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Thermometry

APMP. T-S15

Comparison of blackbody for clinical infrared ear thermometers

Final version

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1. Introduction

Under the Mutual Recognition Agreement (MRA) the metrological equivalence of national measurement standards is determined by a set of comparison chosen and organized by the Consultative Committees of the CIPM working closely with the Regional Metrology Organizations (RMOs).

Infrared ear thermometer (IRET) is an instrument, which measures temperature of a human body. Despite all problems reported in the literature, more and more such thermometers are used not only in medical practice but also in home use. Therefore, they shall meet certain requirements. Essential requirement is related to accuracy. There are several standards in the world, which describe requirements for IRETs. In the EU this is the standard EN 12470-5, which is a harmonized standard and supports the Medical Device Directive (MDD). Other standards are ASTM standard, Designation E 1965 - 98 and the Japan Industrial Standard. The basic requirement for accuracy in EN 12470-5 is that the maximum permissible error of an IRET is ± 0.2 °C in the range from 35.5 °C to 42.0 °C. The International Organization for Standardization (ISO) is developing a new standard for clinical thermometers, which will include also IRETs. To verify the accuracy of an IRET a suitable blackbody is needed.

At the APMP meeting in December 2003 in Singapore, the Technical Committee for Thermometry (TCT) decided to carry out a supplementary comparison of blackbodies for clinical infrared ear thermometers, which was designated as APMP. T-S15. The pilot lab was changed from NMIJ (Japan) to NMISA (South Africa), and to NIM (China) finally, because of the unpredictable reasons. The protocol was approved on 20th June 2017. All the measurements were performed between 1st Aug. 2017 and 18th Mar. 2020.

The objective of APMP. T-S15 comparison was intended to assess and verify the calibration capabilities of participating NMIs in the field of clinical infrared thermometry by determining the radiance temperature of an unknown ear-thermometer blackbody. The temperature range was from 35ºC to 42 ºC. This includes:

1. The contact thermometry techniques and standards used to determine the reference bath temperature.
2. The emissivity and temperature uniformity of reference blackbody cavity.
3. The radiance temperature scale realized by the reference blackbody.
4. The techniques used to determine the infrared radiance temperature difference between the reference and unknown blackbody.

To reach the above objectives, the pilot laboratory (NIM) sent a travelling ear thermometer blackbody to each participating laboratory, where the standard blackbody of the participant was compared using the measurement technique employed by the participant laboratory. The outcome of the comparison can be utilized in establishing new CMC entries from APMP NMIs for the BIPM KCDB Appendix C. The comparison was conducted as an APMP comparison, and therefore the participants were either

APMP members or APMP associate members.

2 Participant laboratories

Nine NMIs were participating in the comparison including the pilot.

Table 1 Contact person and address of participating NMIs

	NMI	Contact person(s)	Address
Pilot	NIM (China)	Dr. Xiaofeng Lu, Ms. Chengyu Bai luxf@nim.ac.cn, baichy@nim.ac.cn	No. 18 Bei San Huan Dong Lu Beijing, 100029 China
Participants	CMS/ITRI (Chinese Taipei)	Mrs. Hsin-yi, Ko Shelley_Ko@itri.org.tw	CMS/ITRI, Rm.300, Bldg. 16, 3F, 321, Sec. 2, Kuang Fu Rd., Hsinchu, 30011,Taiwan, R.O.C.
	NMIJ/AIST (Japan)	Dr. Naohiko Sasajima n.sasajima@aist.go.jp	AIST Tsukuba Central 3, 1-1-1 Umezono, Tsukuba Ibaraki 305-8563, Japan
	SNSU-BSN (RCM LIPI) (Indonesia)	Hidayat Wiriadinata hidayatwr@yahoo.com	Pusat Metrologi LIPI, Kompleks PUSPIPTEK Gedung 420 Setu, Tangerang Selatan, Indonesia 15314
	KRISS (Republic of Korea)	Dr. Yong Shim Yoo ysyoo@kriss.re.kr	267 Gajeong-Ro, Yuseong-Gu, Daejeon 305-340, Korea
	NIMT (Thailand)	Dr. Athikom Manoi athikom@nimt.or.th	3/4-5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120，Thailand
	NMC , A*STAR (Singapore)	Mr Goh Choon Heng, Dr. Wang Li goh_choon_heng@nmc.a-star.edu.sg, wang_li@nmc.a-star.edu.sg	8 CleanTech Loop Unit 01-20 Singapore 637145
	NMIM (Malaysia)	Mrs. Hafidzah Othman, Nafra Mohamad Samiudin hafidzah@sirim.my, nafra@sirim.my	Lot Pt 4803, Bandar Baru Salak Tinggi, 43900 Sepang, Selangor, Malaysia.
	SCL (Hong Kong)	Mr. Julian Cheung cpcheung@itc.gov.hk	36/F, Immigration Tower, 7 Gloucester Road, Wan Chai, Hong Kong

3 Comparison Pattern

The comparison of the ear-thermometer blackbody sources was conducted as a STAR type and consisted of the following phases:

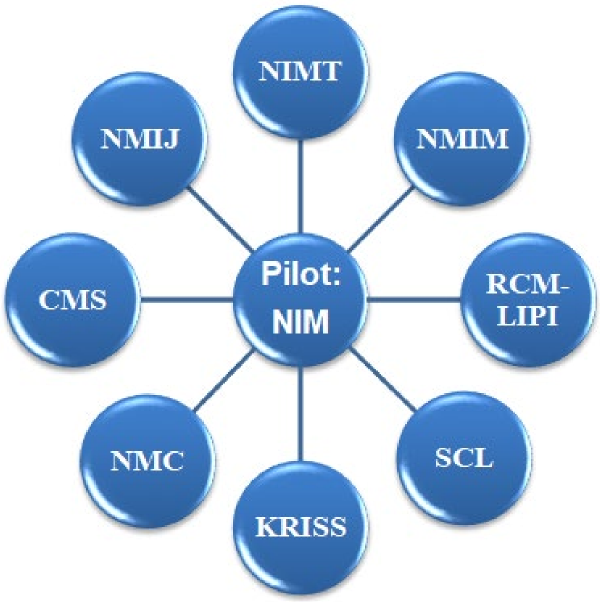


Fig.1 Organization of comparison

- The pilot laboratory selected an ear thermometer blackbody and assessed its performance and suitability as the travelling standard. The pilot laboratory compared this travelling blackbody against his own ear thermometer blackbody standard, to get the relationship between the radiance temperature and the monitor PRT.

- The blackbody was transported to one participant, who made his own measurements on the travelling blackbody. Then the travelling blackbody was returned to the pilot laboratory, which again compared this travelling blackbody against the pilot's standard.

- Repeat the above step and sequence until all the participants completed the same measurements on the travelling blackbody.

- The pilot laboratory assessed the travelling blackbody performance again after all the comparison measurements were completed.

All the dates of the measurements of the participant NMIs and the pilot lab are shown in Table 2.

Table 2 Measurement date of all the comparison measurements

NMI	Measurement date	Report submitted date
NIM	1 Aug. 2017 ~ 2 Aug. 2017	
NIMT	8 Sep. 2017 ~ 10 Sep. 2017	28 Jul. 2018
NIM	9 Nov. 2017 ~ 13 Nov. 2017	
NMIM	28 Dec. 2017 ~ 9 Jan. 2018	19 Nov. 2018

NIM	26 Jan. 2018 ~ 30 Jan. 2018	
CMS /ITRI	7 Mar. 2018 ~ 13 Mar. 2018	2 Jan. 2020
NIM	17 May 2018 ~ 21 May 2018	
NMC, A*STAR	18 Jul. 2018 ~ 20 Jul. 2018	15 Nov. 2019
NIM	17 Aug. 2018 ~ 28 Aug. 2018	
NIM*	17 Sep. 2018 ~ 19 Sep. 2018	
SCL	19 Oct. 2018 ~ 23 Oct. 2018	1 Nov. 2018
NIM	12 Nov. 2018 ~ 14 Nov. 2018	
KRISS	14 Jan. 2019 ~ 16 Jan. 2019	14 Nov. 2020
NIM	18 Feb. 2019 ~ 20 Feb. 2019	
NIM**	2 Jul. 2019 ~ 3 Jul. 2019	
SNSU-BSN (RCM LIPI)	6 Aug. 2019 ~ 8 Aug. 2019	26 Jun. 2020
NIM	12 Nov. 219 ~ 14 Nov. 2019	
NMIJ/AIST	18 Dec. 2019 ~ 20 Dec. 2019	1 Apr. 2021
NIM	16 Mar. 2020 ~ 18 Mar. 2020	

*The monitor PRT was taken out to be calibrated after one-year circulation. After calibration, the PRT was installed and sealed into the traveling standard again.

**There was a long delay waiting the next participant NMI preparation, a repeat calibration was carried out before the blackbody was sent to the next participant.

4. Travelling standard

The design of the travelling blackbody provided by the pilot (NIM) was a simple blackbody radiator. The blackbody operated in the temperature range from 35°C to 42 °C. The shape of the blackbody cavity was cylinder-conical with a circular aperture 10 mm in diameter, made of copper and shown in Fig.2. A reference thermistor sensor was placed at a position close to the bottom of the cavity to control the temperature. There was a 6.5 mm well which allows another precise PRT to monitor the temperature of blackbody. In the comparison, the PRT was used to monitor the stability and indicate the temperature of the travelling blackbody, and it was sealed to avoid being taken out. The technical specification for the instruments is given in the following Table 3.

Table 3 Specifications for travelling standard: Ear-thermometer blackbody

Model /Serial No.	305-L/20141016
Temperature range	35 °C ~ 42 °C
Aperture of blackbody	10 mm

Effective emissivity	Higher than 0.999
Stability	0.005 °C
Homogeneity	0.007 °C
Control sensor	Thermistor
Power supply	100 to 240 VAC
Mass	Approx. 10 kg
Outer dimensions	240 mm (w) × 100 mm (h) × 370 mm (d)

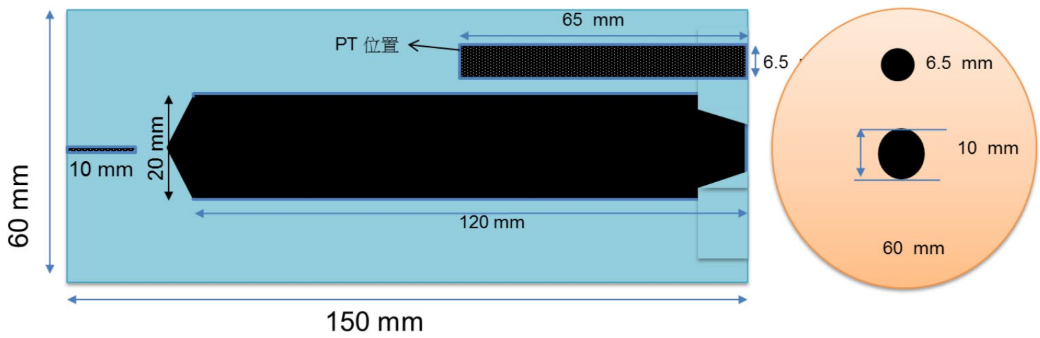


Fig.2 The design of the cavity for the ear thermometer blackbody

5. Equipment and measuring conditions at participating laboratories

The participant NMI calibrated the travelling blackbody by comparison against his own reference standard blackbody according to his local calibration protocol for the ear thermometer blackbody. The comparators must be ear thermometers which should satisfy the conditions (resolution less than 0.1 °C, repeatability better than 0.1 °C/10 times etc.) in chapter 6.1 of APMP T.S-15 comparison protocol. The calibration must be made at the following temperatures: 35.5 °C, 37.0 °C and 41.5 °C. At each temperature, the resistance of the monitor PRT, the indicated temperature on the screen of the traveling blackbody, and the determined radiance temperature of the travelling blackbody were recorded. The number of days of measurement were altered according to the local calibration protocol that was applied.

All labs carried out the measurements for the travelling blackbody in the sequence from 41.5 °C to 35.5 °C, except for NMIM and SNSU-BSN in the reverse. Although in the protocol it was suggested that the travelling blackbody was calibrated from high to low temperature, this was only to shorten the stability time from one temperature to the next temperature point. There was no difference in the measurements, the only requirement was that the travelling blackbody was sufficiently stable in temperature.

Detailed description of standard equipment for ear thermometer comparison and transfer ear thermometers at participating NMIs are listed in Table 4.

Table 4 Detailed description of reference standard equipment at participant NMIs

NMI	Cavity Standard	Resistance Thermometer	Bridge	IRET model	IRET numbers
NIM	CN	SPRT	Fluke 1594A	MicroLife IR1DF1 UEBE 0870 & CITIZEN CT810	6
NIMT	JIS	SPRT	Fluke 1595A	Braun IRT 4520	3
NMIM	EN	PT100	ASL F200	Braun IRT6520 & Pro4000	2
CMS/ITRI	ASTM	SPRT	Fluke 1594A	Genius	1
NMC, A*STAR	JIS	SPRT	ASL F700	Braun IRT 6020 & Pro 6000	2
SCL	EN	SPRT	ASL F17A	Braun ThermoScan 7	2
KRISS	JIS	SPRT	ASL F700A	Microlife IR150	3
SNSU-BSN	JIS	PT100	Hart 1575A	Microlife AG 9443	1
NMIJ	JIS	PRT	Fluke 1594A	Citizen Watch CT-810	3

6. Measurement results

In the 6.5 mm well of the blackbody, the precise PRT was used to monitor the stability and indicate the temperature of the travelling blackbody. During the whole comparison period, the PRT was calibrated at triple point of water (TPW), gallium (Ga) and indium (In) fixed points several times by the pilot to check its stability. The calibration results of the PRT are shown in Table 5.

Table 5 Calibration results of Monitor PRT in the travelling blackbody

	1-Apr-2016	12-Jan-17	31-Aug-18	19-Mar-20
R_{TP}/Ω	25.5848	25.5852	25.5856	25.5860
W_{In}	1.60957	1.60956	1.60957	
W_{Ga}	1.118094	1.118092	1.118093	1.118090
a10	-0.00038	-0.00040	-0.00039	

The monitor PRT drift is illustrated in Figs. 3 and 4.

In Fig.3, the drift of the monitor PRT was observed about unidirectional 5 mK per year at TPW. While, the resistance ratio between Ga/In fixed points and TPW (W_{Ga} /W_{In}) was stable. The conversion temperature drift of the PRT was derived as unidirectional and about 5 mK per year either.

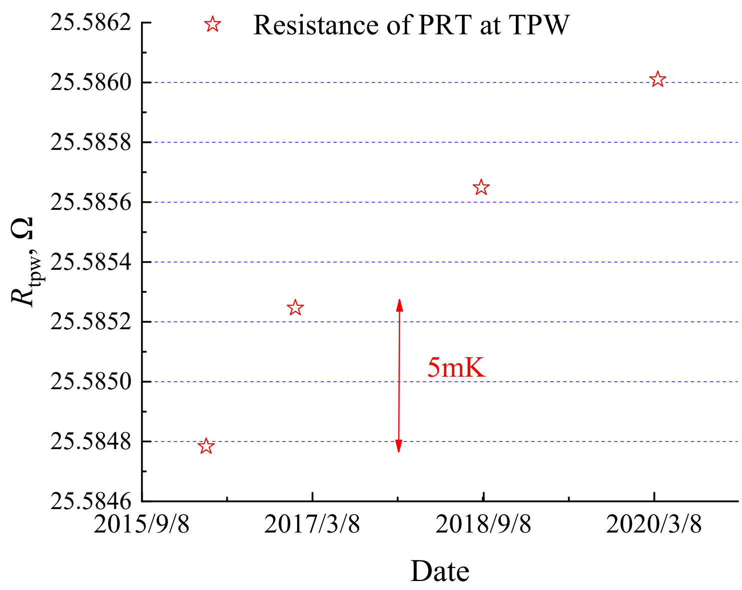


Fig.3 Resistance drift of monitor PRT at TPW

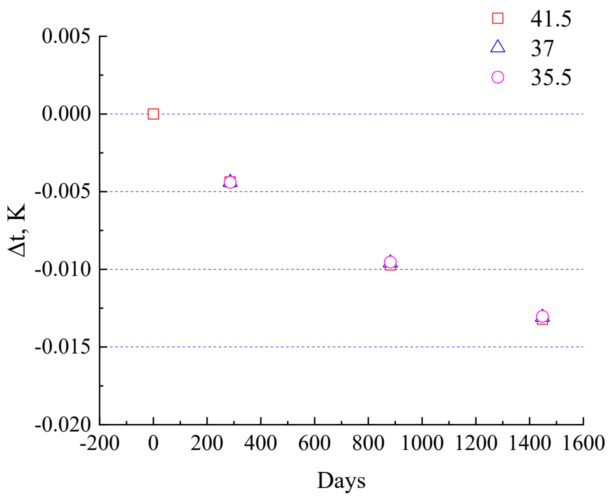


Fig.4 Conversion temperature drift of monitor PRT from 35.5 ºC to 41.5 ºC with measurement days

In Fig4. the first calibration date (1st Apr. 2016) was assumed as the first day (1) of the comparison and the interval days away from the first day were used as the X axis parameter for the drift correction. The drift correction can be easily made using a simulated polynomial line through the data points along with the interval days. The uncertainty of drift correction was estimated as no more than 5 mK.

The radiance temperature and the monitor PRT temperature with drift correction for the travelling blackbody measured at the pilot lab (NIM) is shown in Fig.5, Fig.6 and Fig.7 for 35.5 °C, 37.0 °C and 41.5 °C separately. In the results, most of the discrepancy between the radiance temperature and monitor temperature is within 20 mK to 40 mK, which is assumed to be the repeatability of measurement.

