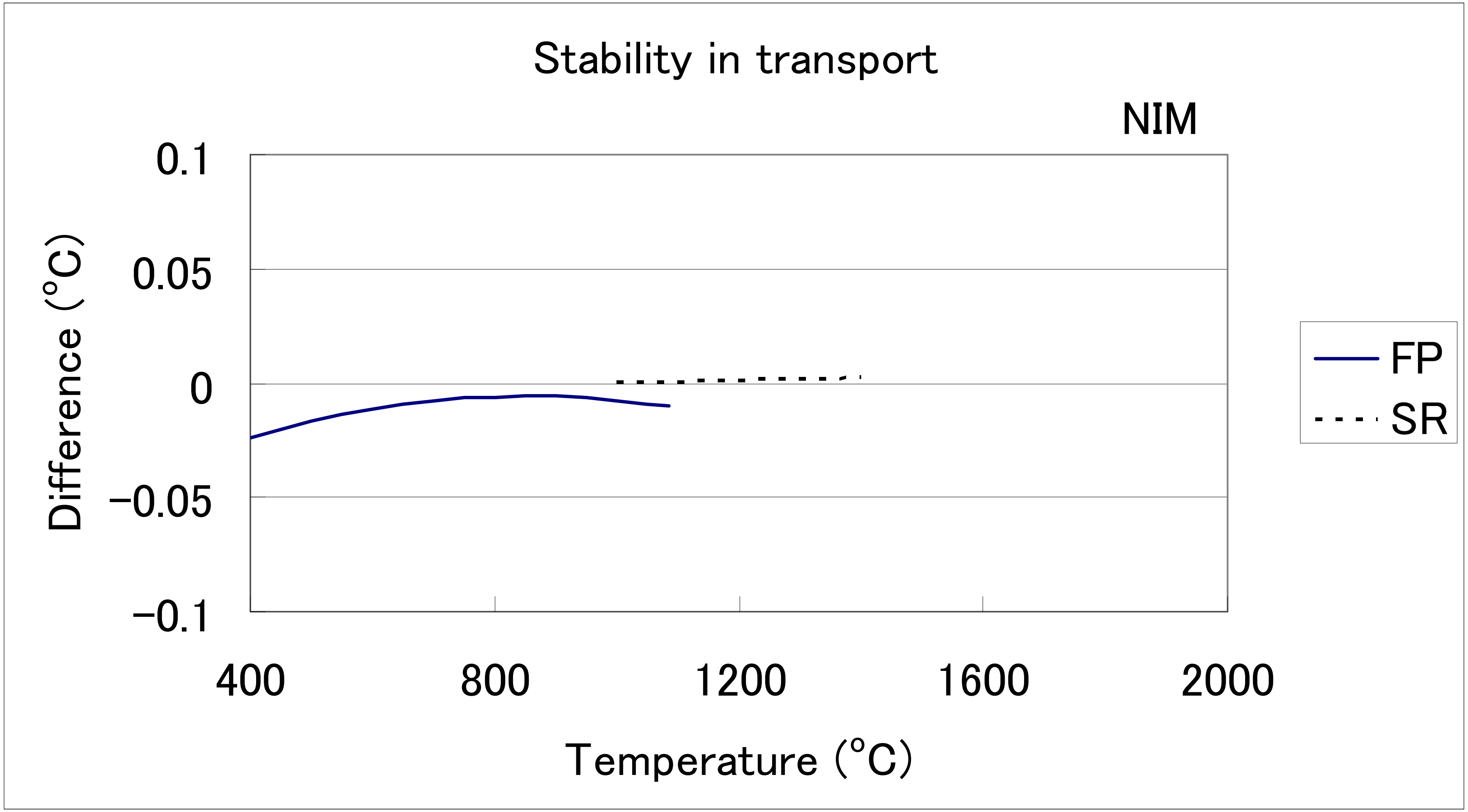
A2 Stability in the comparison with NML/CSIRO



A3 Stability in the comparison with NMC/SPRING



A4 Stability in the comparison with NIM



Appendix B : Results of comparison at each institute

B1 Results of comparison at KRISS

B2 Results of comparison at NML/CSIRO

B3 Results of comparison at NMC/SPRING

B4 Results of comparison at NIM

Appendix B : Results of comparison at each institute

B1 Results of comparison at KRISS

APMP-Comparison 400°C to 2000°C Appendix B
KRISS Result of measurements Difference from NMIJ
Thermogage blackbody 2000/10/24 t(KRISS)-t(NMIJ)

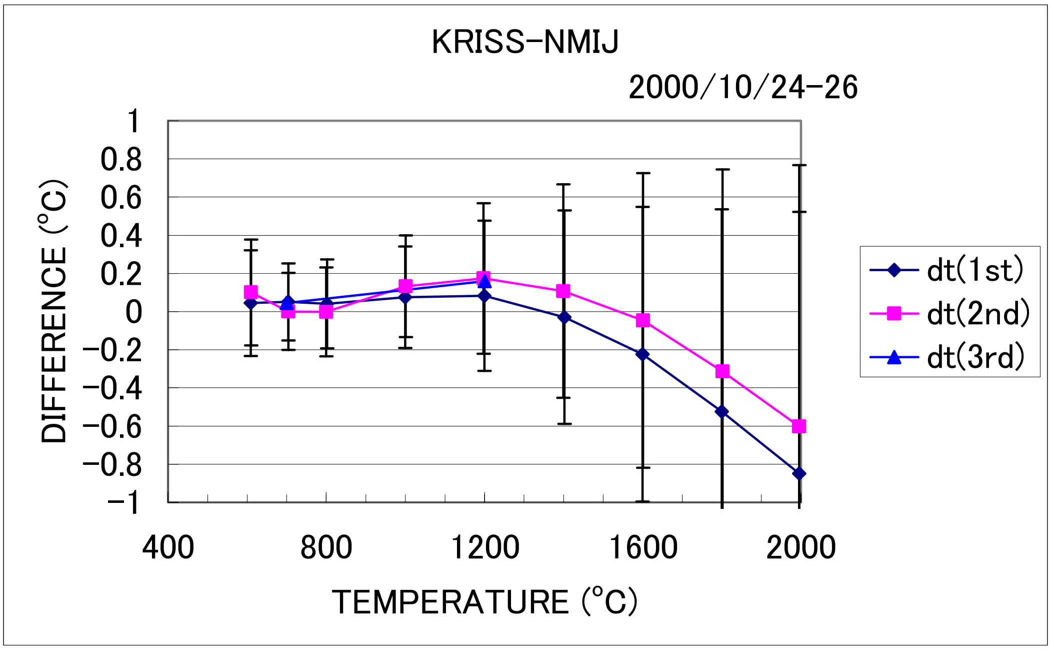
t set	t(KRISS)	s(KRISS)	t(NMIJ)	s(NMIJ)	dt(1st)	s(total)	NE	2s total
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]
600	608.79	0.25	608.74	0.12	0.04	0.28	0.16	0.55
700	704.01	0.15	703.96	0.14	0.05	0.20	0.25	0.40
800	801.91	0.15	801.87	0.18	0.04	0.23	0.17	0.47
1000	999.48	0.2	999.40	0.18	0.08	0.27	0.28	0.53
1200	1199.93	0.3	1199.85	0.25	0.08	0.39	0.21	0.79
1400	1402.23	0.4	1402.26	0.39	-0.03	0.56	-0.05	1.12
1600	1599.40	0.5	1599.63	0.59	-0.22	0.77	-0.29	1.54
1800	1799.38	0.65	1799.90	0.84	-0.52	1.06	-0.49	2.12
2000	1994.54	0.8	1995.39	1.11	-0.85	1.37	-0.62	2.74

Thermogage blackbody 2000/10/25

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]
600	609.89	0.25	609.79	0.12	0.10	0.28	0.36	0.55
700	703.96	0.15	703.96	0.14	0.00	0.20	0.00	0.40
800	799.91	0.15	799.91	0.18	0.00	0.23	0.00	0.47
1000	1001.27	0.2	1001.14	0.18	0.13	0.27	0.50	0.53
1200	1197.93	0.3	1197.76	0.25	0.17	0.39	0.44	0.79
1400	1399.26	0.4	1399.16	0.39	0.11	0.56	0.19	1.12
1600	1601.09	0.5	1601.14	0.59	-0.05	0.77	-0.06	1.54
1800	1801.35	0.65	1801.66	0.84	-0.31	1.06	-0.30	2.12
2000	1994.70	0.8	1995.30	1.11	-0.60	1.37	-0.44	2.74

Thermogage blackbody 2000/10/26

t set	t(KRISS)	s(KRISS)	t(NMIJ)	s(NMIJ)	dt(3rd)	s(total)	NE	2s total
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]
700	701.05	0.15	701.00	0.15	0.04	0.21	0.21	0.42
1200	1200.73	0.3	1200.57	0.28	0.16	0.41	0.39	0.82



B2 Results of comparison at NML/CSIRO

APMP-Comparison ITS-90 above silver point Appendix B

CSIRO Result of measurements Difference from NMIJ

Heatpipe blackbodies 2000/11/28 t(CSIRO)-t(NMIJ)

t set	t(CSIRO)	s(CSIRO)	t(NMIJ)	s(NMIJ)	dt(0th)	s(total)	NE	2s total	Heatpipe
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]	
400	398.51	0.15	398.31	0.28	0.20	0.32	0.63	0.63	Cs

CSIRO Result of measurements Difference from NMIJ

Heatpipe blackbodies 2000/11/29 t(CSIRO)-t(NMIJ)

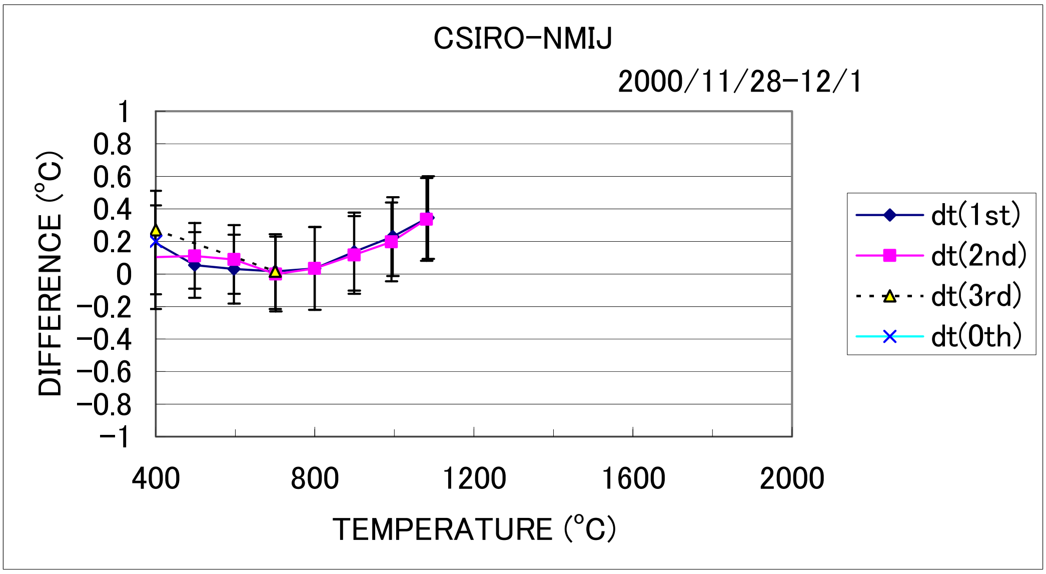
t set	t(CSIRO)	s(CSIRO)	t(NMIJ)	s(NMIJ)	dt(1st)	s(total)	NE	2s total	Heatpipe
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]	
400	398.96	0.15	398.77	0.28	0.19	0.32	0.61	0.64	Cs
500	497.78	0.16	497.73	0.12	0.06	0.20	0.27	0.40	Cs
600	596.62	0.17	596.59	0.12	0.03	0.21	0.14	0.42	Cs
700	700.60	0.19	700.58	0.14	0.02	0.23	0.07	0.46	Na
800	800.18	0.18	800.15	0.18	0.03	0.25	0.13	0.51	Na
900	899.00	0.18	898.86	0.16	0.14	0.24	0.57	0.48	Na
1000	995.97	0.17	995.74	0.18	0.23	0.24	0.95	0.48	Na
1085	1085.61	0.15	1085.26	0.20	0.35	0.25	1.36	0.51	Na

