



Understanding the CMC Process in the CCT

Gregory F. Strouse and Karen Garrity
National Institute of Standards and Technology
Associate Director for Measurement Services

Bureau
♦ **I**nternational des
♦ **P**oids et
♦ **M**esures



Outline

- ◆ Organizational
 - CCT Working Group for CMCs
 - CMC Review Protocols and Review Process
- ◆ Technical
 - Comparison Models
 - Case Studies

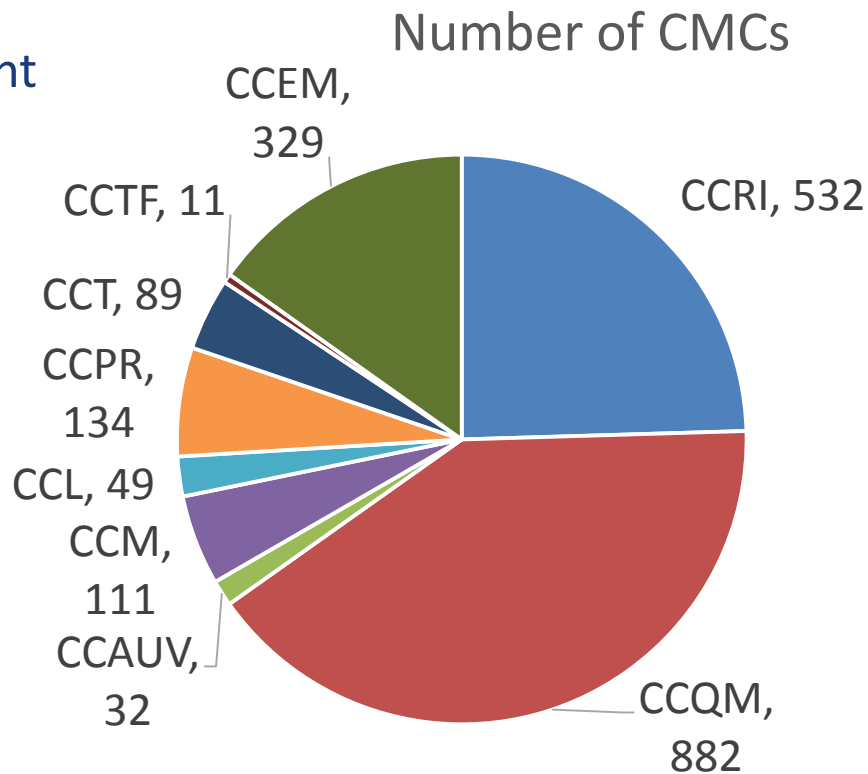
Roles of the RMOs in CMCs



Each RMO has Metrology Working Groups that mirror the CIPM Consultative Committees

BIPM KCDB CMCs – NIST

- ◆ NIST has over 2169 CMCs at last count
- ◆ Earlier adoption of a NIST-wide quality program
- ◆ More deliberate approach to comparisons
- ◆ Increased involvement of staff with international colleagues
- ◆ Increased effectiveness of SIM
- ◆ Significant work load for Key Comparisons and CMC reviews



Supporting Temperature and Humidity CMCs

– CIPM and RMO Key Comparisons

- ♦ CCT K1 – ITS-90: 0.65 K to 34.6 K
 - CCT K1.1
 - EURAMET.T-K1
- ♦ CCT K2 – ITS-90: 13.8 K to 273.16 K
 - CCT K2.1, K2.2, K2.3, K2.4, K2.5
- ♦ CCT K3 – ITS-90: 83.8 K to 933.5 K
 - CCT K3.1, K3.2
 - APMP.T-K3, K3.1, K3.4, K3.5, K3.6
 - COOMET.T-K3, K3.1, K3.2, K3.3
 - EURAMET.T-K3, K3.2, K3.3, K3.4, K3.5
- ♦ CCT K4 – ITS-90: Al FP and Ag FP
 - APMP.T-K4, K4.1
 - EURAMET.T-K4
- ♦ CCT K5 – ITS-90: 961 °C to 1700 °C
 - CCT K5.1
 - APMP.T-K5
 - COOMET.T-K5
 - EURAMET.T-K5
- ♦ CCT K6 – Humidity: Dew and Frost Point
 - CCT K6.1, K6.2
 - APMP.T-K6
 - EURAMET.T-K6, K6.1
 - SIM.T-K6.1, K6.2, K6.3, K6.4, K6.5
- ♦ CCT K7 – ITS-90: Water Triple Point
 - APMP.T-K7, K7.1
 - COOMET.T-K7
 - EURAMET.T-K7, K71., K7.2, K7.3, K7.4
- ♦ CCT K8 – Humidity: Dew Point
 - EURAMET.T-K8
- ♦ CCT K9 – ITS-90: SPRTs – 83.8 K to 692.7 K
 - EURAMET.T-K9, K9.1
 - SIM.T-9.1
- ♦ CCT K10 – ITS-90: 960 °C to 3000 °C

10 CIPM Key Comparisons
52 RMO Key Comparison

JCRB and CC WGs for CMCs

- ◆ 2002 –JCRB created a Terms of Reference to allow Consultative Committees to create a Working Group to:
 - Establish and maintain CMC Service Category Lists
 - Coordinate and conduct the CMC review process
 - Identify future need for Key and Supplemental Comparisons
 - CC WG comprised of RMO Working Group representative
 - ◆ CCT added a chair position that is not one of the RMO WG representatives

CIPM MRA-D-04: Calibration and Measurement Capabilities in the context of the CIPM MRA – Section 8: CMC inter-regional review through the CC Working Groups on CMCs

Origin of CCT WG8 (WG-CMC)

- ◆ First RMO meeting occurred at the 7th Temperature Symposium in 2002
 - Attempt to understand the different ways RMOs were reviewing each other CMC submissions
 - Philosophical differences in implementing the MRA and JCRB directives created
 - Unforeseen problems in getting Thermometry RMOs to accept each other's CMCs
 - Non-harmonized service categories caused confusion of what CMCs could be submitted

CCT WG CMC Terms of Reference

- ◆ Follows the spirit of the JCRB Terms of Reference
 - Establish and maintain service categories
 - Agree on detailed technical review criteria
 - Coordinate / conduct reviews of RMO submitted CMCs for Appendix C
 - Provide guidance on the range of CMCs supported by Key Comparisons
 - Examine the sufficiency of existing comparisons for supporting CMCs and recommend new comparisons
 - Coordinate the review of existing CMCs based on new results of comparisons

What Needs a Key Comparison – How Far Does the Light Shine ?