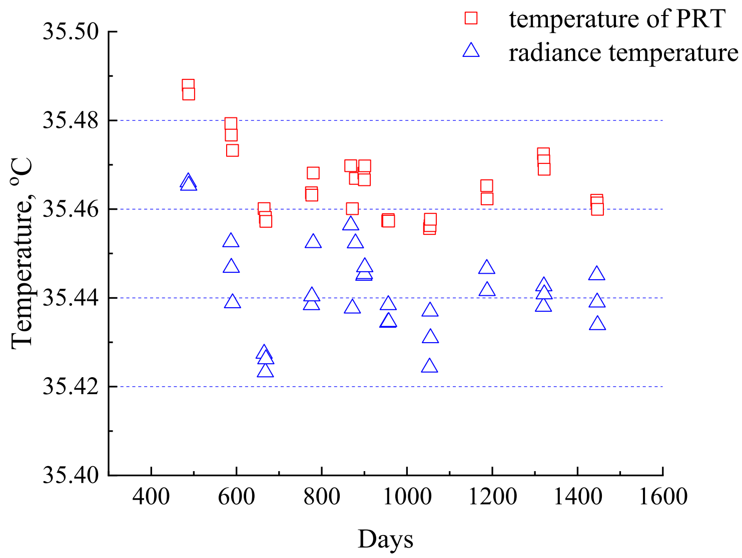


Fig.5 The radiance and monitor PRT temperature of the travelling blackbody at 35.5 °C measured at NIM

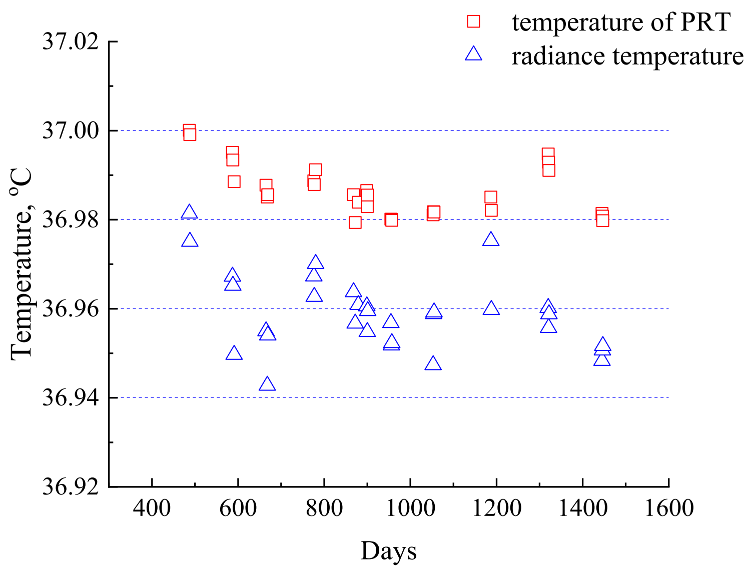


Fig.6 The radiance and monitor PRT temperature of the travelling blackbody at 37.0 °C measured at NIM

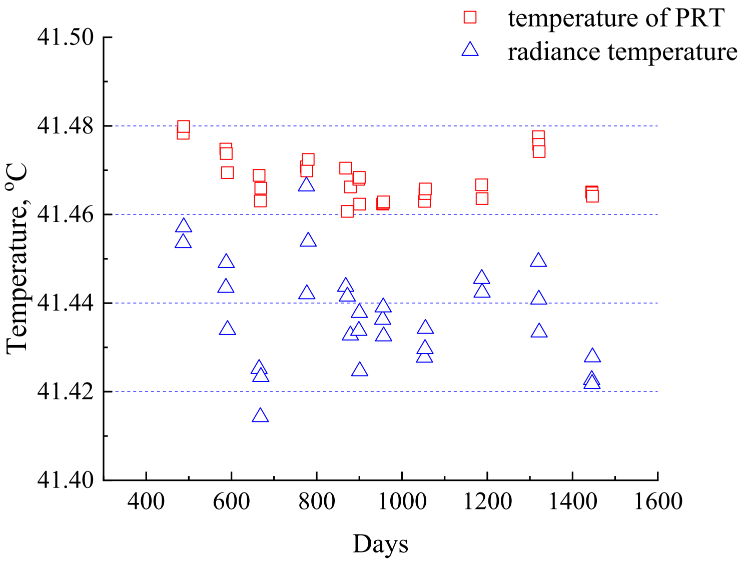


Fig.7 The radiance and monitor PRT temperature of the travelling blackbody at 41.5 °C measured at NIM

The environmental temperature could affect the thermal conduction of the monitor PRT and the radiance temperature of the blackbody due to its emissivity. Since the emissivity of the blackbodies were all higher than 0.999, the influence of the environmental temperature on radiance temperature could be ignored within emissivity correction.

After the wire of the monitor PRT coiled into the 6.5 mm well, the heat leakage was greatly decreased. According to the measurement results at NIM, shown in Fig.8, the difference between the radiance and PRT temperatures showed a slight dependence on the environmental temperature, especially when the environmental temperature was below 20 °C. We did not correct for the effect of the environmental temperature. Since the environmental temperature of the participant NMI was between about 20 °C and 26 °C, the uncertainty from environmental temperature effect was estimated as the standard deviation, which was 6 mK, 7 mK and 9 mK for 35.5 °C, 37.0 °C and 41.5 °C points respectively.

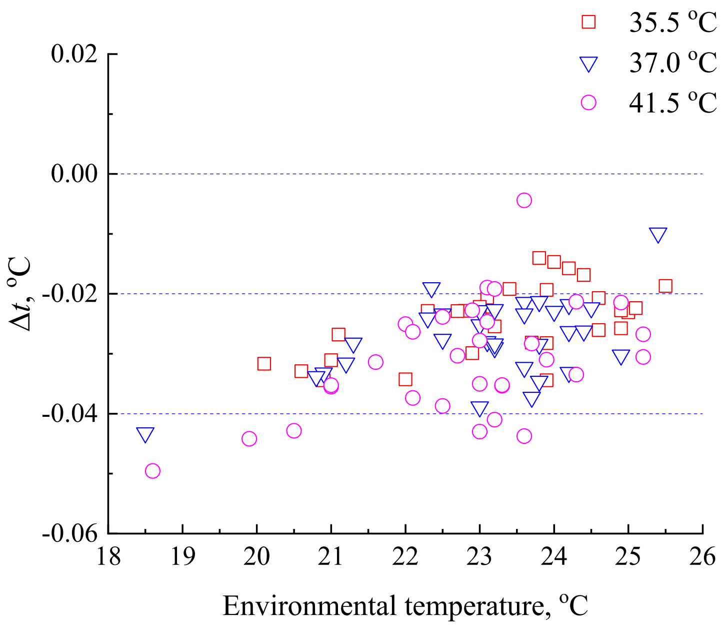


Fig.8 The environmental temperature effect for the discrepancy of the radiance and monitor PRT temperature measured at NIM

For the participant NMIs, the original report results and estimated uncertainty are listed in Appendix B. The temperature of the blackbody, from the reading of the monitor PRT after correction for drift, and the radiance temperature measured at the participant NMIs are shown in Fig.9, Fig.10 and Fig.11 separately. The drift correction of the PRT was done simply estimated from the polynomial of the fit from the data shown in Fig.4. Only one participant measurement of the monitor PRT resistance is obviously biased from others, two participants' measurement of radiance temperature are also observed offset from the average values.

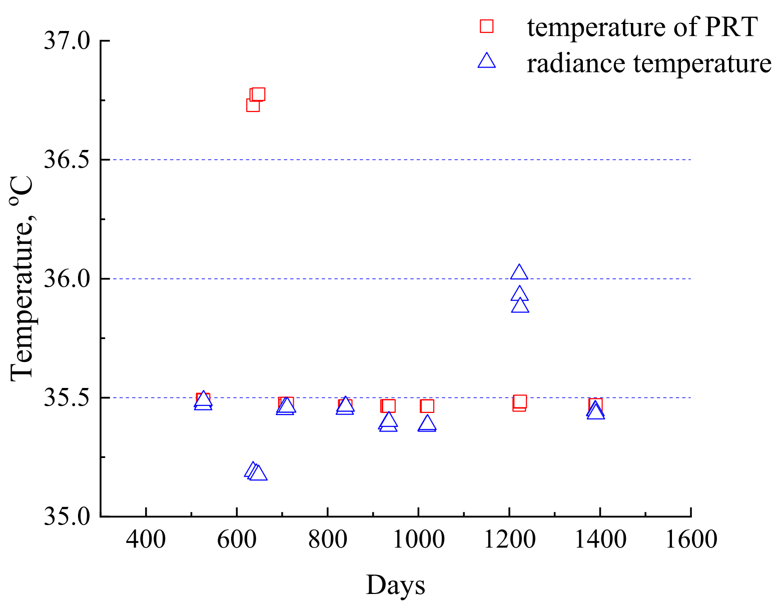


Fig.9 The radiance and monitor PRT temperature of the travelling blackbody at 35.5 ºC measured at participant NMIs excluding pilot lab

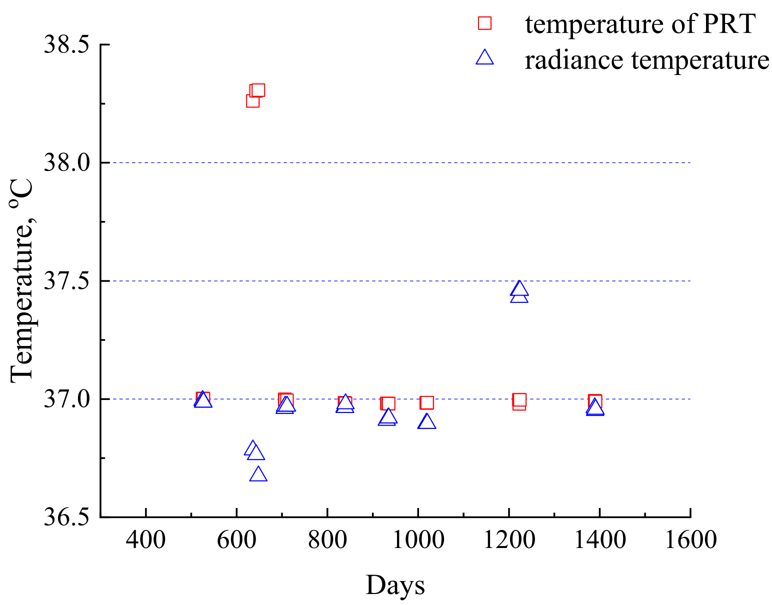


Fig.10 The radiance and monitor PRT temperature of the travelling blackbody at 37.0 ºC measured at participant NMIs excluding pilot lab

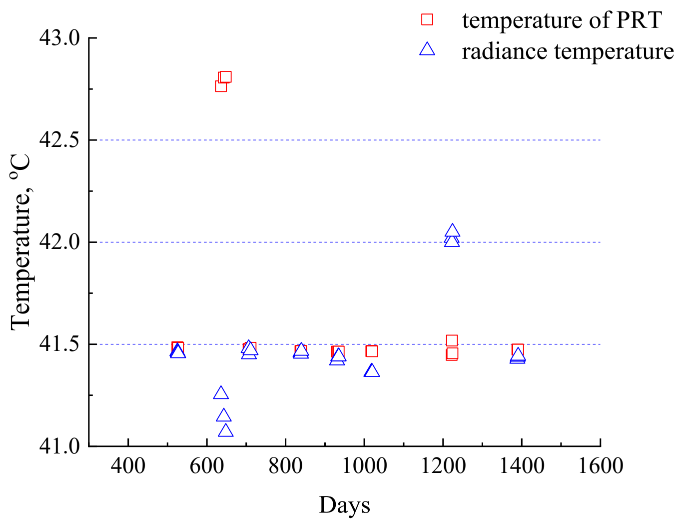


Fig.11 The radiance and monitor PRT temperature of the travelling blackbody at 41.5 ºC measured at participant NMIs excluding pilot lab

7. Analysis of the results

In general, the results show good agreement between the blackbodies for calibration of IRETs at the majority of participating NMIs. The ISO standard for clinical thermometers (IEC ISO 80601-2-56, Medical electrical equipment — Part 2-56:

Particular requirements for basic safety and essential performance of clinical thermometers for body temperature measurement) states that the BB used for laboratory calibration of IRETs must have an uncertainty of no greater than 0.07 °C (k = 2). The comparison results show that the majority of the BBs agree within the requirements of the standard, especially taking into account the comparison measurement uncertainties, such as the repeatability of the measurements, the long-term stability and placement of the ear thermometer comparator within the blackbody aperture etc.

The uncertainty from the travelling blackbody should be estimated independently. Except the uncertainty from the comparison process, which was already considered in the participant NMIs, the uncertainty sources from the stability correction of monitor PRT and the environment temperature effect are analyzed in the Table 6. The emissivity drift of travelling blackbody was estimated by the discrepancy between the radiance temperature and monitor PRT temperature from only the pilot data. Although there was a needle-size piece of coating peeling observed, there was not much difference in the discrepancy between the radiance temperature and monitor PRT temperature at pilot lab. Here the emissivity drift is ignored finally.

Table 6 Uncertainty of travelling blackbody, ºC

Source of uncertainty	35.500	37.000	41.500
Drift correction of monitor PRT	0.005	0.005	0.005
Environment temperature effect	0.0058	0.0066	0.0095
Combined uncertainty	0.0078	0.0086	0.0103

The participant results being referred to are the Δt values (differences between the radiance and PRT temperatures). The results and estimated uncertainties of the participant measurements are given in Table 7. As in the comparison protocol, the results of the pilot laboratory measurements over the entire period of the comparison is averaged for each nominal indicated temperature (t_{nom}), after correcting the drift of the PRT thermometer, to give one pilot result for each t_{nom}. The final uncertainty associated with the pilot results included the standard deviation of the pilot measurements (after correction of results for any drift). The participant reports in Appendix B where more information can be found about the components that are included in the uncertainty budgets.

Table 7 Comparison results of discrepancy between the radiance and PRT temperature, ºC

NMIs	Setting temperature	Δt (Radiance - PRT)	Uncertainty k=2
NIM	35.500	**-0.024**	**0.041**
NIMT	35.500	**-0.010**	**0.042**
NMIM	35.500	**-1.577**	**0.993**

CMS	35.500	**-0.016**	**0.050**
NMC	35.500	**-0.004**	**0.040**
SCL	35.500	**-0.075**	**0.100**
KRISS	35.500	**-0.081**	**0.044**
BSN	35.500	**0.465**	**0.149**
NMIJ	35.500	**-0.027**	**0.030**

NMIs	Setting temperature	Δt (Radiance - PRT)	Uncertainty k=2
NIM	37.000	**-0.027**	**0.041**
NIMT	37.000	**-0.012**	**0.042**
NMIM	37.000	**-1.549**	**0.950**
CMS	37.000	**-0.029**	**0.060**
NMC	37.000	**-0.013**	**0.040**
SCL	37.000	**-0.064**	**0.100**
KRISS	37.000	**-0.087**	**0.042**
BSN	37.000	**0.459**	**0.149**
NMIJ	37.000	**-0.034**	**0.030**

NMIs	Setting temperature	Δt (Radiance - PRT)	Uncertainty k=2
NIM	41.500	**-0.031**	**0.043**
NIMT	41.500	**-0.023**	**0.042**
NMIM	41.500	**-1.636**	**0.972**
CMS	41.500	**-0.011**	**0.090**
NMC	41.500	**-0.007**	**0.040**
SCL	41.500	**-0.030**	**0.102**
KRISS	41.500	**-0.102**	**0.044**
BSN	41.500	**0.550**	**0.150**
NMIJ	41.500	**-0.037**	**0.040**

The reference value (SCRV) is calculated for each t_{nom} using the weighted mean with cut-off of all the participant results, including the average pilot results, at that t_{nom}. The average of the 5 smallest values of uncertainty is adopted as the cut-off value, which is 0.039 ºC, 0.039 ºC and 0.042 ºC for 35.5 ºC, 37.0 ºC and 41.5 ºC respectively. The weight for each participant, including the pilot, was the inverse of the square of the standard measurement uncertainty for that participant at that t_{nom}. If participant's claimed uncertainty was lower than the cut-off value, the cut-off value was used as the weight for the participant. The weighted mean, y, is calculated according to Equation (1):

$$y = \frac{x_1/u^2(x_1) + \cdots + x_N/u^2(x_N)}{1/u^2(x_1) + \cdots + 1/u^2(x_N)} \quad (1)$$

where x_1 through to x_N are the results from participants 1 through N and u (x_1) through to u (x_N) are the associated standard uncertainties for participants 1 through N with cut-off. The standard deviation $u(y)$ associated with y is calculated according to Equation (2) with cut-off either:

$$\frac{1}{u^2(y)} = \frac{1}{u^2(x_1)} + \cdots + \frac{1}{u^2(x_N)} \tag{2}$$

A consistency check of the results is carried out in the form of a chi-squared test by calculating the observed chi-squared value, χ^2_{obs}, according to Equation (3) and assigning the degrees of freedom, ν, according to Equation (4).

$$\chi^2_{\text{obs}} = \frac{(x_1 - y)^2}{u^2(x_1)} + \cdots + \frac{(x_N - y)^2}{u^2(x_N)} \tag{3}$$

$$\upsilon = N - 1 \tag{4}$$

The consistency check is to be regarded as failing if

$$Pr\,\{\chi^2(\upsilon) > \chi^2_{obs}\} < 0.05 \tag{5}$$

where *Pr* denotes 'probability of'. The consistency check does not fail; therefore, the calculated reference value (weighted mean with cut-off) is taken as the final reference value, along with its associated uncertainty.

The obvious deviations were observed in NMIM and BSN results. Their submitted results could not pass the consistency check. There could be some problems existing in the comparison process with the local BB, which needs further investigation in their labs. The SCRV and uncertainties are calculated based on the Equation (1) and (2) excluding the results from NMIM and BSN, and is shown in Table 8.

Table 8 Comparison results of SCRV and the uncertainty, °C

Setting temperature	Δt_{SCRV}	$u_{\text{weighted mean}}$	u_{BB}	U_{SCRV}, k=2
35.500	-0.0278	0.0085	0.0078	0.023
37.000	-0.0345	0.0086	0.0086	0.024
41.500	-0.0376	0.0091	0.0103	0.028

It's seen that the differences (radiance temperature and contact temperature) of travelling blackbody are generally negative. According to the estimated emissivity of the travelling blackbody 0.999, the radiance temperature is calculated about 12 mK, 13 mK and 17 mK lower than the real temperature at 35.5°C, 37.0°C and 41.5°C respectively. The SCRV biases were obviously larger than the emissivity correction. The reason could come from the emissivity of the travelling blackbody being lower than estimated, and the temperature discrepancy between the monitor PRT and the blackbody radiating surface caused by the thermal conduction.

Note: KRISS resubmitted revised data in November 2020 and the revised data was used for the analysis in the report. However, the revised data is 30 mK farther away from the SCRV compared to the first data submitted in January 2019. In the measurement of 2020, the heat-treated old standard cavity with rust on the outer was used in the bath filled with silicon oil instead of water and was compared against the new KRISS standard. KRISS thought they had overlooked the fact that the walls of the old cavity were thicker, since the rust on the outer surface of the cavity was growing and was peeling off into the bath.

The final comparison results (differences between the participant data and the SCRV) with the uncertainties claimed are shown in Figs. 12 to 17.