Heatpipe blackbodies 2000/11/30

t set	t(CSIRO)	s(CSIRO)	t(NMIJ)	s(NMIJ)	dt(2nd)	s(total)	NE	2s total	Heatpipe
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]	
400	398.53	0.15	398.43	0.28	0.10	0.32	0.33	0.64	Cs
500	497.65	0.16	497.53	0.12	0.11	0.20	0.55	0.40	Cs
600	596.63	0.17	596.55	0.12	0.09	0.21	0.42	0.42	Cs
700	701.92	0.19	701.92	0.14	0.00	0.23	0.00	0.46	Na
800	799.10	0.18	799.07	0.18	0.03	0.25	0.13	0.51	Na
900	899.42	0.18	899.31	0.16	0.12	0.24	0.49	0.48	Na
1000	992.81	0.17	992.61	0.18	0.20	0.24	0.81	0.48	Na
1085	1081.56	0.15	1081.22	0.20	0.34	0.25	1.32	0.51	Na

Heatpipe blackbodies 2000/12/1 t(CSIRO)-t(NMIJ)

t set	t(CSIRO)	s(CSIRO)	t(NMIJ)	s(NMIJ)	dt(3rd)	s(total)	NE	2s total	Heatpipe
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]	
400	388.7558	0.15	388.4846	0.28	0.27				Cs
700	702.05	0.19	702.03	0.14	0.02	0.23	0.07	0.46	Na



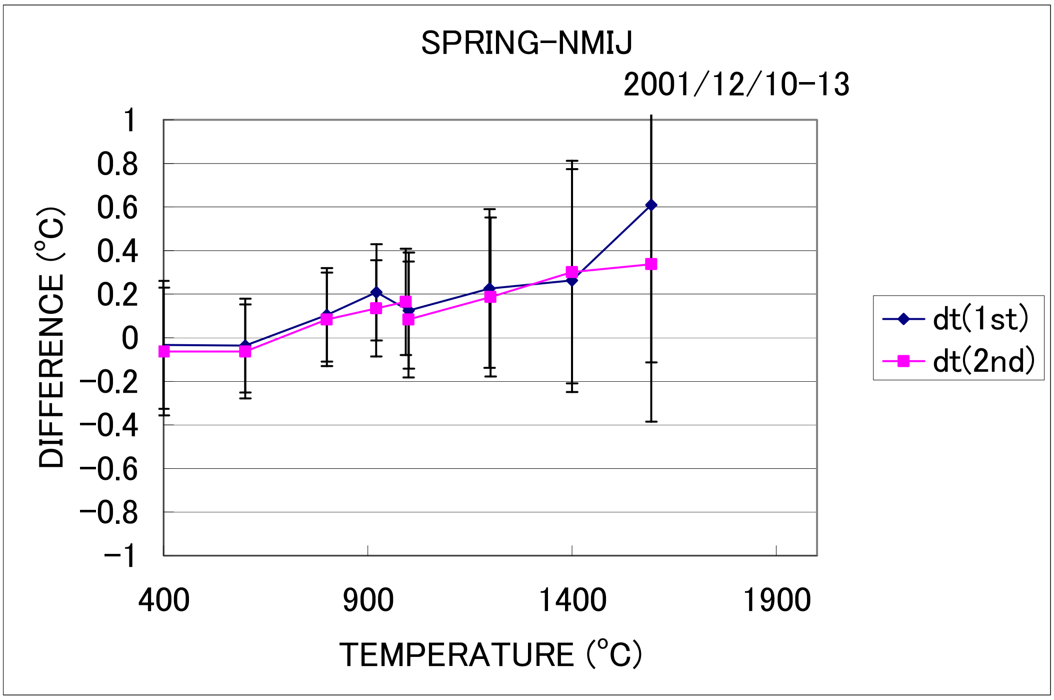
B3 Results of comparison at NMC/SPRING

APMP-Comparison 400°C to 2000°C   Appendix B
SPRING Result of measurements   Difference from NMIJ
Blackbody 2001/12/10-11   t(SPRING)-t(NMIJ)

t set	t(SPRING)	s(SPRING)	t(NMIJ)	s(NMIJ)	dt(1st)	s(total)	NE	2s total	Furnace
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]	
400	399.55	0.10	399.58	0.28	-0.03	0.29	-0.11	0.59	Potassium heatpipe
600	599.94	0.18	599.98	0.12	-0.04	0.22	-0.17	0.43	Potassium heatpipe
800	799.53	0.12	799.43	0.18	0.10	0.21	0.49	0.43	Potassium heatpipe
920	921.58	0.15	921.37	0.16	0.21	0.22	0.95	0.44	Potassium heatpipe
1000	1000.54	0.20	1000.41	0.18	0.12	0.27	0.47	0.53	LAND
1200	1198.60	0.26	1198.38	0.25	0.23	0.36	0.62	0.73	LAND
1400	1400.16	0.33	1399.90	0.39	0.26	0.51	0.51	1.02	LAND
1600	1594.83	0.42	1594.22	0.59	0.61	0.72	0.84	1.45	LAND

Blackbody 2001/12/12-13

t set	t(SPRING)	s(SPRING)	t(NMIJ)	s(NMIJ)	dt(2nd)	s(total)	NE	2s total	Furnace
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]	
400	400.25	0.10	400.31	0.28	-0.06	0.29	-0.22	0.59	Potassium heatpipe
600	600.25	0.18	600.31	0.12	-0.06	0.22	-0.29	0.43	Potassium heatpipe
800	800.02	0.12	799.94	0.18	0.08	0.21	0.39	0.43	Potassium heatpipe
920	921.03	0.15	920.89	0.16	0.13	0.22	0.61	0.44	Potassium heatpipe
995	993.60	0.17	993.44	0.18	0.16	0.24	0.68	0.49	Potassium heatpipe
1000	1000.15	0.20	1000.06	0.18	0.08	0.27	0.31	0.53	LAND
1200	1200.81	0.26	1200.62	0.25	0.19	0.36	0.51	0.73	LAND
1400	1400.58	0.33	1400.28	0.39	0.30	0.51	0.59	1.02	LAND
1600	1594.44	0.42	1594.11	0.59	0.34	0.72	0.47	1.45	LAND



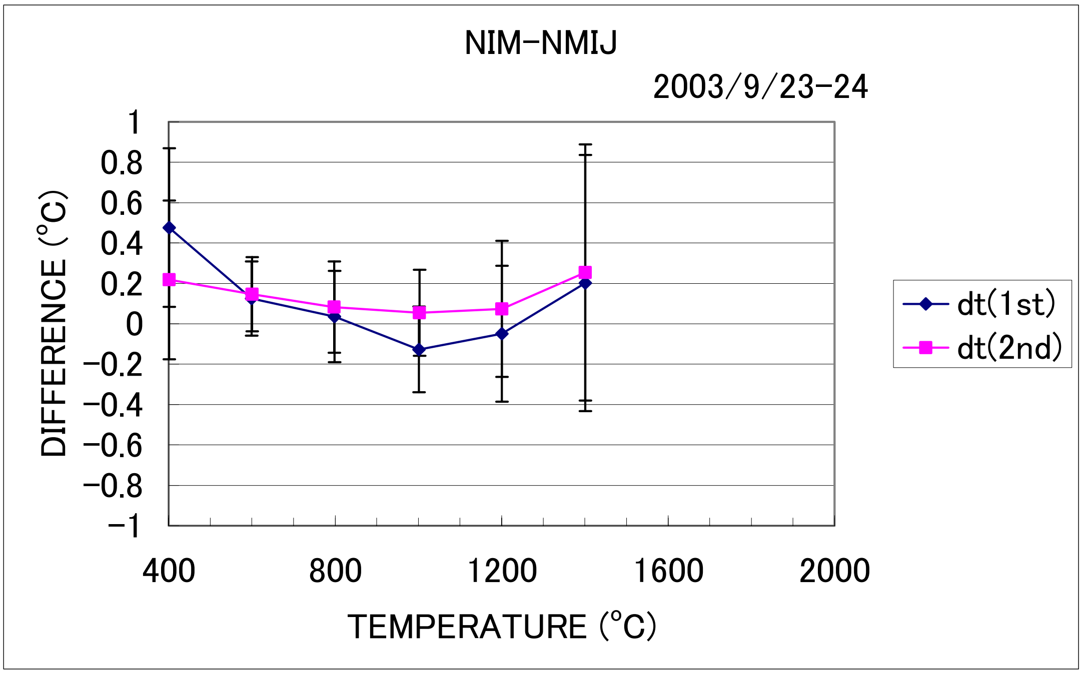
B4 Results of comparison at NIM

APMP−Comparison 400°C to 2000°C Appendix B
NIM Result of measurements Difference from NMIJ
Blackbodies 2003/9/23 t(NIM)−t(NMIJ)

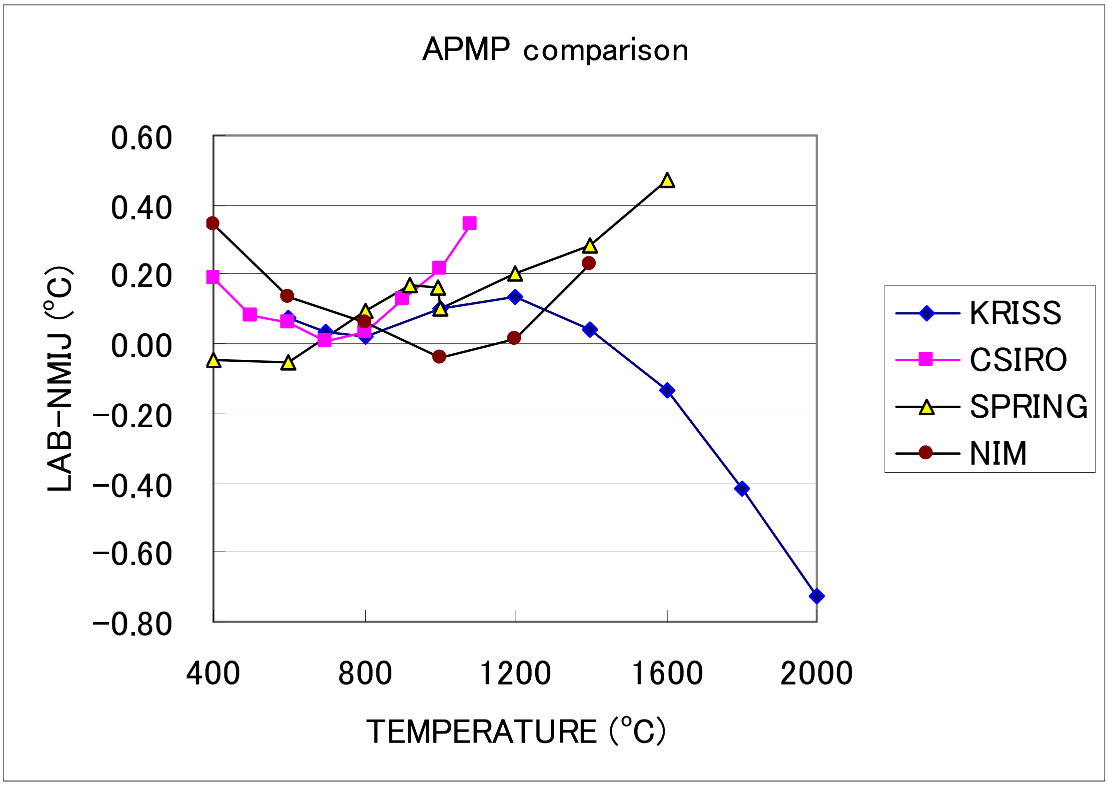
t set	t(NIM)	s(NIM)	t(NMIJ)	s(NMIJ)	dt(1st)	s(total)	NE	2s total	Blackbody
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]	
400	401.54	0.28	401.06	0.28	0.48	0.39	1.21	0.79	BF−1000
600	599.50	0.14	599.37	0.12	0.12	0.18	0.68	0.37	BF−1000
800	798.12	0.14	798.08	0.18	0.04	0.23	0.16	0.45	BF−1000
1000	1001.08	0.12	1001.21	0.18	−0.13	0.21	−0.60	0.43	BF−1400
1200	1200.83	0.22	1200.88	0.25	−0.05	0.34	−0.15	0.67	BF−1400
1400	1401.31	0.50	1401.10	0.39	0.20	0.63	0.32	1.27	BF−1400

