COMPARISON OF A RADIATION THERMOMETER IN THE RANGE FROM -30 °C TO 600 °C BETWEEN MIRS/UL-FE/LMK AND NPL

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Abstract: The article presents the results of comparison in the field of radiation thermometry, where the artefact was a radiation thermometer, which is used as the reference radiation thermometer (national standard) in Slovenia in the range below 600 °C. The comparison was performed to compare the realization of the ITS-90 through the calibration of a radiation thermometer between MIRS/UL-FE/LMK and NPL. Results confirmed calibration measurement capabilities (CMC) of MIRS/UL-FE/LMK which will be entered to the Key Comparison Database (KCDB) of the Bureau International des Poids et Mesures (BIPM).

Keywords: radiation thermometer, interlaboratory comparison, blackbody, size of source effect

1. Introduction

The Slovenian holder of a national standard for thermometry MIRS/UL-FE/LMK agreed with the UK national measurement institute NPL the measurements to compare the realization of the ITS-90 through the calibration of a radiation thermometer in the range from -30 °C to 600 °C. The chosen radiation thermometer is one of the Slovenian national standards for temperature and provides traceability of radiation thermometry in Slovenia in the range from -30 °C to 600 °C. The range was agreed to verify the calibration measurement capabilities of MIRS/UL-FE/LMK in the field of radiation thermometry, in which the last extensive interlaboratory comparison within EURAMET TC Thermometry was conducted almost 20 years ago in the project called TRIRAT [1]. MIRS/UL-FE/LMK joined the project in the last stage but due to the problems with the reference radiation thermometer we were not able to perform the measurements. The comparison of realization in the field of radiation thermometry between MIRS/UL-FE/LMK and NPL was agreed in the scope of EURAMET TC Thermometry project number 1394 in March 2016. For the comparison measurements the protocol was written in which the details of preparation, execution and analysis of results were given.

2. Protocol of comparison

It was agreed that the coordinator for the comparison was MIRS/UL-FE/LMK which also provided the transfer standard and all necessary provisions (protocol, spreadsheets for analysis of results, final report) for the comparison to be executed successfully. Measurements were performed first at the MIRS/UL-FE/LMK, then at the NPL and repeated at the MIRS/UL-FE/LMK. At each set temperature (-30 °C, 0 °C, 100 °C, 250 °C, 400 °C and 600 °C) at least 12 measurements of the

thermometer reading and the temperature of the blackbody source were taken. At 250 °C the measurements were performed in the LT (low temperature range -50 °C to 300 °C) and MT (middle temperature range 150 °C to 1000 °C). The results were entered to the template (Excel spreadsheet) provided by the coordinator. The positioning (centering, aligning and focusing) of the radiation thermometer in front of the blackbody furnaces was made following own procedures of both participants. Besides comparison measurement also ambient conditions (temperature, relative humidity) and other relevant data about used equipment (reference standards and their traceability, emissivity, the size of aperture, dimensions, shape and temperature homogeneity of a blackbody) were given.
The measurements to determine the size-of-source effect (SSE) of the transfer standard were performed at all set temperatures but 0 °C by the direct method. The value of SSE was used as one component in the uncertainty budget.

2.1 Transfer standard

The transfer standard used was the radiation thermometer Heitronics Transfer Radiation Thermometer TRT II, serial number 3330.
The detector type A has the spectral range from 8 μm to 14 μm in the low temperature range from -50 °C to 300 °C, where its nominal target size is 6,8 mm at the distance of 380 mm. The detector operates at the wavelength of 3,9 μm in the middle temperature range from 150 °C to 1000 °C, where its nominal target size is 5,6 mm at the distance of 360 mm.
Manual setting of emissivity was not possible. Emissivity setting resolution was 0,001 and could only be set in the dedicated software via interface to the value of 1,000. The response time was 1 second. Heat-up time of the thermometer was 1 hour.