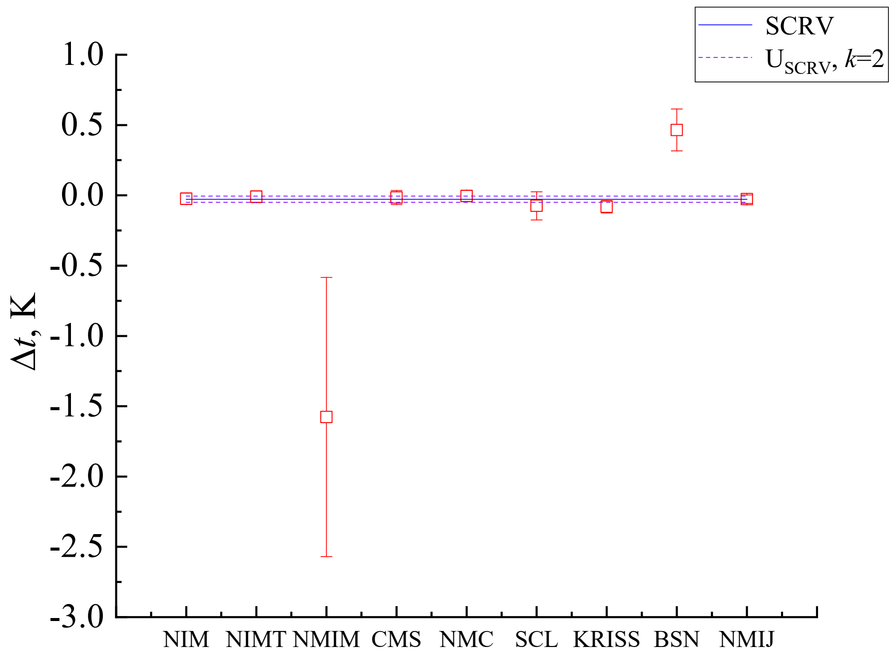


Fig.12 The discrepancy between the radiance and monitor PRT temperature of the travelling blackbody at 35.5 °C measured at the participating NMIs

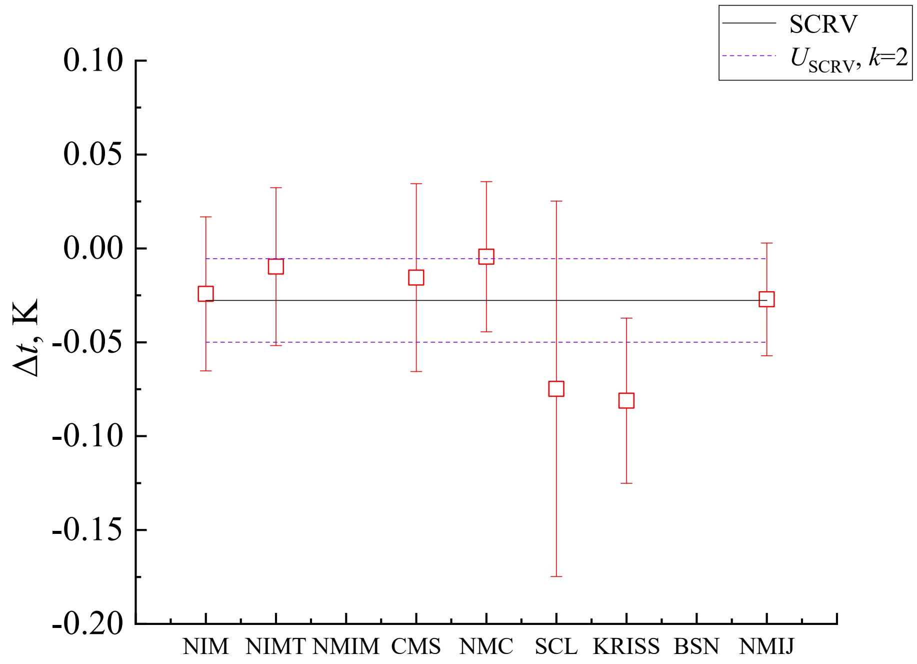


Fig.13 The discrepancy between the radiance and monitor PRT temperature of the travelling blackbody at 35.5 °C measured at the participating NMIs (Zoomed in)

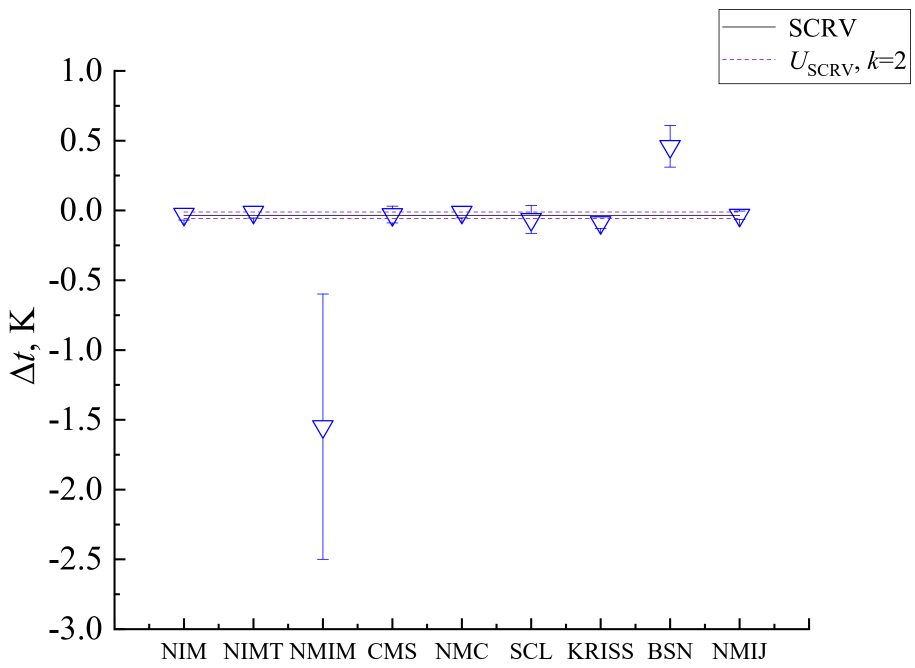


Fig.14 The discrepancy between the radiance and monitor PRT temperature of the travelling blackbody at 37.0 °C measured at the participating NMIs

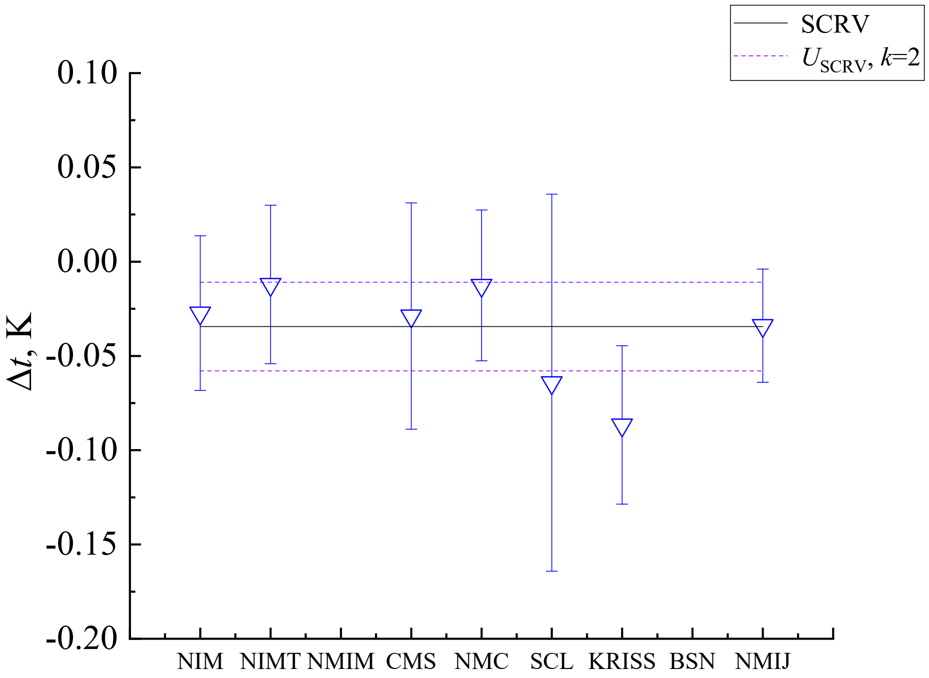


Fig.15 The discrepancy between the radiance and monitor PRT temperature of the travelling blackbody at 37.0 °C measured at the participating NMIs (Zoomed in)

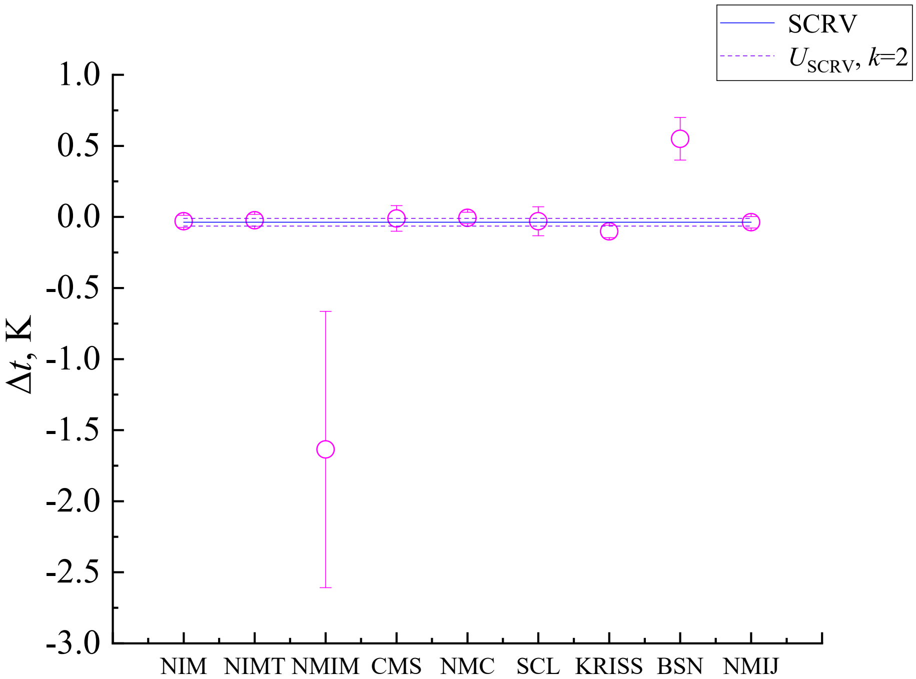


Fig.16 The discrepancy between the radiance and monitor PRT temperature of the travelling blackbody at 41.5 °C measured at the participating NMIs

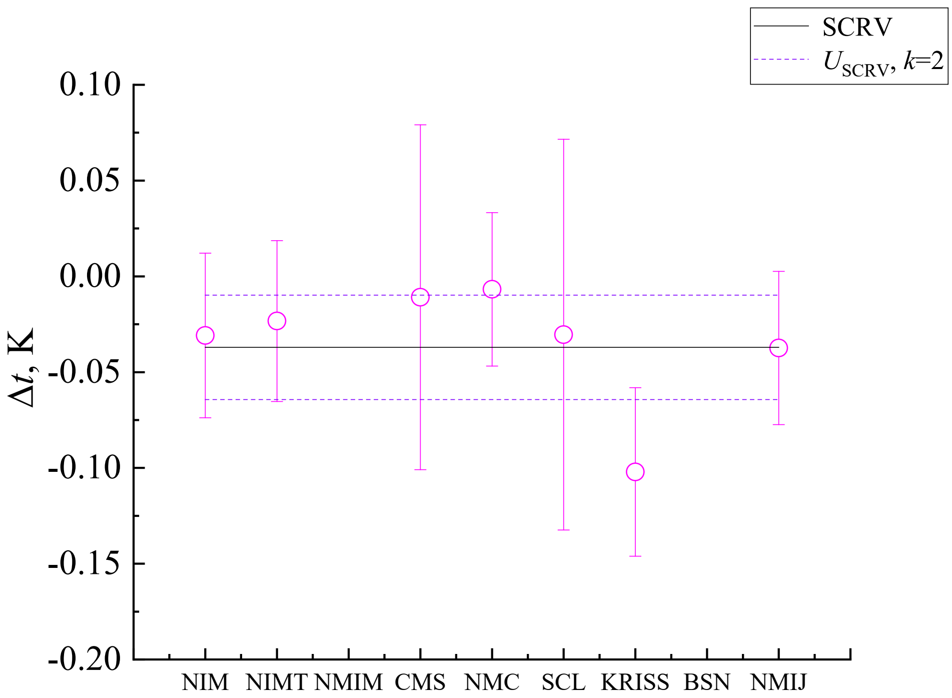


Fig.17 The discrepancy between the radiance and monitor PRT temperature of the travelling blackbody at 41.5 ºC measured at the participating NMIs (Zoomed in)

8. Conclusions

A comparison of radiance temperature scales for IR ear thermometers have been performed successfully over the temperature range from 35.5 °C to 41.5 °C using one travelling blackbody in APMP. The radiance temperature of the travelling blackbody cavity has been compared directly to the standard blackbodies of the participating NMIs using IR ear thermometers with high resolutions and good short-term stabilities. There are some outliers in the results, but, in general, the radiance temperatures realized by the participant NMIs agree to well within ± 0.03 ºC, which is agreeing with each other within the measurement uncertainties. The results also demonstrate comparable quality of the blackbody cavities recommended in the ASTM, JIS, EN and CN standards.

The results of this comparison can be used to underpin the Calibration and Measurement Capabilities (CMCs) of the participants, both for the calibration of ear thermometers and the ear thermometer blackbodies.

There are some recommendations from the comparison process.
1. Not much discrepancy was observed among cavity standards recommended for ear thermometer: EN, ASTM, JIS, CN.
2. SPRT or precise PRT whose accuracy and stability better than 10 mK is recommended to measure the temperature of ear thermometer blackbody within bath.
3. Accuracy of the resistance measurement should be better than 10 mK.

4. Test mode in which an ear thermometer has a higher resolution and is without any correction, should be switched to in the calibration of the ear thermometer. The ear thermometer should be switched to the test mode either if used as a comparator in the calibration of the ear-thermometer blackbody.

APPENDIX A – THE PROTOCOL OF THE COMPARISON

APMP supplementary comparison of blackbody for clinical infrared ear thermometers

APMP.T-S15: 35.5 °C to 41.5 °C

Draft Protocol (Final Version, 26th June 2017)

Xiaofeng Lu, Chengyu Bai, Zundong Yuan / NIM

1. Introduction

The objective of this comparison is intended to assess and verify the calibration capabilities of participating NMIs in the field of ear thermometry by determining the infrared radiance temperature of an unknown ear-thermometer blackbody. This includes:

5. The contact thermometry techniques and standards used to determine the reference bath temperature.
6. The emissivity and temperature uniformity of reference blackbody cavity.
7. The radiance temperature scale realized by the reference blackbody
8. The techniques used to determine the infrared radiance temperature difference between the reference and unknown blackbody.

To reach the objectives, a pilot laboratory (NIM) will send a transfer blackbody to each participating laboratory, where a standard blackbody of the participant will be compared using the measurement technique employed by the participant laboratory. The outcome of the comparison will be utilized in reviewing new CMC entries from APMP NMIs for the BIPM KCDB Appendix C. The comparison is conducted as an APMP comparison, and therefore the participants are either APMP members or APMP associate members.

The approach taken in this comparison was discussed firstly between NIM, NMIJ and CMS. The artifact and methodology are summarized below.

1. NIM has modified a commercial ear-thermometer blackbody system without bath from CMS.
2. The temperature controller is operated based on a Thermistor, and the set temperature has been modified.
3. The pilot lab will be able to use the agreement between the controller and monitor PRT values as a check on the stability of the transfer blackbody during transit.
4. A pre-set switch on the front allows selecting one of 3 preset temperature set-points to be used for the comparison.

This protocol describes the objectives of the comparison, its organization and the procedures to be followed by the participants. It follows the 'Guidelines for key comparisons' established by the

BIPM [1], and is based on current best practice.

All participants of this comparison accept the general instructions and the technical protocol written down in this document and commit themselves to follow the procedures.

2. Participating NMIs (tentative):

Table 1 Participating NMIs and contact person

	NMI	Contact person(s)	Address
Pilot	NIM (China)	Dr. Xiaofeng Lu Senior Researcher luxf@nim.ac.cn	No. 18 Bei San Huan Dong Lu Beijing, 100029 China
Participants	CMS/ITRI (Chinese Taipei)	Mrs. Hsin-yi, Ko Senior Researcher Shelley_Ko@itri.org.tw	CMS/ITRI, Rm.300, Bldg. 16, 3F, 321, Sec. 2, Kuang Fu Rd., Hsinchu, 30011,Taiwan, R.O.C.
	NMIJ/AIST (Japan)	Dr. Naohiko Sasajima Senior research scientist n.sasajima@aist.go.jp	AIST Tsukuba Central 3, 1-1-1 Umezono, Tsukuba Ibaraki 305-8563, Japan
	RCM LIPI (Indonesia)	Hidayat WiriadinataResearcher hidayatwr@yahoo.com	Pusat Metrologi LIPI, Kompleks PUSPIPTEK Gedung 420 Setu, Tangerang Selatan, Indonesia 15314
	KRISS (Republic of Korea)	Dr. Yong Shim Yoo Principal Research Scientist ysyoo@kriss.re.kr	267 Gajeong-Ro, Yuseong-Gu, Daejeon 305-340, Korea
	NIMT (Thailand)	Mr. Athikom Manoi Metrologist athikom@nimt.or.th	3/4-5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120， Thailand
	NMC , A*STAR (Singapore)	Mr Goh Choon Heng Senior Technical Executive goh_choon_heng@nmc.a-star.edu.sg	1 Science Park Drive, #02-27 , Singapore 118221
	NMIM (Malaysia)	Mrs. Hafidzah Othman/ Nafra Mohamad Samiudin Deputy Director / Metrologist hafidzah@sirim.my， nafra@sirim.my	LOT PT 4803, BANDAR BARU SALAK TINGGI, 43900 SEPANG, SELANGOR, MALAYSIA.
	SCL (Hong Kong)	Mr. Julian Cheung Electronics Engineer cpcheung@itc.gov.hk	36/F, Immigration Tower, 7 Gloucester Road, Wan Chai, Hong Kong

3. Comparison Scheme

The comparison of the ear-thermometer blackbody will be conducted as a STAR type and will consist of the following phases:

- The pilot laboratory selects a blackbody and assesses its performance and suitability as a transfer standard.

- The pilot laboratory compares this transfer blackbody against its own standards.
- The blackbody is transported to one participant, who makes his own measurements on the transfer blackbody. Then the transfer blackbody is returned to the pilot laboratory, which again compares this transfer blackbody against the pilot's standards.
- Repeat the above step and sequence until all the participants complete the same measurements on the transfer blackbody. The pilot laboratory assesses the transfer blackbody performance again after all the comparison measurements are completed.
- The pilot laboratory prepares the draft report on the comparison.