Blackbodies 2003/9/24

t set	t(NIM)	s(NIM)	t(NMIJ)	s(NMIJ)	dt(2nd)	s(total)	NE	2s total	Blackbody
[° C]	[° C]	[° C]	[° C]	[° C]	[° C]	[° C]		[° C]	
400	401.69	0.28	401.47	0.28	0.22	0.39	0.55	0.79	BF−1000
600	600.55	0.14	600.40	0.12	0.15	0.18	0.80	0.37	BF−1000
800	797.59	0.14	797.50	0.18	0.08	0.23	0.37	0.45	BF−1000
1000	1002.63	0.12	1002.58	0.18	0.05	0.21	0.26	0.43	BF−1400
1200	1200.96	0.22	1200.89	0.25	0.07	0.34	0.22	0.67	BF−1400
1400	1401.43	0.50	1401.17	0.39	0.25	0.63	0.40	1.27	BF−1400



B5 Results of comparison at all institutes



Appendix C : Uniformity of radiation source

C1 Horizontal uniformity of Thermogage blackbody at KRISS at 700 ^{o}C, 1200 ^{o}C and 2000 ^{o}C

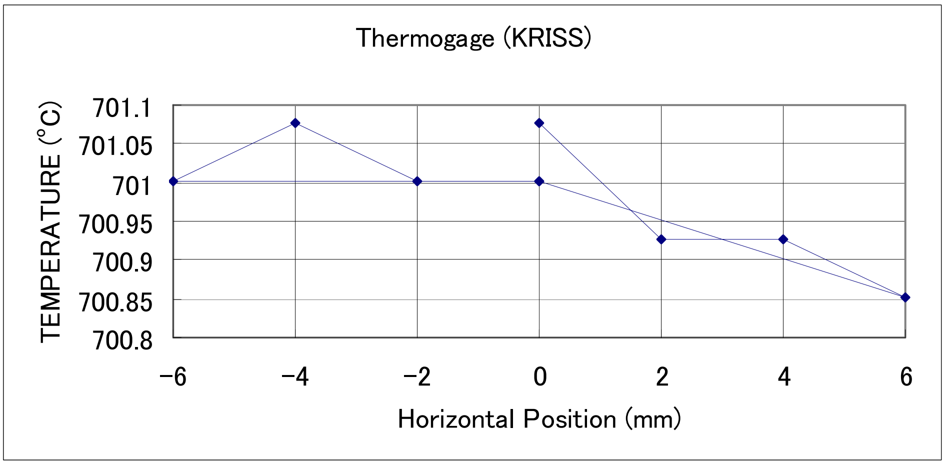
C2 Horizontal and vertical uniformity of Heat-pipe Blackbodies at NML/CSIRO at 400 ^{o}C, 700 ^{o}C and 1000 ^{o}C

C3 Horizontal uniformity of Land blackbody at NMC/SPRING at 1000 ^{o}C and 1600 ^{o}C

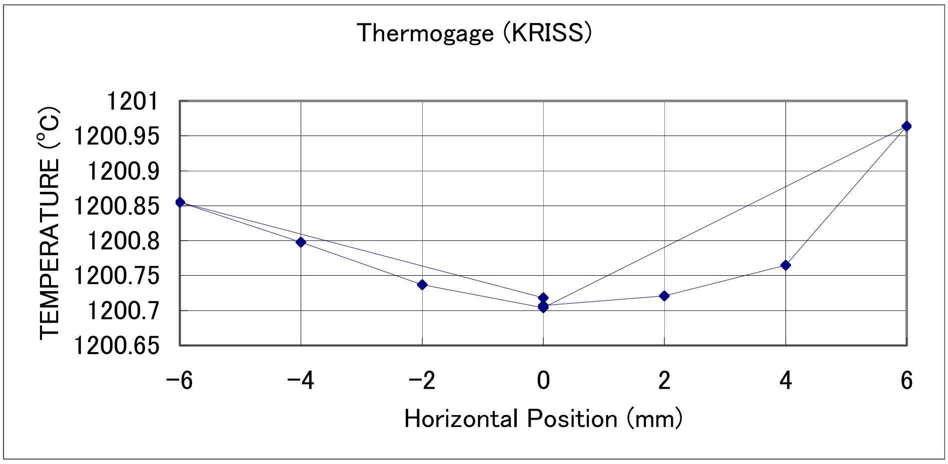
C4 Horizontal uniformity of Heat-pipe blackbody at NMC/SPRING at 400 ^{o}C, 600 ^{o}C, 800 ^{o}C and 920 ^{o}C .

C1 Radiance distribution in horizontal position of KRISS Thermogage blackbody

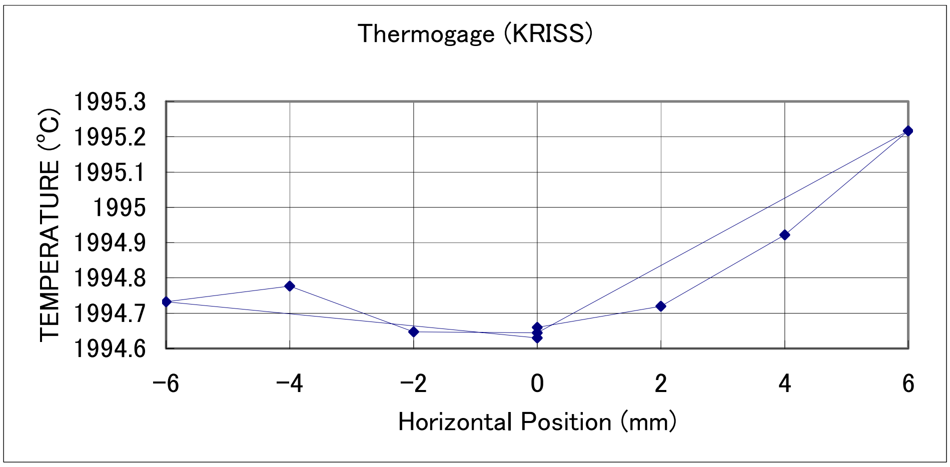
(A) 700°C



(B) 1200°C

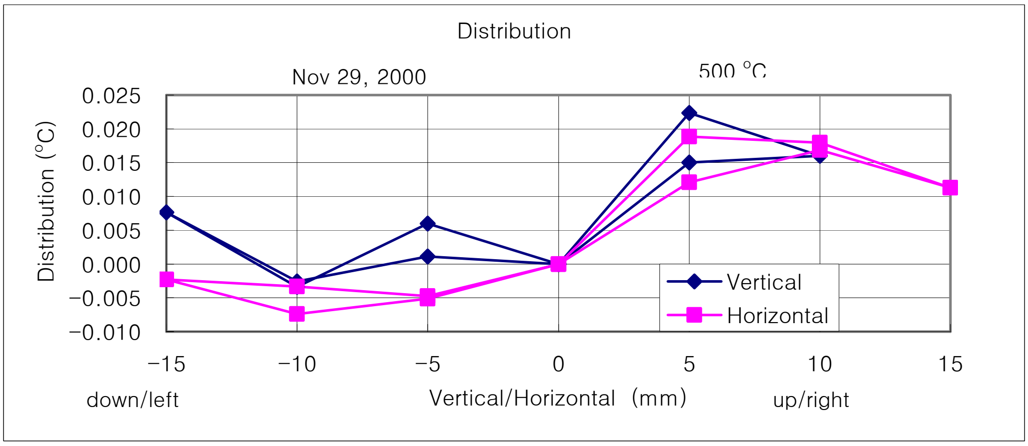


(C) 2000°C

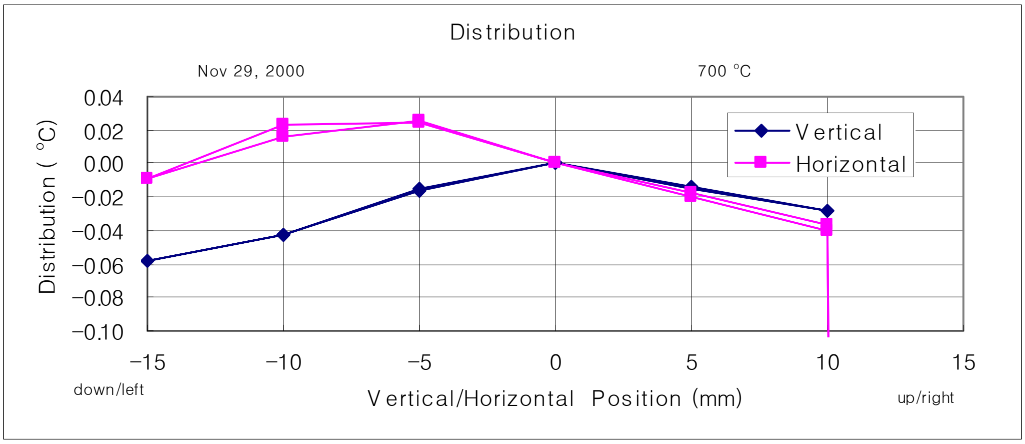


C2 Radiance distribution in Horizontal and vertical position of CSIRO Heat-pipe blackbody

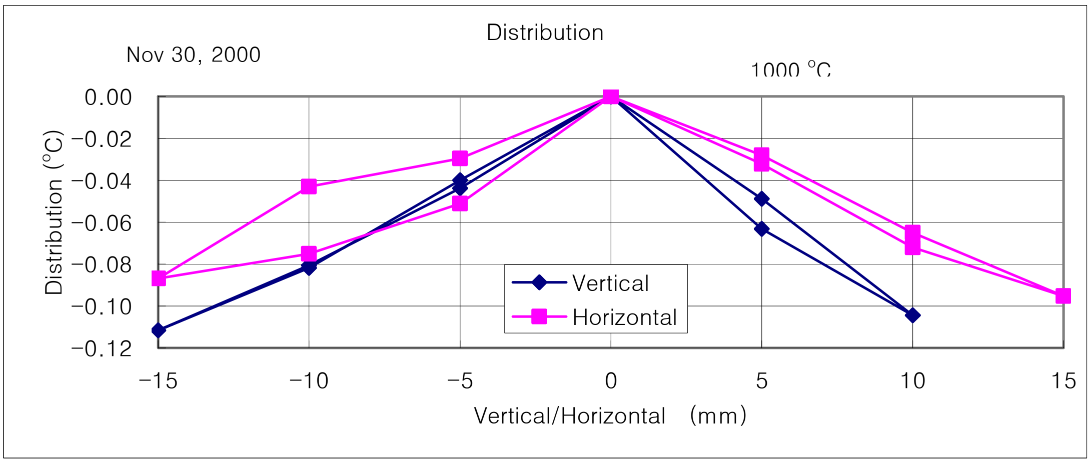
(A) 500°C (Cs)



