

# CCT experience (comparisons and CMCs)

**BIPM-SIM Training course: KCDB2.0**

**April 22<sup>nd</sup>, 2022**



# Background

- Peculiarities of the CCT, with respect to the other CCs, in dealing with comparisons and CMCs:
  - CMCs:
    - **CMC review protocols**: a set of technical guidelines used in the CMC review process
  - Comparisons
    - **Working Group on Key Comparisons (WG-KC)**: a specific WG that oversees all aspects of key comparison documentation

# Overview

## ➤ **CMC review protocols:**

- Origin of CMC Review Protocols
- Preparation of CMC Review Protocols: CCT WG-CMC
- CMC Service Categories
- CMC Review Protocols: general principles and key elements
- CMC review process: flowchart diagram

## ➤ **WG-KC:**

- Tasks
- Membership
- CCT KC/SC review process
- Checklists for pilots

# The origin of CMC Review Protocols (2002)

- First meeting of RMO chairs in 2002 (ITS-7, Chicago):
  - Attempt to understand the different non-harmonized ways RMOs were reviewing each other's CMC submissions
  - Philosophical differences in implementing the MRA and the JCRB directives created:
    - Unforeseen problems in having an RMO accept the CMCs of another RMO
    - Non-harmonized service categories and uncertainty evaluation approaches caused confusion until approval

# The origin of CMC Review Protocols (2002)

- JCRB created *Terms of Reference* to allow CCs to create WGs on CMCs
- In 2002, the CCT, following the spirit of the JCRB *Terms of Reference*, created the WG-CMC:
  - to establish and maintain CMC service categories
  - **to agree on detailed CMC technical review criteria → CMC Review Protocols**
  - to coordinate/conduct reviews of CMCs submitted by the RMOs for posting in Appendix C of the KCDB
  - to examine the sufficiency of existing comparisons for supporting CMCs and recommend new comparisons
  - to coordinate the review of existing CMCs based on new results of KC/SCs

# Preparation of CMC Review Protocols: CCT WG-CMC

- **Chair:** Jovan Bojkovski, MIRS/UL-FE/LMK (Slovenia)
- **AFRIMETS:** Efrem Ejigu, NMISA (South Africa)
- **APMP:** Hisashi Abe, NMIJ/AIST (Japan)
- **COOMET:** Anatolii Pokhodun, VNIIM (Russia)
- **EURAMET:** Dolores del Campo, CEM (Spain)
- **GULFMET:** Miltiadis Anagnostou, EMI (UAE)
- **SIM:** Andrew Todd, NRC (Canada)



# CMC Service Categories

<https://www.bipm.org/documents/20126/41594877/Classification+of+services+in+Thermometry/601bc4bf-fbfa-a886-6961-9d2db9eca3d4>

## ➤ Services classified in 3 branches:

- Temperature
- Humidity
- Thermophysical quantities

## ➤ Using the Service Category List:

- **NMI:** to identify which service category to apply to each submitted CMC
- **RMO (WG-CMC):** to identify which review protocol is needed to review the CMCs submitted by its NMIs
- **CCT WG-CMC:** to identify which review protocols must be developed and needs for future KC/SCs
- **JCRB/BIPM:** to classify accepted CMCs for entry into Appendix C of the KCDB