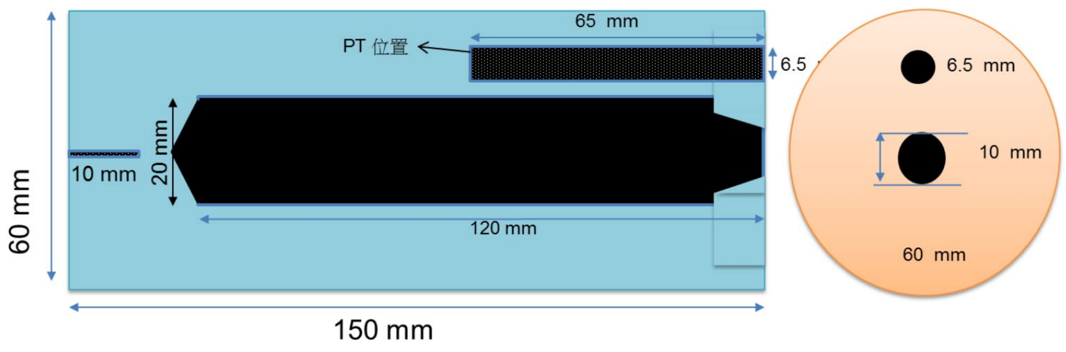
4. Description of the transfer-blackbody

The design of the transfer blackbody provided by the pilot (NIM) is a simple blackbody radiator. The blackbody operates in the temperature range from 35ºC to 42 ºC. The shape of the blackbody cavity is cylinder-conical with a circular aperture 10 mm in diameter, made of copper. A reference thermistor sensor is placed at a position close to the bottom of the cavity to control the temperature. There is a 6.5 mm well which allows another precise PRT to monitor the temperature of blackbody. In the comparison, the PRT is used to monitor the stability and indicate the temperature of the blackbody.

Table 2 Transfer device: Ear-thermometer blackbody

Ear-thermometer blackbody model /Serial No.	305-L/20141016
Manufacture	CMS
Temperature range	35 ºC ~ 42 ºC
Aperture of blackbody	ϕ 10 mm
Effective emissivity	Higher than 0.999
Stability	0.005 ºC
Homogeneity	0.007 ºC
Control sensor	Thermistor
Power supply	100 to 240 VAC

Fuse	Fast acting type; L=20 mm, ϕ=5.1 mm Voltage rating:250 V; Current rating:2.5 A
Mass	Approx. 10 kg
Outer dimensions	240 mm (w) × 100 mm (h) × 370 mm (d)



5. Shipping

The transfer blackbody shall be shipped by commercial carrier. The shipping by the commercial carrier shall be arranged by the participating NMI paying the fare for the shipping (roughly 2,000 USD). The same courier service must cover door-to-door transportation: from pick up at the pilot to the participating NMI, and return back to the pilot. The pick-up dates and the commercial carrier name and contact must be given to the pilot prior to pick up. It is critical that the shipment arrangement be made well in advance so as not to delay the progress of the comparison campaign. In case of any difficulties or problems, the pilot must be consulted immediately.

For those countries belonging to the ATA CARNET treaty, unless another method is found more appropriate, CARNET and any necessary accompanying documents will be prepared and paid for by the pilot NMI. When shipping, the CARNET documents must not be packed inside the cargo. For those countries not belonging to the ATA CARNET treaty, arrangements will be made for each case upon discussion with the relevant participant. In all cases the package must be indicated to be opened only by laboratory personnel.

It is the responsibility of each laboratory to obtain insurance to cover the price of the transfer artifact (which is roughly 15,000 USD) for transport between the laboratories.

Before sending the instrument, the laboratory shall inform the pilot laboratory.

The instrument has to be tightly packed to prevent the damage while being transported. The dimensions and the weight of the cargo are given in Table 3.

Table 3 Dimensions and weight of cargo in carrying case

Transfer device component	Container Form	Dimensions	Weight

Ear-thermometer blackbody	Plastic case in carton	500 mm (w) × 600 mm (h) × 700 mm (d)	15 kg

After arrival of the package, the participant should immediately check for any damage of the devices, and report to the pilot institute by completing and sending the form given in Appendix 1.

6. Measurements

6.1 Infrared ear thermometers used for comparators

Since commercial-type ear thermometers may vary individually, every participant should select appropriate ones equipped with the calibration mode satisfying the following conditions before starting the comparison.

- The measurement temperature range should be at least from 35 °C to 42 °C.
- The indicating resolution should be less than 0.1 °C.
- As for the repeatability, the standard deviation should be within 0.1 °C in ten succeeding measurements.

In addition, how many ear thermometers prepared by the participants should be according to their local calibration protocol.

6.2 Measurements at the pilot laboratory

1) Before dispatch of the transfer device, the pilot performs a full characterization of the instrument which consists of the following.

- Calibration of the PRT with the TPW and Indium fixed point, which is then sealed in the 6.5mm well. Photograph of the seal will be taken and kept to make sure the seal is not damaged during comparison.
- PRT reading will be recorded in the measurement temperature range of 35.5 °C to 41.5 °C which will serve as reference for the stability check of the transfer blackbody.
- Variation in measured values at 90 degree rotations of the ear thermometers.
- Calibration of the transfer blackbody by comparison measurements of the transfer blackbody against the reference blackbody with three selected ear thermometer on one day. Repeat the same calibration process on two more days.

2) After return from the previous participant and before dispatch to the next, the pilot performs intermediate check measurements of the instrument.

- Stability of the transfer blackbody will be checked with the PRT in the measurement temperature range of 35.5 °C to 41.5 °C.
- Repeat the calibration of the transfer blackbody against the reference blackbody.
- The PRT will be recalibrated in the same way as mentioned above after one year. The PRT will be sealed in the 6.5mm well again by the pilot. The PRT reading is taken once more in the measurement temperature range of 35.5 °C to 41.5 °C to verify the reproducibility of the value before and after PRT recalibration.

3) After return of the transfer device from the last participant, the pilot repeats the full characterization of the instruments described in 1. The PRT will be calibrated in the same way at last step.

6.3 General instructions for participant laboratories and initial tests

- Measurements should be performed in a laboratory with a room temperature of 20 °C to 26 °C and relative humidity of 5 % to 80 %, the stability of room temperature should be controlled within 2 °C during one temperature point measurement on one day.
- On receiving the blackbody, the participant should open the packaging according to the instructions in Appendix 5.
- Inspect the transfer-blackbody and cavity for any damage. If any problems are detected the participant should inform the pilot laboratory immediately.
- The transfer blackbody could be connected to the power line of AC 100 V to 240 V. Please prepare the power cable yourself. A stabilized low-noise power supply is recommended for improving the stability of temperature.
- The transfer standard blackbody should be set at a place away from air louvers of the air conditioner of the laboratory so that the blackbody is not affected by the airflow.
- Turn on the transfer BB and set to 35.5 °C using the button on the front panel.
- Connect the monitor PRT leads to a resistance measuring system and check that after 60 minutes or more of operation the resistance is stable at the 4 mΩ (10 mK) level for more than 10 minutes. If not, contact the pilot laboratory for instructions.
- The expanded uncertainty of the resistance measuring system should be smaller than 10 mK for a standard PRT of 25 Ω.

6.4 Measurement protocol for the participating laboratories

The participant should calibrate the transfer ear blackbody by comparison with a reference variable temperature blackbody owned by the NMI according to his local calibration protocol. The comparator must be ear thermometers which should satisfy the conditions in 6.1. The calibration must be made at all of the following temperatures: 35.5 °C, 37.0 °C and 41.5 °C. At each temperature, the resistance of the monitor PRT, the indicated temperature on the screen of the traveling blackbody, and the determined radiance temperature of the transfer blackbody are recorded. Appendix 2 shows an example of the measurement report form. The number of days of measurement should be altered according to the local calibration protocol that was applied.

7. Results and reporting

- **Participants** are to summarize their comparison measurement results. The room temperature is also necessary recorded during every temperature point measurements. Appendix 2 shows an example of the measurement report form.
- **Participants** are to provide a brief description of their calibration technique, equipment and reference standards on the form provided below and also in Appendix 3.

  1. Reference blackbody

  Reference blackbody cavity: type: (eg. Enxx,JISxx,ASTM, other) XXXX
  Cavity serial #: XXXXX
  Bath serial #: XXXXX
  Cavity shape and dimensions: aperture, length, inside diameter etc. XXXXXX
  Description of fluid bath or furnace: (short description) XXXXXXX

  2. Temperature measurement of reference blackbody

  Type of reference sensor: (eg. IPRT, SPRT, thermistor etc) XXXXXX

Serial number of reference sensor(s): XXXXX
Calibration of reference sensor: (eg. comparison in baths, TPW/Ga Fixed pts etc.) XXXXX
Type of measuring instrument: (e.g. ASL-F700, HART super thermometer etc) XXXX
Serial number of measuring instrument or: XXXXX
Measurement current: XXXX
Depth of insertion of sensor into bath: XXX
3. Radiance temperature measurements
Type of ear thermometer (s) used: (e.g. BraunXX) XXXXX
Serial No. of ear thermometers used: XX,XX,XX,XX
Short description of radiance temperature difference measurement procedure: XXXXXX
4. Temperature measurement of transfer blackbody PRT
Type of measuring instrument: (e.g. ASL-F700, HART super thermometer etc) XXXXXX
Serial number of measuring instrument: XXXXX
Measurement current: XXXX

- **Participants** are to provide an uncertainty analysis following the details provided below and the same in Appendix 4.
  The uncertainty budget should include the following components, to which others can be added if necessary.
  1. Calibration uncertainty for the reference blackbody cavity
     a) Temperature uniformity
     b) Temperature stability
     c) Cavity emissivity
  2. Calibration uncertainty for the reference thermometer
     a) Calibration uncertainty for probe
     b) Drift in sensor since calibration
     c) Resistance measurement error
  3. Measurement of infrared radiance temperature difference
     a) Type-A random uncertainty
     b) Systematic error due to short term sensor drift
     c) Resolution of an infrared ear thermometer
- **All the results** need to be submitted to the pilot within **two months** after all the measurements at the NMI are completed.
- After reception of the results of the measurements of all participants the Draft A report will be prepared and circulated.
- The pilot will present the results using reference values of weighted mean with cut-off of all the participant results.
- The final decision on the presentation and interpretation of the results will be taken together with the participants and the TCT.
- The publication of the results will be discussed with the participants. The pilot plans to list the participants as co-authors, if there is general consensus on this.

8. Evaluating:

The evaluation of the calibration results from each participant will be made by the pilot lab based on the initial and final calibration results and the intermediate check measurement results at the pilot, and the reports by the participants.

Details of the analysis including the determination of the reference values are described below:

The results of all the pilot laboratory measurements over the entire period of the comparison will be averaged for each nominal indicated temperature (t_{nom}), after correction for drift of the PRT thermometer if necessary, to give one pilot result for each t_{nom}. The final uncertainty associated with the pilot results will include the standard deviation of the pilot measurements (after correction of results for any drift).

A reference value will be calculated for each t_{nom} using the weighted mean with cut-off of all the participant results, including the average pilot results, at that t_{nom}. The weight for each participant, including the pilot, is the inverse of the square of the standard measurement uncertainty for that participant at that t_{nom}, with the average of the 5 smallest values of uncertainty adopted as the cut-off value for the weight. The weighted mean, y, will be calculated according to Equation (1):

$$y = \frac{x_1/u^2(x_1) + \cdots + x_N/u^2(x_N)}{1/u^2(x_1) + \cdots + 1/u^2(x_N)} \tag{1}$$

where x_1 through to x_N are the results from participants 1 through N and u (x_1) through to u (x_N) are the associated standard uncertainties for participants 1 through N, which will include any additional uncertainty components such as that due to the thermometer drift (if any).
The standard deviation $u(y)$ associated with y will be calculated according to Equation (2):

$$\frac{1}{u^2(y)} = \frac{1}{u^2(x_1)} + \cdots + \frac{1}{u^2(x_N)} \tag{2}$$

The evaluation of the results will be based on the following two criteria which are in close accordance to the CCT/WG8 radiation thermometry CMC review protocol [5]:

$$|V_{\mathrm{NMI,SC}} - V_{\mathrm{SCRV}}| < \sqrt{U_{\mathrm{NMI,SC}}^2 + U_{\mathrm{SC}}^2 + U_{\mathrm{SC\,RV}}^2} \tag{3}$$

$$U_{\mathrm{NMI,SC}} > \sqrt{U_{\mathrm{SC}}^2 + U_{\mathrm{SC\,RV}}^2} \Big/ 3 \tag{4}$$

Here,

$V_{\mathrm{NMI,SC}}$ is the reported value by the participants.

V_{SCRV} is the comparison reference value calculated as the weighted mean with cut-off of the reported values from the participating APMP member NMIs and the pilot. If there is significant instability in the transfer devices, then this drift may also be corrected for.

$U_{\mathrm{NMI,SC}}$ is the expanded uncertainty claimed by the participant NMI in the report.

U_{SC} is the expanded comparison measurement uncertainty, and takes into account the instability of the transfer device.

$U_{\mathrm{SC\,RV}}$ is the expanded uncertainty of the reference value.

9. Measurement schedule:

Nine NMIs are participating in the comparison including the pilot. Each participant needs to be well prepared before the transfer device arrives. The NMIs must complete all measurements and dispatch the standards back to the pilot within three weeks of reception.

The commercial carrier arrangements must be prepared by the participants. It is critical that each participant have these arranged timely so as not to delay the progress.

Table 4 Measurement schedule. NIM makes intermediate check measurements between all participant NMI measurements, which are included in the transportation period of one month.

Period	NMI	Measurement Period		
May. 2017	NIMT	5.14 /8.10	~	5.28 /10.16
Jul. 2017	NMIM	6.30	~	7.14
Aug. 2017	CMS	8.14	~	8.31
Oct. 2017	NMIJ	9.30	~	10.14
Nov. 2017	NMC, A*STAR	11.14	~	11.30
Jan. 2018	RCM LIPI	12.30	~	1.14
Feb. 2018	SCL	2.26	~	3.10
Apr. 2018	KRISS	4.10	~	4.25

11. References

[1] Measurement Comparisons in the CIPM MRA. CIPM MRA-D-05, Version 1.6, 2016.
[2] T. J. Quinn, "Guidelines for key comparisons carried out by Consultative Committees", 1 March 1999, BIPM, Paris.
[3] J. Ishii, T. Fukuzaki, H. C. McEvoy, R. Simpson, G. Machin, J. Hartmann, B. Gutschwager, and J. Hollandt, "A comparison of blackbody cavities for infrared ear thermometers of NMIJ, NPL, and PTB" TEMPMEKO 2004.
[4] CCT/WG8 radiation thermometry CMC review protocol: Version 29th Oct. 2009 and Revised 17th May 2010

APPENDIX B –THE PARTICIPANTS‘ SUBMITTING RESULTS

Comparison Result of NIM

Since before sent to and after returned from the participant NMI, the pilot lab NIM performed intermediate check measurements of the travelling instrument, with repeating the calibration of the travelling blackbody against the reference blackbody. So NIM’s measurement results were summarized here.

Table B.1 Ear-thermometer-blackbody measurement report from NIM

Calibration results of travelling BB at 35.5 °C

Date	Set temperature	Average Resistance of monitor PRT	Average Radiance temperature measured	Room temperature	Room humidity
1-Aug-17	35.500	29.1848	35.466	23.1	54.6-61.6
2-Aug-17	35.500	29.1846	35.465	23.1	56.8-60.3
9-Nov-17	35.500	29.1841	35.452	21.1	31.8-33.7
10-Nov-17	35.500	29.1838	35.447	22.9	56.8-60.3
13-Nov-17	35.500	29.1835	35.439	20.9	16.9-17.2
26-Jan-18	35.500	29.1822	35.427	20.6	13.3-12.7
29-Jan-18	35.500	29.1820	35.424	22	10.7-11.3
30-Jan-18	35.500	29.1819	35.426	21	11.1-8.5
17-May-18	35.500	29.1827	35.438	23.2	13.3-12.7
18-May-18	35.500	29.1826	35.440	22.8	41.4-43.0
21-May-18	35.500	29.1831	35.452	24.2	37.0-42.5
17-Aug-18	35.500	29.1834	35.456	23.8	70
21-Aug-18	35.500	29.1824	35.438	23	57.6-64.2
28-Aug-18	35.500	29.1831	35.452	24	57.2-68.2
17-Sep-18	35.500	29.1832	35.445	25	35.6-41.3
18-Sep-18	35.500	29.1831	35.444	23	44.5-63.9
19-Sep-18	35.500	29.1834	35.447	24.9	50.7-56.3
12-Nov-18	35.500	29.1822	35.434	22.7	30.1-38.4
13-Nov-18	35.500	29.1822	35.438	23.4	31.0-35.1
14-Nov-18	35.500	29.1822	35.434	22.3	36.2-42.1
18-Feb-19	35.500	29.1821	35.424	20.1	30.1-38.4
19-Feb-19	35.500	29.1821	35.437	23.9	24.7-33.5
20-Feb-19	35.500	29.1823	35.432	24.9	36.2-42.1
2-Jul-19	35.500	29.1831	35.447	25.5	32.2-36.7
3-Jul-19	35.500	29.1828	35.442	24.6	34.9-38.8
12-Nov-19	35.500	29.1839	35.438	23.9	37.6-39.0
13-Nov-19	35.500	29.1837	35.443	23.9	27.1-30.5

14-Nov-19	35.500	29.1836	35.441	23.7	25.8-29.9
16-Mar-20	35.500	29.1829	35.445	24.4	22.8-28.6
17-Mar-20	35.500	29.1828	35.439	25.1	22.3-26.0
18-Mar-20	35.500	29.1827	35.434	24.6	16.7-25.6

Table B.2 Ear-thermometer-blackbody measurement report from NIM

Calibration results of travelling BB at 37.0 ºC

Date	Set temperature	Average Resistance of monitor PRT	Average Radiance temperature measured	Room temperature	Room humidity
1-Aug-17	37.000	29.3374	36.981	22.3	54.6-61.6
2-Aug-17	37.000	29.3373	36.975	23.1	56.8-60.3
9-Nov-17	37.000	29.3370	36.967	21.3	31.8-33.7
10-Nov-17	37.000	29.3368	36.965	23	56.8-60.3
13-Nov-17	37.000	29.3363	36.950	20.9	16.9-17.2
26-Jan-18	37.000	29.3363	36.955	20.1	13.3-12.7
29-Jan-18	37.000	29.3361	36.942	18.5	10.7-11.3
30-Jan-18	37.000	29.3361	36.954	21.2	11.1-8.5
17-May-18	37.000	29.3365	36.967	23.6	13.3-12.7
18-May-18	37.000	29.3364	36.963	23	41.4-43.0
21-May-18	37.000	29.3368	36.970	23.8	37.0-42.5
17-Aug-18	37.000	29.3363	36.963	23	70
21-Aug-18	37.000	29.3357	36.957	23.2	57.6-64.2
28-Aug-18	37.000	29.3361	36.961	23.6	57.2-68.2
17-Sep-18	37.000	29.3364	36.960	24.2	35.6-41.3
18-Sep-18	37.000	29.3360	36.954	23.2	44.5-63.9
19-Sep-18	37.000	29.3363	36.959	24.4	50.7-56.3
12-Nov-18	37.000	29.3358	36.957	22.5	30.1-38.4
13-Nov-18	37.000	29.3358	36.952	23.2	31.0-35.1
14-Nov-18	37.000	29.3358	36.952	22.5	36.2-42.1
18-Feb-19	37.000	29.3360	36.947	20.8	30.1-38.4
19-Feb-19	37.000	29.3360	36.959	24	24.7-33.5
20-Feb-19	37.000	29.3360	36.960	24.2	36.2-42.1
2-Jul-19	37.000	29.3364	36.975	25.4	32.2-36.7
3-Jul-19	37.000	29.3361	36.960	24.5	34.9-38.8
12-Nov-19	37.000	29.3375	36.960	23.8	37.6-39.0
13-Nov-19	37.000	29.3373	36.956	23.7	27.1-30.5
14-Nov-19	37.000	29.3371	36.959	23.6	25.8-29.9
16-Mar-20	37.000	29.3362	36.948	24.2	22.8-28.6
17-Mar-20	37.000	29.3361	36.951	24.9	22.3-26.0
18-Mar-20	37.000	29.3360	36.951	23.8	16.7-25.6

