CCT-K8 Comparison of realizations of local scales of dew-point temperature of humid gas

Dew-point Temperature: 30 °C to 95 °C

Technical protocol (Approved CCT WG.KC)

Contents

1. INTRODUCTION

1.1 Under the Mutual Recognition Arrangement (MRA)[1] the metrological equivalence of national measurement standards will be determined by a set of key comparisons chosen and organized by the Consultative Committees of the CIPM working closely with the Regional Metrology Organizations (RMOs).

1.2 At the 24th Meeting of the CCT in May 2008, it was agreed to organise a CCT Comparison in dew-point temperature (high range) as a follow-up of the existing CCT-K6 dew-point temperature comparison, as proposed by CCT-WG6 (Now WG-Hu).

1.3 The completed registration form for the proposed CCT-Kx high range dew-point key comparison was submitted on 26/09/2008 and registered in the KCDB database on 29/09/2008

1.4 This technical protocol has been drawn up by the Coordinator in consultation with the nominated participants listed in Section 2. It is based on the protocol developed by CCT/WG6 and designed to encourage coherence between CCT-K8 and the corresponding RMO-K8s.

1.5 The procedure outlined in this document cover the technical operations to be followed during measurement of the travelling standards. The procedure, which follows the guidelines established by the BIPM[2,3] is based on current best practice in the use of dew/frost-point hygrometers and takes account of the experience gained from the CCT-K6, EURAMET.T-K6, EURAMET.T-K8 and APMP.T-K8.

1.6 This comparison is aimed at establishing the degree of equivalence between realisations of local scales of dew-point temperature of humid gas, in the range from 30 °C to 95 °C, among the participating national metrology institutes (NMI)[4].

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[1] *MRA, Mutual Recognition Arrangement, BIPM, 1999.*

[2] *T.J. Quinn, "Guidelines for key comparisons carried out by Consultative Committees", Appendix F to the MRA, BIPM, Paris.*

[3] *CIPM MRA-D-05. "Measurement comparisons in the CIPM MRA"*

[4] *The term national metrology institute and acronym (NMI) also encompasses the designated institutes (DI) throughout the document.*

2. ORGANIZATION

2.1 Participants

2.1.1 A list of participants is given in table 1. Details of mailing and electronic addresses are given in **Appendix A.**

2.1.2 The participants are divided into two groups. Each group will form a comparison loop. To link the loops to each other, the loops have besides the two Pilots one common participant who measures also both travelling standards.

2.1.3 INTA is the Coordinator of the comparison and the Pilot for both loops, taking main responsibility for running the comparison. NIST is Assistant Pilot. The third, common participant is BEV/E+E who also covers the full range of the comparison, complementing the capability of NIST.

2.1.4 By their declared intention to participate in this key comparison, the laboratories accept the general instructions and the technical protocol written down in this document and commit themselves to follow strictly the procedures of this protocol as well as the version of the "Guidelines for Key Comparisons" in effect at the time of the initiation of the Key Comparison.

2.1.5 Once the protocol and list of participants have been approved, no change to the protocol or list of participants may be made without prior agreement of all participants.

2.1.6 All participants must submit an uncertainty budget of their humidity standards.

Table 1 List of participants (*C*=Coordinator, *P*=Pilot, *L*=Linking laboratory)

RMO	NMI	Country	Role	Loop
APMP	Korea Research Institute of Standards and Science (KRISS)	KR		1
	National Metrology Centre (NMC-A*STAR)	SG		1
	National Metrology Institute of Japan (NMIJ), AIST	JP		1
COOMET	VNIIFTRI East Siberian Branch (VNIIFTRI)	RU		1
EURAMET	Instituto Nacional de Técnica Aeroespacial (INTA)	ES	***C, P***	1, 2
	Istituto Nazionale di Ricerca Metrologica (INRiM)	IT		2
	National Physical Laboratory (NPL)	GB		2
	Physikalisch-Technische Bundesanstalt (PTB)	DE		2
	E+E Elektronik Ges.m.b.H. (BEV/E+E)	AT	***L***	1, 2
SIM	National Institute for Standards and Technology (NIST)	US	***P***	1, 2

2.2 Method of comparison

2.2.1 The comparison is of the realization of local scales of dew-point temperature at the participating NMIs.

2.2.2 The comparison will be made by calibration of travelling standards purchased by *Centro Español de Metrología* (CEM) and deposited at INTA as part of the

Spanish humidity national metrology infrastructure. The travelling standards will measure dew-point temperature of a sample of moist gas produced by a participant's standard generator.

2.2.3 The comparison is carried out in two parallel loops with separate travelling standards (See Fig. 2.2.1). Measurements will start in the Pilot and Assistant Pilot laboratories. The other participants in the loop will then perform comparison measurements at the dew-point temperatures required. The last participant will then return the travelling standard to the Pilot to carry out final measurements to monitor drift. The draft of a time schedule for this comparison can be found in **Appendix B**. Allowing between 4 and 6 weeks per set of measurements (including shipping), this comparison will have a duration of approximately 10 months.

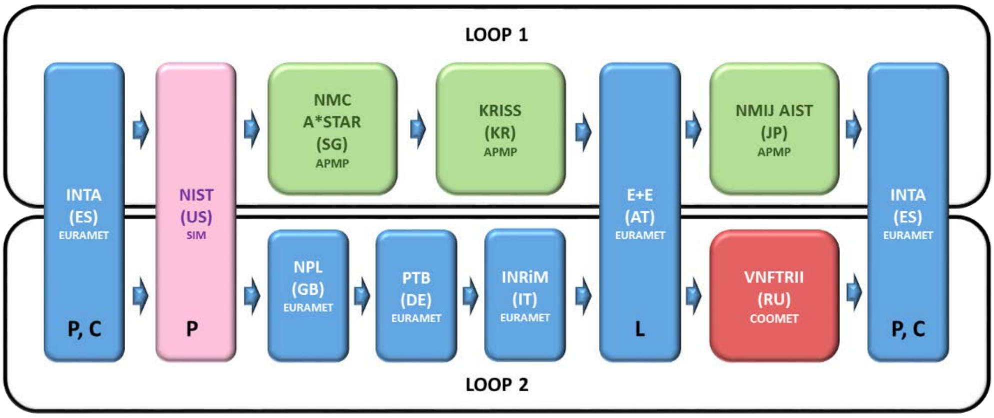

Fig. 2.2.1 Circulation scheme

2.2.4 All results are to be communicated directly to the Pilot (INTA) within three weeks after the completion of the measurements by a laboratory. If this time is seriously exceeded without coordination with the Pilot, the results of this laboratory may be excluded from the comparison. Exclusion of a participant's results from the report may occur if the results are not available in time to prepare the draft report.

2.2.5 Each participant must inform the Pilot within 24 hours of the arrival and despatch of the travelling standards, with copy to the Coordinator. If for some reason, the measurement facility is not ready or customs clearance takes too much time in a country, the participating laboratory must contact the Pilot immediately.

2.2.6 In case of serious difficulty with customs, or other delays which might over-run the time period of the ATA Carnet, the Pilot may request the instruments be returned to the holder of the ATA Carnet (INTA) or to the Assistant Pilot laboratory (NIST), or the sequence of participation may be changed to the most practical arrangement.

2.2.7 The Coordinator (INTA) must be informed about any delays in the schedule.

2.3 Handling of artefacts

2.3.1 The artefacts should be examined immediately upon receipt at the laboratory. All participants are expected to follow all instructions in the operator's manual provided by the instrument manufacturer. For proper unpacking, subsequent packing and shipping to the next participant, detailed instructions have been provided in **Appendix C** of this protocol. During packing and unpacking, all participants should check the contents with the packing list.

2.3.2 The travelling standards should only be handled by authorized persons and stored in such a way as to prevent damage.

2.3.3 During operation of the travelling standards, if there is any unusual occurrence, e.g., loss of heating control, large oscillations, etc. the Pilot laboratory should be notified immediately before proceeding.

2.4 Transport of artefacts

2.4.1 The transportation process begins when the artefact leaves the sending laboratory and does not end until it reaches the destination laboratory. All participants should follow the following general guidelines:

(1) Plan the shipment well in advance. The recipient should be aware of any customs issues in their country that could delay the testing schedule. The shipping laboratory must be aware of any national regulations covering the travelling standard to be exported.

(2) Mark the shipping container "**FRAGILE SCIENTIFIC INSTRUMENTS**" “**TO BE OPENED ONLY BY LABORATORY STAFF**” and with arrows showing "**THIS WAY UP**"; attach shock indicators and seal the container (e.g. with old calibration marks etc.).

(3) Determine the best way to ship the travelling standard to the next participant. In general ground transportation by truck with an approved courier must be preferred.

(4) Obtain the recipient's current shipping address. If possible, have it shipped directly to the laboratory. Note that the addresses in **Appendix A** may be outdated.