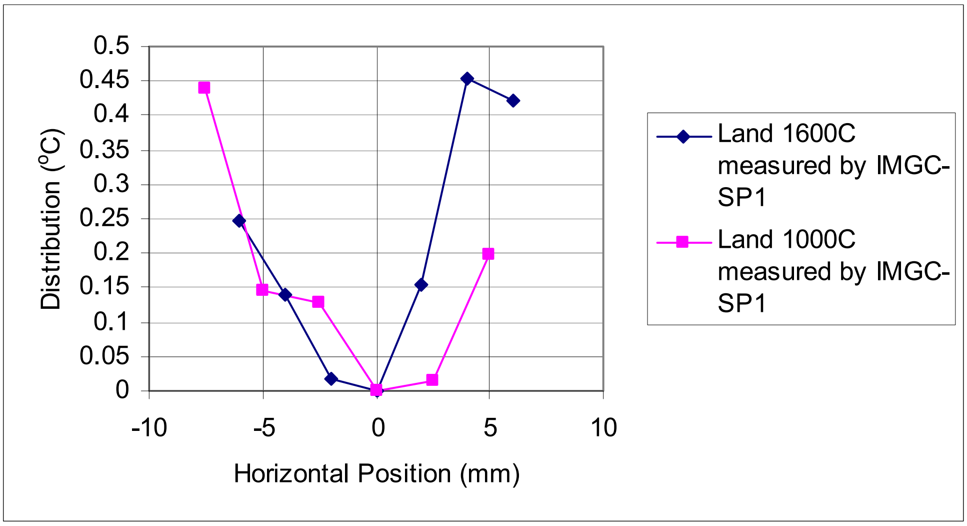
(B) 700°C (Na)



(C) 1000°C (Na)

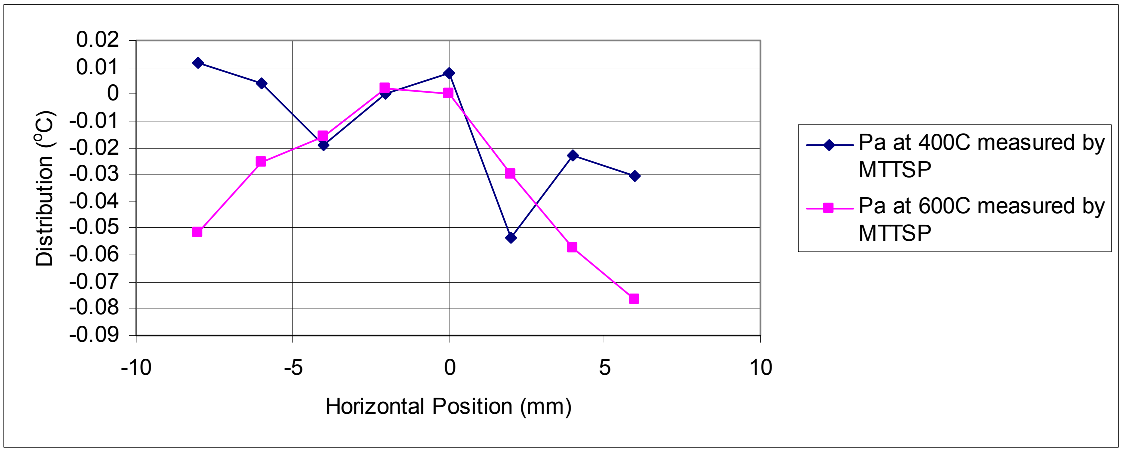


C3 Horizontal uniformity of Land blackbody at NMC/SPRING at 1000 ^{o}C and 1600 ^{o}C

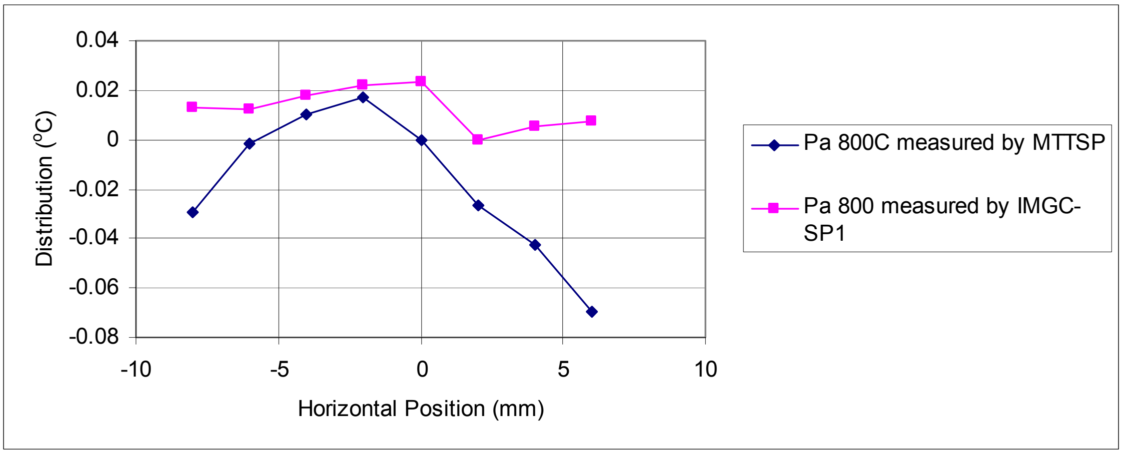


C4 Horizontal uniformity of Heat-pipe blackbody at NMC/SPRING at 400 °C, 600 °C, 800 °C and 920 °C .

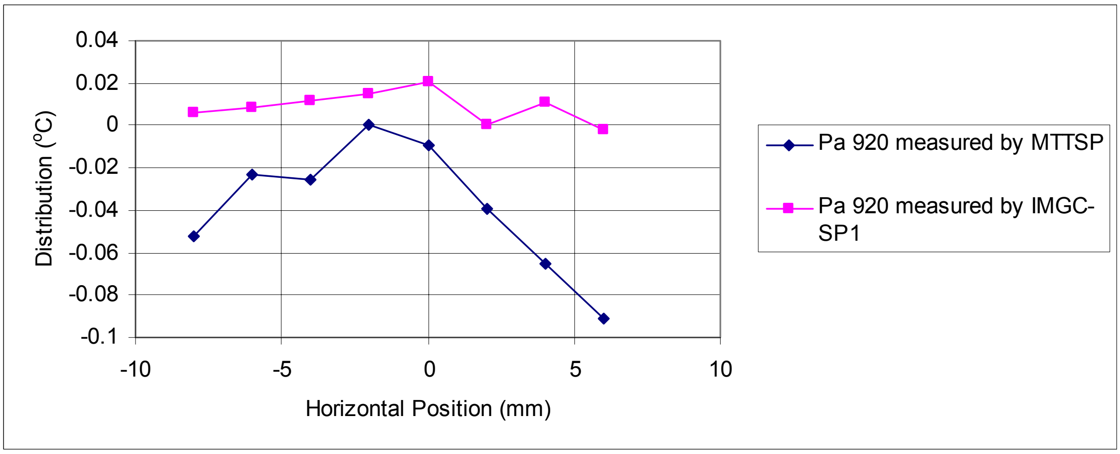
(A) 400° C and 600°C



(B) 800°C



(C) 920°C



Appendix D : Result of comparison at each temperature. Scatter in the figure are expanded uncertainty of *k*=2.