2.2 Blackbodies

In MIRS/UL-FE/LMK four variable temperature blackbodies were used. In the temperature range from -30 °C to 250 °C three copper cavities of the same aperture 60 mm and length of the cavity 42 cm with 120 ° end cone were used in three commercial baths (Tamson T2500). The complete setup was manufactured at MIRS/UL-FE/LMK. The cavities were sandblasted and painted with the high emissivity paint (Pyromark 800, flat black) several times until the surface was completely covered with the paint. After the final painting the cavity was heated for 24 hours at 100 °C to allow the paint to dry and bake to the surface. Emissivity of the cavities is 0,9992. The reference temperature of blackbodies was measured with three PRTs (100 ohms) with the uncertainty of U(2s)=25 mK.
The first bath was filled with ethanol and was used from -30 °C to 0 °C. Temperature stability of the blackbody was 14 mK (2s) while temperature homogeneity was 20 mK (2s).
The second bath was filled with the middle temperature silicon oil and was used from 50 °C to 150 °C. Temperature stability of the blackbody was 60 mK (2s) while temperature homogeneity was 134 mK (2s).
The third bath was filled with the high temperature silicon oil and was used from 150 °C to 250 °C. Temperature stability of the blackbody was 70 mK (2s) while temperature homogeneity was 94 mK (2s).
In the range from 300 °C to 600 °C the cesium heat pipe was used. The Inconel cavity has the aperture diameter of 50 mm, length of the cavity is 50 cm, and 120 ° end cone. Emissivity of the cavity is 0,9994. Temperature stability of the blackbody was 56 mK (2s) while temperature homogeneity was 130 mK (2s).

In NPL four variable temperature blackbodies were used. In the temperature range from -40 °C to 50 °C the ammonia heat pipe was used. Its cavity has the aperture diameter of 75 mm, the length of 300 mm, and 120 ° end cone. Emissivity of the cavity is 0,9993. Temperature stability of the blackbody was 26 mK (2s) while temperature homogeneity was 30 mK (2s).

In the temperature range from 50 °C to 1000 °C the wide range cavity is used but in the comparison this blackbody was used in the range from 100 °C to 250 °C. Its Inconel cavity has the aperture diameter of 30 mm, the length of 245 mm, with pyramid end wall. The cavity was used in the furnace with 3 heated zones. Emissivity of the cavity is 0,999. Temperature stability of the blackbody was 26 mK (2s) while temperature homogeneity was 60 mK (2s).
In the range from 300 °C to 400 °C the cesium heat pipe was used. The Inconel cavity has the aperture diameter of 41 mm, length of the cavity is 358 mm, and 120 ° end cone. Emissivity of the cavity is 0,9994. Temperature stability of the blackbody was 26 mK (2s) while temperature homogeneity was 32 mK (2s).
At the temperature of 600 °C the sodium heat pipe was used. The Inconel cavity has the aperture diameter of 41 mm, length of the cavity is 358 mm, and 120 ° end cone. Emissivity of the cavity is 0,9994. Temperature stability of the blackbody was 30 mK (2s) while temperature homogeneity was 40 mK (2s).

2.3 Uncertainty budget

Uncertainty budget was based on the uncertainty components given in the document CCT-WG5 on Radiation Thermometry Uncertainty Budgets for Calibration of Radiation Thermometers below the Silver Point [2]. Some values for uncertainties, which could not be measured, referred to the mentioned document. Example of the uncertainty budget at 250 °C for MIRS/UL-FE/LMK is given in Table 1, while for NPL is given in Table 2.

Table 1: Uncertainty budget of MIRS/UL-FE/LMK at 250 °C (LT range)

250 °C (HT oil bath)	description	quantity	probability distribution	value / mK
Blackbody	calibration temperature (standard deviation)	$u_{1A}(T)$	normal	12
	calibration temperature (reference thermometer)	$u_{1B}(T)$	normal	25
	blackbody emissivity, non-isothermal	$u_5(T)$	rectangular	110
	reflected ambient radiation	$u_6(T)$	normal	50
	cavity bottom heat exchange	$u_7(T)$	rectangular	30
	convection	$u_8(T)$	rectangular	75
	cavity bottom uniformity	$u_9(T)$	normal	50
	ambient conditions	$u_{10}(T)$	normal	30
Radiation thermometer LT range	size of source effect	$u_{11}(S)$	rectangular	100
	resolution of instrument	$u11b$ (S)	rectangular	29
	non-linearity	$u_{12}(S)$	normal	0
	reference temperature	$u_{13}(T)$	normal	0
	ambient temperature	$u_{14}(S)$	normal	10
	athmosferic absorption	$u_{15}(S)$	normal	0
	gain ratios	$u_{16}(S)$	normal	0
	noise	$u_{17}(S)$	normal	10
	combined standard uncertainty			191
	expanded uncertainty / mK			381
	rounded uncertainty / K			0,4

