29th Oct. 2009

(Revised 17th May 2010)

Radiation Thermometry Review Protocol

Scope: To provide a method of reviewing thermometry CMC's in the sub-field of radiation thermometry for acceptance in Appendix C of the KCDB. Covers service category numbers 1.1.2, 1.2.2, 1.4 and 2.5 of the "CLASSIFICATION OF SERVICES IN THERMOMETRY (May 2008)" in the KCDB.

Review guidelines (cf. Table 1):

Items Used for Defining ITS-90 (Service categories 1.1.2, 1.2.2, 1.4)

IF <Criterion 1: OK> & <Criterion 2: OK >

THEN: Scrutiny at the level determined by Scrutiny Rule 0, 1 or 2 (rule selected according to Table 1)

ELSE: RMO and WG8 scrutiny

Items Used for Disseminating ITS-90 (Service category 2.5)

IF <Criterion 1: OK> & <Criterion 2: OK >

THEN: Scrutiny at the level determined by Scrutiny Rule 0 or 3 (rule selected according to Table 1)

ELSE: RMO scrutiny.

Scrutiny levels classified by Cut-off values ($U_{\text{Table }X}$) of Table 1

Scrutiny Rule 0

Accept without scrutiny

Scrutiny Rule 1

IF	$U_{\text{CMC}} / U_{\text{Table }X} \geq 1$	THEN: Accept without scrutiny
IF	$1 > U_{\text{CMC}} / U_{\text{Table }X} \geq 2/3$	THEN: RMO scrutiny
IF	$2/3 > U_{\text{CMC}} / U_{\text{Table }X}$	THEN: RMO scrutiny and WG8 scrutiny

Scrutiny Rule 2

IF	$U_{\text{CMC}} / U_{\text{Table }X} \geq 3/2$	THEN: Accept without scrutiny
IF	$3/2 > U_{\text{CMC}} / U_{\text{Table }X} \geq 1$	THEN: RMO scrutiny
IF	$1 > U_{\text{CMC}} / U_{\text{Table }X}$	THEN: RMO scrutiny and WG8 scrutiny

Scrutiny Rule 3

IF	$U_{\text{CMC}} / U_{\text{Table }X} \geq 1$	THEN: Accept without scrutiny
IF	$1 > U_{\text{CMC}} / U_{\text{Table }X}$	THEN: RMO scrutiny

($U_{\text{Table }X}$: U value in "Table X", where X=2 to 6 as indicated in Table 1 "Cut-off values")

Table 1 Radiation thermometry CMC review guidelines[*0]

Service category		Examples of instrument or artifact	Condition	Criterion 1 KC/SC	Criterion 2 Additional	Scrutiny rule No.	Cut-off values
1. Items Used for Defining ITS-90							
1.1.2	Primary fixed point cells for radiation thermometry	Ag/Au/Cu point blackbody cell	KC of FP available	"KC(FP)[*1] result OK"	–	0	–
			KC[*2] of ITS-90 scale only	"KC(Scale)[*3] result OK"	–	0	–
				"KC(Scale)[*3] result OK wth U_{NMIKCFP}"	–	1	Table 2
			Not a primary realization	–	"Ref. standard[*4] CMC OK"	2	Table 2
1.2.2	Complete apparatus realizing fixed points for radiation thermometry	Ag/Au/Cu point blackbody furnace	KC of FP available	"KC(FP)[*1] result OK"	–	0	–
			KC[*2] of ITS-90 scale only	"KC(Scale)[*3] result OK"	–	0	–
				"KC(Scale)[*3] result OK wth $U_{\mathrm{NMI\ KC\ FP}}$"	–	1	Table 2
			Not a primary realization	–	"Ref. standard[*4] CMC OK"	2	Table 2
1.4	Standard Radiation Thermometers	0.65 μm / 0.9 μm standard radiation thermometer with direct ITS-90 realization, 0.65 μm / 0.9 μm standard radiation thermometer calibrated by comparison above 962 °C	Same wavelength[*5] as KC	"KC result OK"	–	0	–
			Not same wavelength as KC but same wavelength[*5] as SC	"KC result OK"	"SC result OK"	0	–
			Not same wavelength as KC and no SC with same wavelength[*5]	"KC result OK"	–	1	Table 3
			Not a primary realization	–	"Ref. standard[*6] CMC OK"	2	Table 3
2. Items Used for Disseminating ITS-90							
2.5.1	Secondary fixed-point blackbody cells and complete instruments	Hg/Ga/In/Sn/Zn/Al/Ag point blackbody cell/furnace	SC of FP available	"SC(FP)[*1] result OK"	–	0	–
			SC[*2] of ITS-90 scale only	"SC(Scale)[*3] result OK"	–	0	–
				"SC(Scale)[*3] result OK wth $U_{\mathrm{NMI\ SC\ FP}}$"	–	3	Table 4
			Not a primary realization	–	"Ref. standard[*6] CMC OK"	3	Table 4
2.5.2	Variable temperature blackbody radiation sources	VTBB calibrated by a standard radiation thermometer, VTBB calibrated by radiance comparison against a standard VTBB		–	"Ref thermometer[*7] CMC OK"	3	Table 3,5
2.5.3	Strip lamps	Vacuum lamps, gas filled lamps		"KC result OK"	–	0	–
2.5.4	Radiation thermometers	3.9 μm / 8–14 μm radiation thermometer including thermal imagers calibrated by VTBB against a reference thermometer, 0.9 μm / 1.6 μm radiation thermometer calibrated by 3-fixed-point / 4-fixed-point interpolation	Same wavelength[*5] as SC	"SC result OK"	–	0	–
			Not same wavelength[*5] as SC	"SC result OK"	–	3	Table 5
			No SC	–	"Ref. standard[*8] CMC OK"	3	Table 5
	Visual optical pyrometers	Disappearing filament pyrometer		–	"Ref. standard[*9] CMC OK"	3	Table 6