D1 Result at 400 °C

D2 Result at 500 °C

D3 Result at 600 °C

D4 Result at 700 °C

D5 Result at 800 °C

D6 Result at 900 °C

D7 Result at 1000 °C

D8 Result at1085 °C

D9 Result at 1200 °C

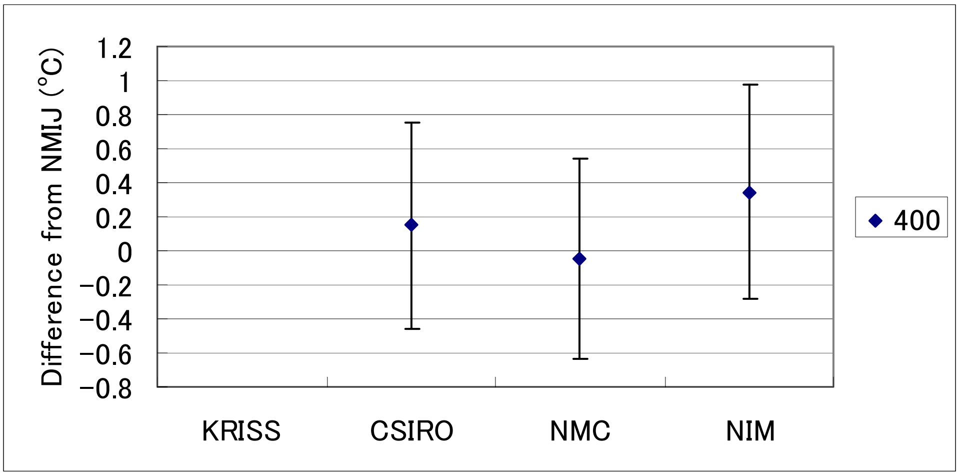
D10 Result at 1400 °C

D11 Result at 1600 °C

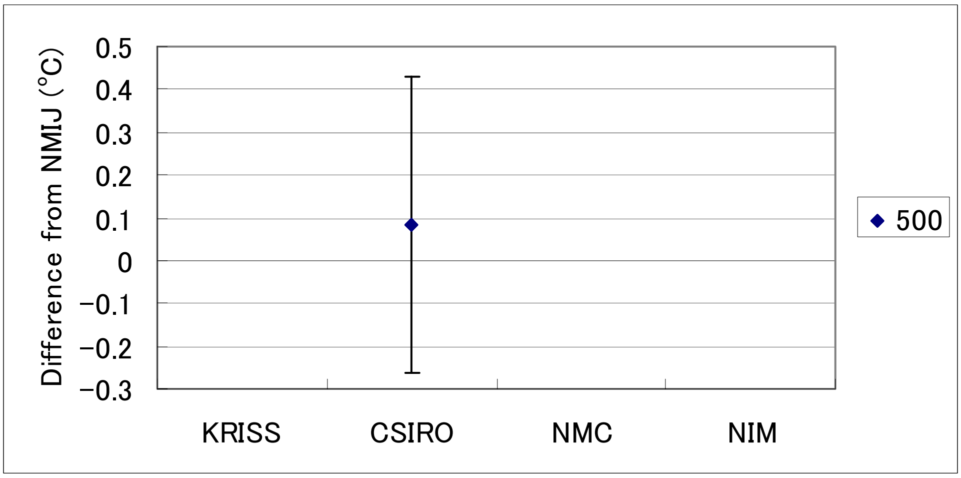
D12 Result at 1800 °C

D13 Result at 2000 °C

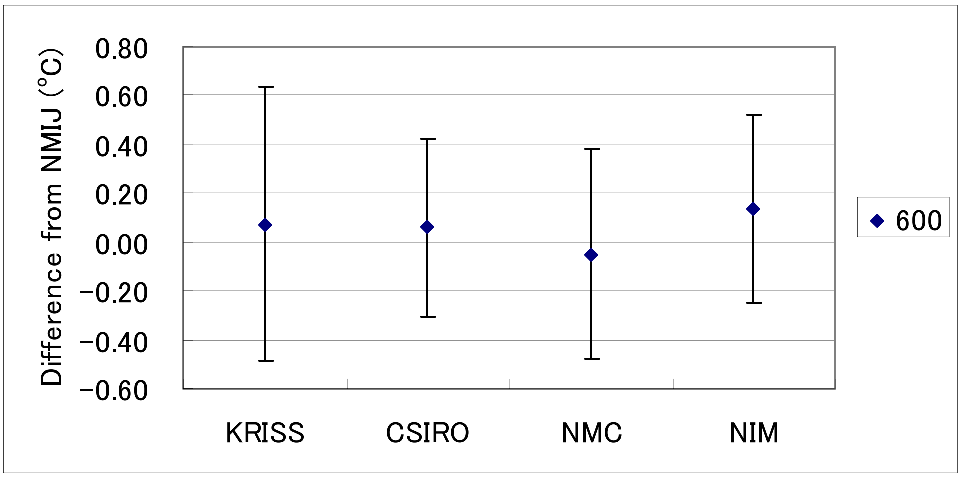
D1 Result at 400 °C



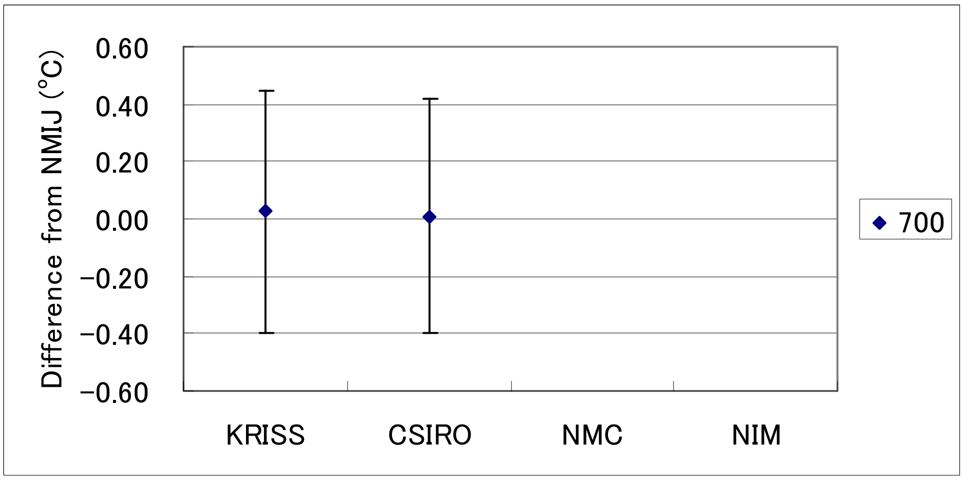
D2 Result at 500 °C



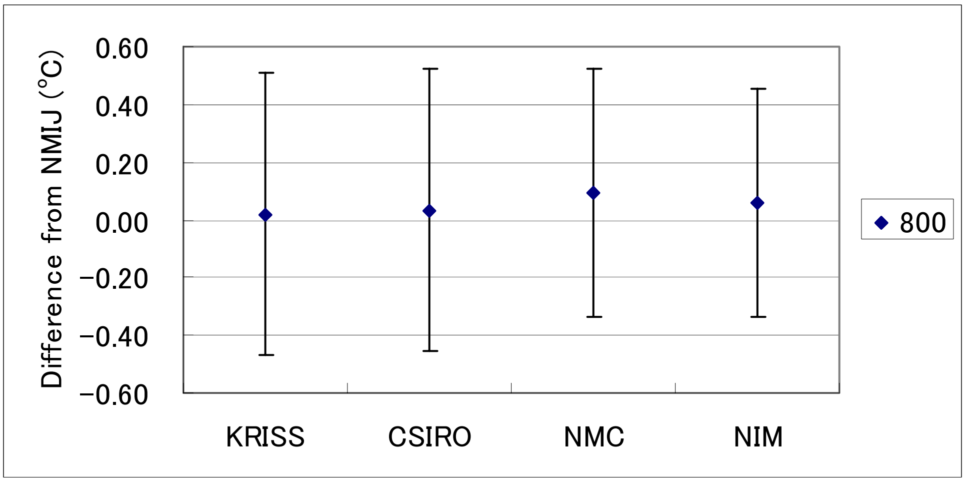
D3 Result at 600 °C



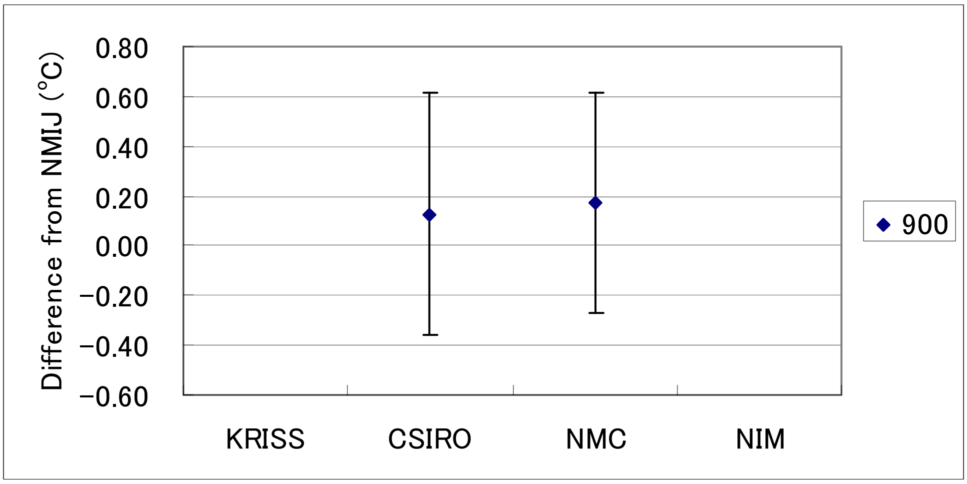
D4 Result at 700 °C



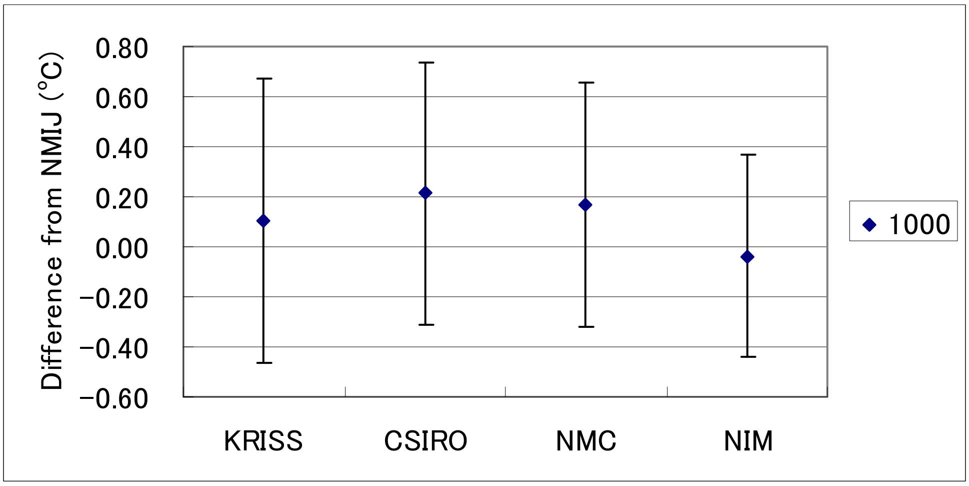
D5 Result at 800 °C