Table 2: Uncertainty budget of NPL at 250 °C (LT range)

250 °C (Wide range furnace)	description	quantity	probability distribution	value / mK
Blackbody	calibration temperature (standard deviation)	$u_{1A}(T)$	normal	0
	calibration temperature (reference thermometer)	$u_{1B}(T)$	normal	13
	blackbody emissivity, non-isothermal	$u_5(T)$	rectangular	125
	reflected ambient radiation	$u_6(T)$	normal	26
	cavity bottom heat exchange/ gradients	$u_7(T)$	rectangular	173
	convection	$u_8(T)$	rectangular	29
	cavity bottom uniformity	$u_9(T)$	normal	30
	ambient conditions	$u_{10}(T)$	normal	0
Radiation thermometer LT range	size of source effect	$u_{11}(S)$	rectangular	0
	alignment on calibration source	$u11a$ (S)	rectangular	58
	resolution of instrument	$u11b$ (S)	rectangular	29
	non-linearity	$u_{12}(S)$	normal	0
	reference temperature	$u_{13}(T)$	normal	0
	ambient temperature	$u_{14}(S)$	normal	0
	athmosferic absorption	$u_{15}(S)$	normal	0
	gain ratios	$u_{16}(S)$	normal	0
	noise	$u_{17}(S)$	normal	11
	combined standard uncertainty			229
	expanded uncertainty / mK			458
	rounded uncertainty / K			0,5

3. Results

Results of comparison measurements in terms of correction and associated uncertainties as well as claimed CMCs are given in Table 3. The same results are also presented for all measured temperatures in Figures 1 to 7. In Figure 8 the SSE is presented as measurements were performed at MIRS/UL-FE/LMK at 250 °C for LT and MT range. We used a dedicated system for measuring the SSE with the direct method [3]. It consisted of a water cooled copper holder for aluminum plates with apertures of a different diameter and thickness of 2 mm. We used apertures with diameters from 60 mm to 11,9 mm. The results are presented only down to 13,9 mm aperture diameter because at 11,9 mm aperture the signal dropped for more than 5 %.

The results of comparison confirmed the acceptable level of equivalence between MIRS/UL-FE/LMK and NPL in realization of the ITS-90 through the calibration of a radiation thermometer in the range from -30 °C to 600 °C.

As an additional tool of acceptable level of equivalence also the E_{n} number (Equation 1) was calculated for each measured temperature, where X is a measured value and U is the expanded measurement uncertainty at particular temperature. The E_{n} numbers for all measured temperatures are given in Table 3.

$$E_n = \frac{X_{\mathrm{LMK}} - X_{\mathrm{NPL}}}{\sqrt{U_{\mathrm{LMK}}^2 + U_{\mathrm{NPL}}^2}} \qquad (1)$$

Table 3: Results of comparison measurements

	MIRS-UL/FE-LMK			NPL			
Set	Corr.	*U (95%)*	CMC	Corr.	*U (95%)*	CMC	E_n
°C	K	K	K	K	K	K	/
-30	-0,81	0,4	0,4	-0,51	0,2	0,1	-0,67
0	-0,26	0,4	0,4	-0,07	0,2	0,1	-0,42
100	0,41	0,4	0,4	0,81	0,4	0,1	-0,71
250 (LT)	0,69	0,4	0,4	1,10	0,5	0,2	-0,69
250 (MT)	0,37	0,4	0,4	0,74	0,5	0,2	-0,61
400	0,95	0,5	0,5	1,40	0,2	0,2	-0,83
600	1,66	0,5	0,5	1,70	0,3	0,3	-0,07