Table B.3 Ear-thermometer-blackbody measurement report from NIM

Calibration results of travelling BB at 41.5 °C

Date	Set temperature	Average Resistance of monitor PRT	Average Radiance temperature measured	Room temperature	Room humidity
1-Aug-17	41.500	29.7888	41.453	22	54.6-61.6
2-Aug-17	41.500	29.7889	41.457	22.9	56.8-60.3
9-Nov-17	41.500	29.7885	41.443	21.6	31.8-33.7
10-Nov-17	41.500	29.7884	41.449	23.1	56.8-60.3
13-Nov-17	41.500	29.7880	41.434	21	16.9-17.2
26-Jan-18	41.500	29.7880	41.425	19.9	13.3-12.7
29-Jan-18	41.500	29.7874	41.413	18.6	10.7-11.3
30-Jan-18	41.500	29.7877	41.423	20.5	11.1-8.5
17-May-18	41.500	29.7883	41.466	23.6	13.3-12.7
18-May-18	41.500	29.7882	41.442	23	41.4-43.0
21-May-18	41.500	29.7885	41.453	23.1	37.0-42.5
17-Aug-18	41.500	29.7883	41.444	25.2	70
21-Aug-18	41.500	29.7873	41.442	23.2	57.6-64.2
28-Aug-18	41.500	29.7879	41.433	24.3	57.2-68.2
17-Sep-18	41.500	29.7881	41.433	23	35.6-41.3
18-Sep-18	41.500	29.7881	41.438	25.2	44.5-63.9
19-Sep-18	41.500	29.7875	41.424	22.5	50.7-56.3
12-Nov-18	41.500	29.7876	41.436	22.1	30.1-38.4
13-Nov-18	41.500	29.7876	41.439	22.5	31.0-35.1
14-Nov-18	41.500	29.7876	41.433	22.7	36.2-42.1
18-Feb-19	41.500	29.7877	41.428	21	30.1-38.4
19-Feb-19	41.500	29.7879	41.429	23.3	24.7-33.5
20-Feb-19	41.500	29.7880	41.435	23.9	36.2-42.1
2-Jul-19	41.500	29.7882	41.445	24.9	32.2-36.7
3-Jul-19	41.500	29.7878	41.442	24.3	34.9-38.8
12-Nov-19	41.500	29.7893	41.449	23.7	37.6-39.0
13-Nov-19	41.500	29.7891	41.441	23.3	27.1-30.5
14-Nov-19	41.500	29.7890	41.433	23.2	25.8-29.9
16-Mar-20	41.500	29.7881	41.422	23	22.8-28.6
17-Mar-20	41.500	29.7881	41.421	23.6	22.3-26.0
18-Mar-20	41.500	29.7880	41.427	22.1	16.7-25.6

Reporter: Chengyu Bai

Date: 23 Apr. 2021

Appendix 3: Measurement equipment and standards

Reference blackbody

Reference blackbody cavity: type: JJG1164-2019 Verification Regulation of Infrared Ear Thermometers

Cavity serial #: E-02

Bath serial #: 211042

Cavity shape and dimensions: aperture=10mm, length=118mm, inside diameter=60mm

Description of fluid bath or furnace: water bath with heating and cooling system. Working zone: φ138×330mm, Stability: 7mK, uniformity: 10mK

Temperature measurement of reference blackbody

Type of reference sensor: SPRT

Serial number of reference sensor(s): 161002

Calibration of reference sensor: TPW, Ga and In Fixed Points

Type of measuring instrument: Fluke 1594A

Serial number of measuring instrument: B0A044

Measurement current: 1mA

Depth of insertion of sensor into bath: 300mm

Radiance temperature measurements

Type of ear thermometer (s) used: CITIZEN model CT810, Microlife model IR1DF1, UEBE model 0870

Serial No. of ear thermometers used: CITIZEN model CT810/ Serial No.0801513 and 0801529, Microlife model IR1DF1/ Serial No. 45# and 46#, UEBE model 0870 l/ Serial No.161900548 and 161900060.

Short description of radiance temperature difference measurement procedure:

(1) Inspect the ear thermometer blackbody under calibration (UUC) on any damage or contamination and clean it if necessary.
(2) Set ear thermometers into calibration mode and stabilize them at ambient temperature and humidity for minimum of 30 minutes.
(3) Measure and record ambient temperature and humidity.
(4) Measure the STBB with IRETs, and record the reading of IRETs and resistance of SPRT simultaneously.
(5) Measure the UUC with IRETs, and record the reading of IRETs and temperature of UUC simultaneously.
(6) Repeat step (4) to (5) for 9 times at one temperature point.
(7) Repeat step (3) to (6) at all temperature settings.

Temperature measurement of transfer blackbody PRT

Type of measuring instrument: Fluke 1594A

Serial number of measuring instrument: B0A044

Measurement current: 1mA

Description of calibration technique

Gloves not used.

Appendix 4: Uncertainty Analysis.

Source of uncertainty		**35.5 °C**	**37.0 °C**	**41.5 °C**
Uncertainty from the reference blackbody	Calibration of SPRT (K)	0.0025	0.0025	0.0025
	Drift of SPRT (K)	0.0029	0.0029	0.0029
	Resistance measurement(K)	0.003	0.003	0.003
	Uniformaty of bath(K)	0.012	0.012	0.012
	Stability of Bath(K)	0.006	0.006	0.006
	Emissivity(K)	0.006	0.007	0.009
Uncertainty from the travelling blackbody	Resistance of monitor PRT(K)	0.003	0.003	0.003
	Repeatiability on one day(K)	0.003	0.003	0.003
	Reproducibility on three days(K)	0.012	0.012	0.012
	Resolution of ear thermometer (K)	0.003	0.003	0.003
	Combined standard uncertainty(K)	0.020	0.021	0.021
	Expanded uncertainty(K)，*k*=2	**0.041**	**0.041**	**0.043**

Comparison Result of NIMT

Appendix 2: Ear-thermometer-blackbody measurement report form

Institute name	**National Institute of Metrology (Thailand)**		
The start date	8 Sep 2017	Ending date	10 Sep 2017
Calibration results of transfer BB			
Date of measurement (Day 1)	8 Sep 2017		
Room temperature (ºC)	23.1 to 24.4	Room humidity (% rh)	54.4 to 56.3
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.5	29.18527077	35.500	35.4828
37.0	29.33762506	37.000	36.9944
41.5	29.78953005	41.500	41.4655
Date of measurement (Day 2)	9 Sep 2017		
Room temperature (ºC)	23.18 to 24.89	Room humidity (% rh)	52.3 to 56.6
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.5	29.18509549	35.500	35.4705
37.0	29.33758042	37.000	36.9866
41.5	29.78938372	41.500	41.4609
Date of measurement (Day 3)	10 Sep 2017		

Room temperature (ºC)	22.6 to 24.0	Room humidity (% rh)	55.5 to 61.5
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.5	29.18499425	35.500	35.4884
37.0	29.33752755	37.000	36.9871
41.5	29.78915667	41.500	41.4550

Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant (ºC)	Uncertainty of the measurement (k=2) (K)
35.5	29.18512017	35.500	35.4806	0.042
37.0	29.33757768	37.000	36.9894	0.042
41.5	29.78935681	41.500	41.4605	0.042

Reporter: Athikom Manoi

Date: 28 July 2018

Appendix 3: Measurement equipment and standards

Reference blackbody

Reference blackbody cavity: type: (eg. Enxx,JISxx,ASTM, other) JIS T 4207:2005

Cavity serial #: N/A

Bath serial #: AX06XPK01

Cavity shape and dimensions: aperture, length, inside diameter etc.

The cavity shape is cylindro-conical with 20-mm opening aperture diameter and 200 mm in length. The cavity is made of copper with its thickness less than 1 mm and coated with high emissivity material. The effective emissivity of the cavity is estimated to be higher than 0.9995.

Description of fluid bath or furnace: (short description)

The cavity is fully immersed horizontally in the liquid bath and water was used as a medium.

Temperature measurement of reference blackbody

Type of reference sensor: (eg. IPRT, SPRT, thermistor etc) SPRT

Serial number of reference sensor(s): 1563

Calibration of reference sensor: (eg. comparison in baths, TPW/Ga Fixed pts etc.)

The SPRT was calibrated in the range of the triple point of water (TPW, 0.01 °C) to the freezing point of Zn (419.527 °C). The uncertainty of the calibration is 5 mK (k=2).

Type of measuring instrument: (e.g. ASL-F700, HART super thermometer etc)

Super thermometers model 1595A, Fluke

Serial number of measuring instrument or: B36135

Measurement current: 1 mA

Depth of insertion of sensor into bath: 13.8 cm

Radiance temperature measurements

Type of ear thermometer (s) used: (e.g. BraunXX) Braun IRT 4520

Serial No. of ear thermometers used: 30312K03889, 34713K07051, 33613K05959

Short description of radiance temperature difference measurement procedure:

A set of three infrared ear thermometers (IRETs), Braun IRT 4520, were used as comparators. The indicated value in temperature of the IRETs was read out visually and recorded by the operator.

For the first measuring point, i.e. 41.5 °C, the first cycle of the measurement started by using the first comparator to measure radiance temperature against NIMT blackbody and immediately after that against the transfer blackbody. The measurement was performed for 10 repeating times, i.e. 10 data of NIMT blackbody temperature and 10 data of the transfer blackbody temperature measured by the first IRET conjunction with measurement data of NIMT blackbody temperature and transfer PRT resistance. Then, the second cycle was carried out as the first cycle but the second comparator was used instead, and so on for the third cycle. After that, the comparison was performed for the 37.0 °C and 35.5 °C measurement points with the same processes as the first point. All three measurement points were performed within one day. The same procedures as the first day were repeated twice. Finally, results of the comparison had to analyse from 3 set of data measured on three separate days and each set composed of three results from three comparators.

The measurements were performed in controlled temperature and humidity room. The room temperature was controlled at (23 ± 2) °C and the room humidity was controlled in the range (55 ± 10) % rh

Temperature measurement of transfer blackbody PRT

Type of measuring instrument: (e.g. ASL-F700, HART super thermometer etc)
Super thermometers model 1595A, Fluke
Serial number of measuring instrument: B36135
Measurement current: 1 mA

Description of calibration technique

Gloves were not used in the measurements.

Appendix 4: Uncertainty Analysis.

The table below shows the standard uncertainty of each component uncertainty in the comparison.

Type	Source of uncertainty	35.5 °C	37.0 °C	41.5 °C
A	Type-A random uncertainty (K)	0.016	0.013	0.012
B	Calibration of the SPRT (K)	0.003	0.003	0.003
B	Drift of the SPRT (K)	0.003	0.003	0.003
B	Accuracy of the SPRT indicator (K)	0.003	0.003	0.003
B	Display resolution of SPRT indicator (K)	0.000	0.000	0.000
B	Display resolution of the comparator (K)	0.003	0.003	0.003
B	Changing of ambient temperature (K)	0.002	0.002	0.002
B	Uniformity and stability of the standard blackbody (K)	0.010	0.010	0.010
B	Heat loss inside cavity of the standard blackbody (K)	0.001	0.001	0.001
B	Uncertainty of the standard cavity emissivity (K)	0.006	0.007	0.009
u_c	Combined standard uncertainty	0.0208	0.0188	0.0189
U	**Expanded uncertainty**	**0.042**	**0.038**	**0.038**

Comparison Result of NMIM

Appendix 2: Ear-thermometer blackbody measurement report form

IR no 1

Name : ThermoScan
Model : IRT6520
Serial Number : 02416k85186
Manufacturer : Braun

Institute name	National Metrology Institute of Malaysia		
The start date	2017/12/28	Ending date	2018/1/9
Calibration results of transfer BB			
Date of measurement (Day 1)	2017/12/28		
Room temperature (°C)	22 ± 1 °C	Room humidity (%rh)	55 ± 2 %rh
Set temperature (°C)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (°C)	Average Radiance temperature measured by participant (°C)
35.5	29.310186	35.500	35.1
37.0	29.464769	37.000	36.8
41.5	29.918378	41.500	41.2
Date of measurement (Day 2)	2018/1/4		
Room temperature (°C)	22 ± 1 °C	Room humidity (%rh)	56 ± 2 %rh
Set temperature (°C)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (°C)	Average Radiance temperature measured by participant (°C)
35.5	29.314533	35.500	35.1
37.0	29.469066	37.000	36.7
41.5	29.922588	41.500	41.0

Date of measurement (Day 3)	2018/1/9		
Room temperature (°C)	22 ± 1 °C	Room humidity (%rh)	56 ± 2 %rh
Set temperature (°C)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (°C)	Average Radiance temperature measured by participant (°C)
35.5	29.314973	35.500	35.1
37.0	29.46935	37.000	36.6
41.5	29.922911	41.500	40.9

Appendix 3: Measurement equipment and standards

IR no 1

Reference blackbody

Reference blackbody cavity: type:	EN12470-5:2003
Bath Serial # :	A82066
Cavity shape and dimensions :	Aperture Ø 10mm, length 105mm, inside diameter Ø 39mm.
Description of fluid bath or furnace	

Temperature measurement of reference blackbody

Type of reference sensor	PT100
Serial number of reference sensor	PO 111482-1-17
Calibration of reference sensor	Comparison in baths
Type of measuring instrument	Precision Thermometer ASL F200
Depth of insertion of sensor into bath	200 mm

Radiance temperature measurements

Type of ear thermometer (s) used:	Braun ThermoScan IRT6520
Serial number of measuring instrument	02416k85186
Short description of radiance temperature difference measurement procedure	

Temperature measurement of transfer blackbody PRT

Type of measuring instrument:	HP 3458A Multimeter
Serial number of measuring instrument	2823A15103
Measurement current	1 mA

Description of calibration technique

The liquid bath blackbody furnace was set to temperature of 35.5 °C, and then it was allowed to stabilize for 3 hours. To measure the temperature of cavity, the standard reference sensor (PT100) was used. It was placed closed to the tip of cavity of blackbody. Infrared ear thermometer was used to check the radiance temperature for every measurement. 10 reading was recorded. Same method was applied for other temperature point (37 °C and 41.5 °C). For environment controlled the room temperature was set at 22 ± 3 °C with humidity of 55 ± 10 %rh.

Appendix 2: Ear-thermometer blackbody measurement report form

IR no 2

Name : ThermoScan
Model : Pro4000
Serial Number : 26715K00053
Manufacturer : Braun

Institute name	National Metrology Institute of Malaysia		
The start date	2017/12/28	Ending date	2018/1/9
Calibration results of transfer BB			
Date of measurement (Day 1)	2017/12/28		
Room temperature (°C)	22 ± 1 °C	Room humidity (%rh)	56 ± 2 %rh
Set temperature (°C)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (°C)	Average Radiance temperature measured by participant (°C)
35.5	29.310223	35.500	35.3
37.0	29.464759	37.000	36.8
41.5	29.918333	41.500	41.4
Date of measurement (Day 2)	2018/1/4		
Room temperature (°C)	22 ± 1 °C	Room humidity (%rh)	56 ± 2 %rh
Set temperature (°C)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (°C)	Average Radiance temperature measured by participant (°C)
35.5	29.314598	35.500	35.2

37.0	29.469056	37.000	36.8
41.5	29.922627	41.500	41.3
Date of measurement (Day 3)	2018/1/9		
Room temperature (°C)	22 ± 1 °C	Room humidity (%rh)	56 ± 2 %rh
Set temperature (°C)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (°C)	Average Radiance temperature measured by participant (°C)
35.5	29.314866	35.500	35.3
37.0	29.469378	37.000	36.8
41.5	29.923074	41.500	41.3

Reporter: Nafra Mohamad Samiudin

Date: 19 Nov 2018

Appendix 3: Measurement equipment and standards

IR no 2

Reference blackbody

Reference blackbody cavity: type:	EN12470-5:2003
Bath Serial # :	A82066
Cavity shape and dimensions :	Aperture Ø 10mm, length 105mm, inside diameter Ø 39mm.
Description of fluid bath or furnace	

Temperature measurement of reference blackbody

Type of reference sensor	PT100
Serial number of reference sensor	PO 111482-1-17
Calibration of reference sensor	Comparison in baths
Type of measuring instrument	Precision Thermometer ASL F200
Depth of insertion of sensor into bath	200 mm

Radiance temperature measurements

Type of ear thermometer (s) used:	Braun ThermoScan Pro4000
Serial number of measuring instrument	26715K00053
Short description of radiance temperature difference measurement procedure	

Temperature measurement of transfer blackbody PRT

Type of measuring instrument:	HP 3458A Multimeter
Serial number of measuring instrument	2823A15103
Measurement current	1 mA

Description of calibration technique

The liquid bath blackbody furnace was set to temperature of 35.5 °C, and then it was allowed to stabilize for 3 hours. To measure the temperature of cavity, the standard reference sensor (PT100) was used. It was placed closed to the tip of cavity of blackbody. Infrared ear thermometer was used to check the radiance temperature for every measurement. 10 reading was recorded. Same method was applied for other temperature point (37 °C and 41.5 °C). For environment controlled the room temperature was set at 22 ± 3 °C with humidity of 55 ± 10 %rh.

Appendix 4: Uncertainty Analysis.