- ◆ Primary realization

- ITS-90 fixed-point cells

- ◆ Linkage to CCT Key Comparison

- CCT or RMO Key Comparison, CCT or RMO Supplementary Comparison

- ◆ Secondary realization

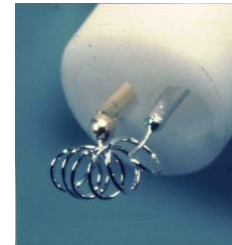
- Industrial platinum resistance thermometers

- ◆ ***Evidence supporting using the higher-level service***

- Key Comparison Report or KCDB CMCs (e.g., SPRTs)

Hierarchy of ITS-90 traceability

- ◆ Fixed-point cell testing
 - ITS-90 defining thermometric devices
 - Used to calibrate
Standard Platinum Resistance Thermometers (SPRTs)
- ◆ SPRT calibration
 - Defining interpolating devices
 - Calibrated using ITS-90 fixed-point cells
 - Used to calibration Industrial thermometers
- ◆ Industrial thermometer calibration
 - Compared against SPRTs



What Needs a Supplementary Comparison?

- ◆ Supplementary Key Comparisons are done to tie results from KC's to Regional Metrology Labs.
- ◆ They test specific needs not covered in a Key Comparison
- ◆ Typically carried out by RMOs
- ◆ Establish degrees of equivalence between NMIs often for industrial thermometer measurement capabilities in the range of 0 °C to 1100 °C.
 - Thermocouple supplementary comparison test the EMF measurement process, comparison process and mounting process

CMC Service Categories – Temperature and Humidity

- ◆ Service Category List divided into 3 main parts
 - Temperature
 - Humidity
 - Thermophysical Quantities
- ◆ Using the Service Category List
 - NMI
 - ◆ Identify which service category to apply to each submitted CMC
 - RMO WG
 - ◆ Identify which review protocol is needed to review their NMI's submitted CMCs
 - ◆ Identify RMO Key and Supplemental Comparison needs
 - CCT WG
 - ◆ Identify which review protocols are needed
 - ◆ Identify CIPM Key and Supplemental Comparison needs
 - JCRB / BIPM
 - ◆ Classify accepted CMCs for entry into Appendix C of the BIPM KCDB
- ◆ Modifications to the Service Category List are requested through RMO WG Chair

CLASSIFICATION OF SERVICES IN THERMOMETRY July 2016

- ◆ https://kcdb.bipm.org/AppendixC/T/T_services.pdf
- ◆ Very structured and tiered to minimize any questions as to what the CMC entry refers to
- ◆ First step in an NMI's quest for CMC entry into the JCRB KCDB appendix C.

CCT WG CMC Review Protocols

- ◆ Harmonized CMC submission, review and acceptance process
- ◆ Designed to be scientifically based (not political)
- ◆ Uniformly applied across the RMOs
- ◆ Publicly available
 - All documents are on the BIPM website
- ◆ Key Elements
 - Agreed cutoff criterion based on literature uncertainty values
 - Specific list of evidence items required for acceptance
 - How a comparison is used to review a CMC
 - Level of scrutiny increases as uncertainty values decrease
 - NMI participation in Key and Supplemental Comparisons

CCT WG CMC Review Protocols

| | | | |
|-----------------------------------|-------------------------------|-----------------------|-------------------------|
| Temperature scales and the kelvin | Future redefinition of the SI | Guides to Thermometry | CIPM MRA – CMCs and KCs |
| Meeting reports | Strategy document | Member bibliographies | CCT |

Guidance documents:

-  Classification of services in T  KCDB
-  CMC Review Protocol: TPW
-  CMC Review Protocol: Radiation Thermometry
-  CMC Review Protocol: ITS-90 SPRT Subrange
-  CMC Review Protocol: Calibration of fixed point cells (excluding the TPW) and calibration of SPRTs at fixed points
-  CMC Review Protocol: Calibration of industrial thermometers
-  CMC Review Protocol: Humidity
-  CMC Review protocol: Calibration of high-temperature fixed points
-  CMC Review Protocol: Humidity generators
-  CMC Review Protocol: Relative humidity
-  Registration and progress report form for KCs and SCs
-  Publication of a Final Report in *Metrologia's Technical Supplement*

A NIST CMC Entry Completed Through This Review Process

Temperature. Resistance thermometer, **0 °C to 30 °C**

Absolute expanded uncertainty
($k = 2$, level of confidence 95%) in
°C: **0.002**

Thermistor

Comparison bath: distilled water

Hysteresis uncertainty for each
thermistor must be added to the
combined uncertainty quoted in the
Calibration Report

Approved on 12 July 2007

Internal NMI service identifier:
NIST/31130S

Two Types of CCT CMC Review Protocols

- ◆ Based on cutoff tables
 - CMC cutoff values determines review level
- ◆ Based on algorithms
 - Equations relate CMCs to specific levels of review
- ◆ A *properly substantiated* CMC uncertainty claim may be smaller than the lowest criterion value
- ◆ Tiered screening process for most protocols
 - Tier 1 NO RMO-level detailed review
 - Tier 2 RMO-level DETAILED review required
 - Tier 3 CCT WG-level DETAILED review required
- ◆ Most CMCs receive CCT WG acceptance (88%)
 - RMO review before CCT WG CMC review is critical to success

Cutoff Criteria Model – SPRTs

- ◆ CMC cutoff values determines review level
 - **No review needed**
 - ◆ $U_{\text{CMC}} / U_{\text{comb}} \geq 1$ and U_{CMC} (FPs) OK
 - **RMO scrutiny and CCT WG CMC acceptance**
 - ◆ $1 > U_{\text{CMC}} / U_{\text{comb}} \geq 2/3$ and U_{CMC} (FPs) OK
 - **RMO scrutiny and CCT WG CMC scrutiny**
 - ◆ $U_{\text{CMC}} / U_{\text{comb}} < 2/3$ and U_{CMC} (FPs) OK

| ITS-90 subrange | U_{comb} range, mK | |
|-----------------|-----------------------------|-------|
| Ar to 0.01 °C | 0.53 | 0.082 |
| Hg to Ga | 0.29 | 0.20 |
| 0 to Sn | 0.082 | 0.91 |
| 0 to Zn | 0.082 | 0.95 |