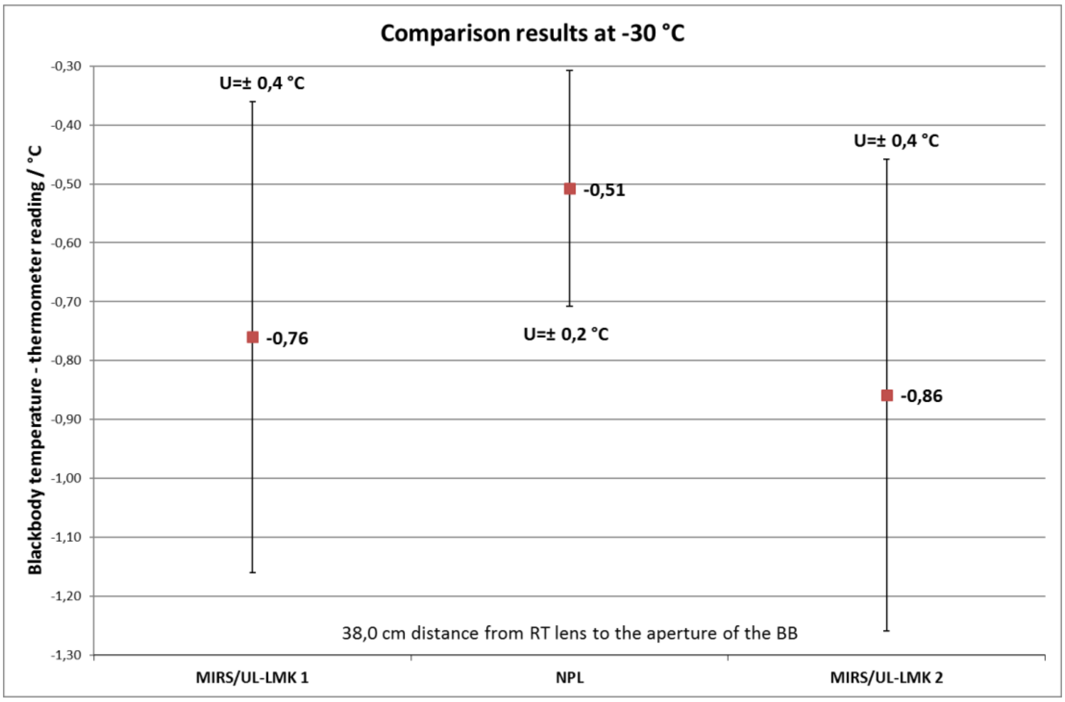

Figure 1: Results of comparison between MIRS/UL-FE/LMK and NPL at -30 °C

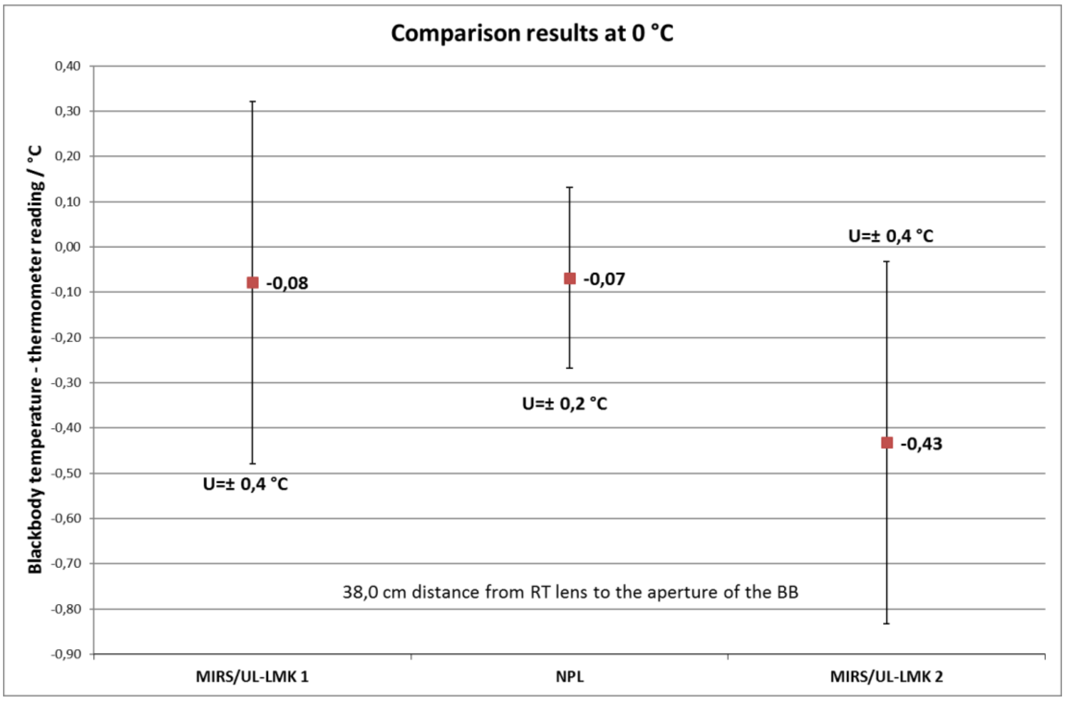

Figure 2: Results of comparison between MIRS/UL-FE/LMK and NPL at 0 °C