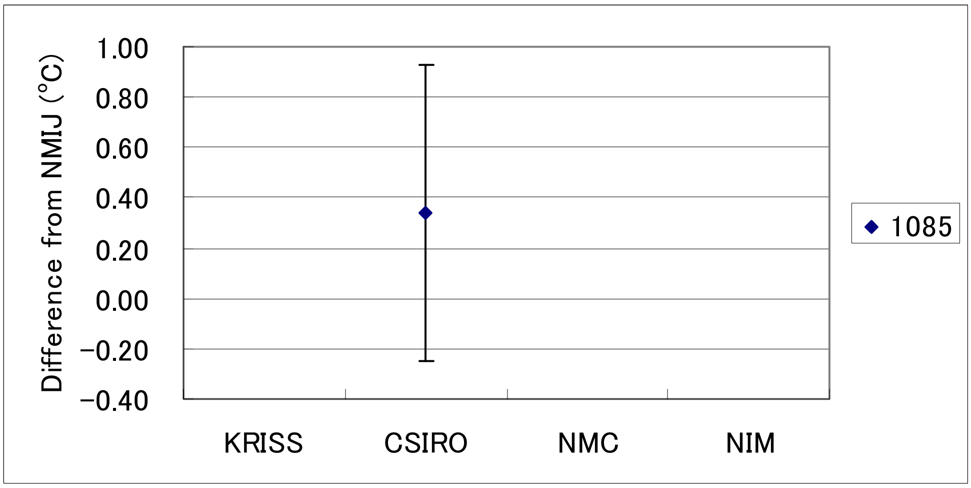
D6 Result at 900 °C



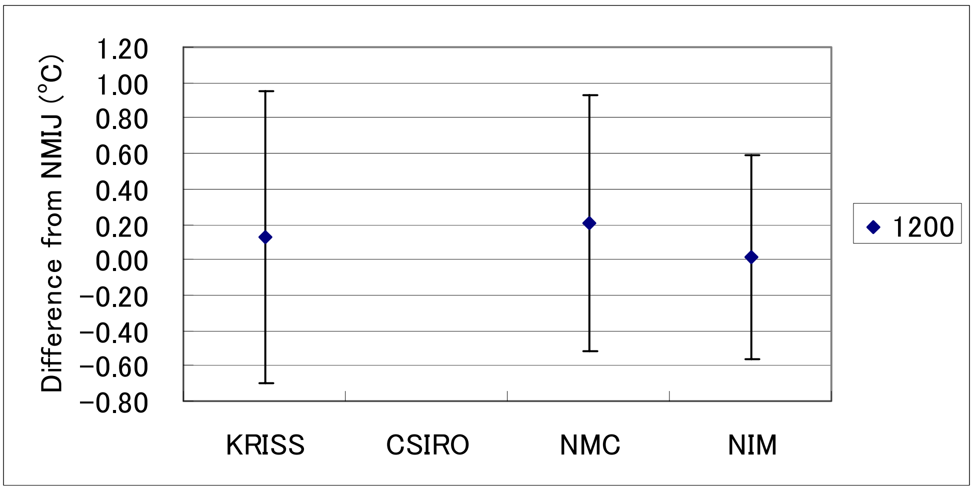
D7 Result at 1000 °C



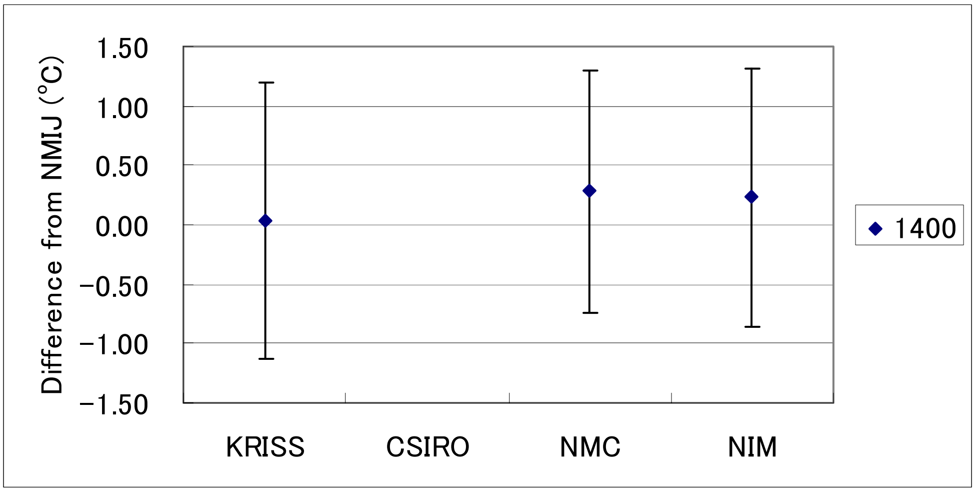
D8 Result at1085 °C



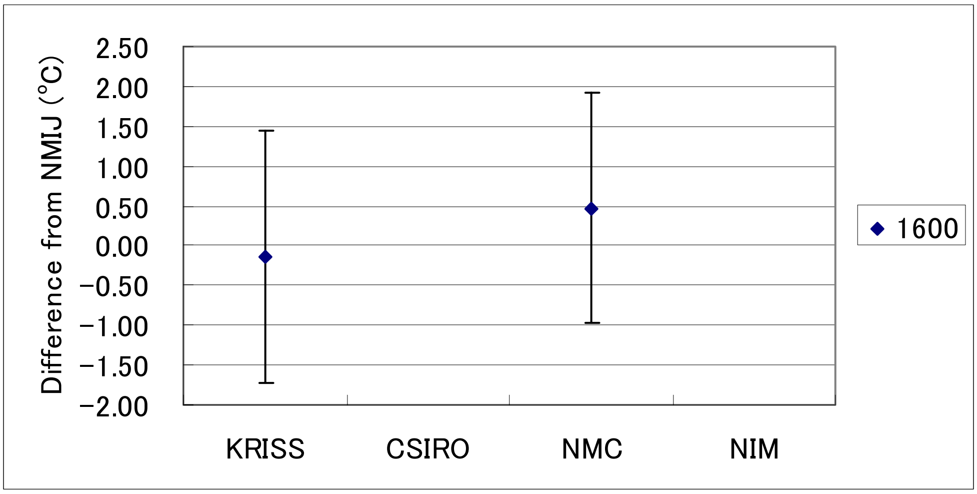
D9 Result at 1200 °C



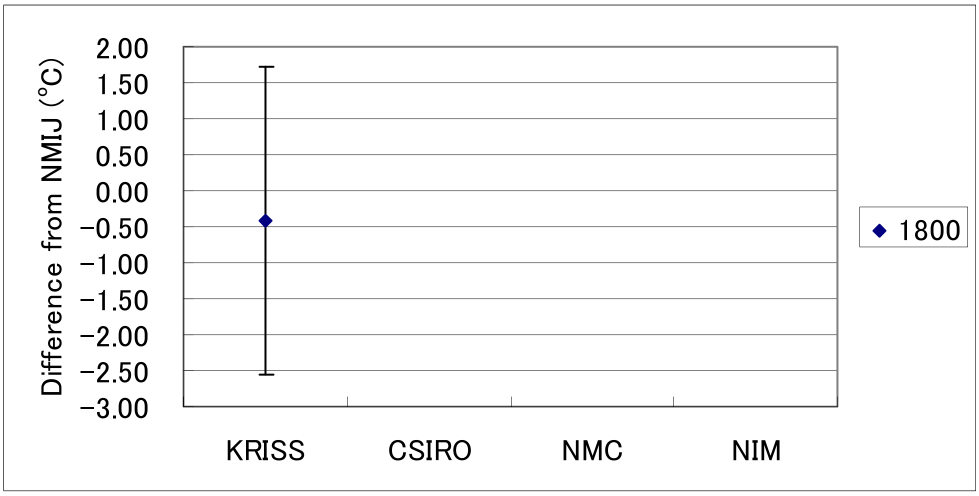
D10 Result at 1400 °C



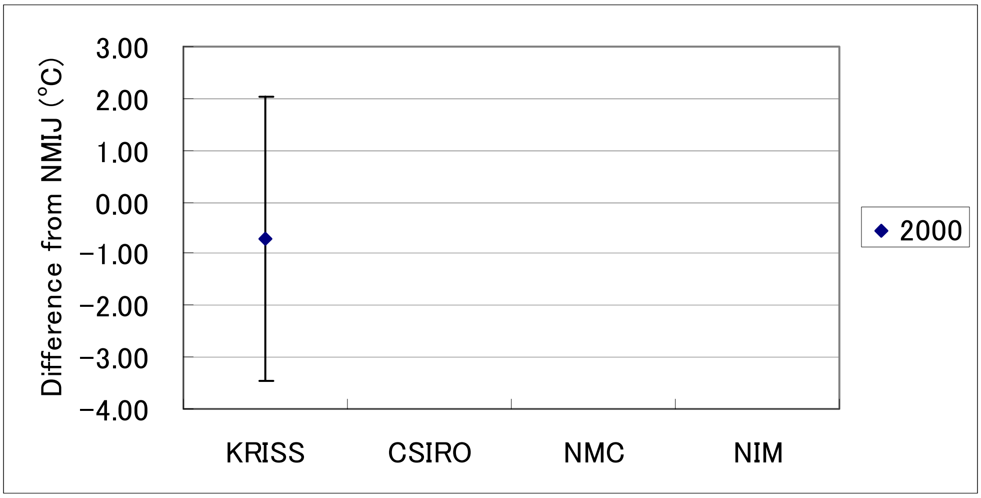
D11 Result at 1600 °C



D12 Result at 1800 °C



D13 Result at 2000 °C



Appendix E : Calculation of the APMP Key Comparison reference value

E1 Difference between KRISS and NMIJ

E2 Difference between NML/CSIRO and NMIJ

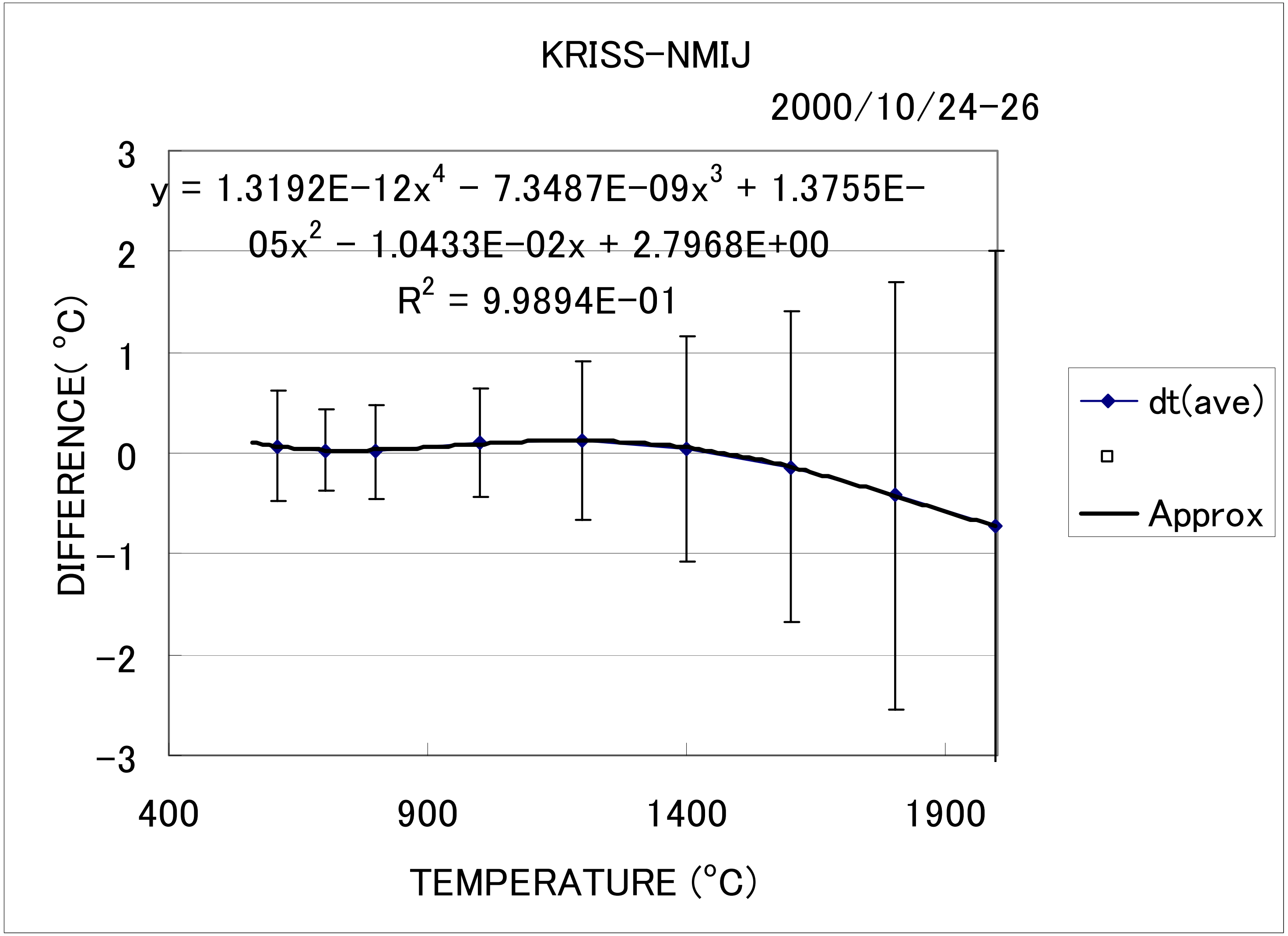
E3 Difference between NMC/SPRING and NMIJ