### CLASSIFICATION OF SERVICES IN THERMOMETRY

January 2021

#### METROLOGY AREA: THERMOMETRY

##### BRANCH: TEMPERATURE

1. Temperature – Items used for defining ITS-90
  - 1.1 Primary fixed-point cells
    - 1.1.1 Cells for contact thermometry
    - 1.1.2 Cells for radiation thermometry
  - 1.2 Complete apparatus realizing fixed-points
    - 1.2.1 Apparatus for contact thermometry
    - 1.2.2 Apparatus for radiation thermometry
  - 1.3 Standard platinum resistance thermometers (SPRTs)
    - 1.3.1 Capsule-type SPRTs
    - 1.3.2 Long-stem SPRTs including HTSPRTs
  - 1.4 Standard radiation thermometers
    - 1.4.1 Standard radiation thermometers
2. Temperature – Items used for disseminating ITS-90 and PLTS 2000
  - 2.1 Secondary fixed-point cells and apparatus for contact thermometry
    - 2.1.1 Secondary fixed-points and apparatus for contact thermometry
  - 2.2 Resistance thermometers
    - 2.2.1 Rhodium-iron resistance thermometers
    - 2.2.2 Platinum resistance thermometers (PRTs)
    - 2.2.3 Thermistors and other resistive thermometers
  - 2.3 Thermocouples
    - 2.3.1 Noble-metal thermocouples
    - 2.3.2 Base-metal thermocouples
    - 2.3.3 Pure-metal thermocouples
  - 2.4 Liquid-in-glass thermometers
    - 2.4.1 Liquid-in-glass thermometers
  - 2.5 Radiation thermometry
    - 2.5.1 Secondary fixed-point blackbody cells and complete instruments
    - 2.5.2 Variable temperature blackbody radiation sources
    - 2.5.3 Strip lamps
    - 2.5.4 Radiation thermometers and visual optical pyrometers
  - 2.6 Other thermometers
    - 2.6.1 Air temperature sensors
    - 2.6.2 Other thermometers
  - 2.7 Temperature sensors with display unit
    - 2.7.1 Temperature sensors with display unit
  - 2.8 Other measurement services
    - 2.8.1 Bridge linearity
    - 2.8.2 Compensation wires for cold junction
    - 2.8.3 Wires for melting-point measurements for thermocouples
    - 2.8.4 Temperature indicators
    - 2.8.5 Phase-transition temperature of reference materials
    - 2.8.6 Dry-well block calibrators

# CMC Review Protocols: general principles

- Practical, pragmatic technical guidelines designed to let the CMC review process proceed according to:
  - A set of objective numerical criteria
  - Specified technical evidence
- Scientifically based:
  - Judge CMC on its technical merit
  - Remove political discussions
  - Reduce the possibility of disagreement
- Uniformly applied across all RMOs
- Publicly available in the BIPM website: <https://www.bipm.org/en/committees/cc/cct/publications>



# List of CMC Review Protocols

- Calibration of fixed point cells (excluding the TPW)  
and calibration of SPRTs at fixed points
- TPW
- Calibration of high temperature fixed points
- ITS-90 SPRT Subrange
- Calibration of industrial thermometers
- Radiation thermometry
  
- Humidity (dew-point temperature)
- Relative humidity
- Humidity generators
  
- Thermal diffusivity
- IR spectral emissivity

# CMC Review Protocols: key elements

- Agreed **cutoff criteria** based on literature uncertainty values
- Agreed **list of specific evidence items** required for CMC acceptance
- **Mathematical algorithms** involving KC data and claimed CMC uncertainty to review a CMC (for example, involving  $U_{\text{CMC}}$ ,  $U_{\text{NMI KC}}$ ,  $T_{\text{NMI}} - \text{KCRV}$ , ...)
- Satisfactory participation in pertinent KC/SC
- Level of scrutiny increases as uncertainty value decreases

1. *No review is needed if*

1.1 
$$\frac{|T_{\text{NMI}} - \text{KCRV}|}{\sqrt{U_{\text{CMC}}^2(k=2) + U_{\text{comparison}}^2(k=2)}} < 1,$$

where  $T_{\text{NMI}}$  is the result of the NMI in the Key Comparison and  $U_{\text{comparison}}$  is the combined uncertainty of the KCRV and any other components related to the comparison that are not included in the uncertainty of the KCRV or in the uncertainty quoted by the NMI in the KC (e.g., drift of the transfer artefact),

and

1.2 
$$U_{\text{CMC}}(k=2) \geq U_{\text{NMI, KC}}(k=2),$$
  
where  $U_{\text{NMI, KC}}$  is the uncertainty quoted by the NMI in the KC,

and

1.3 
$$U_{\text{CMC}}(k=2) > \frac{U_{\text{comparison}}(k=2)}{3}.$$

2. *Scrutiny by the RMO Thermometry WG is needed if*

2.1 Condition 1.1 is not satisfied, but 
$$\frac{|T_{\text{NMI}} - \text{KCRV}|}{\sqrt{U_{\text{CMC}}^2(k=3) + U_{\text{comparison}}^2(k=3)}} < 1$$

and

2.2 conditions 1.2 and 1.3 are satisfied

and

2.3 
$$U_{\text{CMC}}(k=2) \geq \text{Table\_1\_value}.$$

# CMC Review Protocols: three-tier review screening process

➤ For most review protocols, a three tier review screening process identifies the level of review required for the CMC acceptance:

- Tier 1: No RMO-level detailed review required
- Tier 2: RMO-level detailed review required
- Tier 3: CCT WG-CMC-level detailed review required

## 1. No review is needed if

$$1.1 \quad \frac{|T_{NMI} - KCRV|}{\sqrt{U_{CMC}^2(k=2) + U_{comparison}^2(k=2)}} < 1,$$

where  $T_{NMI}$  is the result of the NMI in the Key Comparison and  $U_{comparison}$  is the combined uncertainty of the KCRV and any other components related to the comparison that are not included in the uncertainty of the KCRV or in the uncertainty quoted by the NMI in the KC (e.g., drift of the transfer artefact),

and

$$1.2 \quad U_{CMC}(k=2) \geq U_{NMI, KC}(k=2),$$

where  $U_{NMI, KC}$  is the uncertainty quoted by the NMI in the KC,

and

$$1.3 \quad U_{CMC}(k=2) > \frac{U_{comparison}(k=2)}{3}.$$

## 2. Scrutiny by the RMO Thermometry WG is needed if

$$2.1 \quad \text{Condition 1.1 is not satisfied, but } \frac{|T_{NMI} - KCRV|}{\sqrt{U_{CMC}^2(k=3) + U_{comparison}^2(k=3)}} < 1$$

and

2.2 conditions 1.2 and 1.3 are satisfied

and

$$2.3 \quad U_{CMC}(k=2) \geq \text{Table\_1\_value}.$$

CMC\_review\_protocol\_-\_FP\_cells\_and\_SPRTs\_at\_FPs\_2010-05-05[1].doc

5 May 2010

**Table 1.** Cut-off criteria for review of fixed point CMCs (excluding calibration of TPW cells). Values are estimated from the 25<sup>th</sup> percentile of results of CCT K2, K3 and K4.

**Fixed point cells for capsule SPRT calibration**

Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK	Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK	Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK
e-H <sub>2</sub>	0.33	Ne	0.32	Hg	0.16
17 K	0.26	O <sub>2</sub>	0.20		
20.3 K	0.24	Ar	0.18	Ga	0.20

**Fixed point cells for long-stem SPRT calibration**

Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK	Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK	Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK
Ar	0.38	Ga	0.20	Zn	0.90
Hg	0.23	In	0.70	Al	1.90
		Sn	0.60	Ag	3.00

## 3. Scrutiny by the RMO Thermometry WG and CCT WG8 is needed

in all cases not satisfying conditions 1.1 through 1.3 or 2.1 through 2.3, for example