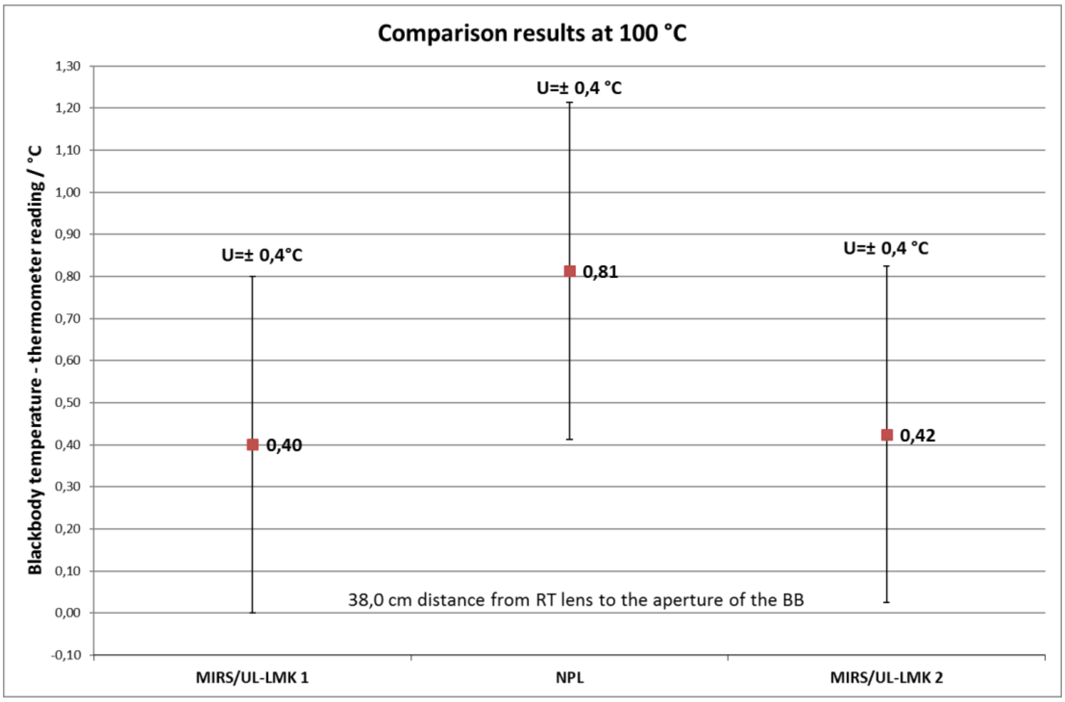

Figure 3: Results of comparison between MIRS/UL-FE/LMK and NPL at 100 °C

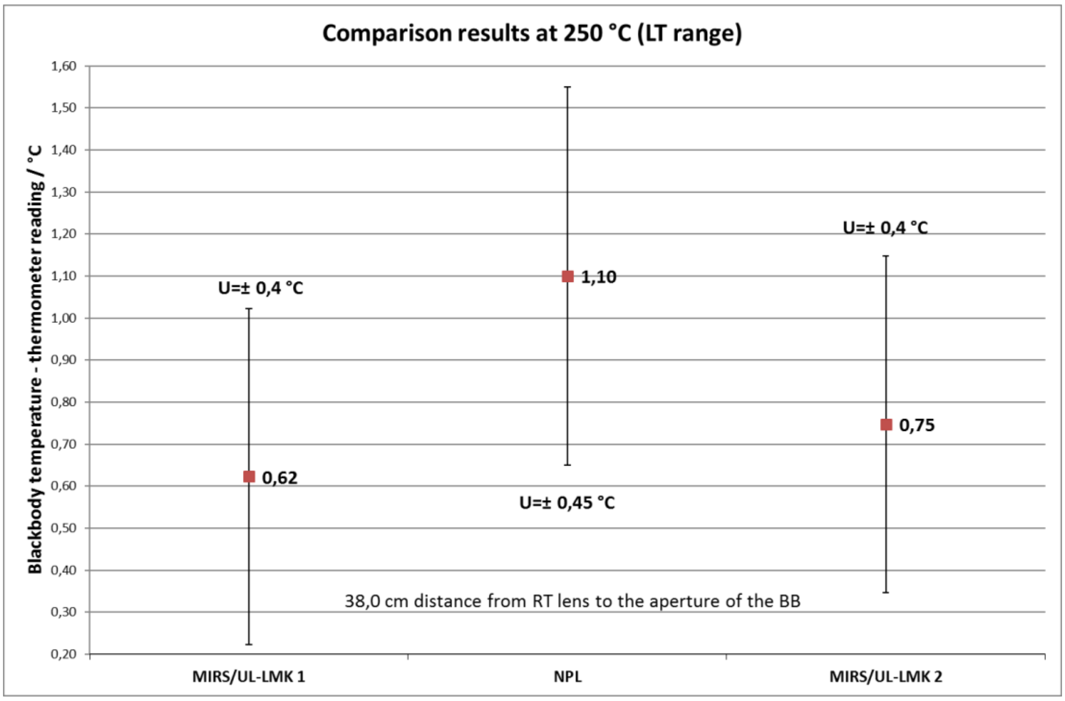

Figure 4: Results of comparison between MIRS/UL-FE/LMK and NPL at 250 °C (LT range)