IR no 1

Set point temperature 35.5 °C

	Uncertainty Component	Uncertainty Value	Probability Distribution	Divisor	Sensitivity Coefficient	Standard Uncertainty	Remarks
1	*Calibration uncertainty for the reference blackbody cavity*						
a	Temperature uniformity	0.200	R	√3	1	0.115	
b	Temperature stability	0.0035	R	√3	1	0.002	
c	Cavity emissivity	0.728	R	√3	1	0.420	
2	*Calibration uncertainty for the reference thermometer*						
a	Calibration uncertainty for probe	0.040	Normal	2	1	0.020	
b	Drift in sensor since calibration	0.0014	R	√3	1	0.001	
3	*Measurement of infrared radiance temperature difference*						
a	Type-A random uncertainty	0.04534	Normal	1	1	0.045	
b	Systematic error due to short term sensor drift	0.400	R	√3	1	0.231	
c	Resolution of an infrared ear thermometer	0.050	R	√3	1	0.029	
	Combined uncertainties (Uc)	Normal				0.496	
	Expanded Uncertainty (U)	Normal *k*=2				0.993	

Set point temperature 37.0 °C

	Uncertainty Component	Uncertainty Value	Probability Distribution	Divisor	Sensitivity Coefficient	Standard Uncertainty	Remarks
1	*Calibration uncertainty for the reference blackbody cavity*						
a	Temperature uniformity	0.200	R	√3	1	0.115	
b	Temperature stability	0.0035	R	√3	1	0.002	
c	Cavity emissivity	0.735	R	√3	1	0.424	
2	*Calibration uncertainty for the reference thermometer*						
a	Calibration uncertainty for probe	0.040	Normal	2	1	0.020	
b	Drift in sensor since calibration	0.0014	R	√3	1	0.001	
3	*Measurement of infrared radiance temperature difference*						
a	Type-A random uncertainty	0.03073	Normal	1	1	0.031	
b	Systematic error due to short term sensor drift	0.300	R	√3	1	0.173	
c	Resolution of an infrared ear thermometer	0.050	R	√3	1	0.029	
Combined uncertainties (Uc)			Normal			0.475	
Expanded Uncertainty (U)			Normal k=2			0.950	

Set point temperature 41.5 °C

	Uncertainty Component	Uncertainty Value	Probability Distribution	Divisor	Sensitivity Coefficient	Standard Uncertainty	Remarks
1	*Calibration uncertainty for the reference blackbody cavity*						
a	Temperature uniformity	0.200	R	√3	1	0.115	
b	Temperature stability	0.0035	R	√3	1	0.002	
c	Cavity emissivity	0.756	R	√3	1	0.437	
2	*Calibration uncertainty for the reference thermometer*						
a	Calibration uncertainty for probe	0.040	Normal	2	1	0.020	
b	Drift in sensor since calibration	0.0014	R	√3	1	0.001	
3	*Measurement of infrared radiance temperature difference*						
a	Type-A random uncertainty	0.03350	Normal	1	1	0.033	
b	Systematic error due to short term sensor drift	0.300	R	√3	1	0.173	
c	Resolution of an infrared ear thermometer	0.050	R	√3	1	0.029	
Combined uncertainties (Uc)			Normal			0.486	
Expanded Uncertainty (U)			Normal k=2			0.972	

IR no 2

Set point temperature 35.5 °C

	Uncertainty Component	Uncertainty Value	Probability Distribution	Divisor	Sensitivity Coefficient	Standard Uncertainty	Remarks
1	*Calibration uncertainty for the reference blackbody cavity*						
a	Temperature uniformity	0.200	R	√3	1	0.115	
b	Temperature stability	0.0035	R	√3	1	0.002	
c	Cavity emissivity	0.728	R	√3	1	0.420	
2	*Calibration uncertainty for the reference thermometer*						
a	Calibration uncertainty for probe	0.040	Normal	2	1	0.020	
b	Drift in sensor since calibration	0.0014	R	√3	1	0.001	
3	*Measurement of infrared radiance temperature difference*						
a	Type-A random uncertainty	0.01000	Normal	1	1	0.010	
b	Systematic error due to short term sensor drift	0.100	R	√3	1	0.058	
c	Resolution of an infrared ear thermometer	0.050	R	√3	1	0.029	
Combined uncertainties (Uc)			Normal			0.441	
Expanded Uncertainty (U)			Normal k=2			0.882	

Set point temperature 37.0 °C

	Uncertainty Component	Uncertainty Value	Probability Distribution	Divisor	Sensitivity Coefficient	Standard Uncertainty	Remarks
1	***Calibration uncertainty for the reference blackbody cavity***						
a	Temperature uniformity	0.200	R	√3	1	0.115	
b	Temperature stability	0.0035	R	√3	1	0.002	
c	Cavity emissivity	0.735	R	√3	1	0.424	
2	***Calibration uncertainty for the reference thermometer***						
a	Calibration uncertainty for probe	0.040	Normal	2	1	0.020	
b	Drift in sensor since calibration	0.0014	R	√3	1	0.001	
3	***Measurement of infrared radiance temperature difference***						
a	Type-A random uncertainty	0.01795	Normal	1	1	0.018	
b	Systematic error due to short term sensor drift	0.200	R	√3	1	0.115	
c	Resolution of an infrared ear thermometer	0.050	R	√3	1	0.029	
	Combined uncertainties (Uc)		Normal			0.456	
	Expanded Uncertainty (U)		Normal *k*=2			0.912	

Set point temperature 41.5 °C

	Uncertainty Component	Uncertainty Value	Probability Distribution	Divisor	Sensitivity Coefficient	Standard Uncertainty	Remarks
1	***Calibration uncertainty for the reference blackbody cavity***						
a	Temperature uniformity	0.200	R	√3	1	0.115	
b	Temperature stability	0.0035	R	√3	1	0.002	
c	Cavity emissivity	0.756	R	√3	1	0.437	
2	***Calibration uncertainty for the reference thermometer***						
a	Calibration uncertainty for probe	0.040	Normal	2	1	0.020	
b	Drift in sensor since calibration	0.0014	R	√3	1	0.001	
3	***Measurement of infrared radiance temperature difference***						
a	Type-A random uncertainty	0.02603	Normal	1	1	0.026	
b	Systematic error due to short term sensor drift	0.200	R	√3	1	0.115	
c	Resolution of an infrared ear thermometer	0.050	R	√3	1	0.029	
	Combined uncertainties (Uc)		Normal			0.468	
	Expanded Uncertainty (U)		Normal *k*=2			0.936	

Comparison Result of CMS

Appendix 2: Ear-thermometer-blackbody measurement report form

Institute name	**CMS/ITRI**		
The start date	20180307	Ending date	20180313
Calibration results of transfer BB			
Date of measurement (Day 1)	20180308		
Room temperature (ºC)	23.4	Room humidity (% rh)	53.5
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.5	29.18373	35.500	35.45
37.0	29.33749	37.000	36.96
41.5	29.78882	41.500	41.48
Date of measurement (Day 2)	20180309		
Room temperature (ºC)	**21.8**	Room humidity (% rh)	58.3
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.5	29.18294	35.500	35.46
37.0	29.33689	37.000	36.97
41.5	29.78854	41.500	41.45
Date of measurement (Day 3)	20180313		

Room temperature (ºC)	21	Room humidity (% rh)	38
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.5	29.18375	35.500	35.46
37.0	29.33708	37.000	36.97
41.5	29.78937	41.500	41.47

Reporter:

Hsin-yi,Ko

Date:

2020.01.02

Appendix 3: Measurement equipment and standards

Reference blackbody

Reference blackbody cavity: type: ASTM

Cavity serial #: CMS-101

Bath serial #: CMS-TV4000-101

Cavity shape and dimensions: aperture, length, inside diameter etc.:

Property	**Dimension/material**
temperature range	15 °C to 45 °C
length of cavity	202 mm
Aperture of cavity	10 mm
cavity shape	Cylinder with 36.4 degree
Cavity wall thickness	2 mm
Black paint	Nextel velvet-coating 811-21.
emissivity of coating	>0.95 for 8 μm<λ <15 μm
Coating thickness	<50μm
fluid medium	water

Description of fluid bath or furnace:TV-4000++TLC15-5

The TV4000 have a bath volume of 40 liters which with a temperature range from -5 °C to +230°C. Temperature stability is +/- 0.01 °C. The bath is fitted with a double window of which the front panel is detachable for cleaning purposes.

Temperature measurement of reference blackbody

Type of reference sensor: SPRT

Serial number of reference sensor(s): 094867-5

Calibration of reference sensor: TPW/Ga Fixed pts etc.

Type of measuring instrument: FLUKE 1594A

Serial number of measuring instrument: B52263

Measurement current: 1 mA

Depth of insertion of sensor into bath: 210 mm

Radiance temperature measurements

Type of ear thermometer (s) used: Genius

Serial No. of ear thermometers used: J0325162

Short description of radiance temperature difference measurement procedure:

Fix the ear thermometer in the right position. Record the calibration data T1 and the temperature of the reference blackbody (owned by CMS) TS1 in the data sheet. Measured the transfer blackbody and record it T2. The radiance temperature T was calculated by equation 1.

T=T2+(TS1-T1)

Temperature measurement of transfer blackbody PRT

Type of measuring instrument: FLUKE 1594A

Serial number of measuring instrument: B52263

Measurement current: 1 mA

Description of calibration technique

1. An IR ear thermometer was used a cal. mode.

2. The reference laboratory conditions is an ambient temperature of (23 ± 5) °C and a relative humidity of (50 ± 20) %.which is follow EN-12470-5:2003.
3. Such as order of measurement, gloves was used etc.

CMS calibrates the transfer blackbody by comparison with a reference thermometer with a variable temperature blackbody as a source. The reference thermometer is a SPRT which direct realization of the ITS-90.

The calibration system diagram is illustrated in Fig. 1.

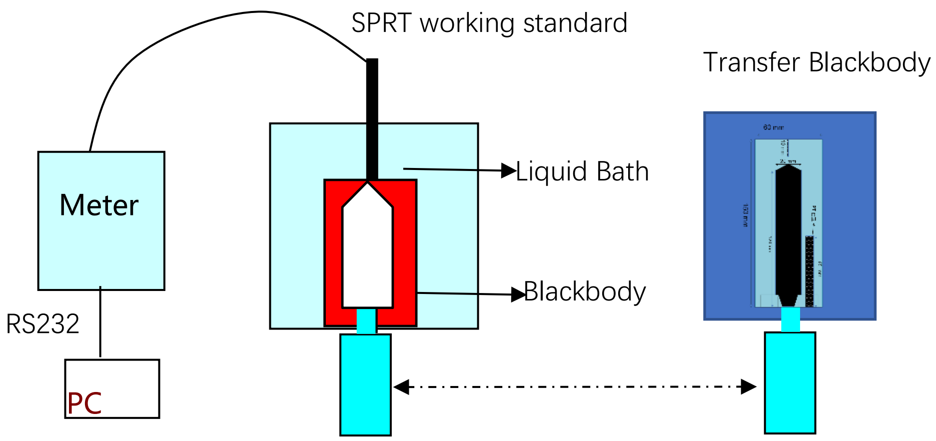


Fig 1 calibration system diagram

Appendix 4: Uncertainty Analysis.

The uncertainty budget should include the following components, to which others can be added if necessary.

- All contributions should be stated at the level of one standard uncertainty.
- Include a brief description of how each uncertainty is estimated.

4. Calibration uncertainty for the reference blackbody cavity
   a) Temperature uniformity
      The temperature uniformity of the temperature controlled stirred water bath are assessed by measuring the temperature difference by two calibrated PRTs which contacts with the cavity immersed in the water bath at two positions. One of which is placed at the tip of the cavity while the other is also placed at the outer surface of the cavity but at a vertical distance of 121 mm from the tip.
   b) Temperature stability
      The short-term stability of the system was evaluated by changing the blackbody SPRT temperatures for a duration of 60 min at three selected temperatures
   c) Cavity emissivity

The effective emissivity of blackbody cavity is evaluated by using Monte Carlo method. The calculations of effective emissivity of an opaque surface are based on reciprocity theorem and the technique of inverse ray tracing.

5. Calibration uncertainty for the reference thermometer
   a) Calibration uncertainty for probe
      The calibration uncertainty of the SPRT can be obtained from its calibration certificate. The SPRT of this system is traceable to the National Measurement Laboratory. The expanded uncertainty and the coverage factor are stated in the calibration certificate. Dividing the expanded uncertainty with its coverage factor, then u= 0.008 °C/2.00 =0.004 °C(at 37 °C). Its relative uncertainty R is estimated to be 10 %. The degrees of freedom are 50.
   b) Drift in sensor since calibration
      The maximum drift of SPRT can be acquired from the calibration certificates and then be taken as the half span of the rectangular probability distribution. The standard uncertainty is therefore u= 0.004/2√3 °C=0.0011 °C(at 37 °C). Its relative uncertainty R is estimated to be 0 %. The degrees of freedom are ∞.
   c) Resistance measurement error
      The resistance measurement uncertainty of the precision digital thermometer obtained from its calibration certificate. The standard uncertainty is therefore u= 0.000025 Ω (at 25 Ω). Its relative uncertainty R is estimated to be 10 %. The degrees of freedom are 50.
6. Measurement of infrared radiance temperature difference
   a) Type-A random uncertainty
      The ambient temperature will affect the sensor and therefore the reading out will vary. This variation is taken as the uncertainty due to the repeatability of the reading out of the radiation thermometer on the same day. The standard deviation of the repeatability of the reading out is 0.020 °C(13 times) at 35.5 °C. The degrees of freedom= 12
   b) Systematic error due to short term sensor drift
      The short term sensor drift uncertainty is due to the reading out of the radiation thermometer on three days. The standard deviation of the repeatability of the reading out is 0.0058 °C(3 times) at 35.5 °C. The degrees of freedom= 2
   c) Resolution of an infrared ear thermometer
      The resolution of the unit being calibrated is 0.01 K. The probability distribution is assumed to be rectangular. The standard uncertainty is u = Resolution / 2√3=0.01/ 2√3≒0.003 K. Its relative uncertainty is estimated to be 0 % and the degrees of freedom is ∞.

Uncertainty Sources	35.5 °C	37 °C	41.5 °C
Temperature uniformity	3 mK	7 mK	10 mK

Temperature stability	6.2 mK	2.8 mK	2.0 mK
Cavity emissivity at (23.0±2) °C	8.5 mK	8.5 mK	12.5 mK
Reference temperature	4 mK	4 mK	4 mK
Drift in sensor since calibration	1.15 mK	1.15 mK	1.44 mK
Resistance measurement error	0.0025 mK	0.0025 mK	0.0025 mK
Type-A random uncertainty	20 mK	21 mK	33 mK
Systematic error due to short term sensor drift	5.8 mK	5.8 mK	15.3 mK
Resolution of an infrared ear thermometer	3 mK	3 mK	3 mK
Combined uncertainty	24.1 mK	25.1 mK	40.2 mK
Expanded uncertainty (k=2)	0.05 °C	0.06 °C	0.09 °C

Appendix 2: Ear-thermometer-blackbody measurement report form

Institute name	NMC , A*STAR		
The start date	18 July 2018	Ending date	20 July 2018
Calibration results of travelling BB			
Date of measurement (Day 1)	18 July 2018		
Room temperature (ºC)	Ave. 24.2	Room humidity (% rh)	Ave. 42.8
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.500	29.1828	35.500	35.451
37.000	29.3361	37.000	36.966
41.500	29.7879	41.500	41.459
Date of measurement (Day 2)	19 July 2018		
Room temperature (ºC)	Ave. 24.1	Room humidity (% rh)	Ave. 43.2
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.500	29.1828	35.500	35.465
37.000	29.3359	37.000	36.964
41.500	29.7879	41.500	41.453
Date of measurement (Day 3)	20 July 2018		
Room temperature (ºC)	Ave. 24.2	Room humidity (% rh)	Ave. 43.5
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.500	29.1828	35.500	35.464

37.000	29.3359	37.000	36.980
41.500	29.7879	41.500	41.467

Reporter：Goh Choon Heng

Reviewed by: Wang Li

Date：15 Nov 2019

Appendix 3: Measurement equipment and standards

1) Reference Blackbody:

- Reference blackbody cavity: Chino type (JIS)
- Bath serial number: AX039AC
- Aperture: Diameter 20 mm
- Length: 200 mm
- Inside Diameter: 60 mm

A cylindrical cone cavity with a conical aperture is designed based on Monte Carlo calculations. The cavity is fully immersed in a temperature controlled stirred water bath with about 20 liter water horizontally. The temperature of the water close to the bottom of the cavity is measured with a SPRT. The cavity's material is copper and the cavity wall's thickness is less than 1 mm. The inner surface of the cavity is coated with high-emissivity black paint (Nextel velvet coating)

2) Temperature measurement of reference blackbody

- Type of reference sensor: SPRT
- Serial number of SPRT: 1802
- Calibration of reference sensor:

Water triple point cell, Gallium melting point cell, Tin freezing point cell and Zinc freezing point cell.

- Type of measuring instrument: ASL F700
- Serial number: 5920006534
- Measuring current : 1 mA
- Depth of insertion of sensor into bath: 15 cm

3) Radiance temperature measurements

- Type of ear thermometers used:

(IRET1) Braun, model IRT 6020, serial no. 24614k34152
(IRET2) Braun, model Pro 6000, serial no. 08617k51602

4) Temperature measurement of transfer blackbody PRT

- Type of measuring instrument used: Fluke, model 1529, serial no. A7A604
- Measuring current : 1 mA

5) Description of calibration technique:

5.1 The transfer blackbody was set to 41.5 °C around 6.30 pm the day before the measurement. The measurements were performed the next day at 41.5 °C, 37.0 °C and 35.5 °C, from high to low temperatures. After completed the last reading, it was set to 41.5 °C again and kept there for overnight in order to carry out the measurements next day.

5.2 Cotton hand gloves were used during the measurements. The Braun ear thermometers were inserted with the new probe covers and avoid touching the covers after installation. During the measurement, the ear thermometers were held in the horizontal position with their probes fully inserted through the aperture of the blackbody and they were aligned along the centre position of the blackbody cavity without touching the side of the blackbody cavity.

5.3 The measurement steps are as below:

- The IRET1 will measure the temperature of the reference blackbody and the reference SPRT's temperature are also taken. Leave the ear thermometer on the table for 1 min before proceeding to next measurement (step 1).
- Next, the IRET1 will measure the temperature of the transfer blackbody and the resistance value of the transfer blackbody's PRT are also taken. Leave the ear thermometer on the table for 1 min before proceeding to next measurement (step 2).
- The measurement sequence will be step 1 → step 2 → step 1, as one set data
- Repeat 10 sets of data for each temperature setting.
- Repeat step 5.3 for IRET2.

5.4 The measurements were performed with the IRET held in vertical position as well. No significant differences were observed

Appendix 4: Uncertainty Analysis.