" – " means no criterion/value applicable/needed

"KC/SC result OK" means[*10]:

$$|V_{\mathrm{NMI,KC/SC}} - V_{\mathrm{KC/SCRV}}| < \sqrt{U^2_{\mathrm{NMI\,CMC}}(k=2) + U^2_{\mathrm{KC/SC}}(k=2) + U^2_{\mathrm{KC/SC\,RV}}(k=2)}$$

and

$U_{\text{NMI CMC}} \geq U_{\text{NMI KC/SC}}$

and

$$U_{\text{NMI CMC}} > \sqrt{U^2_{\text{KC/SC}}(k=2) + U^2_{\text{KC/SC RV}}(k=2)} \Big/ 3$$

for the temperature indicated in Table 7.

"KC/SC result OK with $U_{\text{NMI KC/SC FP}}$" means:

$$|V_{\text{NMI,KC/SC}} - V_{\text{KC/SC RV}}| < \sqrt{U^2_{\text{NMI CMC}}(k=2) + U^2_{\text{KC/SC}}(k=2) + U^2_{\text{KC/SC RV}}(k=2)}$$

and

$U_{\text{NMI CMC}} \geq U_{\text{NMI KC/SC FP}}$

and

$$U_{\text{NMI CMC}} > \sqrt{U^2_{\text{KC/SC}}(k=2) + U^2_{\text{KC/SC RV}}(k=2)} \Big/ 3$$

for the temperature indicated in Table 7.

"Ref standard / thermometer CMC OK" means:

Reference standard / thermometer CMC approved for the same temperature

and

$U_{\text{NMI CMC}} > U_{\text{Ref CMC}}$

Here,
- $U_{\text{NMI CMC}}$ is the NMI's CMC uncertainty.
- $U_{\text{KC/SC}}$ is the uncertainty of the KC/SC
- $U_{\text{KC/SC RV}}$ is the uncertainty of the KC/SC reference value
- $U_{\text{NMI KC/SC}}$ is the NMI's KC/SC uncertainty
- $U_{\text{NMI KC/SC FP}}$ is the uncertainty of the NMI's fixed point in the KC/SC
- $U_{\text{Ref CMC}}$ is the CMC of the reference standard
- $V_{\text{NMI,KC/SC}}$ is the NMI's KC/SC result
- $V_{\text{KC/SCRV}}$ is the KC/SC reference value

Notes

*0: For CMCs not requiring a KC, documented evidence may include comparisons that are not registered in the KCDB.

*1: Key/supplementary comparison of fixed points such as in COOMET T-K5.