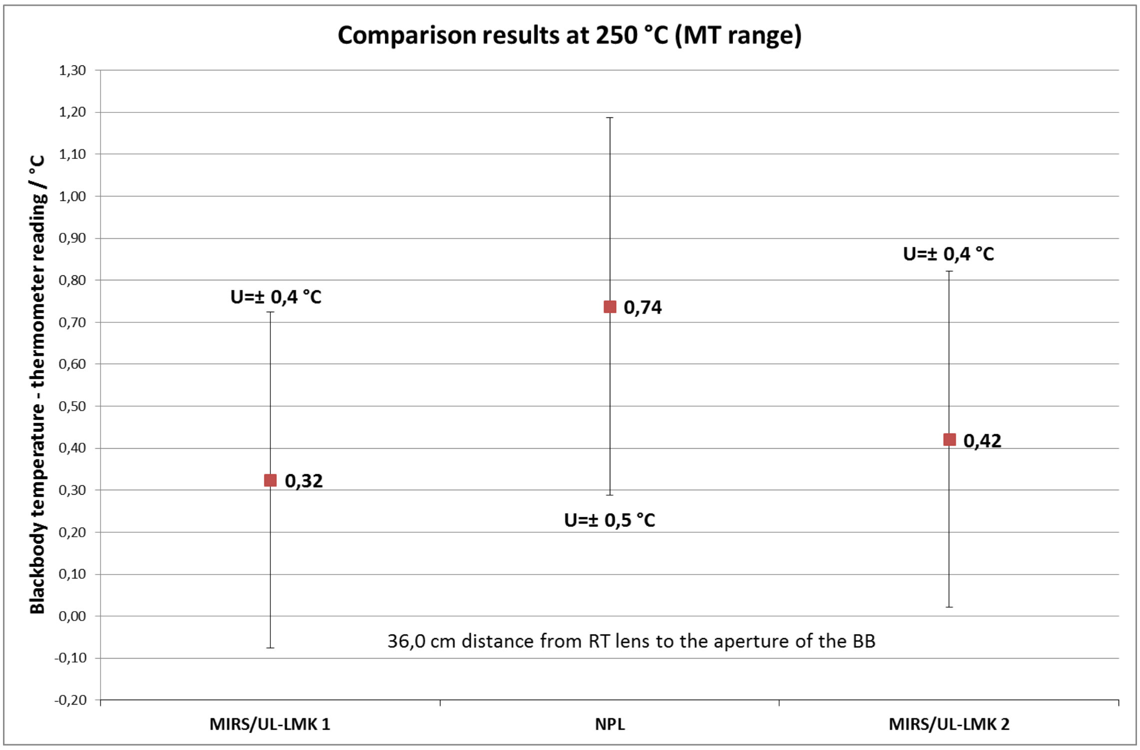

Figure 5: Results of comparison between MIRS/UL-FE/LMK and NPL at 250 °C (MT range)