Algorithm Criteria Model – Industrial Thermometers

- ◆ Equations relate CMCs to specific levels of review

- **Conditions flagging RMO review**

- ◆ Calibration in liquid baths or heatpipes

$$U_{\text{CMC}} < 4 \text{ mK} + 0.006\% |t|$$

- ◆ Calibration in furnaces and blocks

$$U_{\text{CMC}} < 20 \text{ mK} + 0.1\% |t|$$

- ◆ For thermistors

$$t < -50 \text{ °C or } t > 100 \text{ °C}$$

- **Scrutiny elements if flagged**

- ◆ Method of evaluating hysteresis

(ice point is insufficient for the smallest uncertainties) – U_{DUT}

- **RMO Scrutiny elements applicable to all DUTs**

- ◆ Supplementary comparison

- ◆ Traceability to higher-level service











- ◆ Calibration report is clear on interpolation method

- ◆ Calibration method

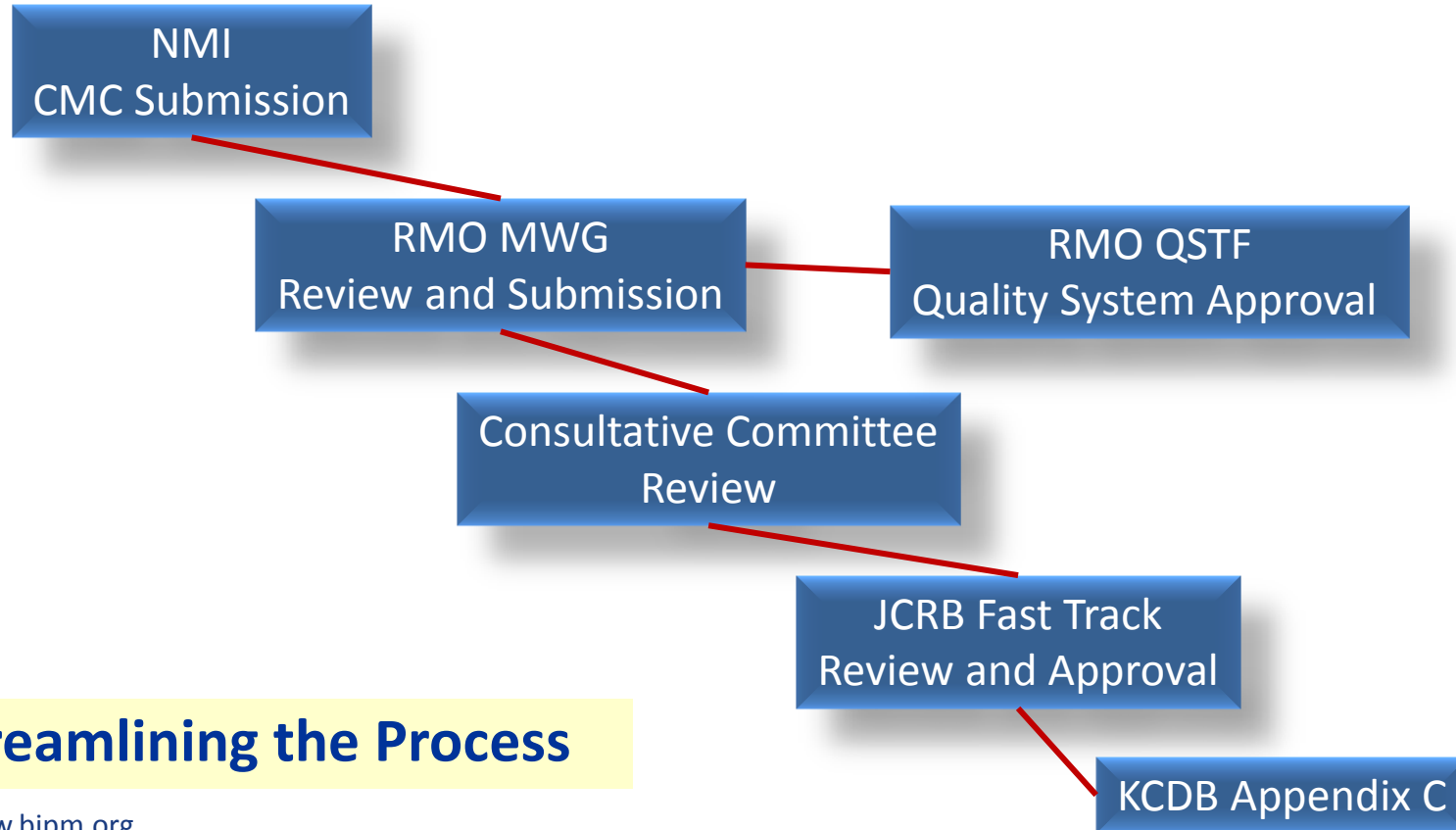
- ◆ Details of uncertainty analysis methods

WG CMC Communication – BIPM Discussion Forum

- ◆ CMCs for review
- ◆ CMC review protocols in development
- ◆ Guest access available on request

| CCT-WG8 Discussion Forum - Calibration and Measurement Capabilities | |
|--|--------------------------------------|
|  | ITS-90 Fixed Points |
|  | High-Temperature Fixed Points |
|  | SPRT Calibration Subranges |
|  | Radiation Thermometry |
|  | Industrial Thermometry |
|  | Humidity |
|  | Meeting Minutes |
|  | %RH CMC Review Protocol |
|  | Fast-tracked CMCs |
|  | CMC review protocols for review/vote |

CCT CMC – Submission Review Approval



Streamlining the Process

Step by Step – Submission Review Approval

RMO MWG Review and Submission

- ◆ RMO WG Chair submits CMCs to RM review committee for review
- ◆ Review uses accepted CCT review protocol
- ◆ Approved CMCs are submitted to CCT WG CMC Chair and BIPM Discussion Forum

RMO QSTF Quality System Approval

- ◆ RMO QSTF reviews NMI Quality System
- ◆ Approved Quality System allows CMCs to be reviewed, approved and published in the BIPM KCDB

Step by Step – Submission Review Approval

Consultative Committee Review

- ◆ CCT WG CMC Chair uses BIPM Discussion Forum to monitor review process by RMOs
- ◆ Approved CMCs are submitted to the JCRB Fast Track for final review
- ◆ Approved CMCs published in BIPM KCDB Appendix C