E4 Difference between NIM and NMIJ

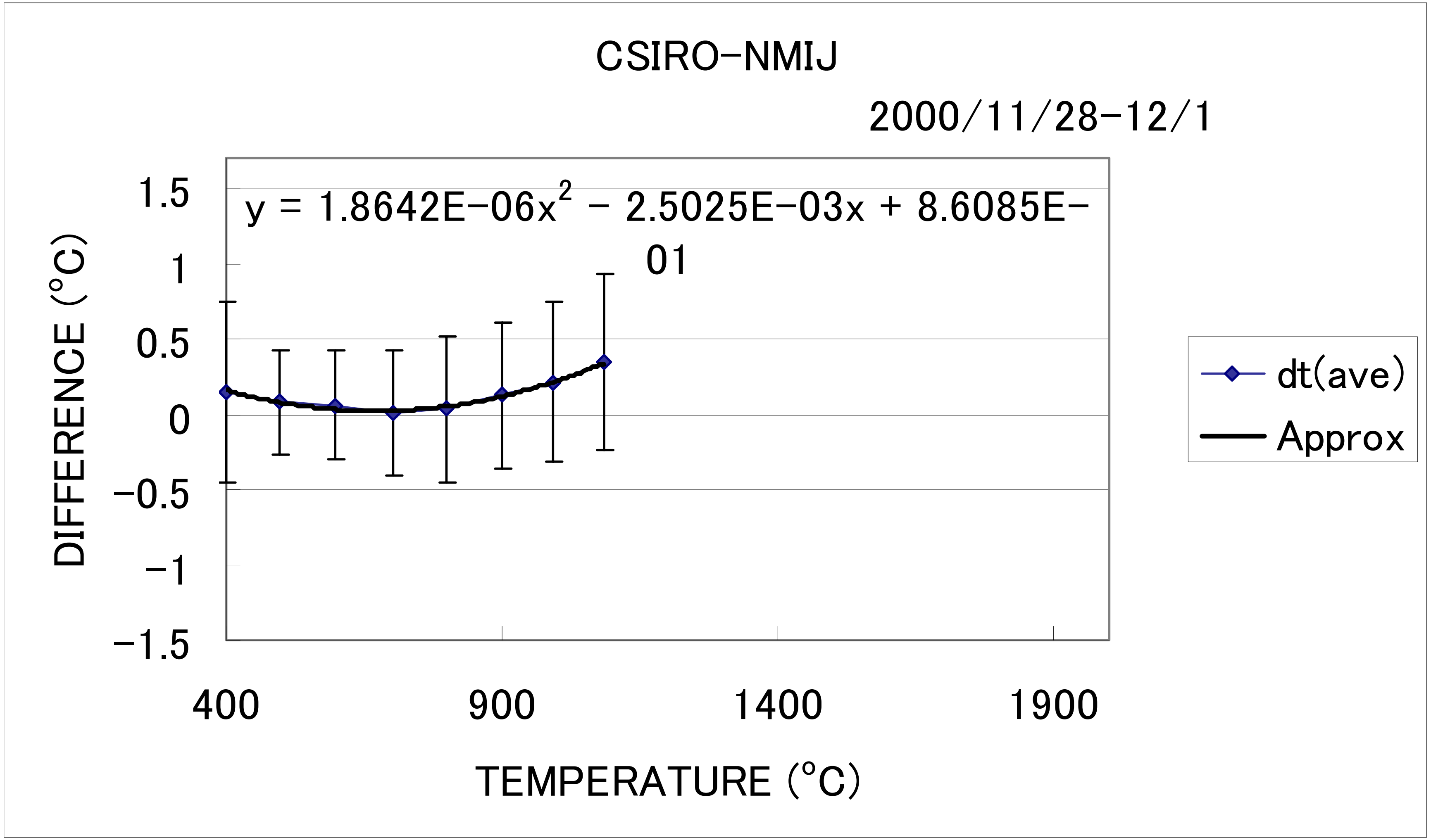
E5 Average of the difference

E6 Difference from APMP Average

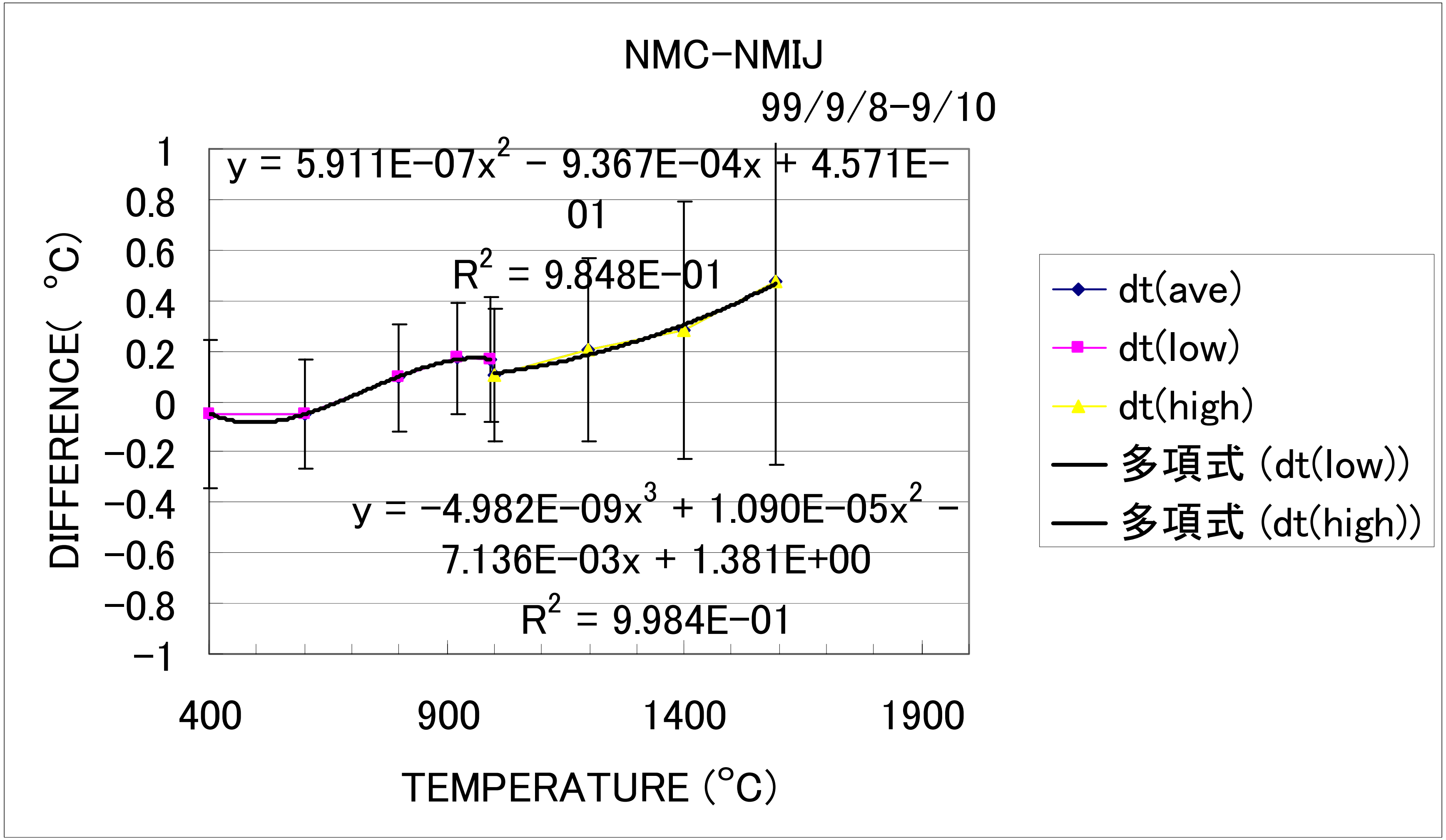
E1 Difference between KRISS and NMIJ



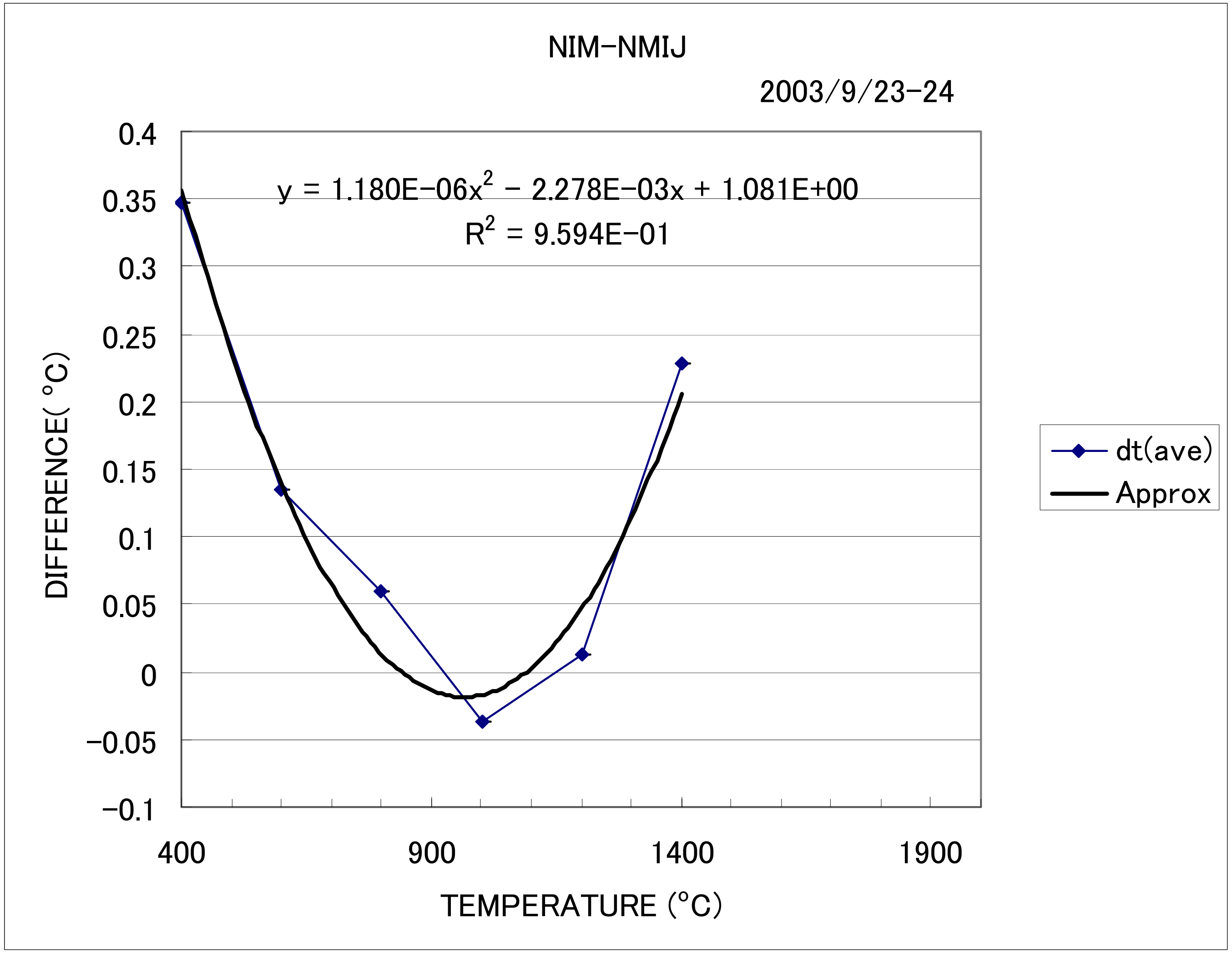
E2 Difference between NML/CSIRO and NMIJ



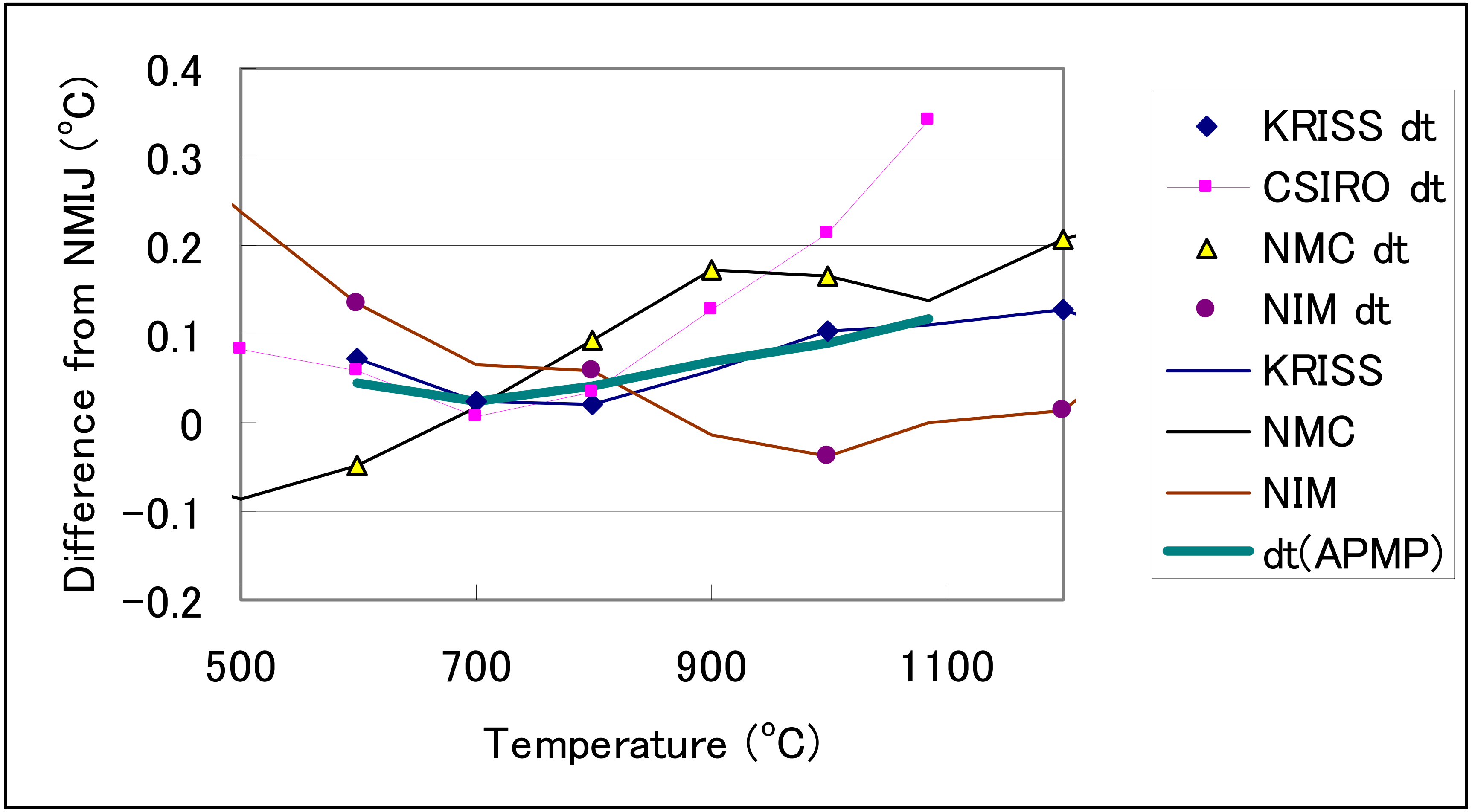
E3 Difference between NMC/SPRING and NMIJ