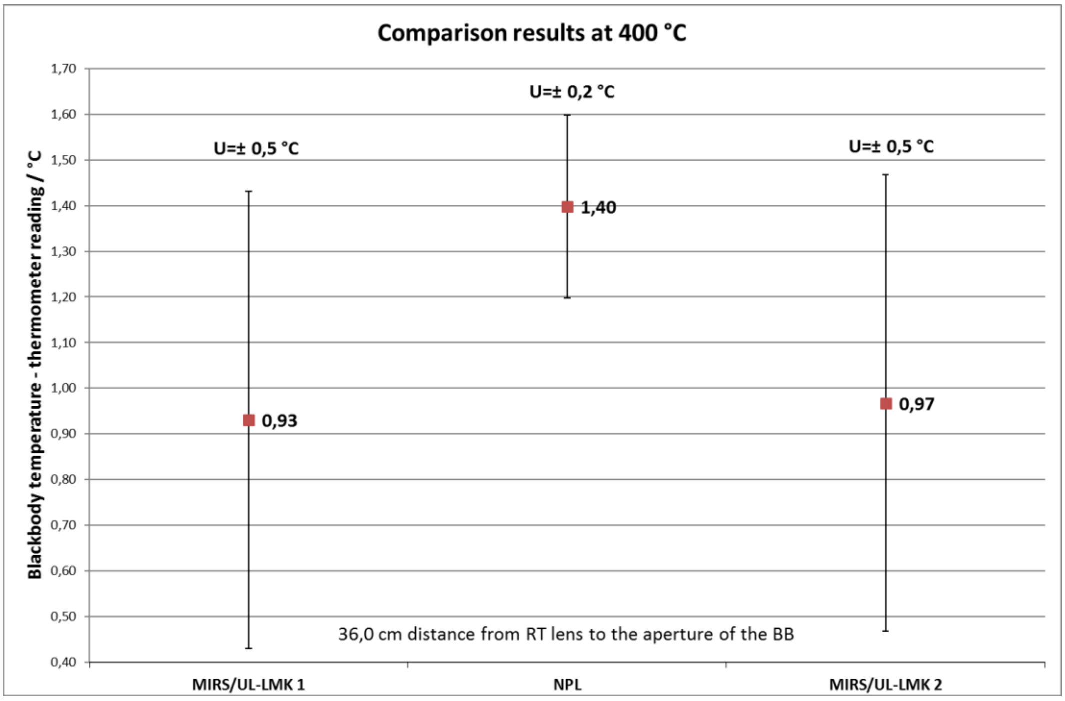

Figure 6: Results of comparison between MIRS/UL-FE/LMK and NPL at 400 °C

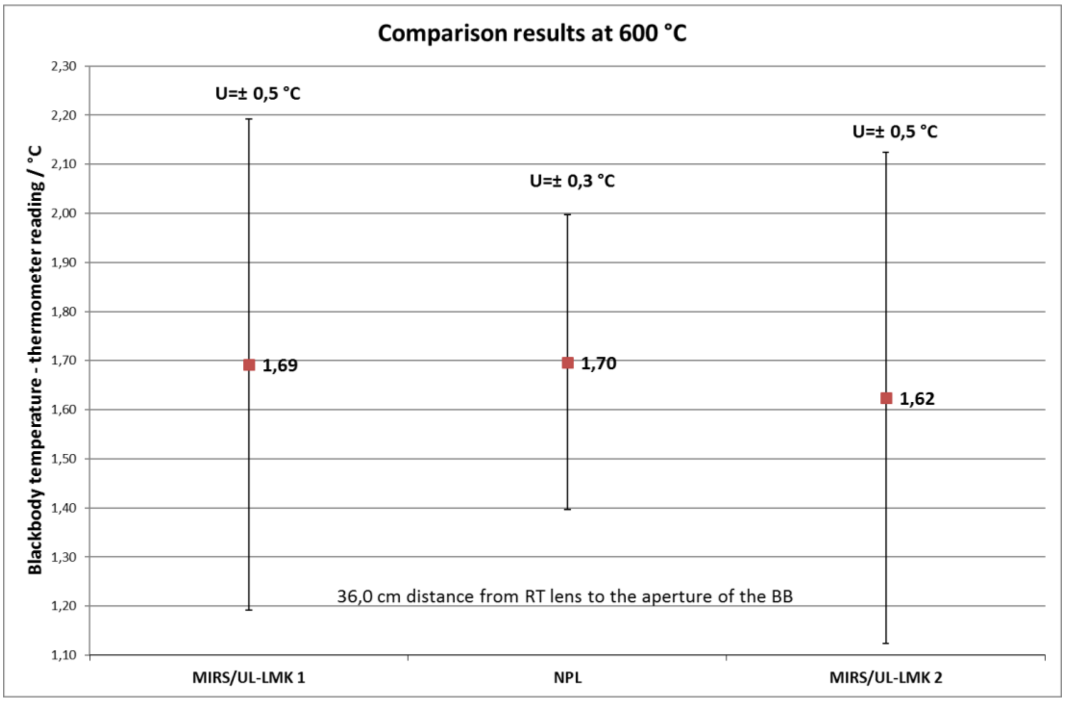

Figure 6: Results of comparison between MIRS/UL-FE/LMK and NPL at 600 °C

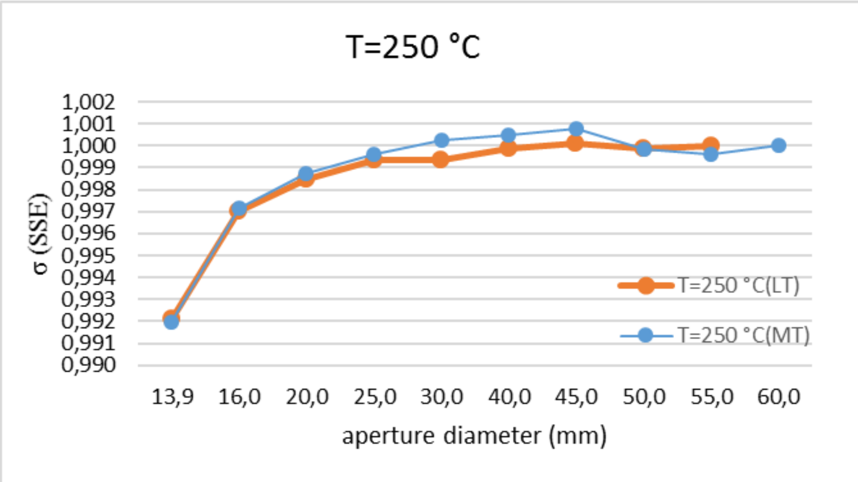

Figure 7: Results of SSE measurements at 250 °C

4. Discussion and conclusions

The main objective of the comparison was to confirm the CMCs of MIRS/UL-FE/LMK which were submitted to the KCDB of the BIPM. The results showed good agreement of realizations of the ITS-90 in both institutes but in the range from -30 °C to 600 °C.

There are also strong demands for regional ILCs in radiation thermometry, especially because the last comparison within EURAMET TC Thermometry ILC was dated 20 years ago (October 1996 to April 2002). Such ILCs are not only important for those institutes which would like to submit their CMCs to the KCDB but also to regularly check the performance of national laboratories.

References

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