(5) Coordinate the shipping schedule with the recipient. The sending laboratory should provide the recipient with the details of the carrier, the tracking number (AWB or other reference), the exact travel mode, and the estimated time of arrival.

(6) Instruct the recipient to confirm receipt and condition upon arrival to the sender and the Pilot. A form for reporting on the receipt of the travelling standards is shown in **Appendix D.**

2.4.2 Each travelling standard is supplied with its shipping container, which is sufficiently robust to ensure safe transportation.

2.4.3 The artefacts will be accompanied by a suitable customs ATA Carnet. Care should be taken with the timing of the ATA Carnet, which only lasts for one year.

2.5. Costs

2.5.1 Each laboratory is responsible for the cost of shipping to the next participant including any customs charges and insurance.

2.5.2 Each laboratory pays its share of the services[5] provided by MBW Calibration AG. The participants will be invoiced by MBW Calibration AG after completion of the comparison.

3. DESCRIPTION OF THE TRAVELLING STANDARDS

3.1. Artefacts

3.1.1 Centro Español de Metrología (CEM) lends one travelling standard per loop for the key comparison. The instruments are state-of-the-art, commercially available chilled-mirror dew-point hygrometers.

3.1.2 Details of travelling standards:
The two travelling standards are new and of the same type:

Model:	MBW 373 HX
Size (in packing case):	75 x 55 x 58 cm
Weight (in packing case):	40 kg
Manufacturer:	MBW Calibration AG
Owner:	Centro Español de Metrología (CEM)
Electrical supply:	230 V / 50 Hz
Electrical connection:	Instrument socket IEC/EN 60320-2-2 (socket C14/plug C13) The instrument is supplied with a Schuko (Continental Europe) plug Standard CEE 7/VII
Power consumption:	300 W
Tube connectors:	Swagelok® 6 mm
Accessories:	Endoscope, 4-wire cable for resistance measurements (3 m), heated flexible hose with 6 mm Swagelok® connectors, pressure measurement insert, condensation trap, flowmeter, operating manual
Approximate value for insurance and customs declaration:	40 000 EUR

[5] MBW Calibration AG, will provide technical support on site with the transfer standards or at the factory premises in Switzerland, as applicable.

Serial numbers of the instruments are:

Loop 1	Loop2
08-1215	08-1216

4. MEASUREMENT INSTRUCTIONS

4.1. Measurement process

4.1.1 All participants should refer to the operating manuals for instructions and precautions for using the travelling standards. Participants may perform any initial checks of the operation of the hygrometers that would be performed for a normal calibration. In the case of an unexpected instrument failure at a participant institute, the Pilot institute should be informed in order to revise the time schedule, if necessary, as early as possible.

4.1.2 Sample gas generated by a participant's standard generator, is introduced into the inlet of a travelling standard hygrometer through the supplied heated flexible hose terminated with Swagelok® 6 mm connectors. The electrical connector of the hose is plugged into the appropriate socket near the gas inlet terminal. For all dew-point temperatures, normal precautions (heating) should be used to protect against condensation in sample lines. Special care has to be taken with the connection between the end of the heated hose and the input terminal of the instrument. This point has to be heated externally to prevent condensation at high dew-point temperatures.

4.1.3 Measurements are carried out at nominal dew-point temperatures of 30 °C, 50 °C, 65 °C, 80 °C, 85 °C, 90 °C and 95 °C (refer to 4.1.4 for limited range at high dew-point temperatures). These values are chosen in accordance with the maximum dew-point, participants can generate.

4.1.4 If the scope of a laboratory does not cover the whole range of this comparison, the laboratory is allowed to limit measurements to the highest nominal dew-point temperature specified in 4.1.3 that is within the scope.

4.1.5 Measurements should be done in rising order of dew-point temperature.

4.1.6 The values of dew-point temperature applied to the travelling standards should be within ± 0.5 °C of the agreed nominal values for the comparison, and ideally closer than this. Deviations greater than this may increase the uncertainty in the comparison, for a particular result.

4.1.7 The measurements are to be performed at a system absolute pressure not to exceed 108 kPa. Participants should take into account that the flow which has to be adjusted for a constant volumetric at the conditions of the mirror depends strongly on the system pressure and the ambient pressure. Please note that the supplied rotameters are calibrated for use at 1013.25 hPa and 20 ºC. it is recommended that all measurements are performed at the same nominal system pressure that is applicable to the laboratory conditions. For laboratories at a suitable altitude above sea level, it is recommended that the nominal system pressure be set to 101.3 kPa and for other laboratories at the most convenient value up to 105.0 kPa.

4.1.8 If the type of generator used (e.g. two pressure generator) requires a precise pressure measurement at the point of condensation (mirror), pressure should be measured as close as possible to the outlet terminal of the hygrometer. The hygrometers are **NOT** equipped with a gas pump, so the outlet of the measuring cell is directly connected to the rear outlet terminal. The remaining pressure drop between the point of condensation and the point of pressure measurement shall be determined as accurately as possible. A possible value for this pressure drop found during the initial tests in the Pilot laboratories is approximately 18 Pa at a flow rate of the wet gas of 0.5 l/min. This should be verified with own measurements by each participant. For this purpose, a special adaptor has been provided to be inserted instead of the endoscope to act as a pressure measurement port.

Attention: Great care should be placed when inserting or removing this so as not to damage the internal o-ring seal in the endoscope port. It should be inserted or removed slowly whilst turning slightly to avoid pinching the O-ring.

A 6 mm connector is also available at the top of the the 12 mm tee at the instrument outlet (see Fig. 1) in order to connect for measurement of pressure drop between head and exit.

Important: For the purpose of this comparison the reference point for all measurements is taken as the point of condensation (mirror). Therefore, the applied reference dew-point temperature should be given for this condition, making due allowance for any pressure drops between the point of saturation and the point of condensation.

4.1.9 Special care has to be taken to avoid condensation and subsequently plugging by water in the outlet lines. A suitable heating and tubes with a greater inner diameter while measuring high dew-point temperatures will help prevent this fault.

4.1.10 Due to dew-point temperatures above ambient temperature the condensing water from the outlet of the hygrometer must be separated before entering the variable area flowmeter (rotameter) e.g. by a condensation trap (use hoses or tubes with large inner diameter). Doing this, the water content exceeding saturation conditions at room temperature is removed. This requires a correction of the flow rate indicated by the variable-area flow meter and the laboratory's flow measurement [6]. Further examples are given in **Appendix G**. Participants should contact the pilot in advance of receiving the instruments if they require assistance in determining the values for their exact laboratory

[6] *Mitter H, Böse N, Benyon R and T. Vicente, "Pressure drop considerations in the characterization of dew-point transfer standards at high temperatures". Int. Journal of Thermophysics (2012), Vol. 33, Issue 8-9, pp 1726-1740*

conditions. The following table shows this correction assuming saturation condition at 20 °C (room temperature), volume expansion, according to the system pressure of 101.3 kPa and temperature of the heated head and tube and is calculated for a wet gas flow of 0.5 l/min.

Dew-point temperature °C	Head temperature °C	Volume of water %	Indicated flow rate after the condensation trap l/min
30	60	4.2	0.44
50	80	12.3	0.38
65	95	24.9	0.31
80	110	47.1	0.21
85	115	57.4	0.17
90	115	69.5	0.12
95	115	83.7	0.06

Table 2: Example of indicated flow rate after the condensation trap for the selected dew-point for a system pressure of 101.3 kPa, room temperature 20 ºC.

4.1.11 A suitable condensation trap and variable-area flowmeter (rotameter) has been provided[7]. This should be connected to the instrument outlet directly (see Fig. 1).