$$U_{CMC}(k=2) < U_{NMI, KC}(k=2)$$

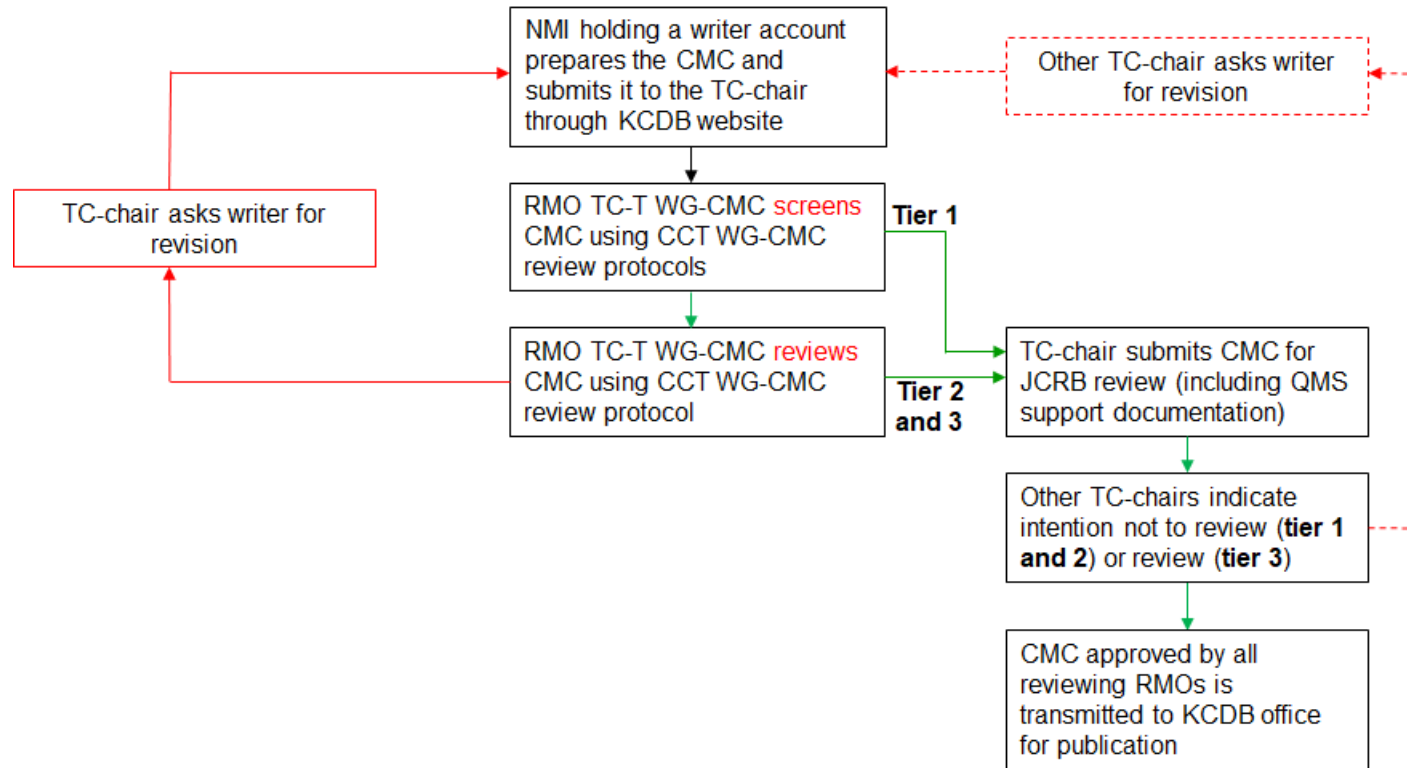
or

$$\text{condition 1.1 not satisfied and } U_{CMC}(k=2) < \text{Table\_1\_value}.$$

# CMC Review Protocols: additional principles

- A CMC uncertainty claim smaller than the lowest cut off criterion value does not mean automatic rejection but requires further scrutiny
- CCT WG-CMC does not decide the uncertainty that an NMI should use to achieve acceptance

# CMC Review Process: flow diagram



# WG-KC tasks

- *“To oversee all aspects of key comparison documentation*
  - *Starting with the Technical Protocol*
  - *Ending with the Draft B Report and the KCDB entry*
  
- *Including provision of advice to pilots on:*
  - *Calculation of the Degrees of Equivalence*
  - *Key Comparison Reference Value*
  - *Linkage between RMO and CIPM key comparisons”*
  
- **In practice:**
  - **Review the initial Technical Protocol and all its subsequent iterations until approval**
  - **Review the Draft B Report and all its revisions until approval**

# WG-KC membership

- A pool of experts from all RMOs
- Membership based on expertise
- Number of reviewers per document:
  - 3 reviewers for KCs
  - 2 reviewers for SCs

## ➤ Current membership:

1. Megumi Akoshima
2. Stephanie Bell
3. Robert Benyon
4. Rien Bosma
5. Helen McEvoy
6. Christopher Meyer
7. Andrea Peruzzi
8. Steffen Rudtsch
9. Richard Rusby
10. Gregory Strouse
11. Andrew Todd
12. Rod White
13. Inseok Yang
14. Yuan Zundong

NMIJ (Japan)  
NPL (UK)  
INTA (Spain) → on leave  
Independent Researcher (Netherlands)  
NPL (UK)  
NIST (USA)  
NRC (Canada)  
PTB (Germany)  
NPL (UK)  
NIST (USA)  
NRC (Canada)  
Independent researcher (New Zealand)  
KRISS (Korea)  
NIM (China)