JCRB Fast Track Review and Approval

- ◆ Approved CMCs published in BIPM KCDB Appendix C

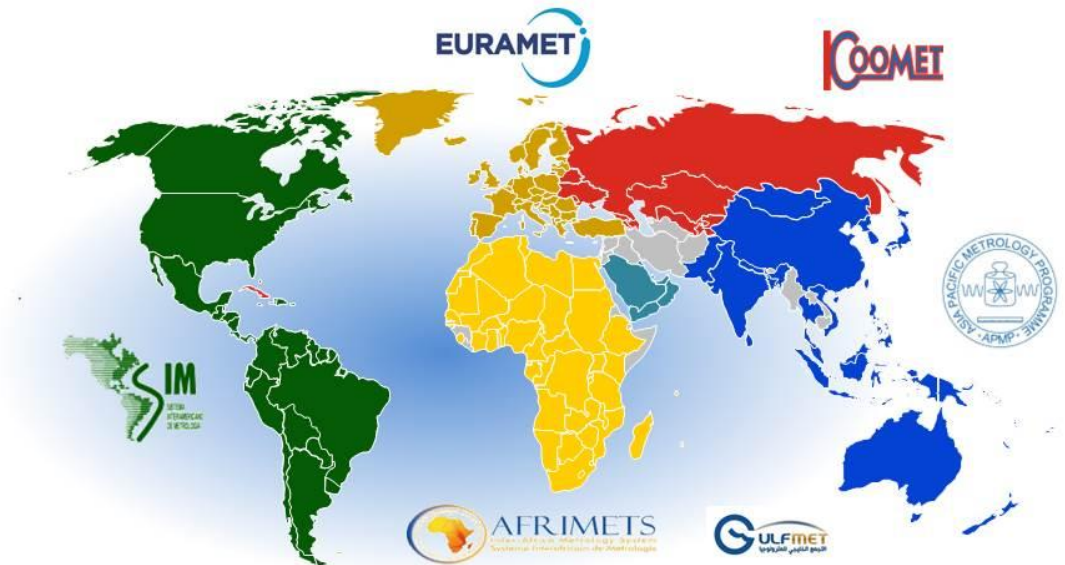
CCT WG CMC - Expectations

- ◆ RMOs register ALL of comparisons in the KCDB
- ◆ Satisfactory participation in or linkage to a KC for applicable CMCs
 - Unsatisfactory KC result requires explanatory documentation
- ◆ KCRV is not used as baseline for a correction term
- ◆ CMCs are traceable to the SI, not to the KCRV
- ◆ Technical responses to questions expected within two months
- ◆ Development DUT Uncertainty document in process
 - DUT uncertainty terms and their evaluation to harmonize CMCs
- ◆ Most submitted CMCs pass at one of the three levels of scrutiny

Overview of Accepted Temperature and Humidity CMCs

◆ 62 Countries (66 total NMIs and DIs)

- AFRIMETS 1
- APMP 14
- COOMET 8
- EURAMET 32
- SIM 11



What is a Key Comparison ? Proficiency Test ?

- ◆ A Key Comparison (KC) is one of the set of comparisons selected by a CIPM Consultative Committee (CC) or Regional Metrology Organization (RMO) to test the principal techniques and methods in the field.
- ◆ Proficiency testing (PT) is the determination of the calibration or testing performance of a laboratory or the testing performance of an inspection body against pre-established criteria by means of interlaboratory comparison.

Comparison Protocol – Basic Elements

- ◆ What gets a Key Comparison
- ◆ What are you testing
 - Defining the measurand
- ◆ Type
 - Scheme/Pattern
- ◆ Artifact selection
 - Drift
- ◆ Number of participants
 - How many from each RMO
- ◆ Uncertainties
 - Harmonization
- ◆ Degrees of Equivalence – linking
- ◆ Pilot laboratory

Protocol

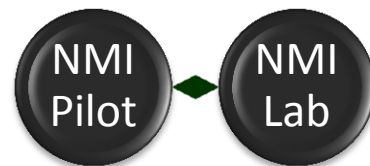
- ◆ T/C Shipped to participating laboratories
- ◆ RMO Lab calibrates and returns T/C
- ◆ Returned thermocouples checked for drift
- ◆ Thermocouples may or may not be sent to another laboratory (image of pattern)
- ◆ They were told to calibrate in increasing temperature only and not re-anneal
- ◆ Could do either fixed point calibration and/or comparison to another reference thermometer
- ◆ Two outcomes will be reported: bilateral differences and differences from a comparison reference value.
- ◆ Please return as received wrapped to a piece of wood.



Types of Comparison Testing Schemes / Patterns

◆ Bilaterals

- Between
 - ◆ NMI Pilot Lab and NMI participant
 - ◆ PT provider and stakeholder
- Useful for those with small uncertainty claims
- Expensive but efficient for participant
 - ◆ Report analysis and generation is simplified
- Often provides lowest comparison uncertainties

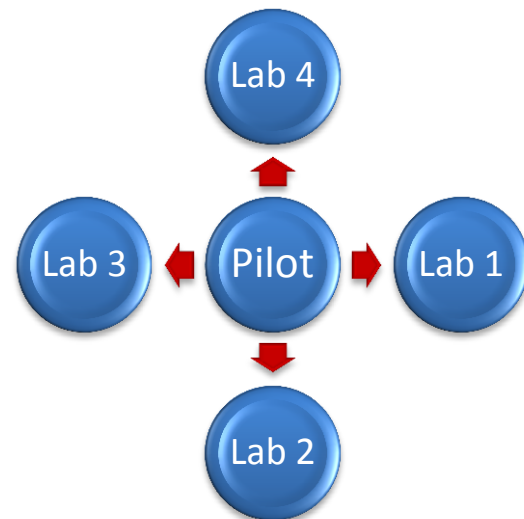


Usually the smallest drift of artifact – often done *post facto* Key Comparison

Types of Comparison Testing Schemes / Patterns

◆ Expanding Star

- Between Pilot and multiple laboratories
- Useful when multiple transfer standards exist
 - ◆ Pilot sends out transfer standards
 - ◆ Simultaneous bilaterals in disguise
- One Report creates lag
 - ◆ PT cannot be completed until all stakeholders finish
- Expensive if transfer artifacts are costly
- Useful when transfer artifacts are destroyed during testing