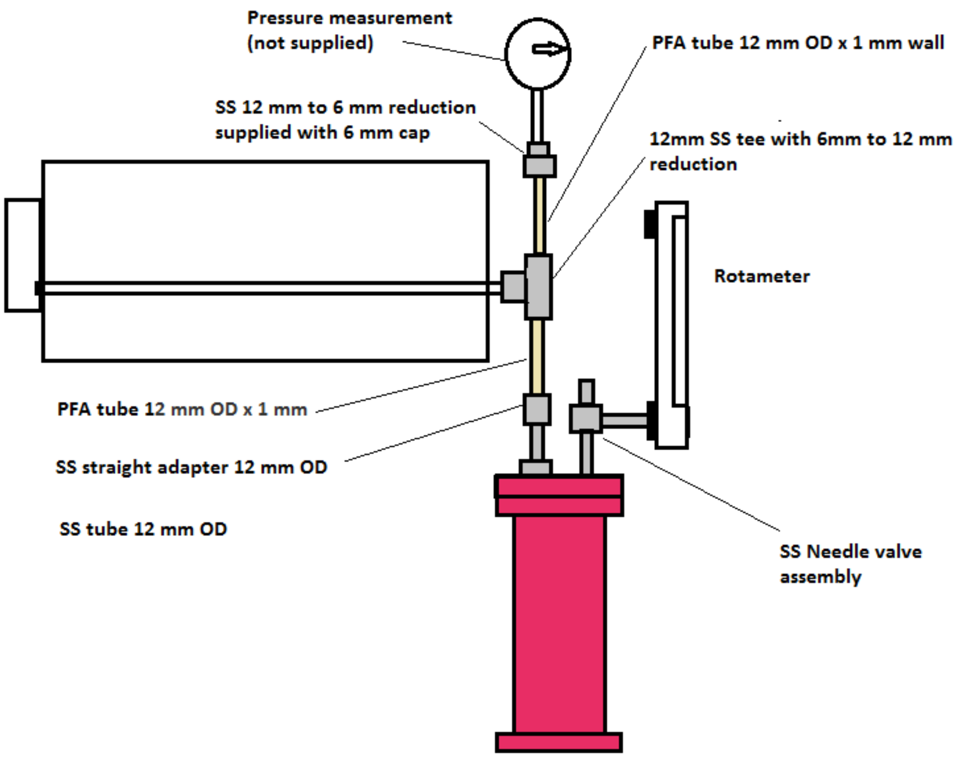

Fig. 1: Schematic of connection of condensation trap with pressure measurement port

[7] *NOTE: Participants may use their own condensation trap if this is more convenient with their generation system.*

4.1.12 Once the flow has been set, the flowmeter should be removed[8] and purged with dry gas. Care must be taken not to touch the needle valve setting whilst removing the flowmeter.

4.1.13 Four sets of measurements are carried out at each generated nominal dew-point temperature. The condensate should be cleared and the mirror cleaned if necessary. The flow after the condensation trap should be readjusted. Where relevant (e.g. significant contribution due to lack of reproducibility of the reference value), values should be taken after returning from another value). This is to reduce the effect of any irreproducibility of the travelling standards [9].

4.1.14 The condensate on the mirror should be cleared and re-formed for each value or repetition of dew-point temperature performing a "Manual Mirror Check" (fixed function key at the bottom bar). The "Automatic Mirror Check" must be disabled (Menu Keys: "Control Setup" → "Mirror Check").

4.1.15 Operation with the travelling standards

Before any humidity measurements, initial actions should be taken:

1) Read the manual "Operating Instructions" delivered by the manufacturer (a copy of the manual is in the transport case).

2) At a volumetric flow rate of 0.5 l/min, the flow-rate indications of the hygrometer, the rotameter and the laboratory flow meter are compared to each other (at a pressure corresponding to the sample gas pressure during dew-point temperature measurements). It is highly recommended to carry out the test in the generator system used in the comparison. In a case of strongly fluctuating sample gas flow, the flow indicator of the hygrometer may show incorrect value. For this test, the dew-point temperature should not exceed room temperature to avoid condensation.

3) When the hygrometer is in a standby mode (i.e. mirror temperature control is switched off), the dew-point temperature indication, resistance of a PRT embedded in the mirror, measured with an external bridge or multimeter, and mirror temperature reading from the RS-232 port are recorded during ten minutes (at least ten measurements). This result should be sent to the Pilot, together with the results of the measurement indicated in section **5.2**, as soon as possible, in order to check the condition of the transfer standard**.**

[8] *NOTE: This is to avoid condensation in the flow meter at higher dew-point temperatures after accumulating water in the condensation trap that could lead to wetting of the flow meter and consequent change the flow through the instrument. Also, sometimes flowmeters tend to oscillate with a back-effect on the instrument.*

[9] *NOTE: It is assumed that the reproducibility of the reference generator is already known. The characterization of the transfer standards has shown that the principal contribution due to lack of reproducibility is the flow setting after the condensation trap and the existence of contamination on the mirror.*

4) Set the hygrometer ready for cleaning with “Mirror Cleaning”.

5) Remove the endoscope carefully following the instructions.

6) Open the measuring head carefully according to the instructions given in the operating manual.

7) Clean the mirror surface using a suitable lint-free tissue or cloth or cotton tips with distilled or de-ionised water preceded by initial cleaning with pure ethanol of p.a. grade if necessary. As the last act of the cleaning procedure it is advantageous to rinse pure distilled water over the mirror which is collected with a cloth below the mirror.

8) Close the measuring head carefully according to the instructions given in the operating manual.

9) Replace the endoscope carefully.

10) Press “OK” for successfully performed mirror cleaning.

Dew-point temperature measurements:

1) Clean the mirror if needed according to the instructions above (no sample gas flow).

2) Set the heater control for the measuring head and the inlet tube to ‘Fixed Mode’ with the target value 30 K **above** the nominal dew-point temperature (Menu Keys: “Control Setup” → “Heater”→”Fixed Mode Target”) and switch on the Heater with the fixed function key at the bottom bar. **Note:** The maximum selectable head temperature is 115 °C. This applies also for dew-point temperatures of 90 °C and above.

3) Wait until the head temperature has stabilized to the pre-set value. To watch this stabilization process, the ‘head temperature’ and the ‘external tube temperature’ should be displayed each on a display line.

4) Set the flow rate of wet sample gas at 0.5 l/min[10] according to an indication by the supplied variable-area flow meter taken from the table 2 in section 4.1.9.

5) **Important:** Press and hold the 0-key (the numerical button for 0) for about 3 seconds until a short beep sounds. This is a special need with both transfer standards to indicate a clean mirror at the right temperature. We have decided to switch off the AUTOLAMP parameter in the instrument setup as this process of manual setting the reflected light intensity to zero gives more stable results over a long period.

[10] *NOTE: Volumetric flow-rate at the measurement head conditions (temperature and pressure).*

6) Start measurements with “Dew/Frost Control” key at the bottom bar (Fixed Function Keys).

7) A homogenous condensate should appear on the mirror; if not, the condensate should be cleared and re-formed with “Mirror Check” (Fixed Function Keys). If necessary, the mirror is cleaned again according to the instructions above. If you experience an oscillating layer thickness with oscillation of the indicated value at very high dew-point temperatures, a new cleaning process may be necessary.

8) After appropriate time of stabilisation, measurements are carried out. The process of collecting data is described below (chapter 4.2). At this time the head temperature and the tube temperature must not increase or decrease.

9) Before changing the sample gas dew-point temperature, make sure that the head temperature and the tube temperature are high enough for the new desired dew-point (see instructions 2 above).

10) Before measuring at the next measurement point, the condensate should be cleared and re-formed with “Mirror Check” (Fixed Function Keys)

4.1.16 Participants should avoid lengthy additional measurements, except those necessary to give confidence in the results of this comparison.

4.1.17 The travelling standards used in this comparison must not be modified, adjusted, or used for any purpose other than described in this document, nor given to any party other than the participants in the comparison. **Important:** Instrument parameters available in the Extended-Access-Menu or via command line on the serial interface of the instrument, must **NOT** be amended without prior written permission of the Pilot.

4.1.18 The Pilot will make an assessment of any drift in the travelling standards during the comparison, based on measurements at the Pilot laboratory at the beginning and end of the comparison period. If drift is found, this will be taken into account in the final analysis of the comparison results.

4.1.19 If poor performance or failure of a travelling standard is detected, the Pilot of the loop will propose a course of action, subject to agreement of the participants.

4.2. Data collection

4.2.1 In the travelling standards, there are two 100-ohm platinum resistance thermometers (PRT) embedded beneath the surface of the chilled-mirror to measure the dew/frost-point temperature. One is used for system measurement and control. The resistance of the other one is measured via a Lemo connector in the rear panel. Dew-point temperature readings used primarily in this comparison are obtained from the resistance of the second PRT. The current applied to the PRT should be nominally 1 mA. The resistance of the PRT should be measured using a calibrated multi-meter or a resistance bridge, and then converted to a corresponding dew-point temperature. The calculation of the temperature is done according to IEC 60751 and is described in **Appendix E.**

Note: The internal parameters also of the first PRT used for the display and the data communication via RS-232 have been set to the nominal values according to IEC 60751. No individual calibration coefficients are stored in the instruments.

4.2.2 Each measured value (incl. its standard uncertainty) is obtained calculating the mean and standard deviation of at least 10 readings of the resistance of the PRT recorded during 10 to 20 minutes.

4.2.3 Participants may apply their own criteria of stability for acceptance of measurements according to their normal calibration procedures.

4.2.4 As a supporting measurement, the digital display readings (and/or digital signal through a serial port in the rear panel) for dew-point temperature, head temperature, flow rate and head pressure in the travelling standard should be monitored. The mean and standard deviation of a set of at least 10 readings, taken over the same period as the dew-point temperature measurements should be reported.