# The CCT KC/SC review process

- The comparison review process is defined by:
  - The [CIPM-MRA-G-11 document](https://www.bipm.org/en/cipm-mra/cipm-mra-documents) (<https://www.bipm.org/en/cipm-mra/cipm-mra-documents>)
  - CCT-specific rules
- CCT-specific rules:
  - CIPM and RMO KCs:
    - Technical Protocol must be formally approved by the WG-KC
    - Final Report must be formally approved by the WG-KC
  - RMO SCs:
    - Can be agreed, conducted and evaluated within the respective RMO
    - On request, the WG-KC reviews both Technical Protocol and Final Report



# Check-lists for pilots

- Within the CCT, we developed check-lists to be used by pilots when preparing comparison protocols and reports.
- These check-lists can help improving the quality of protocols and reports, particularly in the case of unexperienced pilots
- These check-lists could be useful also for the other CCs

# List of headings to guide the comparison pilots in preparing the Technical Protocol (1/2)

"Acronym (CCT-KX, RMO.T-KX.Y, RMO.T-SX)"

Comparison of ...

Technical Protocol

Main authors and affiliations

Date:

Version:

## 1. Introduction

- Initiator of the comparison
- Objectives, quantity and range of the comparison
- Reference documents followed in drawing the technical protocol

## 2 Participants:

- List of participant laboratories (contact persons, their mailing and electronic addresses can be placed in a separate appendix)
- Roles (coordinating group preparing the technical protocol, pilot(s), co-pilot(s), sub-pilot(s), ...)

## 3 Comparison methodology

- Topology of the comparison (loops, circulation scheme, ...)
- Starting date and detailed timetable

## 4. Travelling standard(s)

- Detailed description of the device(s) (make, type, serial number, size, weight, packaging, ... and technical data needed for its operation)
- Advice on handling the travelling standard(s), including unpacking, subsequent packing and shipping to the next participant
- Tests to be carried out on the travelling standard(s) upon receipt before measurement
- Conditions of use of travelling standard(s) during measurement
- Final tests before packaging the travelling standard(s) and ship it to the next laboratory
- Procedure in the case of failure of the travelling standard(s)

# List of headings to guide the comparison pilots in preparing the Technical Protocol (2/2)

## 5. Organizational aspects

- Procedure in the case of unexpected delay at participating institute
- Customs formalities and documents to accompany the travelling standard(s) (ATA carnet or others)
- Financial aspects: responsibility for travelling standard(s) costs, transport costs, customs charges, damage costs
- Insurance on travelling standard(s)

## 6. Communication flows

- From participant to pilot: informing the pilot of the arrival of the travelling standard(s)
- From participant to pilot: communicating measurement delays to the pilot
- From participant to participant informing the next participant when shipping the travelling standard(s)
- From participant to pilot: communicating the measurement results to the pilot
- Due dates and consequences when failing to comply with due dates

## 7. Measurement instructions and procedures

- Measurement instructions (state if there are any specific instructions)
- Measurement procedures (state if there are any specific procedures)

## 8. Reporting the results

- Instructions for reporting the results of tests carried out on the travelling standard(s) upon receipt before measurement
- Instructions for reporting the measurement results (Excel® sheet)
- Instructions for reporting the uncertainties (Excel® sheet)
- Instructions for reporting additional information

## 9. KCRV and Linkage mechanism

- For CIPM KCs: method for calculating the KCRV and its uncertainty
- For RMO KCs: method for linking to the KCRV of the parent CIPM KC

## 10. Document revision history

# List of headings to guide the comparison pilots in preparing the Final Report (1/2)

**"Acronym (CCT-KX, RMO.T-KX.Y, RMO.T-SX)"**

**Comparison of ...**

Report (Draft A)

Authors

Date:

Version:

## **1. Introduction**

- Objectives, quantity and range of the comparison
- Short history of the comparison (the comparison was initiated on..., the protocol was approved on..., the measurements were performed between... and..., ...)

## **2 Participants:**

- List of participant laboratories (contact persons, their mailing and electronic addresses can be placed in a separate appendix)
- Roles (coordinating group preparing the technical protocol, pilot(s), co-pilot(s), sub-pilot(s), ...)

## **3 Comparison Pattern**

- Topology of the comparison (loops, circulation scheme, ...)