41.5 °C (Chino Blackbody, using Braun IRT6020 and Braun Welch Ear Thermometer as transfer thermometer)

	Sources of uncertainty	[U](°C)	k	std. uncertainty (u)	u^2	degree of freedom	u^4/DOF
	Uncertainty originated from reference SPRT						
1	Ref. thermometer	0.003	2	0.00150	2.25E-06	1000000	5.06E-18
2	Resolution of the ref thermometer	0.00001	3.464	0.000003	8.33E-12	1000000	6.94E-29
3	Due to immersion error	0.010	1.732	0.005774	3.33E-05	1000000	1.11E-15
4	Repeatability of ref thermometer	0.00013	1	0.000133	1.77E-08	39	8.06E-18
5	Reproducibility of ref thermometer	0.00051	1	0.000351	1.23E-07	5	1.68E-15
	Uncertainty originated from reference blackbody						
6	Ref. blackbody's cavity non uniformity	0.020	1.732	0.011547	1.33E-04	1000000	1.78E-14
7	Ref blackbody stability	0.002	1.732	0.001155	1.33E-06	1000000	1.78E-18
8	Ref. blackbody <>1 (0.999)	0.015	1.732	0.008660	7.50E-05	1000000	5.63E-15
	Uncertainty originated from transfer infrared Ear Thermometer (IRET)						
9	Transfer IRET's resolution	0.01	3.464	0.002887	8.33E-06	1000000	6.94E-17
10	Repeatability of IRET over ref Blackbody	0.00212	1	0.002120	4.49E-06	39	5.18E-13
11	Repeatability of IRET over test Blackbody	0.00285	1	0.002854	8.15E-06	19	3.49E-12
12	Reproducibility ref BB	0.00732	1	0.007319	5.36E-05	5	5.74E-10
13	Reproducibility test BB	0.00648	1	0.006480	4.20E-05	5	3.53E-10

Note: Standard deviation of the mean is taken for S/N 4,5,10,11,12 and 13

sum u^2	0.000362	sum u^4/DOF	9.31E-10
Combined Uncer. (Uc)	0.019	EDOF	**141**
		k	2.00
		Expanded Uncer. (EU	**0.0380**
		Round up (°C)	**0.04**

37 °C (Chino Blackbody, using Braun IRT6020 and Braun Welch Thermometer as transfer thermometer)

	Sources of uncertainty	[U](°C)	k	std. uncertainty (u)	u^2	degree of freedom	u^4/DOF
	Uncertainty originated from reference SPRT						
1	Ref. thermometer	0.003	2	0.0015	2.25E-06	1000000	5.06E-18
2	Resolution of the ref thermometer	0.00001	3.464	0.000003	8.33E-12	1000000	6.94E-29
3	Due to immersion error	0.010	1.732	0.005774	3.33E-05	1000000	1.11E-15
4	Repeatability of ref thermometer	0.00003	1	0.000032	1.03E-09	39	2.74E-20
5	Reproducibility of ref thermometer	0.00014	1	0.000351	1.23E-07	5	1.68E-15
	Uncertainty originated from reference blackbody						
6	Ref. blackbody's cavity non uniformity	0.020	1.732	0.011547	1.33E-04	1000000	1.78E-14
7	Ref blackbody stability	0.002	1.732	0.001155	1.33E-06	1000000	1.78E-18
8	Ref. blackbody <>1 (0.999)	0.011	1.732	0.006351	4.03E-05	1000000	1.63E-15
	Uncertainty originated from transfer infrared Ear Thermometer (IRET)						
9	Transfer IRET's resolution	0.01	3.464	0.002887	8.33E-06	1000000	6.94E-17
10	Repeatability of IRET over ref Blackbody	0.00218	1	0.002184	4.77E-06	39	5.83E-13
11	Repeatability of IRET over test Blackbody	0.00253	1	0.002528	6.39E-06	19	2.15E-12
12	Reproducibility ref BB	0.00590	1	0.005904	3.49E-05	5	2.43E-10
13	Reproducibility test BB	0.00693	1	0.006925	4.80E-05	5	4.60E-10

Note: Standard deviation of the mean is taken for S/N 4,5,10,11,12 and 13

sum u^2	0.000313	sum u^4/DOF	7.06E-10
Combined Uncer. (Uc)	0.018	EDOF	**139**
		k	2.00
		Expanded Uncer. (EU	**0.035**
		Round up (°C)	**0.04**

35.5 °C (Chino Blackbody, using Braun IRT6020 and Braun Welch Ear Thermometer as transfer thermometer)

	Sources of uncertainty	[U](°C)	k	std. uncertainty (u)	u^2	degree of freedom	u^4/DOF
	Uncertainty originated from reference SPRT						
1	Ref. thermometer	0.003	2	0.0015	2.25E-06	1000000	5.06E-18
2	Resolution of the ref thermometer	0.00001	3.464	0.000003	8.33E-12	1000000	6.94E-29
3	Due to immersion error	0.010	1.732	0.005774	3.33E-05	1000000	1.11E-15
4	Repeatability of ref thermometer	0.00007	1	0.000069	4.70E-09	39	5.66E-19
5	Reproducibility of ref thermometer	0.00034	1	0.000351	1.23E-07	5	1.68E-15
	Uncertainty originated from reference blackbody						
6	Ref. blackbody's cavity non uniformity	0.020	1.732	0.011547	1.33E-04	1000000	1.78E-14
7	Ref blackbody stability	0.002	1.732	0.001155	1.33E-06	1000000	1.78E-18
8	Ref. blackbody <>1 (0.999)	0.010	1.732	0.005774	3.33E-05	1000000	1.11E-15
	Uncertainty originated from transfer infrared Ear Thermometer (IRET)						
9	Transfer IRET's resolution	0.01	3.464	0.002887	8.33E-06	1000000	6.94E-17
10	Repeatability of IRET over ref Blackbody	0.00168	1	0.001683	2.83E-06	39	2.06E-13
11	Repeatability of IRET over test Blackbody	0.00260	1	0.002597	6.74E-06	19	2.39E-12
12	Reproducibility ref BB	0.00574	1	0.005742	3.30E-05	5	2.17E-10
13	Reproducibility test BB	0.00429	1	0.004295	1.84E-05	5	6.80E-11

Note: Standard deviation of the mean is taken for S/N 4,5,10,11,12 and 13

sum u^2	0.000273	sum u^4/DOF	2.88E-10
Combined Uncer. (Uc)	0.017	EDOF	**259**
		k	2.00
		Expanded Uncer. (EU	**0.033**
		Round up (°C)	**0.04**

Comparison Result of SCL

Appendix 2: Ear-thermometer-blackbody measurement report form

Institute name	**Standards and Calibration Laboratory**		
The start date	19.10.2018	Ending date	23.10.2018
Calibration results of transfer BB			
Date of measurement (Day 1)	19.10.2018		
Room temperature (ºC)	22.2 — 23.1	Room humidity (% rh)	44.9 — 49.5
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.5	29.182890	35.5	35.39
37.0	29.335904	37.0	36.91
41.5	29.787699	41.5	41.42
Date of measurement (Day 2)	22.10.2018		
Room temperature (ºC)	22.7 — 23.8	Room humidity (% rh)	43.5 — 52.7
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.5	29.182930	35.5	35.38
37.0	29.335841	37.0	36.92
41.5	29.787719	41.5	41.44

Date of measurement (Day 3)	23.10.2018		
Room temperature (ºC)	22.1 — 23.4	Room humidity (% rh)	45.3 — 49.3
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.5	29.182904	35.5	35.40
37.0	29.335838	37.0	36.92
41.5	29.787685	41.5	41.44

Reporter：　Julian Cheung

Date：　1.11.2018

Appendix 3: Measurement equipment and standards

Reference blackbody

Reference blackbody cavity: type: EN 12470-5:2003
Cavity serial #: TE29
Bath serial #: 8308544
Cavity shape of ear thermometer blackbody: The design is as the recommendation in EN 12470-5:2003
Aperture diameter: 9.5 mm

Description of fluid bath or furnace:
The stirred liquid bath Heto KB22 (Serial #: 8308544) is used for this comparison. Our blackbody cavity TE29 was immersed in this bath to calibrate infrared ear thermometers. The fluid in the bath used for this comparison is distilled water.

Temperature measurement of reference blackbody
Type of reference sensor: SPRT (ASL CTP5000-T25B)
Serial number of reference sensor(s): PO00031792-1-4
Calibration of reference sensor: From argon triple point to zinc freezing point.
Type of measuring instrument: ASL-F17A
Serial number of measuring instrument: 1029-3/215
Measurement current: 1 mA
Depth of insertion of sensor into bath: 36 cm
Type of standard resistor for ASL-F17A: Oil-type resistor (Tinsley-5685A)
Serial number of resistor: 248795

Radiance temperature measurements
Type of ear thermometer (s) used: Two BRAUN ThermoScan 7
Serial No. of ear thermometers used: 22316K35035, 22416K31393
Short description of radiance temperature difference measurement procedure:
The reference blackbody cavity was calibrated by PTB in 2-years interval. The radiance temperature is calculated by applying the corrections from the latest PTB certificate to the measured bath temperature. The drift of blackbody was evaluated from the calibration history.

Temperature measurement of transfer blackbody PRT
Type of measuring instrument: ASL CTR6500
Serial number of measuring instrument: 020954/01
Measurement current: 1 mA
Type of standard resistor for ASL CTR6500: Oil-type resistor (Tinsley-5685A)
Serial number of resistor: 263407
Description of calibration technique

1. The transfer blackbody standard was allowed to stabilize in the SCL environment for over

24 hours.

2. The transfer blackbody standard was powered by 230 V, 50 Hz mains supply.

3. Measurements were performed at ambient temperature of (23±1) °C and relative humidity of (45±8) %.

4. The measurements were conducted from high temperature to low temperature.

5. The radiance temperature of transfer blackbody was set to the test point and allowed at least 2 hours for stabilisation.

6. The reference blackbody consists of a blackbody cavity immersed in a water bath (Heto KB22). The bath temperature was set to the same test point and allowed enough time for stablisation. The bath temperature was measured by a SPRT (ASL CTP5000-T25B).

7. The radiance temperatures of the two blackbodies were compared by means of two infrared ear thermometers (BRAUN ThermoScan 7).

8. Before the measurements, the sensor of the infrared ear thermometers was covered with a new and clean lens filter. The operator wore gloves before taking temperature readings of the blackbodies using the two infrared ear thermometers.

9. The sensor of the infrared ear thermometer was positioned into the aperture of the reference blackbody for 10 seconds and a thermometer reading was taken. The corresponding resistance of SPRT was measured by an AC Resistance Bridge (ASL-F17A) with sensing current at 1 mA.

10. The sensor of the infrared ear thermometer was positioned into the aperture of the transfer blackbody for 10 seconds and a thermometer reading was taken. The corresponding resistance of monitor PRT of the transfer blackbody was measured by an AC Resistance Bridge (ASL CTR6500) with sensing current at 1 mA.

11. 10 sets of readings of the reference and transfer blackbody were taken for each test point in one minute interval using the two infrared ear thermometers respectively.

12. The Radiance Temperature (transfer blackbody) obtained from each infrared ear thermometer was the mean of ten readings. The mean of radiance temperature (transfer blackbody) obtained from two infrared ear thermometers was the reported Radiance Temperature (transfer blackbody).

Appendix 4: Uncertainty Analysis.

Uncertainty Components	Type	*35.5*	*37*	*41.5*	
Uncertainty due to random effects	A	7.86	7.46	13.06	mK
SPRT Calibration	B	1.00	1.00	1.00	mK
Self heating effect of SPRT	B	0.36	0.36	0.36	mK
SPRT Type 1 non-uniqueness	B	0.31	0.32	0.34	mK
SPRT Type 3 non-uniqueness	B	0.10	0.11	0.12	mK
Bridge Ratio Reading	B	0.33	0.34	0.34	mK
Standard Resistor	B	0.07	0.07	0.07	mK
R(0.01) of SPRT	B	0.22	0.22	0.22	mK
Bath Gradient	B	2.89	2.89	2.89	mK
Infrared ear thermometer repeatability	B	40.00	40.00	40.00	mK
Infrared ear thermometer resolution	B	2.89	2.89	2.89	mK
Calibration of Reference Blackbody	B	25.00	25.00	25.00	mK
Drift of Reference Blackbody	B	11.55	11.55	11.55	mK
Reproducibility of different results	A	2.69	2.85	4.36	mK
Combined standard uncertainty (u_c)		**50**	**50**	**51**	**mK**
Expanded Uncertainty (*U*) (*k*=2)		**100**	**100**	**102**	**mK**

Note 1 : Uncertainty due to random effects

The calculated radiance temperature was taken as the arithmetic mean of 10 measurements. Totally, 6 sets of measurements were taken in 3 days with 2 SCL infrared thermometers. The 10 measurements with largest standard deviation were used to calculate the type A uncertainty.

Note 2 : SPRT Calibration

From in-house calibration using fixed point cells

Note 3 : Self heating effect of SPRT

From in-house calibration.

Note 4: SPRT Type 1 non-uniqueness

The standard uncertainty = $(8.0\text{x}10^{-6})\,|(W-1)(W-W_{Sn})(W-W_{Zn})|(dT/dW)$

where Aij can be found in section 7 of CCT/08-19

Note 5: SPRT Type 3 non-uniqueness

The standard uncertainty is calculated according to Table 7.2 and 7.3 in CCT/08-19

Note 6 : Bridge ratio reading

From the specification of the ASL F17A resistance bridge

Note 7 : Standard Resistor

From in-house calibration

Note 8 : R(0.01) of SPRT

From in-house calibration

Note 9 : Bath gradient

From in-house calibration

Note 10 : Infrared ear thermometer repeatability

Two infrared ear thermometers were used as comparators. The short term repeatability was derived from the observed span during the measurements. The standard uncertainty was taken as 0.04 °C.

Note 11 : Infrared ear thermometer resolution

The resolutions of infrared ear thermometers are 0.01 °C.

The uncertainties is taken as rectangularly distributed with semi-range = 0.5 x resolution

So the standard uncertainty = resolution/ 2/ $\sqrt{3}$

Note 12: Calibration of Reference Blackbody

The blackbody was calibrated by PTB. The uncertainty was from the latest PTB certificate.

Note 13: Drift of Blackbody

It was derived from the calibration history of the blackbody.

Note 14: Reproducibility of different results

The type A uncertainty of 6 sets of measurements in 3 days.

Comparison Result of KRISS

Appendix 2: Ear-thermometer-blackbody measurement report form

Institute name	**KRISS**		
The start date	14/01/2019	Ending date	16/01/2019
Calibration results of transfer BB			
Date of measurement (Day 1)			
Room temperature (ºC)	**23.1**	Room humidity (% rh)	42
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.5	29.1829	35.5	35.382
37.0	29.3362	37.0	36.897
41.5	29.7880	41.5	41.364
Date of measurement (Day 2)			
Room temperature (ºC)	**23.3**	Room humidity (% rh)	42
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.5	29.1829	35.5	35.380
37.0	29.3362	37.0	36.898
41.5	29.7881	41.5	41.365
Date of measurement (Day 3)			
Room temperature (ºC)	**23.2**	Room humidity (% rh)	43
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.5	29.1829	35.5	35.387
37.0	29.3363	37.0	36.897
41.5	29.7879	41.5	41.363

Reporter：　Yong Shim Yoo

Date：　14/11/2020

Appendix 3: Measurement equipment and standards

Reference blackbody

1. Kambic bath : Model OB-15/2 H (Serial #:10103570)
   Description of fluid bath: internal dimensions (cross x immersion depth) in mm : ø225 x 230, temperature range: -10 ℃ ~ 100 ℃, temperature display resolution: 0.01, set up resolution: 0.1 ℃.
2. Reference blackbody cavity: a modified JIS T 4207 (Serial #: None) blackbody cavity with a Teflon-made adapter for ø 10 mm aperture. The cavity is made of copper with its thickness of 2 mm and coated with Pyromark 1200 paint.
   Dimensions: aperture (ø10 mm), length (193 mm), inside diameter (ø 60 mm), bottom apex angle (120°), aperture side conical angle (100°)

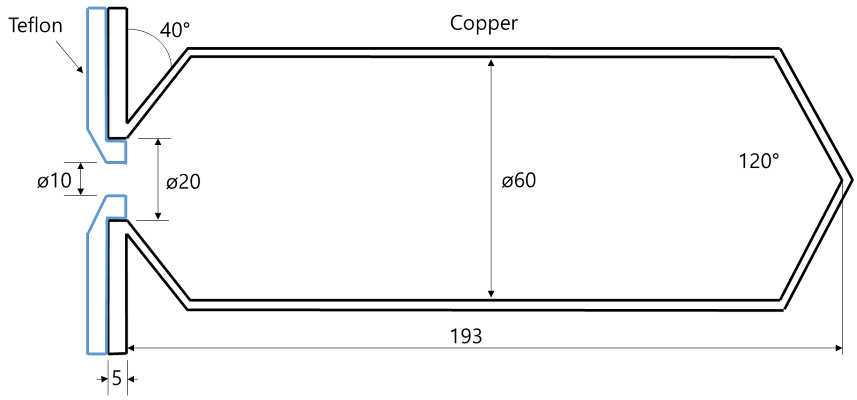


Figure 1 Schematic diagram of the modified JIS T 4207 blackbody cavity with a Teflon-made adapter for ø 10 mm aperture (in mm)

Temperature measurement of reference blackbody

1. Type of reference sensor: ISOTECH SPRT 670SH
2. Serial number of reference sensor(s): 207
3. Calibration of reference sensor: TPW/Sn/Zn Fixed points.
4. Type of measuring instrument: ASL-F700A
5. Serial number of measuring instrument: 6531011545
6. Measurement current: 1 mA
7. Depth of insertion of sensor into bath: 180 mm

Radiance temperature measurements

1. Type of ear thermometer (s) used: microlife IR150

2. Serial No. of ear thermometers used: 160301085, 160301168, 160300088
3. Short description of radiance temperature difference measurement procedure:

- The transfer BB and the reference BB were placed away from air louvers.
- The transfer BB and the reference BB were turned on and set to 41.5 °C at night before every measurement day.
- The temperature of the reference BB was determined from readings by our resistance measuring system ASL-F700A for about 20 minutes.
- The monitor PRT of the transfer BB was connected to our ASL-F700A and then the resistance was read during the comparison measurement.
- Radiance temperatures of both BB were measured by three ear thermometers. Each ear thermometer alternatively read the temperatures of both BB in a short time of 5 seconds to reduce the systematic error due to its short term drift. It read the radiance temperature 10 times from each BB.
- The temperatures of both BB were changed to the next set point.

Temperature measurement of transfer blackbody PRT

1. Type of measuring instrument: ASL-F700A
2. Serial number of measuring instrument: 6531011545
3. Measurement current: 1 mA

Description of calibration technique

- Each ear thermometer alternatively read the temperatures of both BB in a short time of 5 seconds to reduce the systematic error due to its short term drift.
- A holder and two stoppers were used to fast align the tip of the probe with the opening center of the cavity as shown in Figure 2. In addition, the holder protects the ear thermometer from the heat of hands.