4.2.5 Values reported for dew-point temperatures produced by a participant's standard generator should be the value applied to the instruments, after any allowances for pressure and temperature differences between the point of realisation (laboratory standard generator or reference hygrometer) and the point of use (travelling standards).

5. REPORTING OF MEASUREMENT RESULTS

5.1 Participants must report their measurement results of four reproduced measurements, within three weeks of completing their measurements to the Pilot (refer to section 2.2.4).

5.2 The participants shall report to the Pilot the first measurement at a nominal dew-point temperature of 30 ºC within 48 h of it being measured, together with the initial tests performed in **4.1.14**, to check the correct performance of the transfer standard(s).

5.3 The Pilot shall accumulate data continually and should analyse the results for possible anomalies in the travelling standard. If problems arise, the Pilot should consult with the participant that submitted the data as soon as possible, and certainly before the distribution of Draft A of the Report of the comparison.

5.4 The parameter to be compared between the laboratories in this comparison is the difference found between the travelling standards and the laboratory dew-point temperature standard. Note that the values of dew-point temperature reported are “arbitrary” values calculated from the measured resistance output, because of the use of the generalised IEC 60751 relationship. The travelling standards are used simply as comparators.

5.5 Participants should report results to the Pilot in terms of dew-point temperature. The main measurement results comprise:

- values of dew-point temperature applied to the travelling standard, and associated standard uncertainty
- values measured using the travelling standard (and the associated uncertainties derived from standard deviation of the set of readings)
- values of difference between applied dew-point and measured dew-point temperature.

Participants shall submit their results in electronic form, using the Excel template provided in **Appendix F**. Use of this format, including calculations of means and differences, allows participants to see clearly the values and uncertainties of the parameters they are submitting for comparison.

5.6 From the data measured by each participant, results will be analysed in terms of differences between applied and measured dew-point temperatures. In each case, the difference will be taken between the applied (realised) value and the mean (mid-point) between the hygrometer values.

5.7 In addition, the difference between the hygrometer reading on all occasions will be analysed and will serve as a check of consistency.

5.8 The participants should report the conditions of realisation and measurement, as background information to support the main results. These conditions may include, pressure and temperature in saturator or reference hygrometer, pressure difference between saturator or reference hygrometer and travelling standards, measurement traceability, frequency of AC (or DC) resistance measurement, and other items. A template for reporting conditions of measurement is included in the Excel workbook provided in **Appendix F**.

5.9 Participants should provide a description of the operation of their dew-point facilities used in the comparison.

5.10 Participants should also provide an example plot of equilibrium condition (resistance versus time) at a nominal dew-point temperature of 50 °C, over at least one hour.

5.11 Any information obtained relating to the use of any results obtained by a participant during the course of the comparison shall be sent only to the Pilot laboratory and as quickly as possible. The Pilot laboratory will be responsible for coordinating how the information should be disseminated to other participants. No communication whatsoever regarding any details of the comparison other than the general conditions described in this protocol shall occur between any of the participants or any party external to the comparison without the written consent of the Coordinator. The Coordinator will in turn seek permission of all the participants. This is to ensure that no bias from whatever accidental means can occur. Draft B is the first public version.

5.12 If a participant significantly delays reporting of results to the Pilot, then a deadline will be agreed among the participants. If that deadline is not met, then inclusion of those results in the comparison report will not be guaranteed.

6. UNCERTAINTY OF MEASUREMENT

6.1 The uncertainty of the key comparison results will be derived from:

- o the quoted uncertainty of the dew-point temperature realisation (applied dew-point temperature)
- o the estimated uncertainty relating to the short-term stability of the travelling standard at the time of measurement
- o the estimated uncertainty due to any drift of the travelling standard over the period of the comparison (estimated by the Pilots)
- o the estimated uncertainty in mean values due to dispersion of repeated results (reflecting the combined reproducibility of laboratory standard and travelling standards)
- o the estimated uncertainty due to non-linearity of the travelling standards in any case where measurements are significantly away from the agreed nominal value
- o the estimated covariance between applied (laboratory standard) and measured (travelling standard) values of dew-point temperature (if found significant)
- o any other components of uncertainty that are thought to be significant.

6.2 Participants are required to submit detailed analyses of uncertainty for their dew-point standards. Uncertainty analysis should be according to the approach given in JCGM100 (2008): *Evaluation of measurement data - Guide to the expression of uncertainty in measurement*. A list of the all significant components of the uncertainty budget[11] should be evaluated, and should support the quoted uncertainties. Type B estimates of uncertainty may be regarded as having infinite degrees of freedom, or an alternative estimate of the number of degrees of freedom may be made following the methods in the Guide. A template for reporting uncertainty of measurement is included in the Excel workbook provided in **Appendix F**. Individual institutes may add to the template any additional uncertainties they consider relevant.

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[11] *For example, see J. Nielsen, J. Lovell-Smith, M.J. de Groot, S. Bell, Uncertainty in the Generation of Humidity, CCT/03-20 (BIPM, Sèvres Cedex, France, 2003)*

6.3 The Pilot laboratories will collect uncertainty budgets as background information to the uncertainties quoted by participants for the comparison measurements. The Pilots and the Coordinator will review the uncertainty budgets for consistency among participants.

6.3 The uncertainty budget stated by the participating laboratory should be referenced to an internal report and/or a published article.

7. BILATERAL EQUIVALENCE

7.1 Bilateral equivalences at each dew point will be calculated from differences D_{ij} between participants *i* and *j*, where

$$Dij = R_i - R_j \quad , \tag{1}$$

The bilateral degree of equivalence (DoE) is determined as

$$(D_{ij}, U_{ij}) = (D_{ij}, ku(D_{ij})) \, , \tag{2}$$

where the coverage factor k=2 provides a coverage probability of 95 % for sufficiently large effective number of degrees of freedom of $u(D_{ij})$[12].

In this case, $u(D_{ij})$ is given by

$$u^2(D_{ij}) = u^2(x_i) + u^2(x_j) + u^2{}_{drift}, \tag{3}$$

where $u^2{}_{drift}$ is the uncertainty in the comparison due to drift of the hygrometer at a given dew point value. For simplicity, $u^2{}_{drift}$, is assigned a single generalised value at each dew point, irrespective of whether participants measured in immediate succession or separated in time. If drift is observed then then clause 8.4 will be applied.

The DoE will be calculated for each pair of participants at each nominal measurement point.

8. THE KEY COMPARISON REFERENCE VALUE (KCRV)

8.1 The outputs of the key comparison are expected to be:

- Results of individual participants for comparison of the hygrometers against their dew-point temperature reference in terms of mean values for each hygrometer at each measured value, estimated standard uncertainty of each mean result and estimated standard uncertainty of comparison process (e.g.

[12] *Cox, M., The evaluation of key comparison data, Metrologia **39** (2002) 589-595*

effect of long-term stability and non-linearity of the travelling standards) if necessary.

- Estimates of bilateral equivalence between every pair of participants at each measured dew-point temperature.
- A key comparison reference value (KCRV) for each nominal value of dew-point temperature in the comparison. The KCRV will be calculated as a weighted mean of all valid results.
- Estimates of equivalence of each participant to the KCRV. This might be expressed in terms of the Degree of Equivalence (DOE) given as a difference and its uncertainty (Δ ±U), in °C.

8.2 In the field of dew-point standards, the KCRV does not have any absolute significance with respect to an SI unit. It is calculated only for purposes such as the presentation and inter-relation of key comparison data for the MRA.

8.3 In this comparison and other corresponding RMO comparisons, a reference value is calculated for each nominal value of dew point, treating them as separate data populations for this purpose.

For each nominal dew point value, a key comparison reference value (KCRV) will be calculated as the weighted mean, y, of results

$$y = \frac{x_1/u^2(x_1) + \ldots + x_N/u^2(x_N)}{1/u^2(x_1) + \ldots + 1/u^2(x_N)}, \quad (4)$$

this method of calculation has been agreed by CCT Working Group 6 and applied successfully in CCT-K6. For comparison, values of arithmetic mean and median will also calculated. The uncertainty in weighted mean due to dispersion will be calculated from

$$\frac{1}{u^2(y)} = \frac{1}{u^2(x_1)} + \ldots + \frac{1}{u^2(x_N)}. \quad (5)$$

After collection of participant results, data will be checked for outliers, and calculation of the weighted mean will be made both with and without the outlying results. Values of arithmetic mean and median will also be calculated. As well as the uncertainty in weighted mean due to dispersion, an additional uncertainty in KCRV due to drift of the travelling standard will be include, if necessary, as defined in the next section.

8.4 The Pilots will make an assessment of any drift in the travelling standards during the comparison. The assessment will be based on initial and final measurements done by the Pilot. If drift is found, this will be taken into account in the final analysis of the comparison results. If the drift is small compared with uncertainty values reported by the participants, an estimate for the drift may be set to zero with a standard uncertainty calculated according to the ISO Guide. In a case of a significant drift, the effect is taken into account by assigning a time-dependent value to KCRV, or by other suitable method so that the estimates of equivalence can be meaningfully calculated between results taken at different times.