## **4. Travelling standard(s)**

- detailed description of the device(s) (make, type, serial number, size, weight, packaging, ... and technical data needed for its operation)

# List of headings to guide the comparison pilots in preparing the Final Report (2/2)

## **5. Equipment and measuring conditions at participating laboratories**

- Specific measurement instructions or procedures (if any)
- Detailed description of equipment and measuring conditions at participating laboratories

## **6. Measurement results**

- Measurement results at each participating laboratory, including uncertainty of each participating laboratory (the full uncertainty budgets must be reported but can be placed in a separate appendix)

## **7. Analysis of the results**

- Determination of the bilateral equivalence between the participating laboratories (for all comparisons)
- Determination of the KCRV (only for CIPM KCs) and its uncertainty
- Determination of the DoE's (for CIPM KCs and RMO KCs the DoE's must be explicitly reported)
- Linkage to the parent CIPM KC (for RMO KCs)

## **8. Conclusions**

- Concluding remarks (were the objectives achieved?)
- Lessons learned: recommendations for future comparisons

## **9. Appendices**

- Approved protocol
- Document control history (changes applied to the report to address reviewers' comments, ...)

# THANK YOU

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# Example of CMC review protocol: Calibration of fixed-point cells and SPRTs at fixed points

- Covers service categories:
  - 1.1.1 Cells for contact thermometry
  - 1.2.1 Complete apparatus realizing contact thermometry fixed points
  - 1.3 SPRTs (both CSPRTs and LSPRTs)
  
- **Participation in a CCT or RMO KC, or in a bilateral comparison linking to such KCs, is mandatory for acceptance of fixed point CMCs**
  - General principle for CCT thermometry: primary services require a successful participation in a KC
  - Primary services: all service categories starting with a 1

# CMC review protocol for calibration of fixed-point cells and SPRTs at fixed points

## ➤ Three-tier review screening process:

1. No review is needed if ...
2. RMO thermometry WG scrutiny is needed if ...
3. RMO thermometry WG and CCT WG-CMC scrutiny is needed if ...

## ➤ Mathematical algorithms (for 1 and 2)

## ➤ Cut-off criteria (for 2 and 3)

**1. No review is needed if**

1.1  $\frac{|T_{\text{NMI}} - KCRV|}{\sqrt{U_{\text{CMC}}^{-1}(k=2) + U_{\text{comparison}}^{-1}(k=2)}} < 1$ ,  
 where  $T_{\text{NMI}}$  is the result of the NMI in the Key Comparison and  $U_{\text{comparison}}$  is the combined uncertainty of the KCRV and any other components related to the comparison that are not included in the uncertainty of the KCRV or in the uncertainty quoted by the NMI in the KC (e.g., drift of the transfer artefact),

and

1.2  $U_{\text{CMC}}(k=2) \geq U_{\text{NMI,KC}}(k=2)$ ,  
 where  $U_{\text{NMI,KC}}$  is the uncertainty quoted by the NMI in the KC,

and

1.3  $U_{\text{CMC}}(k=2) > \frac{U_{\text{comparison}}(k=2)}{3}$ .

**2. Scrutiny by the RMO Thermometry WG is needed if**

2.1 Condition 1.1 is not satisfied, but  $\frac{|T_{\text{NMI}} - KCRV|}{\sqrt{U_{\text{CMC}}^{-1}(k=3) + U_{\text{comparison}}^{-1}(k=3)}} < 1$

and

2.2 conditions 1.2 and 1.3 are satisfied

and

2.3  $U_{\text{CMC}}(k=2) \geq \text{Table\_1\_value}$ .

CMC\_review\_protocol\_-\_FP\_cells\_and\_SPRTs\_at\_FPs\_2010-05-05[1].doc 5 May 2010

**Table 1.** Cut-off criteria for review of fixed point CMCs (excluding calibration of TPW cells). Values are estimated from the 25<sup>th</sup> percentile of results of CCT K2, K3 and K4.