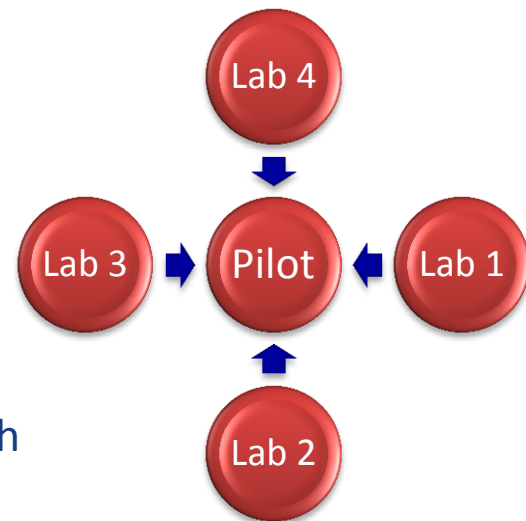


Type K thermocouples

Types of Comparison Testing Schemes / Patterns

◆ Collapsed Star

- Between NMI and pilot laboratory
- Useful when multiple transfer standards exist
 - ◆ Participants send in transfer standards
 - ◆ Simultaneous bilaterals in disguise
- One report creates lag
 - ◆ PT cannot be completed until all stakeholders finish
- Transfer artifact cost burden is on customers
- Customer makes measurements on returned artifacts to close the loop

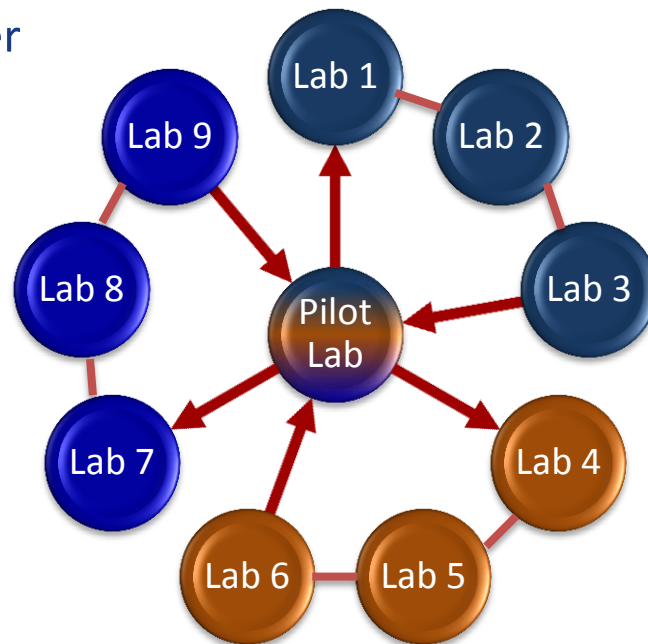


Managing drift of artifact

Types of Comparison Testing Schemes / Patterns

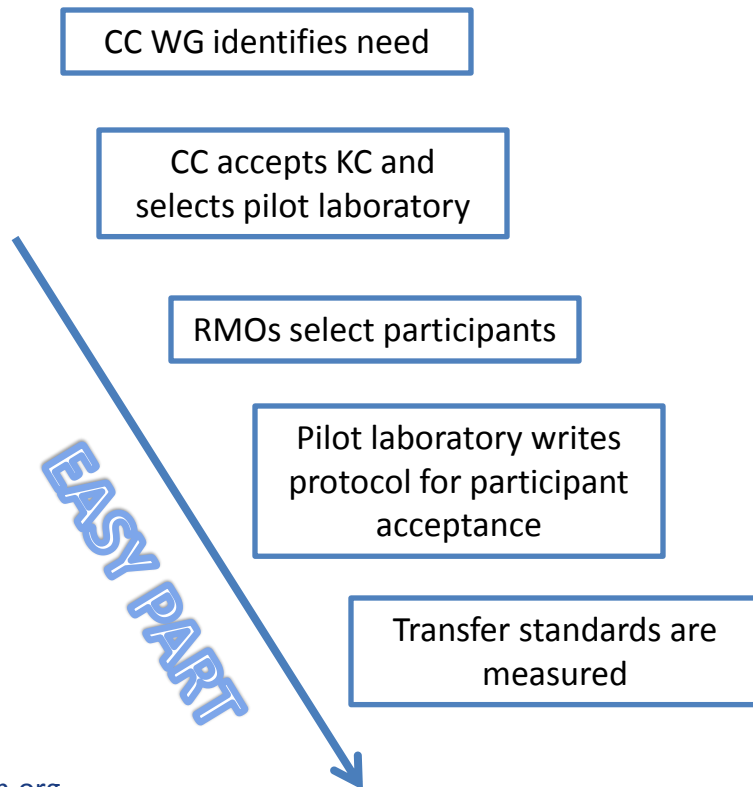
◆ Round Robin / Petal

- Between pilot lab and multiple NMIs
- Multiple testing sites between measurements at pilot laboratory
- Comparison uncertainties are often larger
- Robustness of transfer standard or test item is critical
- Number of labs in each petal is a logistical issue
- Number of transfer standards or test items available
 - ◆ Efficiency
 - ◆ Statistical Analysis