8.5 If a travelling standard fails or performs poorly during the comparison, the Coordinator and Pilots will propose a course of action, subject to agreement of the participants.

8.6 A chi-squared test will be carried out on the results with and without any identified outliers, as a measure of the consistency of the data and uncertainties.

Discrepant results will be identified using the criterion:

$$\left|R_{lab} - R_{KCRV}\right| > 2\sqrt{u^2(R_{lab}) - u^2(R_{KCRV})} \qquad (6)$$

The decision whether to exclude marginally-outlying data will be based on the impact on the KCRV.

Appendix A. DETAILS OF PARTICIPATING INSTITUTES

E+E Elektronik (BEV/E+E) Austria

Address: Langwiesen 7, A-4209 Engerwitzdorf, Austria
Contact: Dr Helmut Mitter
Phone: +43 7235 605 320
Fax: +43 7235 605 383
E-mail: helmut.mitter@epluse.at

Instituto Nacional de Técnica Aeroespacial (INTA) Spain

Address: Centro de Metrología y Calibración, Ctra. a Ajalvir, km. 4
ES-28850 Torrejón de Ardoz
Contact: Dr Robert Benyon
Phone: +34 915 201 711
Fax: +34 915 201 645
E-mail: benyonpr@inta.es

Istituto Nazionale di Ricerca Metrologica (INRiM) Italy

Address: Strada delle Cacce, 73, I-10135 – Torino
Contact: Dr Vito Fernicola
Phone: +39 011 3977 337
Fax: +39 011 3977 347
E-mail: v.fernicola@inrim.it

Korea Research Institute of Standards and Science (KRISS) R. of Korea

Address: 267 Gajeong-Ro Yuseong-Gu Daejeon 305-340
Contact: Dr. Byung Il Choi
Phone: +82 428685275
Fax: +82 428685290
Email: cbi@kriss.re.kr

National Institute for Standards and Technology (NIST) United States of America

Address: Bldg. 221, Rm. B131. 100 Bureau Dr.
Gaithersburg, MD 20899
Contact; Dr. Christopher Meyer
Phone: +1 301 975 4825
Fax: +1 301 548 0206
E-mail: christopher.meyer@nist.gov

National Metrology Centre (NMC-A*STAR) Singapore

Address: 1 Science Park Drive. PSB Building.
Singapore 118221
Contact Dr. Wang Li
Phone: 65 6279 1959
Fax: 65 6279 1996
Email: wang_li@nmc.a-star.edu.sg

National Metrology Institute of Japan (NMIJ), AIST Japan
Address: AIST Tsukuba Central 3,
Tsukuba 305-8563
Contact: Dr Hisashi Abe
Phone +81 29 861 6845
Fax: +81 29 861 4068
Email: abe.h@aist.go.jp

National Physical Laboratory (NPL) United Kingdom
Address: Hampton Road, Teddington, Middlesex, TW11 0LW
Contact: Dr Stephanie Bell
Phone: +44 20 8943 6402
Fax: +44 20 8943 6306
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Physikalisch-Technische Bundesanstalt (PTB) Germany
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Phone: +49 531 592 3241
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Irkutsk. 664056. Russia
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Fax: +7 3952 463848
E-mail: vma@niiftri.irk.ru
dep15@niiftri.irk.ru

Appendix B. PROVISIONAL TIME SCHEDULE FOR THE COMPARISON

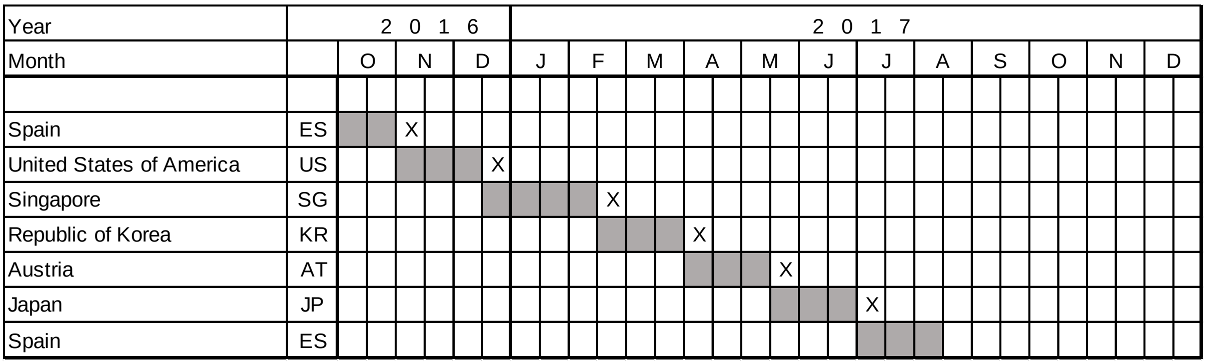

Figure 1: Comparison scheme of loop 1 (One column corresponds to two weeks; ■ = measurement, X = measurement / transportation).

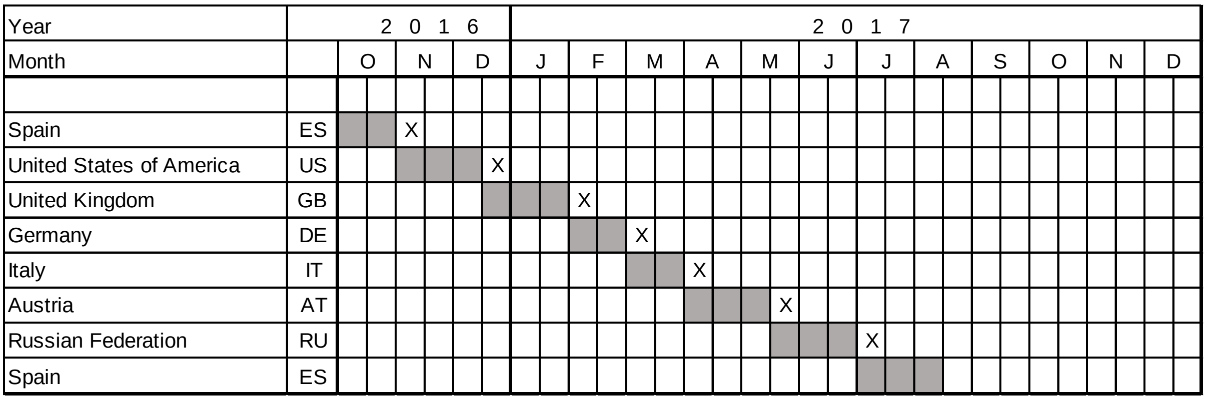

Figure 2: Comparison scheme of loop 2 (One column corresponds to two weeks; ■ = measurement, X = measurement / transportation).

Activity	Start Month	Provisional date
Draft of technical protocol completed by the Coordinator and sent to participants		Nov. 2016
All comments received from participants		Nov. 2016
Submission of a revised protocol to participants for unanimous approval		Nov. 2016
Submission of revised protocol to CCT/WG6 and TC THERM Chairman		Nov. 2016
Travelling standards characterized by the Pilots		Jan. 2009 – Nov 2016
The first set of key comparison measurements according to the protocol at the Pilot laboratories	INTA: Month 1 NIST: Month 2	Oct. 2016 Nov 2016
Travelling standards sent to participant by Co-Pilot	Month 3	Dec. 2016
Completion of measurements	Month 11 approx.	Aug. 2017
Draft A ready	Month 13 approx.	Oct. 2017
Deadline for comments on draft A	Month 14	Nov. 2017
Draft B ready and submitted to CCT/WG.KC	Month 15	Dec. 2017

Appendix C. PACKING / UNPACKING INSTRUCTIONS

CCT-K8

PACKING / UNPACKING INSTRUCTIONS

Table of contents

1. INTRODUCTION

Each instrument is packed in a ZARGES aluminium case that has 10 removable layers of shock-absorbent foam. The layers of foam should be handled with great care to avoid separation of the pre-formed segments.

IMPORTANT:
PACKING & UNPACKING SHOULD ONLY BE PERFORMED BY QUALIFIED LABORATORY PERSONNEL

2. UNPACKING INSTRUCTIONS

2.1 Unpacking

Place transport box in the laboratory at a location close to the point of use and clear an area on a bench/table large enough to take all the contents (hygrometer, condensation trap and accessories). Keep the supplied pallet for despatch. Open the case, releasing the two fastners on one side (it will be necessary to cut the tie wraps blocking the fastners.
Step 1: Remove layer 1 that is the top cover. This exposes layer 2.