Fixed point cells for capsule SPRT calibration					
Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK	Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK	Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK
e-H <sub>2</sub>	0.33	Ne	0.32	Hg	0.16
17 K	0.26	O <sub>2</sub>	0.20		
20.3 K	0.24	Ar	0.18	Ga	0.20

Fixed point cells for long-stem SPRT calibration					
Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK	Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK	Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK
Ar	0.38	Ga	0.20	Zn	0.90
Hg	0.23	In	0.70	Al	1.90
		Sn	0.60	Ag	3.00

**3. Scrutiny by the RMO Thermometry WG and CCT WG8 is needed**

in all cases not satisfying conditions 1.1 through 1.3 or 2.1 through 2.3, for example

$U_{\text{CMC}}(k=2) < U_{\text{NMI,KC}}(k=2)$

or

condition 1.1 not satisfied and  $U_{\text{CMC}}(k=2) < \text{Table\_1\_value}$ .



# CMC review protocol for calibration of fixed-point cells and SPRTs at fixed points: Tier 1

## 1. No review is needed if:

$$1.1 \quad \frac{|T_{NMI-KCRV}|}{\sqrt{U_{CMC}^2(k=2) + U_{Comparison}^2(k=2)}} < 1$$

And

$$1.2 \quad U_{CMC}(k=2) \geq U_{NMI\ KC}(k=2)$$

And

$$1.3 \quad U_{CMC}(k=2) > \frac{U_{Comparison}(k=2)}{3}$$

- 1.1 and 1.2 are obvious
- 1.3 is less obvious

# CMC review protocol for calibration of fixed-point cells and SPRTs at fixed points: Tier 2

## 2. RMO Thermometry WG scrutiny is needed if:

2.1 1.1 is not satisfied, but 
$$\frac{|T_{NMI} - KCRV|}{\sqrt{U_{CMC}^2(k=3) + U_{Comparison}^2(k=3)}} < 1$$

And

2.2 1.2 and 1.3 are satisfied

And

2.3  $U_{CMC}(k=2) \geq \text{Table 1 value}$

Values estimated from 25<sup>th</sup> percentile of K2, K3 and K4 results

Fixed point cells for capsule SPRT calibration					
Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK	Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK	Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK
e-H <sub>2</sub>	0.33	Ne	0.32	Hg	0.16
17 K	0.26	O <sub>2</sub>	0.20		
20.3 K	0.24	Ar	0.18	Ga	0.20

Fixed point cells for long-stem SPRT calibration					
Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK	Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK	Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK
Ar	0.38	Ga	0.20	Zn	0.90
Hg	0.23	In	0.70	Al	1.90
		Sn	0.60	Ag	3.00

# CMC review protocol for calibration of fixed-point cells and SPRTs at fixed points: Tier 3

## 3. RMO thermometry WG and CCT WG-CMC scrutiny is needed if:

For all cases not satisfying conditions 1.1 to 1.3 or 2.1 to 2.3, for example:

$$U_{CMC}(k = 2) < U_{NMI\ KC}(k = 2)$$

Or

$$U_{CMC}(k = 2) < \textit{Table 1 value}$$

Values estimated from 25<sup>th</sup> percentile of K2, K3 and K4 results

Fixed point cells for capsule SPRT calibration					
Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK	Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK	Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK
e-H <sub>2</sub>	0.33	Ne	0.32	Hg	0.16
17 K	0.26	O <sub>2</sub>	0.20		
20.3 K	0.24	Ar	0.18	Ga	0.20

Fixed point cells for long-stem SPRT calibration					
Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK	Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK	Fixed point cell	25 <sup>th</sup> percentile $U(k=2)$ , mK
Ar	0.38	Ga	0.20	Zn	0.90
Hg	0.23	In	0.70	Al	1.90
		Sn	0.60	Ag	3.00

# Application of the algorithms in case of RMO KC or bilateral KC

➤ How to correctly apply the algorithm:  $\frac{|T_{NMI} - KCRV|}{\sqrt{U_{CMC}^2(k=2) + U_{Comparison}^2(k=2)}} < 1$

➤ In case of RMO KC coordinated by a pilot that took part in the parent CCT KC:

- $T_{NMI} - KCRV = (T_{NMI} - T_{Pilot})_{RMO\ KC} - (T_{Pilot} - KCRV)_{CCT\ KC}$

- $U_{Comparison} = \sqrt{U_{KCRV}^2 + U_{RMO\ KC}^2 (T_{NMI} - T_{Pilot}) - U_{NMI}^2}$   

From CCT KC report

From RMO KC report

From RMO KC report