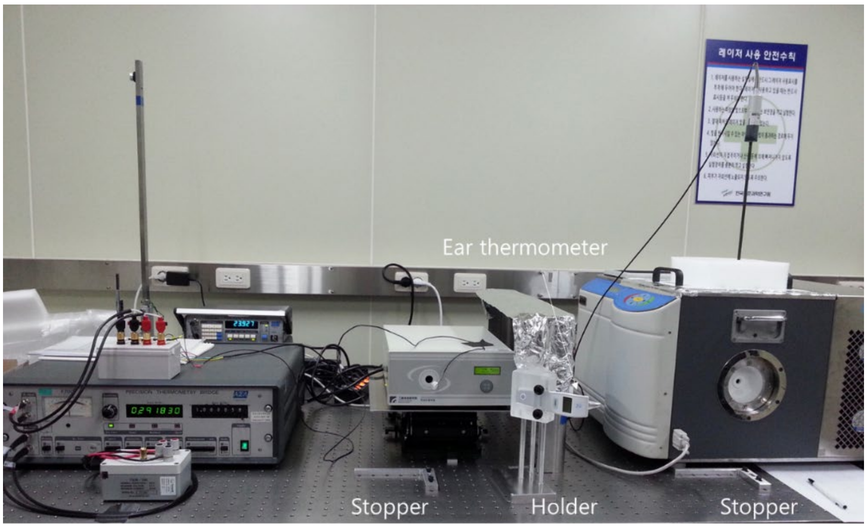


Figure 2 Set up for calibration of the transfer BB using ear thermometers

- **Appendix 4: Uncertainty Analysis.**

Component of uncertainty			Uncertainty contribution (mK)		
			35.5 °C	37 °C	41.5°C
Reference thermometer	Calibration of SPRT		2	2	2
	Drift of SPRT		2	2	2
	Resistance measurement error		1	1	1
Reference blackbody	Temperature stability of water-bath		2	2	2
	Heat loss inside the cavity		1	1	1
	Cavity emissivity	Paint emissivity	5	5	7
		Change in ambient temperature	2	2	2
		Non-isothermal distribution	13	13	14
Ear thermometer	repeatability		16	14	14
	resolution		3	3	3
Combined standard uncertainty (*k*=1)			22	21	22

1. Uncertainty for the reference thermometer
    - **Calibration of SPRT**: The SPRT was calibrated in the range of the triple point of water to the freezing point of Zn point. The uncertainty of the calibration is 2 mK.
    - **Drift of SPRT**: The SPRT was recalibrated after the comparison. The uncertainty due to the drift is 2 mK.
    - **Resistance measurement error**: The resistance of the SPRT was measured by the ASL-F700A. The internal resister was calibrated by a Guildline 100 ohm standard resister (7334-100) with uncertainty of 0.1ppm (*k*=2). The stability of the internal resister for one week was measured within 2 ppm. The uncertainty contribution due to resistance measurement error is estimated to 1 mK.

2. Uncertainty for the reference blackbody
    - **Temperature stability of water-bath**: The temperature homogeneity in the water-bath was measured by using the SPRT at 9 SPRT positions along and around the cavity. The temperature stability in the water-bath was measured at one of 9 SPRT positions for 10 hours. The homogeneity was the same level as the stability. Therefore the stability was only considered as an uncertainty component.
    - **Heat loss inside the cavity**: It was calculated with the emissivity of the paint itself and the cavity.
    - **Cavity emissivity**: It was calculated by using the commercially available software STEEP322. In the calculations, the emissivity of Pyromark 1200 was set to 0.9 ± 0.05 with total diffuse reflection at a wavelength of 11 μm. The ambient temperature was set to (23 ± 2)°C. The emissivity value is estimated with the paint emissivity of 0.9 and the ambient temperature of 23°C, taking into account the non-

isothermal distribution with the linear temperature gradient.

- **Paint emissivity**: the uncertainty contribution of cavity emissivity due to the paint emissivity was estimated by using the emissivity difference from the cavity emissivity calculated with the paint emissivity of 0.85.
- **Change in ambient temperature**: The uncertainty contribution of cavity emissivity due to the ambient temperature was estimated by using the emissivity difference from the cavity emissivity calculated with the ambient temperature of 25℃.
- **Non-isothermal distribution**: The uncertainty contribution of cavity emissivity due to the non-isothermal distribution in the cavity was estimated by using the emissivity difference from the cavity emissivity calculated with the isothermal distribution. The temperature distribution inside the cavity was not measured but quoted from the paper [Physiol. Meas. 25(2004) 1239-1247] conservatively. To be precise, the cavity was assumed to have linear temperature gradient from the tip of the bottom cone to the opening. The temperature difference between the tip and the opening was set to 20 mK.

3. Uncertainty for the ear thermometer
   - **Repeatability**: It was estimated from the standard deviation of the 30 data of the radiance temperature difference between the two BB.
   - **Resolution**: The resolution of the ear thermometer was 10 mK because the ear thermometer was operated in calibration mode.
   - Systematic error due to short term drift: An alternative reading of the temperatures of both BB were performed in a short time of 5 seconds to reduce the systematic error due to its short term drift. Nevertheless, if the systematic error had existed, its effect must have been included in the uncertainty of repeatability.

Appendix 2: Ear-thermometer-blackbody measurement report form

Institute name	**BSN, Indonesia**		
The start date	6-8-2019	Ending date	8-8-2019
Calibration results of transfer BB			
Date of measurement (Day 1)	6 – 8 - 2019		
Room temperature (ºC)	**23**	Room humidity (% rh)	49
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.5	29.183516	35.5	36.02
37.0	29.337602	37.0	37.46
41.5	29.786208	41.5	42.02
Date of measurement (Day 2)	7 – 8 - 2019		
Room temperature (ºC)	**23**	Room humidity (% rh)	49
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.5	29.184876	35.5	35.93
37.0	29.335916	37.0	37.43
41.5	29.793373	41.5	42.00

Date of measurement (Day 3)	8 – 8 - 2019		
Room temperature (ºC)	**23**	Room humidity (% rh)	49
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.5	29.185053	35.5	35.88
37.0	29.337602	37.0	37.46
41.5	29.787077	41.5	42.05

Reporter: Hidayat Wiriadinata

Date: 7 Jul. 2020

Appendix 3: Measurement equipment and standards

Reference blackbody

Reference blackbody cavity: type:,JIS T4207
Cavity serial #: XXXXX
Bath serial #: Scandura 3213
Cavity shape and dimensions: aperture = 12 mm, length = 145 mm, inside diameter = 50 mm.
Description of fluid bath or furnace:
Method of measuring instability and temperature uniformity in stirred water bath using methods that have been reported by Tsai, S.F [Tsai, S., Comparison measurements of infrared ear thermometers against three types of blackbody sources. International Journal of Thermophysics, 2010. 31 (8-9): p. 1821-1831.]

Temperature measurement of reference blackbody
Type of reference sensor: SPRT
Serial number of reference sensor(s): XXXXX
Calibration of reference sensor: comparison in baths
Type of measuring instrument: HART super thermometer1575A

Serial number of measuring instrument or: A76263
Measurement current: 1 mA
Depth of insertion of sensor into bath: XXX

Radiance temperature measurements
Type of ear thermometer (s) used: Microlife AG 9443
Serial No. of ear thermometers used: 16170116
Short description of radiance temperature difference measurement procedure: Before measuring the artifact, the ear thermometer was calibrated against the blackbody reference

Temperature measurement of transfer blackbody PRT
Type of measuring instrument: HART super thermometer 1575A
Serial number of measuring instrument: A76263
Measurement current: 1 mA

Description of calibration technique
such as order of measurement, gloves used etc

- The transfer blackbody was connected to the power line of AC 240 V (a stabilized low-noise power supply).
- The transfer standard blackbody was set at a place away from air louvers of the air conditioner of the laboratory
- Turn on the transfer BB and set to 35.5 ºC using the button on the front panel.
- Connect the monitor PRT leads to super thermometer and check that after 60 minutes or more of operation the resistance is stable at the 4 mΩ (10 mK) level for more than 10 minutes.
- The comparator was an ear thermometers which its resolution is 0.01 °C.
- Calibration has been carried out at temperatures: 35.5 oC, 37.0 oC and 41.5 oC.
- At each temperature, the PRT measurement results were recorded with a super thermometer
- the temperature displayed on the blackbody transfer display was recorded
- the temperature measured with our ear thermometer was also recorded
- when measuring the temperature of the blackbody our hands are equipped with gloves.
- Before and after taking measurements we record the temperature and humidity of the room.

Appendix 4: Uncertainty Analysis.

The uncertainty budget should include the following components, to which others can be added if necessary.

- All contributions should be stated at the level of one standard uncertainty.

- Include a brief description of how each uncertainty is estimated.

7. Calibration uncertainty for the reference blackbody cavity
   a) Temperature uniformity

	35,5	37	41,5
mK	2.0	1.0	1

   b) Temperature stability

	35,5	37	41,5
mK	2.0	3.0	4.0

   c) Cavity emissivity :
   0.99984 ± 0.00005 (2s)
8. Calibration uncertainty for the reference thermometer
   Reference Thermometer : Pt-100 Hart Scientific S.N. 1618B/821461
   a) Calibration uncertainty for probe : u = 0.03 °C
   b) Drift in sensor since calibration : u = 0.01°C
   c) Resistance measurement error : u = 0.04 °C

9. Measurement of infrared radiance temperature difference
   a) Type-A random uncertainty

	35,5	37	41,5
mK	6.7	6.7	6.7

   b) Systematic error due to short term sensor drift

	35,5	37	41,5
mK	50	50	50

   c) Resolution of an infrared ear thermometer

	35,5	37	41,5
mK	10	10	10

Uncertainty budget BBR SNSU-BSN				
Uncertainty component	**Unit**	**Temperature of Blackbody Cavity**		
		35.5 °C	**37 °C**	**41.5 °C**
		Uncertainty		
Stability of water bath	mK	2.0	3.0	4.0
Uniformity of water bath	mK	2.0	1.0	1.0
Heat loss inside cavity	mK	1.5	1.5	1.5
Effective emissivity of isothermal cavity	mK	3.6	3.7	3.8
Effect of temperature distribution of cavity wall	mK	5.2	5.1	5.0
Effect of change in ambient temperature	mK	5.0	5.0	7.0
Calibration of reference thermometer	mK	30	30	30
Drift in sensor	mk	9.9	9.9	9.9
Resistance measurement error	mK	44	44	44
Repeatability reading	mK	6.6	6.6	6.6
Systematic error due to short term sensor drift	mK	50	50	50
Resolution of an infrared ear thermometer	mk	10.0	10.0	10.0
Combined standard uncertainty	**mK**	**74.5**	**74.5**	**74.7**
Extended uncertainty 95% C.L.	**mK**	**149.0**	**149.1**	**149.5**

Comparison Result of NMIJ

Appendix 2: Ear-thermometer-blackbody measurement report form

Institute name	NMIJ/AIST		
The start date	Dec. 18, 2019	Ending date	Dec. 20, 2019
Calibration results of transfer BB			
Date of measurement (Day 1)	Dec. 18, 2019		
Room temperature (ºC)	21.5	Room humidity (% rh)	50.7
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.5	29.1835	35.500	35.446
37.0	29.3373	37.000	36.963
41.5	29.7890	41.500	41.428
Date of measurement (Day 2)	Dec. 19, 2019		
Room temperature (ºC)	22.5	Room humidity (% rh)	49.2
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.5	29.1834	35.500	35.445
37.0	29.3372	37.000	36.952
41.5	29.7890	41.500	41.438

Date of measurement (Day 3)	Dec. 20, 2019		
Room temperature (ºC)	22.4	Room humidity (% rh)	49.3
Set temperature (ºC)	Average Resistance of monitor PRT (Ω)	Average Indicated temperature (ºC)	Average Radiance temperature measured by participant(ºC)
35.5	29.1836	35.500	35.432
37.0	29.3370	37.000	36.957
41.5	29.7889	41.500	41.443

Summary

Set temperature (ºC)	Average Radiance temperature (ºC)	Expanded uncertainty (k = 2) (ºC)
35.50	35.44	0.03
37.00	36.96	0.03
41.50	41.44	0.04

Reporter: Naohiko Sasajima

Date: April 1st, 2021

Appendix 3: Measurement equipment and standards

Reference blackbody

Reference blackbody cavity: type: JIS T4207

Cavity serial #: No serial number

Bath serial #: AX998NK01

Cavity shape and dimensions: aperture, length, inside diameter etc.

Figure l shows the cavity shape and dimensions of the blackbody cavity.

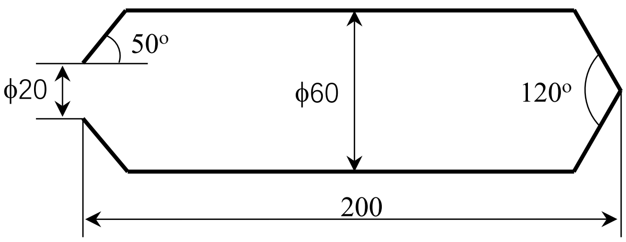


Figure 1 Geometry of the cylindrical cavity of the reference blackbody (unit in mm)

Description of fluid bath or furnace: (short description)

Figure 2 shows a schematic cross-sectional view of the blackbody constructed at NMIJ. The blackbody covers the temperature range from 30 °C to 50 °C. The cavity is manufactured from copper. The thickness of the cavity wall is less than 1 mm. The inner surface of the cavity is coated with high-emissivity black paint (Nextel velvet coatings). The cavity is fully immersed in the temperature-controlled stirred water bath, the volume of which is about 20 liters. The temperature of the water close to the bottom of the cavity is measured by a PRT sensor (Netsusin NSR-160 l00 □).

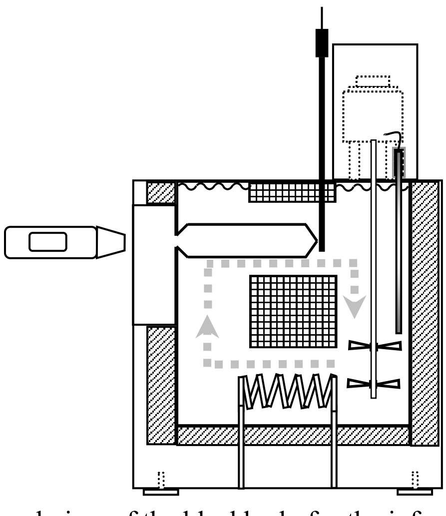


Figure 2: Cross-sectional view of the blackbody for the infrared ear thermometers.

Temperature measurement of reference blackbody

Type of reference sensor: PRT sensor, Netsusin NSR-160

Serial number of reference sensor(s): NS-15023

Calibration of reference sensor: TPW and In fixed point

Type of measuring instrument: Fluke Super-thermometer 1594A

Serial number of measuring instrument: B11055

Measurement current: 0.5 mA
Depth of insertion of sensor into bath: 12 cm

Radiance temperature measurements
Type of ear thermometer (s) used: Citizen Watch CT-810
Serial No. of ear thermometers used: No serial number
Short description of radiance temperature difference measurement procedure:

Three CT-810 ear thermometers, which were manufactured by Citizen Watch with the resolution of 0.01 ºC, were used in the radiance temperature comparison, and 10 continuous comparative measurements were performed for each ear thermometer at each temperature. The measurements were repeated for 3 days to confirm reproducibility. At each temperature, the difference in radiance temperature between the NMIJ reference blackbody and the transfer blackbody was calculated, and the statistical dispersion was calculated from 90 data using analysis of variance. The estimated dispersion was taken into account for contribution of standard uncertainty of the radiance comparison. This uncertainty includes contributions of stability and reproducibility of both the ear thermometer and the transfer blackbody.

Temperature measurement of transfer blackbody PRT
Type of measuring instrument: Fluke Super-thermometer 1594A
Serial number of measuring instrument: B11055
Measurement current: 1 mA

Description of calibration technique
such as order of measurement, gloves used etc.
Gloves used

Appendix 4: Uncertainty Analysis.

Table 1 shows uncertainty budget of body-temperature standard blackbody. Each uncertainty component was estimated as follows.

a1) Fixed-point calibration of PRT

Standard uncertainty of fixed-point calibration of reference platinum resistance thermometer: data from calibration certificate

a2) Self-heating effect of the PRT sensor

Average of the results of measurement by changing stepwise current level for resistance measurement at TPW.

a3) Interpolation error

Data from empirical knowledge

a4) Standard uncertainty of standard resistance

Data from calibration certificate

a5) Stability of resistance measurement

Accuracy of resistance measurement instrument, and long-term stability of reference standard resistance

a6) Long-term stability of reference platinum resistance thermometer

Data from empirical knowledge

a7) Short-term stability of the fluid-bath temperature

Standard deviation of measured temperature of the working fluid

b1) Effective emissivity of the cavity:

Effective emissivity of the cavity is calculated based on the Monte Carlo method, considering geometry of the cavity shape, intrinsic emissivity of the cavity wall, temperature distribution around the cavity (non-isothermal effect), and background thermal radiation from surroundings.

b2) Heat-loss effect of the cavity

Effect of the heat loss of the cavity is estimated on the assumption of a simple radiative heat exchange.

Table 1 Uncertainty budget of body-temperature standard blackbody

			Temperature			
		Type	35.5	37.0	41.5	ºC
Uncertainty in calibration	Fixed-point calibration of PRT	B	5.0			mK
Uncertainty in temperature measurement	Self-heating effect of PRT	B	3.0			mK
	Interpolation error	B	1.0			mK
	Standard resistance	B	1.0			mK

	Stability of resistance measurement	B	1.0			mK
	Long-term stability of reference PRT	B	5.0			mK
	Stability of the water bath	A	1.7	2.2	1.4	mK
Uncertainty in cavity	Effective emissivity（View angle: 90°, Ambient temperature: 23 °C)	B	11	12	16	mK
	Non-isothermal effect	B	1.0			mK
	Instability of ambient temp. (23 °C ± 2 °C)	B	2.0			mK
	Heat loss	B	1.0			mK
Combined standard uncertainty			13.9	14.7	18.1	mK

Table 2 shows uncertainty budget of radiance comparison of body-temperature blackbody. Each uncertainty component was estimated as follows.

c1) Uncertainty in standard blackbody

Standard uncertainty calculated in Table 1.

c2) Uncertainty in dispersion of radiance measurement

Three CT-810 ear thermometers were used in the radiance temperature comparison, and 10 continuous comparative measurements were performed for each ear thermometer at each temperature. The measurements were repeated for 3 days. The dispersion of the measured deviation from the standard blackbody was calculated from the 90 data based on the analysis of variance. The estimated dispersion was taken into account for contribution of standard uncertainty of the radiance comparison. This uncertainty includes contributions of stability and reproducibility of both the CT-810 ear thermometer and the transfer blackbody.

c3) Uncertainty in resolution of an infrared ear thermometer

Calculated from the resolution of 0.01 °C.

Table 2 Uncertainty budget of radiance comparison of body-temperature blackbody

Temperature	35.5	37	41.5	°C
Uncertainty in standard blackbody	13.9	14.7	18.1	mK
Uncertainty in dispersion of radiance measurement	2.6	2.5	3.0	mK
Uncertainty in resolution of an ear thermometer	2.9	2.9	2.9	mK
Combined standard uncertainty	14.4	15.2	18.5	mK
Expanded uncertainty (k = 2)	29	30	37	mK