Fig.1: Layer 2

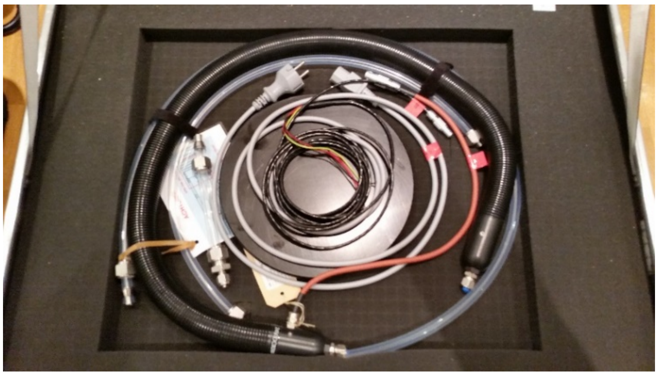

Fig.2: Layer 2 (with instrument operation manual removed)

This has the following contents, that should be removed:
a) Instrument operation manual in an envelope.
b) Shielded cable with LEMO connector for 2nd PRT measurements.
c) Mains cable fitted with European Schuko.
d) 24 V MBW SS heated hose terminated in LEMO connector (for use at inlet if required).
e) 75 cm PFE 12 mm OD tube fitted with 12 mm Swagelok nuts.
f) 100 cm PFE 12 mm OD tube fitted with 12 mm Swagelok nut one end.
g) Short PFE 12 mm OD tube fitted with 12 mm Swagelok nut on one end and a Swagelok 12 mm to 6 mm connector with a 6 mm cap on the other. (For use with condensation trap).
h) Condensation trap support base.

Step 2: Successively remove layers 2 to 6, being careful not to tear the foam and remove the transfer standard. This is best done by two persons, one taking care of the foam. The instrument has two handles that can only be fully opened when the instrument is out of the box, so care has to be taken when removing the instrument. Do not hold by the measuring head.

Fig.3: Layer 5

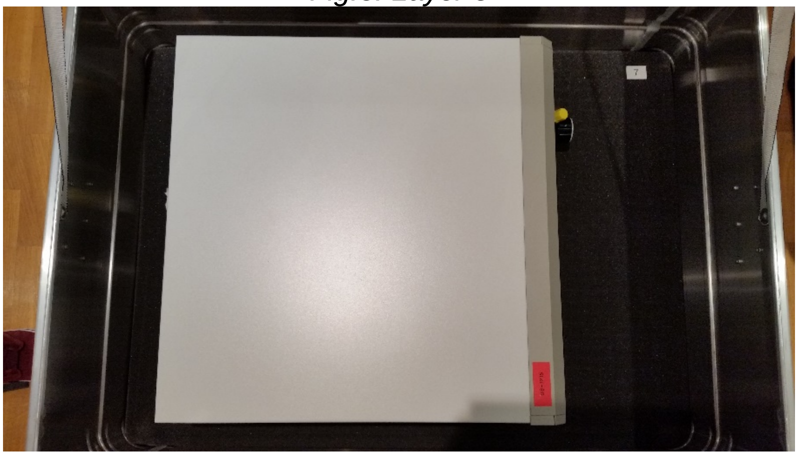

Fig.4: Layer 7

Step 3: Successively remove layers 7 to 10. Once layer 9 has been removed, the condensation trap main body will be visible.

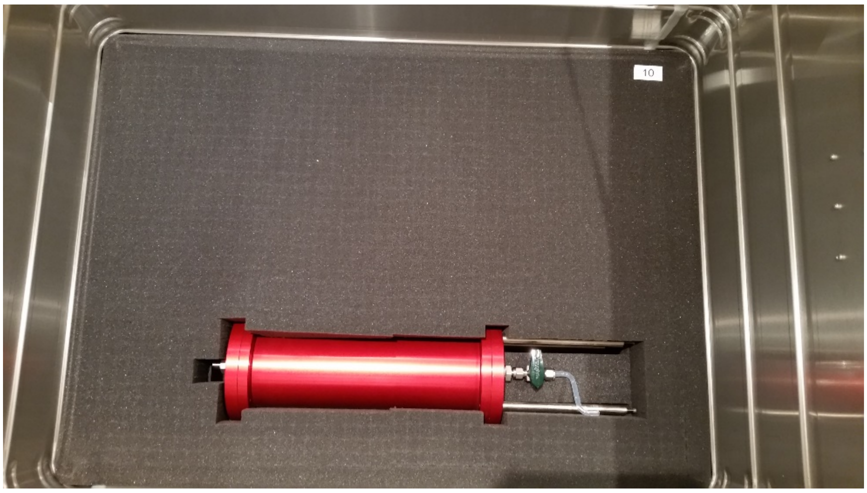

Fig.5: Layer 10

Once layer 10 has been removed, the bottom layer (that should not be removed) is visible:

Fig.6: Bottom layer

It contains:

a) Box of lint-free tissues.
b) Swagelok box that contains [Swagelok SS tee 12 mm with adaptor to 6 mm to connect to instrument outlet, a Swagelok SS 12 mm to 6 mm adaptor to be used as alternative instead of tee if more convenient in instrument set-up, a spare SS 12 mm nut, 12 mm ferrules and insert, a spare LEMO connector for PRT measurement, a SS needle valve assembly with two short lengths of SS tube with 6 mm Swagelok fittings for use with condensation trap] and a ¼" Swagelok connector with o-ring and support ring and a spare o-ring (only to be used if the laboratory needs to have the instrument with ¼" inlet instead of 6 mm). Four SS adaptors from 6 mm to ¼" Swagelok.
c) Spare blank head in red bubble wrap bag.[13]
d) Endoscope case that contains, endoscope, MBW insert for pressure measurement terminated in 6 mm Swagelok fitting, ¼"cap, ¼" nut, set of ¼" nylon ferrules (see Fig. 7).
e) ABB Flowmeter with 6 mm Swagelok at inlet and yellow and red caps (to be removed prior to use).
f) Stainless Steel 12 mm OD insert exit tube for condensation trap.
g) 50 cm PFE 12 mm OD tube fitted with 12 mm Swagelok nuts.
h) Main body of condensation trap.

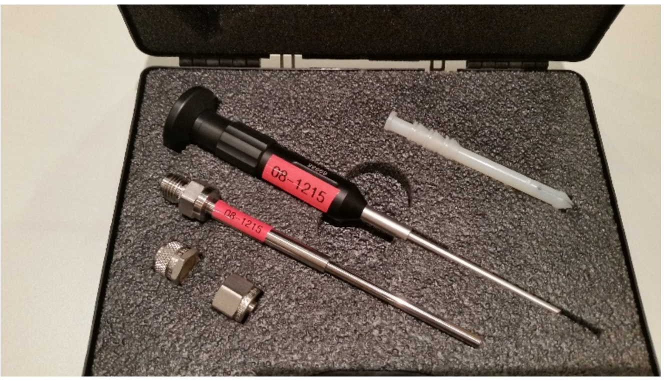

Fig.7: Contents of endoscope case

[13] The spare head is provided forr use in case of troubleshooting or failure of endoscope, photodiode or detector in the main measuring head.

2.2 Assembly of condensation trap

Assemble the condensation trap as follows:

a) Attach the base to the four stainless steel legs of the condensation trap using the Allen screws and washers. The base gas a stand-off so that the screw heads do not touch the work bench. Place the condensation trap in the vertical position (see Fig. 8).
b) Insert the stainless-steel exit insert tube into the 12 mm bore-through coupling and hand tighten the 12 mm Swagelok nut and then tighten just under ¼ turn. (the end with the 12 mm straight connector should protrude from the condensation trap
c) Connect the needle valve assembly and hand tighten the 6 mm Swagelok on the condensation trap end and then tighten just under ¼ turn. Check that the needle valve Swagelok couplings are tight (just under ¼ turn from hand tight).
d) Remove the yellow and red plastic protection caps at the inlet and outlet and attach the flowmeter inlet to the needle valve, keeping the flowmeter vertical. Tighten the 6 mm Swagelok nuts to just under ¼ turn from hand tight.

Fig.8: Condensation trap assembled with flowmeter

3. PACKING INSTRUCTIONS
3.1 Preparation of the transfer standard

Once the instrument has been purged with dry gas at the end of the calibration, switch off the instrument and unplug the mains cable from the mains supply and the instrument.
Turn off the generator gas supply to the instrument. Open the condensation trap drain valve and allow the instrument head to depressurize.
Carefully remove the endoscope and place it in its case, together with the pressure measurement insert, the nylon ferrules, the ¼" Swagelok nut, ¼" and Swagelok cap (see Fig. 7). Close the endoscope case.
Place the yellow screw on cap on the endoscope port on the measurement head.
Disconnect the gas lines at the outlet and inlet of the instrument and place the yellow screw on caps on the inlet and outlet Swagelok connectors.
Unplug the heated line LEMO connector.