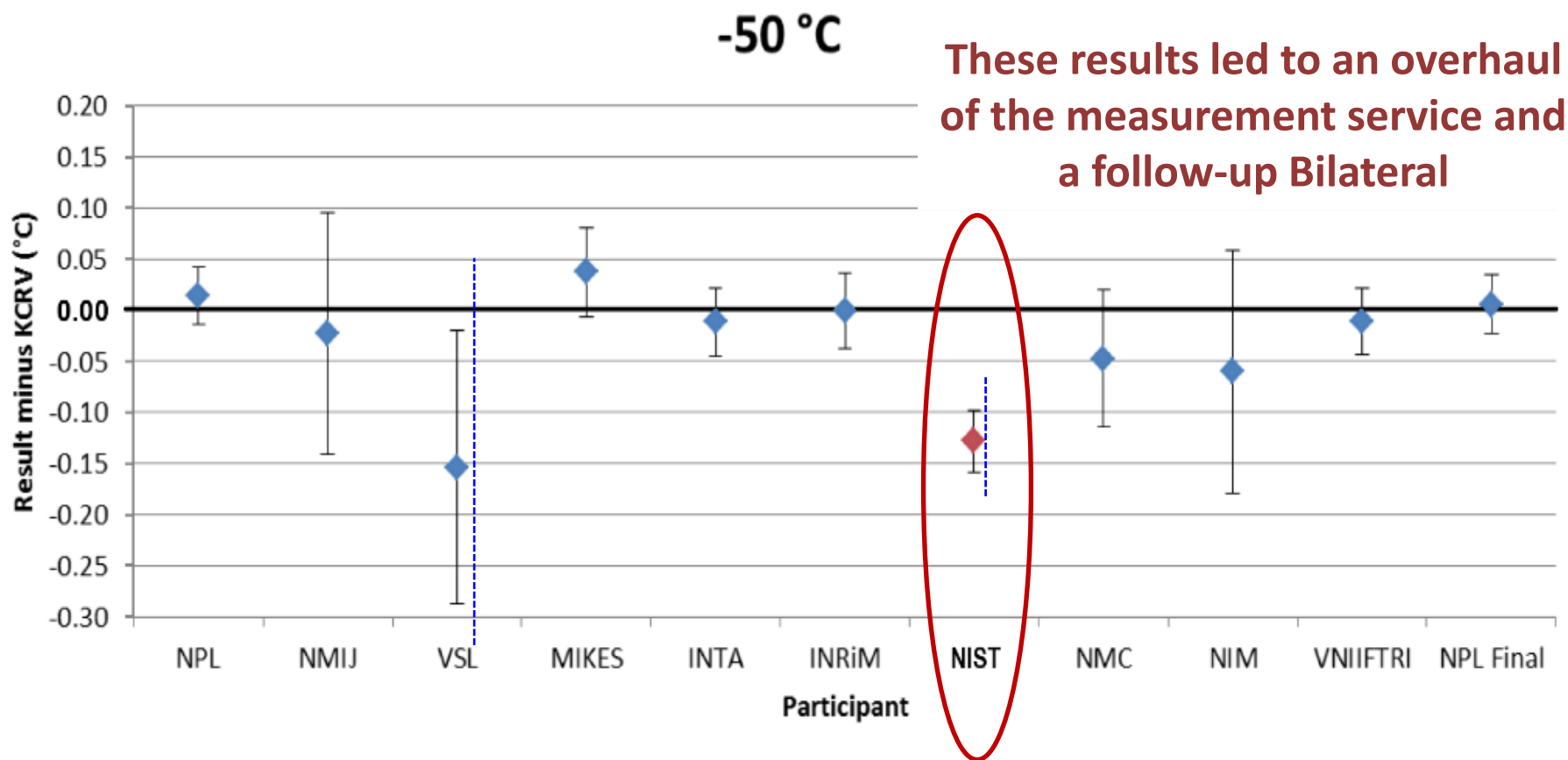
NMI Key Comparisons

Establishing Horizontal Equivalence



Case Study – CCT K6 –

Supporting CMCs after CCT K6 → CCT K6.2 in Progress



Case Study: SIM.T- K6.2 – Bilateral Comparison: NIST and CENAM

Dew/Frost-Point Temperature $-20\text{ }^{\circ}\text{C}$ to $+20\text{ }^{\circ}\text{C}$



- ◆ 2005: protocol submitted to WG-KC
- ◆ 2006: protocol approved by WG-KC
 - Before CCT K6 was started
 - CCT K6 linking to be made in future
 - Traceability to NMI Pressure, temperature standards
 - Protocol ensures similar measurement methods
- ◆ 2008 Comparison measurements performed
- ◆ 2010: participant approved draft sent to WG-KC
- ◆ 2014 Comparison report approved and published in *Metrologia*



Secondary Issues

- ◆ Linking an RMO KC completed before the CC KC
- ◆ Bilaterals
 - Common in RMOs for temperature and humidity
 - “Blind” to participants ?
- ◆ Traceability provenance of artifacts
 - NMIs are required to obtain traceability prior to participation
 - OEM traceability is not acceptable for primary standards
- ◆ Harmonization of uncertainty budgets
- ◆ Prescriptiveness level of protocol

Summary of Uncertainty Components

Uncertainty Components,
°C

| | A | B | C | D | E | F | G | H | I | J | total of 10 Labs |
|--|---|---|---|---|---|---|---|---|---|---|------------------|
| Reference thermometer calibration | X | X | X | X | X | X | | X | X | | 8 |
| Reference thermometer drift | X | X | X | X | X | | | X | X | | 7 |
| Reference thermometer repeatability | X | X | X | X | X | | | X | X | | 7 |
| Reference thermometer readout | X | X | X | X | X | X | | X | | | 7 |
| Test thermocouple repeatability | | | X | X | X | X | X | X | | X | 7 |
| Test thermocouple readout | X | X | X | X | X | X | X | X | | X | 9 |
| Test thermocouple inhomogeneity | X | | | X | X | X | X | X | | X | 7 |
| Test thermocouple stability | X | | X | X | X | | X | X | | | 6 |
| Reference junction temperature uncertainty | X | X | X | X | X | X | X | X | | X | 9 |
| Bath or furnace temperature stability | X | X | X | X | X | X | | X | X | | |
| Bath or furnace temperature non-uniformity | X | X | X | X | X | X | | X | X | | 8 |
| Extraneous emf of wiring, scanners, etc. | X | | | | X | | X | X | | X | 5 |
| Compensating extension wire calibration | | | | | | | X | | | | 1 |
| Compensating extension wire drift | | | | | | | | | | | |
| reference jctn. Ice bath | X | X | X | X | X | X | | X | X | | 8 |
| fixed immersion | X | | | X | | X | | | | | 3 |

Case Study – CCT K7: Water Triple Point

- ◆ A direct comparison of high-quality water triple point cells to quantify differences between cells, and
- ◆ A comparison of the national realizations of the water triple point which served to calibrate the transfer cells.
- ◆ Collapsed star with 21 NMIs
– BIPM was the Pilot Laboratory

Projected Timeline:

| | |
|-----------------------------|------|
| Protocol Agreement | 2002 |
| Transfer Standards to BIPM | 2002 |
| Transfer Standards Returned | 2004 |
| Final Report | 2006 |

BIPM KCDB – CCT K7

The screenshot shows the BIPM KCDB website with the URL: kcdb.bipm.org/Appendix8/KCDB_Ap8_info.asp?cmp_id=459&cmp_cod=CCT-K7&page=5&search=1&cmp_cod_search=8met_id=98bra_id=0&epo_id=0&cmt_id=0&ett_id=0. The page is titled "Key and supplementary comparisons - Information" for CCT-K7. The left sidebar contains navigation links: Information, List / Contact, Participants, Results, Print out, Related links, and Contact us. The main content area provides details about the comparison:

| CCT-K7 | |
|------------------------|---|
| Information | |
| Metrology area, branch | Thermometry, Fixed Point Cells |
| Description | Comparison of water triple point cells |
| Time of measurement | 2002 - 2004 |
| Status | Approved for equivalence, Results available |
| Reference(s) | Metrologia, 2006, 43, Tech. Suppl., 03001 |
| Measurand | Temperature: 273.16 K |
| Transfer device(s) | Water triple point cells |
| Comparison type | Key comparison |
| Consultative Committee | CCT (Consultative Committee for Thermometry) |
| Conducted by | CCT (Consultative Committee for Thermometry) |