*2: Key/supplementary comparison of a scale realized with reference to the relevant fixed point.

*3: Key/supplementary comparison of temperature scales such as in CCT-K5, EUROMET K-5, APMP T-K5 and APMP T-S2.

*4: Reference standard in service category 1.1.2 or 1.2.2 (e.g. of another NMI), to which

the artifact is traceable.

*5: Wavelength range for which the effect of difference in wavelength is small enough that it has no relevance on the U_{CMC}.

*6: Reference standard in the same service category (e.g. of another NMI), to which the instrument/artifact is traceable.

*7: Reference radiation thermometer that is used for calibrating the VTBB under calibration, or reference thermometer that gives the temperature of the standard VTBB.

*8: Reference thermometer that gives the reference temperature of the blackbody, or secondary fixed-point blackbodies.

*9: Reference strip lamp/radiation thermometer, to which the instrument is traceable.

*10: Criteria for evaluating comparison results follow those of the former Radiation Thermometry CMC Review Protocol

Scrutiny items required for RMO and WG8 scrutiny

- Detailed analysis of calibration method and uncertainty analysis according to WG5 uncertainty documents [1, 2], and
- Other supporting evidence, such as Peer Review report or International Comparison results.

Reference

[1] J.Fischer, M.Battuello, M.Sadli, M.Ballico, S.N.Park, P.Saunders, Yuan Z., B.C.Johnson, E.van der Ham, Wang L., F.Sakuma, G.Machin, N.Fox, S.Ugur, M.Matveyev "CCT-WG5 on radiation thermometry, Uncertainty budgets for realization of scales by radiation thermometry", CCT/03-03
Summary in *Temperature, Its Measurement and Control in Science and Industry*, vol.7, D.C.Ripple ed., Melville, New York, pp.631-638 (2003)

[2] J.Fischer, P.Saunders, M.Sadli, M.Battuello, C.W.Park, Yuan Z., H.Yoon, Wang L., E.van der Ham, F.Sakuma, Y.Yamada, M.Ballico, G.Machin, N.Fox, J.Hollandt, M.Matveyev, P.Bloembergen, S.Ugur, "CCT-WG5 on radiation thermometry, Uncertainty budgets for calibration of radiation thermometers below the silver point", Ver. 1.71, CCT-WG5/docs-03 (2008)
Summary in *Int. J. Thermophys.*, vol. 29, pp.1066-1083 (2008)

[3] Kostkowski & Lee, "Theory and Methods of Optical Pyrometry", in *Temperature, Its Measurement and Control in Science and Industry*, vol. 3, pp.449-481 (1962)

Appendix 1: Cut-off values

Table 2 Service Categories 1.1.2/1.2.2

Fixed point	$U(k=2)$ / mK
Ag, Au, Cu	50

The threshold value is the normal uncertainty for the Cu point calibration in [1].

Table 3 Service Categories 1.4/2.5.2

T / K	t / °C	$U(k=2)$ / K
1000	726.85	0.19
1100	826.85	0.18
1200	926.85	0.18
1300	1026.85	0.2
1400	1126.85	0.23
1500	1226.85	0.29
1600	1326.85	0.35
1700	1426.85	0.44
1800	1526.85	0.53
1900	1626.85	0.97
2000	1726.85	1.11
2100	1826.85	1.26
2200	1926.85	1.41
2300	2026.85	1.58
2400	2126.85	1.75
2500	2226.85	1.95
2600	2326.85	1.64
2700	2426.85	1.82
2800	2526.85	2.01
2900	2626.85	2.21
3000	2726.85	2.42

The threshold value is the maximum of the arithmetic mean of the combined normal and best uncertainties for the three schemes in [1].

Table 4 Service Category 2.5.1

Fixed point	$U(k=2)$ / mK
Hg	265
Ga	78
In	71
Sn	96
Zn	174
Al	149
Ag	267

The threshold value is the arithmetic mean of the combined normal and best uncertainties*A1 for the fixed-point calibration in [2].

Note

*A1: “Normal” is evaluated for the wavelength that gives the largest uncertainty among the possible choices of wavelength at that temperature, and “best” for the one that gives the smallest. For instance, for the Ag point, “normal” is evaluated with 3.9 μm, while “best” is evaluated with 0.9 μm.