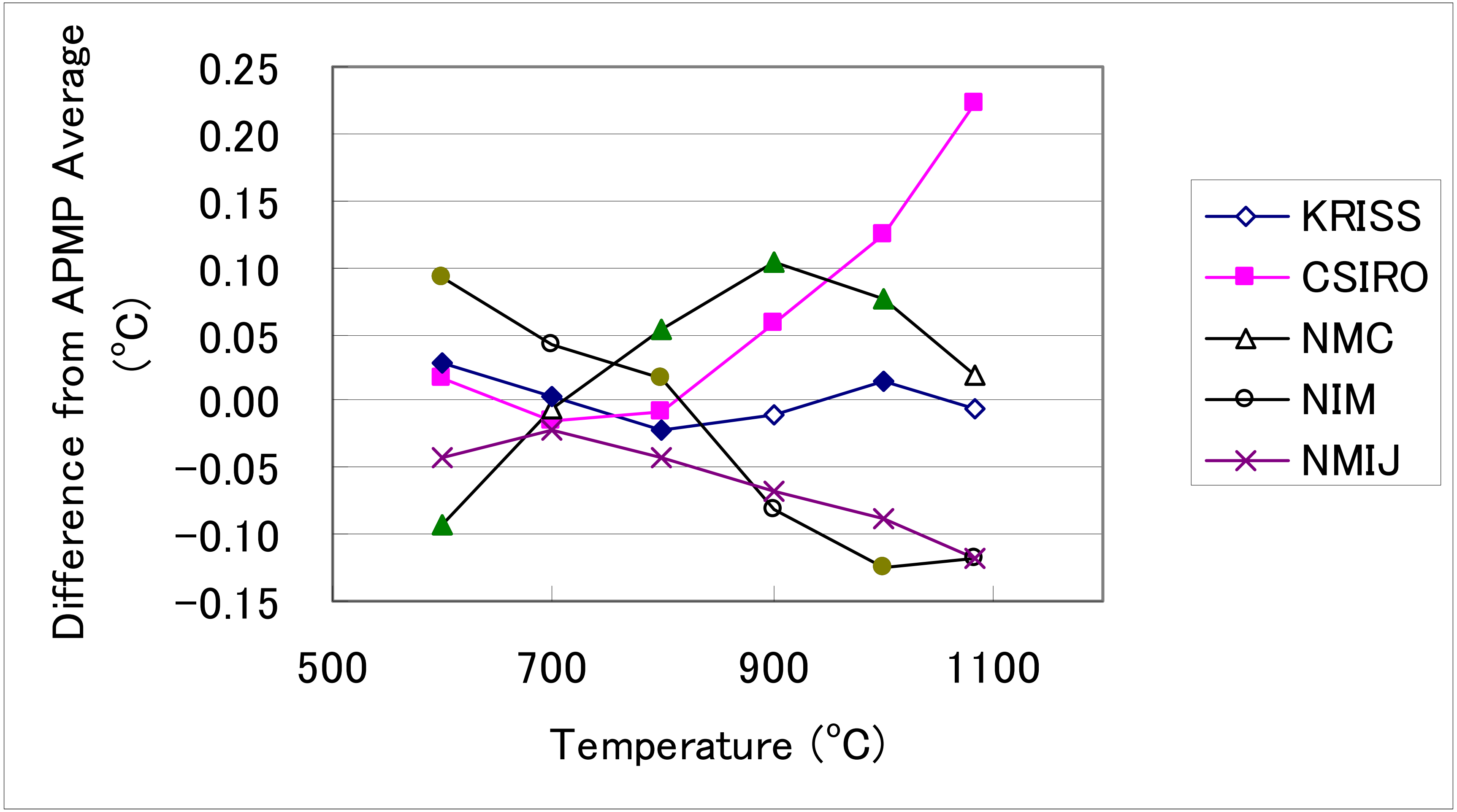
E4 Difference between NIM and NMIJ



E5 Average of the difference



E6 Difference from the APMP Average



Appendix F: APMP-Supplementary Comparison Protocol for Radiation Temperature Scale

APMP Protocol Draft of radiance temperature comparison in 900 nm

2002/05/24

NMIJ

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
   400ºC to 1600 (2000)ºC; defined by ITS-90
   Radiance temperature in 0.9 μm
3. Transfer Instrument
   The transfer instrument is a transportable radiation thermometer with an operational wavelength of 0.9 μm which will be provided by the pilot laboratory (NMIJ). The target size is about 3 mm in diameter at a distance of 40 cm. The output is a dc voltage. The spectral responsivity, non-linearity and size-of-source effect are measured by NMIJ.
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 NMIJ 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 NMIJ after comparison.
   [Type B]
   A radiation thermometrist of a participating laboratory picks up the transfer instrument at NMIJ and takes it with him/her (hand-carrying) to a participating lab. It is suggested for the radiation thermometrist to stay a NMIJ 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 NMIJ by hand-carrying within two 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; on 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 2000.

8. Anticipated Comparison Period

From April 2000 until June 2003.

9. Contact persons

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Director

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Temperature and Humidity Division

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Appendix G: APMP Intercomparison Details for Radiation Temperature Scale

APMP Intercomparison details of radiance temperature comparison in 900 nm

2002/05/24

In principle, a blackbody is used for comparison.

1. Measuring temperature point

Use possible points in below. Values without blanket are more recommended. The measuring temperature should be within ±10°C of the recommended set temperature.

400, (500,) 600, (700,) 800, (900,) 1000, (1100,) 1200, (1300,)
1400, (1500,) 1600, 1800, 2000 °C

2. The measurement is repeated five to seven times at each temperature to see the repeatability of measurement.

Each institute's and NMIJ's radiation thermometers alternately see the blackbody.

3. Measuring distance

50 cm to 100 cm for high temperature blackbody (above 1300°C)
corresponding to the target size of 4 to 8 mm diameter
40 cm to 60 cm for medium temperature (below 1300°C)
corresponding to the target size of 3 to 5 mm diameter

4. A set of measurement is repeated again on a different day

5. Measurement of the radiance distribution of the blackbody

horizontal and if possible vertical data at the low, mid and high temperatures

6. NMIJ 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. Draft uncertainty tables of the calibration of the radiation thermometers used 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. emissivity and transmittance
e. wavelength, if necessary
f. distribution, if necessary

9. What we request for NMIJ radiation thermometer at each institute is
a. Instrument

AC 100 V power source
two digital voltmeter: one good and the other so so
one tripod or stage for the comparison

b. Technical details

alignment to the blackbody and focusing
sufficient warming-up time
cleaning the objective lens before each run
check range setting at each temperature
avoid long illuminating at high temperature

10. Specifications of NMIJ Transfer standard radiation thermometer

a. Center wavelength	900 nm
b. Band width	80 nm
c. Temperature range	400°C to 2000°C
d. Measuring Distance	400 mm to infinity
e. Focal length	f=80 mm
f. Field angle	0.1°
g. Size of source effect	<1%
h. Resolution	<0.1°C at 420°C
i. Detector	S1336-5BK (Hamamatsu Photonics)
j. Ambient temperature detector	IC temperature sensor
k. Feedback resister of Amp.	100 MΩ, 10 MΩ, 1 MΩ, 100kΩ
l. Power source	AC 100 V ± 10%, 50/60 Hz
m. Temperature coefficient	less than ±0.24%/°C

n. Size	320 mm (L), 80 mm (W), 160 mm (H)
o. Screw for tripod	1/4 inch

11. Calibration of transfer radiation thermometer by NMIJ

a. Gain ratio

10/1, 0.1/1, 0.01/1, 0.001/1

b. Ambient temperature coefficient of Silicon detector

21 C to 25 C

c. Fixed point calibration

Cu, Ag, Al and Zn points for temperature 400 C to 1085 C.

d. Spectral responsivity measurement

Compared to a thermopile with 0.2 nm resolution at the center, 1 nm resolution at the middle and 10 nm resolution in the wing.

e. Nonlinearity measurement

Two aperture method.

f. Size of source effect measurement

At distances of 500 mm, 750 mm and 1000 mm. Blackspot of 6 mm diameter and aperture of 18 mm to 140 mm in diameter.

g. Distance effect measurement

Using apertures of 6 mm, 12 mm and 25 mm in diameter and moving from 400 mm to 900 mm.

h. Reproducibility of scales

Compare with the scale of another 900 nm radiation thermometer similarly calibrated. Comparison is made using blackbodies at temperatures 500, 600, 800, 1000, 1200, 1400, 1600, 1800 and 2000 C.

Note that Fixed point calibration and spectral responsivity measurement will be carried out at NMIJ before and after the transport

Extra information

* Output characteristics

The output voltage V of Topcon at temperature T can be expressed by the following equation for the gain 1:

$V(T)= C/\{\exp(c2/(AT+B)-1)$

Here A, B and C are constants to be determined by three or more calibration points and $c2$ is the second constant of radiation.

$c2$=0.014388 m K

From the measured output voltage $Vraw$, at first the correction for the zero offset $V0$ is made.

$Vst=Vraw-V0$

$V0$ is measured before and after the target measurement. Then the gain G and ambient temperature tam are corrected for. The ambient temperature is calculated from the IC temperature output Vic as follows

$tam=(Vic-a)/b+20$

a=-5.3172 mV

b=6.84349 mV/°C

for Topcon 148.

$Vs= Vst/ G /[1+alpha(tam-23)]$

$alpha$=-0.012%/°C

for Topcon 148.

Finally the radiance temperature t [°C] is calculated as follows.

$t=c2/A/\ln(C/Vs+1)-B/A-273.15$

Appendix H: Questionnaires

Questionnaires

1. Blackbody

1.1 Manufacturer and type

1.2 Temperature range

1.3 Aperture diameter

1.4 Distance from the bottom to the aperture (Figure)

1.5 Temperature stability (in 10 minutes)

1.6 Temperature distribution

1.7 Cavity material

1.8 Window

1.9 Warm-up time

1.10 Emissivity

2. Radiation thermometer

2.1 Manufacturer and type

2.2 Temperature range

2.3 Measuring distance from the objective

2.4 Target size

2.5 Aperture ratio (target size/distance)

2.6 Calibration method

2.7 Uncertainty of scale (Table)

2.8 Wavelength center and band width

2.9 Resolution

2.10 Size of Source effect

2.11 Detector

2.12 Feedback resistance for amplifier

2.13 Linearity

2.14 Telescope for alignment

2.15 Stability

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, address, 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)