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The screenshot shows the BIPM KCDB website with the URL: kcdb.bipm.org/Appendix8/KCDB_Ap8_result.asp?cmp_id=459&cmp_cod=CCT-K7&search=1&cmp_cod_search=8met_id=98bra_id=0&epo_id=0&cmt_id=0&ett_id=0. The page is titled "Key and supplementary comparisons - Results" for CCT-K7. The left sidebar is identical to the previous screenshot. The main content area provides details about the results:

Results published on 10 January 2006
[SUBMETT.7](#), [SUBMETT.7-1](#), [SUBMETT.7-2](#), [SUBMETT.7-3](#), [SUBMETT.7-4](#) and [COOMET-K7](#)
 Results are linked to those of CCT-K7

Comparison of water triple point cells

Click on the following link to access results:

[Triple point of water](#)

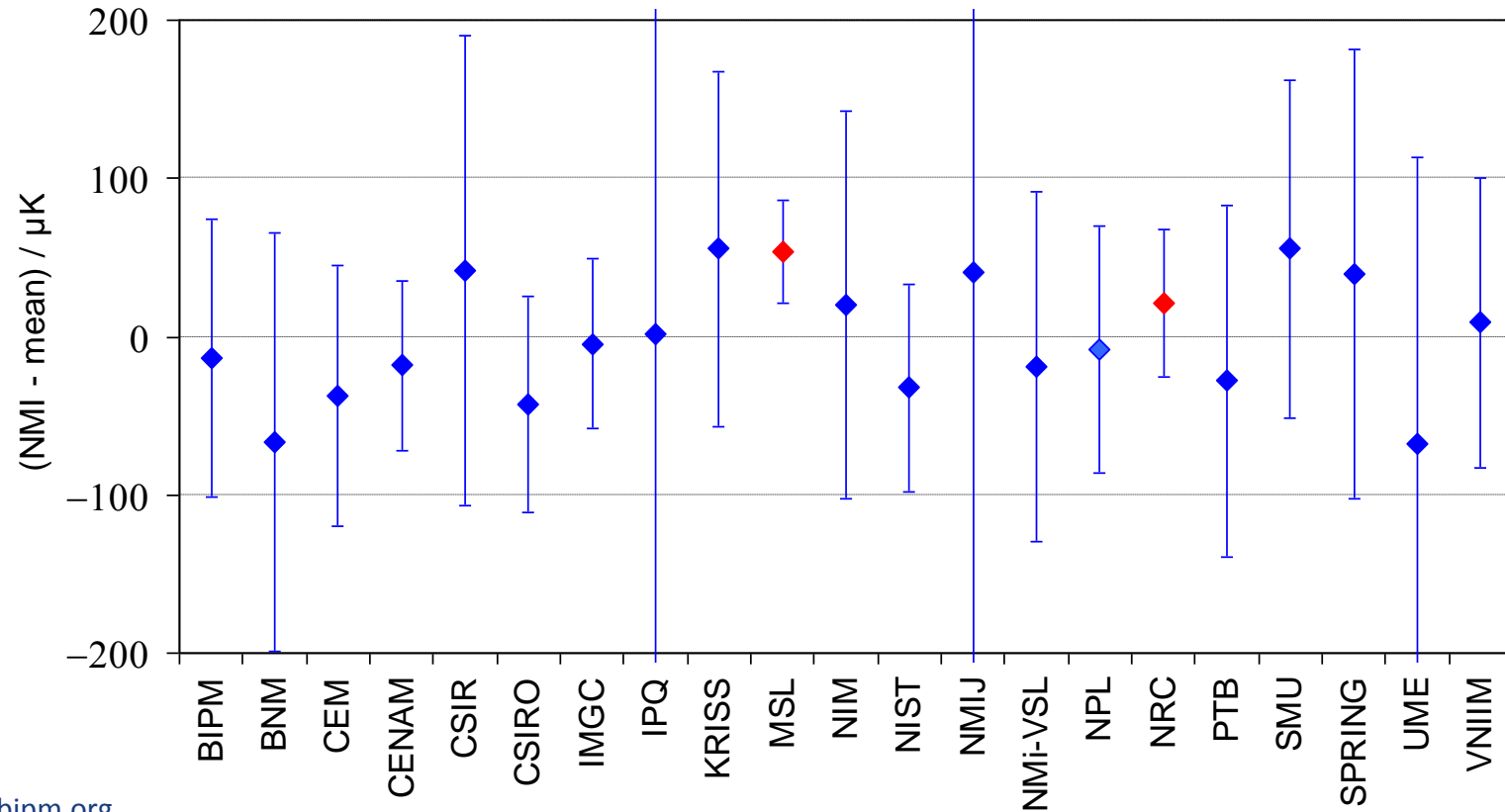
Links are provided to the following .PDF files:

- [Original graph of equivalence](#)
- [Summary Results \(A4 printable format\)](#)
- [CCT-K7 Final Report](#)
- [SUBMETT.7 Final Report](#)
- [SUBMETT.7-1 Final Report](#)
- [SUBMETT.7-2 Final Report](#)
- [SUBMETT.7-3 Final Report](#)
- [SUBMETT.7-4 Final Report](#)
- [COOMET-K7 Final Report](#)