3.2 Disassembly of the condensation trap

The following instructions are to be followed to prepare the condensation trap for packing:

a) Ensure the condensation trap is empty by opening the drain valve.
b) Remove the flowmeter by loosening the 6 mm Swagelok nut at the flowmeter inlet and place the yellow and red plastic protection caps at the inlet and outlet, respectively.
c) Remove the needle valve assembly by loosening the 6 mm Swagelok on the trap end. (*The needle valve Swagelok nuts should not be loosened and the valve assembly should be the valve and the two short lengths of 6 mm tube with their Swagelok nuts and ferrules*).
d) Disconnect the PFE inlet tube assembly from the condensation trap inlet Swagelok 12 mm adaptor.
e) Remove the stainless steel exit insert tube (that should retain its 12 mm adaptor) by loosening the 12 mm Swagelok nut on the condensation trap end.
f) Remove the condensation trap base by loosening the four stainless steel screws and replacing them afterwards in the four support legs of the condensation trap.
g) Disconnect the two 12 mm nuts on the ends of the 12 mm tee (leave the 12 mm to 6 mm adapter on the short length with its 6 mm cap untouched).

3.3 Packing

<u>Step 1</u>: Open the case and carefully remove layers 1 to 9 of the packaging foam until the bottom unnumbered layer is visible. Place the following in the corresponding cut out sections[14] (refer to figure 6):

a) Box of lint-free tissues.
b) Swagelok box that contains [Swagelok SS tee 12 mm with adaptor to 6 mm to connect to instrument outlet, a Swagelok SS 12 mm to 6 mm adaptor to be used as alternative instead of tee if more convenient in instrument set-up, a spare SS 12 mm nut, 12 mm ferrules and insert, a spare LEMO connector for PRT measurement, a SS needle valve assembly with two short lengths of SS tube with 6 mm Swagelok fittings for use with condensation trap] and a ¼" Swagelok connector with o-ring and support ring and a spare o-ring (only to be used if the laboratory needs to have the instrument with ¼" inlet instead of 6 mm).

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[14] *Note: As each element is placed in the box, please tick it off on the despatch form in the measurement protocol*

c) Spare blank head in red bubble wrap bag.
d) Endoscope case that contains, endoscope, MBW insert for pressure measurement terminated in 6 mm Swagelok fitting, ¼”cap, ¼” nut, set of ¼” nylon ferrules (see Fig. 7).
e) ABB Flowmeter with 6 mm Swagelok at inlet and yellow and red caps (to be removed prior to use).
f) Stainless Steel 12 mm OD insert exit tube for condensation trap (including 12 mm adaptor).
g) 50 cm PFE 12 mm OD tube fitted with 12 mm Swagelok nuts.
h) Main body of condensation trap.

Step 2: Place layer 10 (see Fig. 5).
Step 3: Place layers 9, 8 and 7 and put the transfer standard in place (check it has the yellow caps on inlet, outlet and endoscope port (see Fig. 4).
Step 4: Place layers 6 and 5 and put the transfer standard in place (see Fig. 3).
Step 5: Place layers 4, 3 and 2 and place the following components in the cut out (see Fig. 1 & 2).
a) 24 V MBW SS heated hose terminated in LEMO connector (for use at inlet if required)
b) 75 cm PFE 12 mm OD tube fitted with 12 mm Swagelok nuts.
c) 100 cm PFE 12 mm OD tube fitted with 12 mm Swagelok nut one end.
d) Short PFE 12 mm OD tube fitted with 12 mm Swagelok nut on one end and a Swagelok 12 mm to 6 mm connector with a 6 mm cap on the other. (For use with condensation trap).
e) Condensation trap support base
f) Shielded cable with LEMO connector for 2^{nd} PRT measurements.
g) Mains cable fitted with European Schuko plug.
h) Instrument operation manual in an envelope.

Step 6: If you are in an EU member state and the destination is also an EU member State then place the ATA carnet on top of the instrument manual.
Step 7: Place layer 1 and close the case. Place tie-wraps on the two fasteners.
Step 8: If the ATA carnet is to be used then place it in a large envelope marked “ATA CARNET” And fix to the outer top surface of the case.
Step 9: Clearly label the outside of the case in at least two places with the destination[15] and origin address and contact details (be sure to remove the old labels from the previous shipment). Please ensure all the shock indicators are attached and are not in the RED alarm condition. Otherwise replace with new ones.
Step 10: Fix the aluminium transport case to a standard pallet suitable for international shipment. If the laboratory is shipping two instruments in their transport case these should be fitted on one large pallet side by side and never shipped with two separate pallets (See Fig. 9).

Fig.9: Details of cases on pallet

[15] *Please check current details with next participant as defined in the measurement protocol.*

Appendix D. FORM FOR REPORTING ON RECEIPT OF TRAVELLING STANDARDS

TO: *(Pilot Laboratory)*

Dr. Robert Benyon

Fax: 00 34 91520 1645 **E-mail**: benyonpr@inta.es

FROM: *(Participating Laboratory)*

Fax: **E-mail:**

We confirm having received the travelling standard of the CCT Comparison of Dew-point Temperature (CCT/K8):

- ☐ Loop 1: S/N: 08-1215;
- ☐ Loop 2: S/N: 08-1216;

on: ____________________ (date)

After visual inspection

- ☐ No damage has been noticed;
- ☐ The following damage must be reported (attach photograph):

Have the hygrometer transportation packages been opened during transit ? e.g., Customs …

- ☐ No
- ☐ Don’t know (no seals applied)
- ☐ Yes: Please give details:

Is there any damage to the transportation packages?

☐ No

☐ Yes: Please give details (attach photograph):

Are there any visible signs of damage to the instruments?

☐ No

☐ Yes: Please give details (attach photograph):

Do you believe the travelling standards are functioning correctly?

☐ Yes

☐ No: Please indicate your concerns:

PACKING LIST

Received	Items	Dispatched
	Instrument operation manual in an envelope	
	Shielded cable with LEMO connector for 2nd PRT measurements	
	Power cord with Standard CEE 7/VII plug	
	24 V MBW SS heated hose terminated in LEMO connector (for use at inlet if required) and terminated in 6 mm Swagelok	
	24 V MBW SS heated hose terminated in LEMO connector (for use at inlet if required) and terminated in ¼” Swagelok	
	75 cm PFE 12 mm OD tube fitted with 12 mm Swagelok nuts	
	100 cm PFE 12 mm OD tube fitted with 12 mm Swagelok nut one end	
	Short PFE 12 mm OD tube fitted with 12 mm Swagelok nut on one end and a Swagelok 12 mm to 6 mm connector with a 6 mm cap on the other. (For use with condensation trap).	
	Condensation trap support base	
	Dew-point hygrometer MBW 373 HX S/N: _______* with 2 yellow caps on gas inlet and outlet and endoscope port.	
	Box of lint-free tissues	
	Swagelok box that contains: • Swagelok SS tee 12mm with adaptor to 6 mm to connect to instrument outlet, a • Swagelok SS 12mm to 6 mm adaptor • Spare SS 12 mm nut, 12 mm ferrules and insert • Spare LEMO connector for PRT measurement • SS needle valve assembly with two short lengths of SS tube with 6 mm Swagelok fittings for use with condensation trap • SS Swagelok Tube Fitting, Male Connector, 1/4 in. Tube OD x 1/8 in. Male ISO Parallel Thread, Straight Shoulder (SS-400-1-2RS) with o-ring, support ring and spare o-ring. • Two SS Swagelok Tube Fittings, Reducer, 1/4 in. x 6 mm Tube OD SS-400-R-6M with fitted 6mm nut and ferrules. • 6 mm Plug SS-400-P • ¼” Plug SS-6M0-P	
	Spare blank head in red bubble wrap bag	
	Endoscope case that contains: • Endoscope: S/N: _____________* • MBW insert for pressure measurement terminated in 6 mm Swagelok fitting • ¼”cap, ¼” nut, set of ¼” nylon ferrules.	
	ABB Flowmeter with 6 mm Swagelok at inlet and yellow and red caps.	
	Stainless Steel 12 mm OD insert exit tube for condensation trap	
	50 cm PFE 12 mm OD tube fitted with 12 mm Swagelok nuts	
	Main body of condensation trap	
	Zarges K470 IP 65 Aluminium transport case	

*) Please add serial number

Laboratory: ____________________

Date: ____________ Signature: ____________________

Appendix E. IEC 60751 RELATIONSHIP

Based on the international standard IEC 60751:2008, a nominal resistance-temperature characteristic of the PRT in the travelling standard can be defined as follows:

$$R_t = R_0(1 + At + Bt^2)$$

where:

t = Temperature (ITS-90) in °C,
R_t = Resistance of the PRT at temperature t in Ω
R_0 = Nominal resistance of 100 Ω at 0 °C,
A = 3.9083 × 10^{-3} °C^{-1} and
B = –5.775 ×10^{-7} °C^{-2}

Solving the quadratic equation, the temperature can be calculated with

$$t = -\frac{A}{2B} - \sqrt{\frac{A^2}{4B^2} - \frac{R_0 - R_t}{BR_0}}$$

Appendix F. TEMPLATE FOR SUBMISSION OF RESULTS

The template for submission of results is available in electronic form only (Excel workbook). It consists of three worksheets (Results, Conditions and Uncertainty). It will be sent to the participants during the comparison.