Table 5 Service Categories 2.5.2/2.5.4

t / °C	$U(k=2)$ / mK			
	0.9 µm	1.6 µm	3.9 µm	8-12 µm
-40				395
0				322
20			156	304
30			151	299
100			141	305
150		95	151	312
157		93	153	311
200		91	166	303
232		100	175	297
300		129	192	286
400		166	204	400
420	108	171	204	458
500	143	184	204	751
600	196	186	209	
660	208	183	223	
700	207	181	239	
800	186	193	308	
900	202	250	416	
962	272	311	500	
1000	339			
1085	540			

The threshold value is the maximum value of the arithmetic mean of the combined normal and best uncertainties for the VTBB and FPBB scheme at that temperature [2].

Table 6 Service Category 2.5.4

t / °C	$U(k=2)$ / K
800	4.0
1000	3.2
1200	3.4
1400	4.0
1600	4.5
1800	5.1
2000	5.7
2200	6.3
2400	6.8
2600	7.4
2800	8.0

The threshold values are from [3].

Appendix 2: CMC service categories and supporting KCs and SCs

Table 7

Key and Supplemetary Comparisons on KCDB appendix B (as of May 2010)		Field	Radiation Thermometry					
		Comparison name	CCT-K5	APMP T- K5	EUROMET T- K5	COOMET T- K5	EUROMET T- S1	APMP T- S2
		Range, years	Realizations of the ITS-90 between 961 ° C and 1700 ° C 1997 – 1999	Comparison of realization of the ITS-90 using radiation thermometry over the range 962 ° C and 2800 ° C 1997 – 2000	Realizations of the ITS-90 up to 1700 ° C 1999 – 2000	Realizations of the ITS-90 between 961 ° C and 1084 ° C 2008 – 2009	Examination of base parameters for ITS-90 scale realisation in radiation thermometry 2003 – 2004	Calibration of radiation thermometer 2000 – 2003
		Comparison type, Field	Key comparison in Thermometry, Pyrometry	Key comparison in Thermometry, Pyrometry	Key comparison in Thermometry, Pyrometry	Key comparison in Thermometry, Pyrometry Freezing points of Silver, Gold, and Copper	Supplementary comparison in Thermometry, Pyrometry	Supplementary comparison in Thermometry, Pyrometry Temperature: 400 ° C to 2000 ° C
		Status	Approved for equivalence, Results available	Approved for equivalence, Results available	In progress	Proposed	Approved and published	Approved and published
Service category		Supporting temperature range						
1. Items Used for Defining ITS-90								
1.1.2	Primary fixed point cells for radiation thermometry	$T_{CMC} = T_{KC/SC}$ or $T_{KC/SC}(n) < T_{CMC} < T_{KC/SC}(n+1)$	Δ	Δ	Δ	√		
1.2.2	Complete apparatus realizing fixed points for radiation thermometry	$T_{CMC} = T_{KC/SC}$ or $T_{KC/SC}(n) < T_{CMC} < T_{KC/SC}(n+1)$	Δ	Δ	Δ	√		
1.4	Standard Radiation Thermometers	$T_{KC/SC,min} - 60\ K < T_{CMC} < T_{KC/SC,max} + 60\ K$	√	√	√			√
2. Items Used for Disseminating ITS-90								
2.5.1	Secondary fixed-point blackbody cells and complete instruments	$T_{CMC} = T_{KC/SC}$ or $T_{KC/SC}(n) < T_{CMC} < T_{KC/SC}(n+1)$						Δ
2.5.2	Variable temperature blackbody radiation sources	$T_{KC/SC,min} - 60\ K < T_{CMC} < T_{KC/SC,max} + 60\ K$	Δ	Δ	Δ			Δ
2.5.3	Strip lamps	$T_{KC/SC,min} - 60\ K < T_{CMC} < T_{KC/SC,max} + 60\ K$	√	√	√			
2.5.4	Radiation thermometers	$T_{KC/SC,min} - 60\ K < T_{CMC} < T_{KC/SC,max} + 60\ K$						√
	visual optical pyrometers	$T_{KC/SC,min} - 60\ K < T_{CMC} < T_{KC/SC,max} + 60\ K$						
					: Approved	√ : Fully supports CMC		
					: On going	Δ : Partially supports CMC		