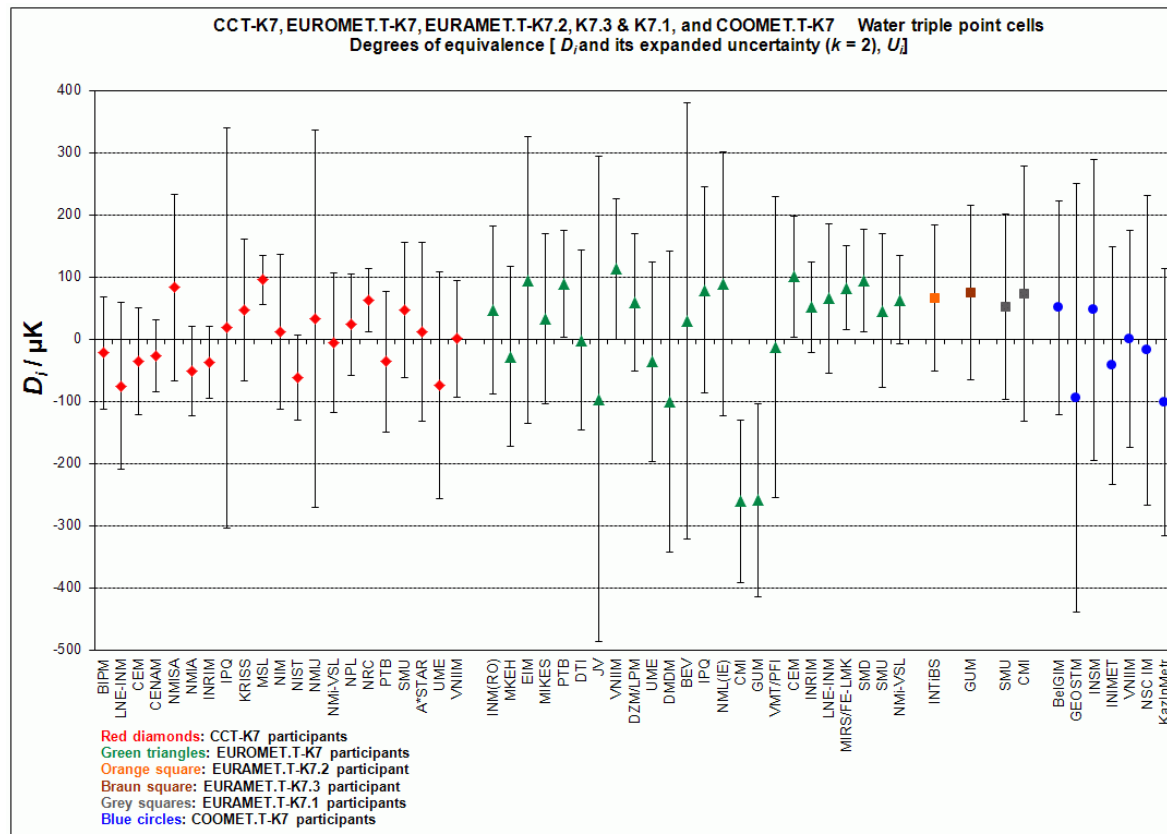
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Results of a Key Comparison

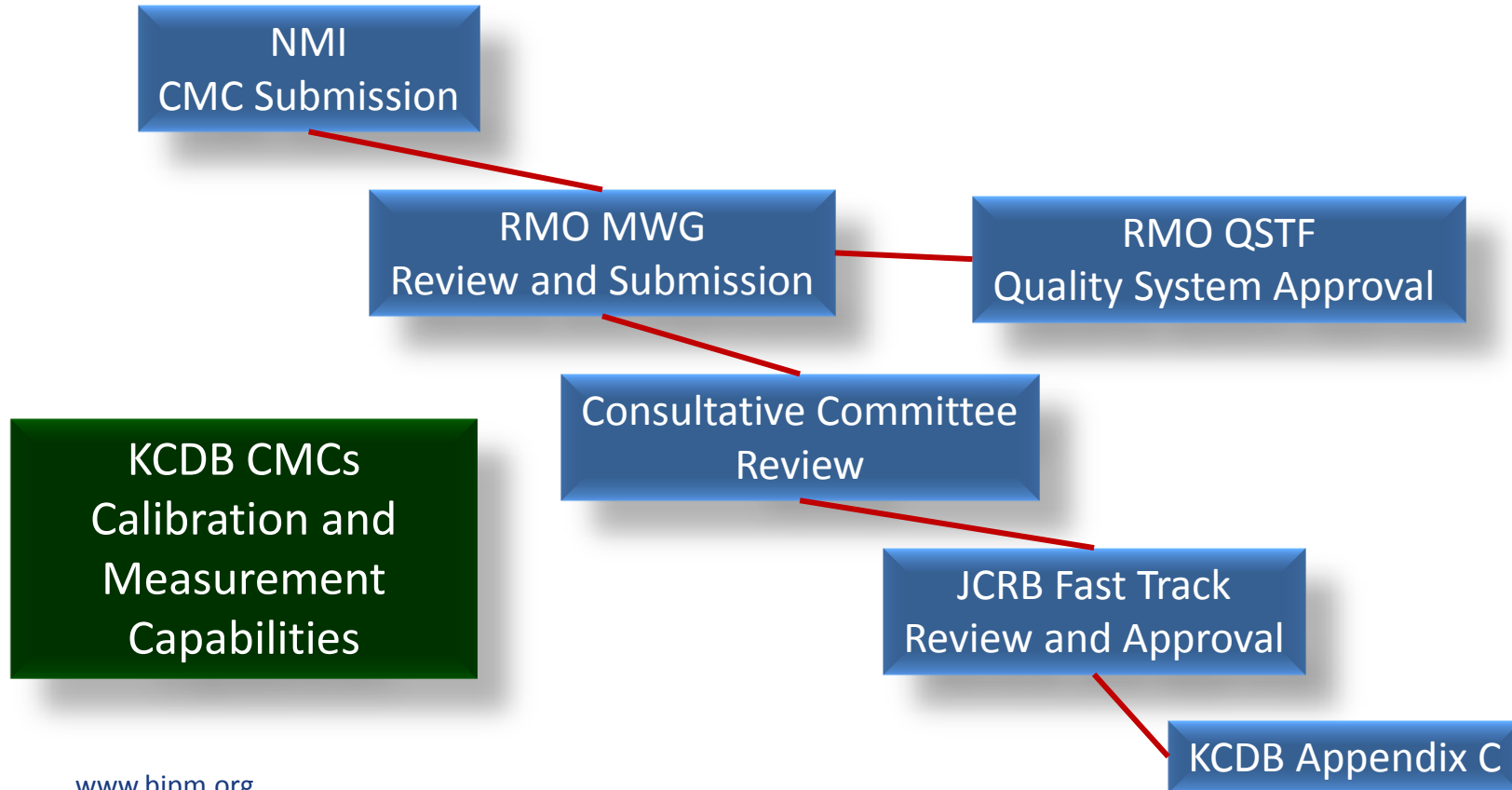
CCT K7: TPW



Combining all K7 comparisons – Degrees of Equivalence



CCT CMC – Submission Review Approval





Thank you – Questions ?

gregory.strouse@nist.gov

kgarrity@nist.gov

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