Appendix G. EXAMPLES OF FLOW-METER SETTINGS

The following table summarises the flowmeter settings for a laboratory temperature of 22 ºC and ambient pressure of 980 hPa and 1013.25 hPa as a function of system pressure.

Ambient conditions		**System pressure [hPa]**		**1013.25**			**1030**			**1050**		
Temp. [ºC]	**Pressure [hPa]**	**dew-point temp. [°C]**	**head temp. [ºC]**	**(1)**	**(2)**	**(3)**	**(1)**	**(2)**	**(3)**	**(1)**	**(2)**	**(3)**
		30	**60**	0.44	0.44	**0.44**	0.44	0.44	**0.45**	0.44	0.45	**0.46**
		50	**80**	0.38	0.38	**0.38**	0.38	0.38	**0.39**	0.38	0.39	**0.40**
		65	**95**	0.31	0.31	**0.31**	0.31	0.32	**0.32**	0.31	0.32	**0.33**
22	**1013.25**	**80**	**110**	0.21	0.21	**0.21**	0.21	0.22	**0.22**	0.22	0.22	**0.23**
		85	**115**	0.17	0.17	**0.17**	0.17	0.17	**0.18**	0.17	0.18	**0.18**
		90	**115**	0.12	0.12	**0.12**	0.12	0.13	**0.13**	0.13	0.13	**0.13**
		95	**115**	0.06	0.06	**0.06**	0.07	0.07	**0.07**	0.08	0.08	**0.08**
		30	**60**	0.44	0.45	**0.46**	0.44	0.46	**0.46**	0.44	0.47	**0.47**
		50	**80**	0.38	0.39	**0.40**	0.38	0.40	**0.40**	0.38	0.41	**0.41**
		65	**95**	0.31	0.32	**0.32**	0.31	0.33	**0.33**	0.31	0.34	**0.34**
22	**980**	**80**	**110**	0.21	0.22	**0.22**	0.21	0.22	**0.23**	0.22	0.23	**0.23**
		85	**115**	0.17	0.17	**0.17**	0.17	0.18	**0.18**	0.17	0.19	**0.19**
		90	**115**	0.12	0.12	**0.12**	0.12	0.13	**0.13**	0.13	0.14	**0.14**
		95	**115**	0.06	0.07	**0.07**	0.07	0.07	**0.07**	0.08	0.08	**0.08**

(1) Volume flow after condensation
(2) Volume flow after needle valve (there occurs some expansion from system pressure to ambient which changes the flow)
(3) Volume flow indicated by the flow meter (here the calibration parameters 1013.25 hPa and 20 °C are corrected to the real conditions ambient temperature and pressure.

Appendix H. GUIDE ON USE OF SWAGELOK FITTINGS

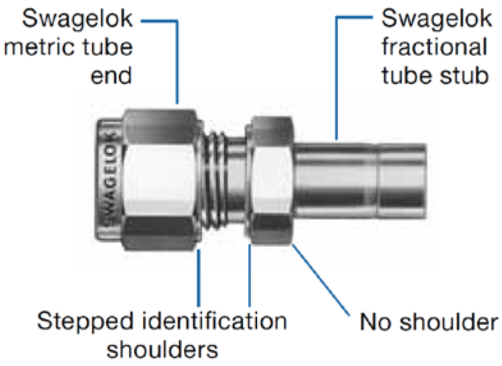
For the correct use of the instruments it is important to distinguish between metric and fractional measurements of connectors and couplings and to correctly tighten them for reproducible, leak-free operation.

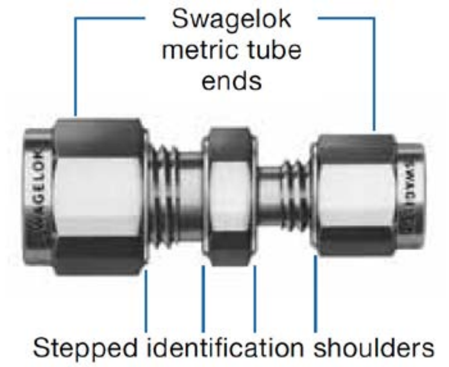
Intermix/Interchange with Other Manufacturers’ Components

The critical interaction of precision parts is essential for reliability and safety. Components of other manufacturers should not be intermixed with the Swagelok fittings supplied.

Metric Swagelok Tube Fittings

Metric tube fittings have a stepped shoulder on the body hex.





Shaped fittings, such as elbows, crosses, and tees, are stamped MM for metric tubing and have no step on the forging.

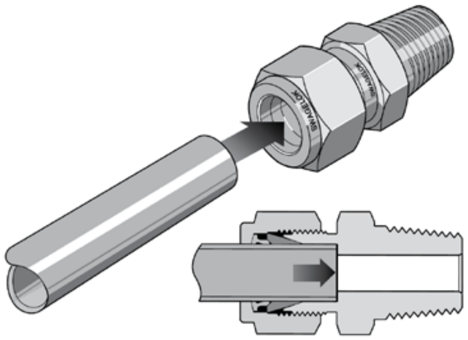
Safety Precautions

- Do not bleed system by loosening fitting nut or fitting plug.
- Do not assemble and tighten fittings when system is pressurized.
- Make sure that the tubing rests firmly on the shoulder of the tube fitting body before tightening the nut.
- Do not mix materials or fitting components from various manufacturers—tubing, ferrules, nuts, and fitting bodies.
- Never turn fitting body. Instead, hold fitting body and turn nut.
- Avoid unnecessary disassembly of unused fittings.

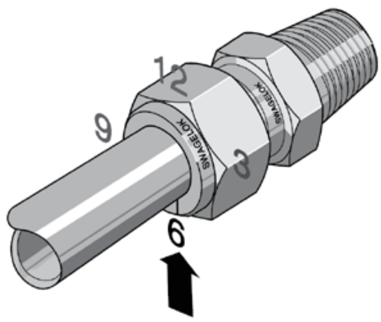
Swagelok Tube Fittings Up to 1 in./25 mm

These instructions apply both to traditional fittings and to fittings with the advanced back-ferrule geometry.

1. Fully insert the tube into the fitting and against the shoulder
rotate the nut finger-tight.

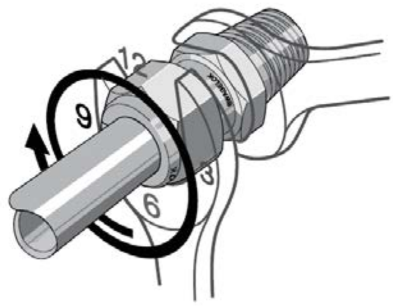


2. Mark the nut at the 6 o’clock position.



3. While holding the fitting body steady, tighten the nut one and one quarter turns to the 9 o’clock position.

For 1/16, 1/8, and 3/16 in.; 2, 3, and 4 mm tube fittings, tighten the nut threequarters turn to the 3 o’clock position.



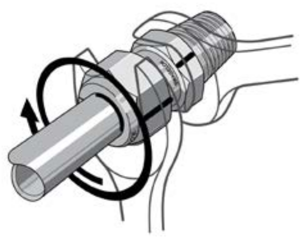
Reassembly—All Sizes

You may disassemble and reassemble Swagelok tube fittings many times.
Always depressurize the system before disassembling a Swagelok tube fitting.

Prior to disassembly, mark the tube at the back of the nut; mark a line along the nut and fitting body flats.
Use these marks to ensure that you return the nut to the previously pulled-up position.

Insert the tube with preswaged ferrules into the fitting until the front ferrule seats against the fitting body.

While holding the fitting body steady, rotate the nut with a wrench to the previously pulled-up position, as indicated by the marks on the tube and flats. At this point, you will feel a significant increase in resistance. Tighten the nut slightly.



Appendix I. DOCUMENT REVISION HISTORY

The following table includes the document revision history. Document version is identified by date.

Date	Description	Changes
10/11/2016	First draft sent to participants and CCT-WG/Hu.	
26/11/2016	Second draft sent to participants	Addressing comments of PTB, BEV/E+E and NMIJ.
14/12/2016	Revised version submitted to CCT WG.KC	Addressing comments of CCT. WG-KC Additional section on Swagelok fittings
21/12/2016	Revised version submitted to CCT WG.KC	Addressing comments of CCT. WG-KC Clarification of spare head and section 4.1.13
22/02/2017	Final version approved by CCT WG.KC	Section 4.1.13 reverted to that of 14/12/2016 (including footnote)