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ETHIOPIAN ACCREDITATION SERVICE

# Specific Guidance for Calibration Laboratories in Thermal Discipline

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## Contents

## 1. Purpose

The purpose of this document is to facilitate the calibration laboratories to carry out calibration activities in accordance with ISO/IEC 17025:2017 adhering to the EAS policy documents.

i. EAS Policy for Accreditation ISO/IEC 17025:2017
ii. EAS Policy for use of Symbol / ILAC MRA mark
iii. EAS Policy on Traceability of measurement results
iv. EAS Policy on CMC and Uncertainty in Calibration
v. EAS Policy on Participation in PT/ILC Participation

In addition to this Laboratories shall also follow other relevant EAS documents.

## 2. Scope

Accreditation by EAS is granted to calibration laboratories when the laboratories operates and demonstrates its competency to carry out calibration in accordance with ISO/IEC 17025:2017 in view of the generic nature of standard, the requirements of this standard needs to be amplified / redefined in the specific fields of calibration. This specific guidance document lays down special requirements in thermal discipline and this further explains the generic requirements for thermal calibration of ISO/IEC 17025:2017. This document supplements the requirements of standard for thermal calibration.

## 3. References

a. The International Temperature Scale of 1990 (ITS-90) HPreston-Thomas, Metrologia 27,3-10(1990)
b. Techniques for approximating The International Temperature Scale of 1990 (ITS-1990) BIPM, Sevres, France.
c. OMIL R 133: Edition 2002 (E), International Recommendations-Liquid-in glass

thermometers.

d. EURAMET cg-8: Guidelines on the Calibration of Thermocouple |TC-T | Version 3.1, 02/2020.

e. EURAMET cg-13: Guidelines on the Calibration of Temperature Block Calibrator |TC-T | Version 4.0, 09/2017.

f. ASTM E220-13: Standard Test Method for Calibration of Thermocouples by Comparison techniques.

g. DAkkS DKD-R5-1: Calibration of Resistance Thermometer.

h. DAkkS DKD-R5-3: Calibration of Thermocouple

i. DAkkS DKD-R5 -7: Calibration of Climate chamber.

j. API (6) Standard 20H: Calibration of Heat Treatment Furnace

k. JCGM 200:2012, International vocabulary of metrology – Basic and general concepts and associated terms (VIM) 3rd edition (Version 2008 with minor corrections).

l. MSL technical Guide 22: Calibration of Low temperature Infrared Thermometers

m. DIN-VDI/VDE 3511 Part 4.3 – Temperature Measurements in Industry-Radiation thermometry- Standard test methods for radiation thermometers with one wavelength range.

n. ASTM E1965-98(2016) Standard Specification for Infrared Thermometers for Intermittent Determination of Patient Temperature.

Note: Latest versions of relevant standard(s) should be followed.

## 4. Recommended Facility of Scope of Accreditation

Specific Requirements in Thermal calibration are given below -

| S. No. | Description of Device under Calibration/ Equipment | Relevant Standard/ Guidelines | Calibration Method | Permanent Facility | Onsite Calibration | Mobile Facility |
|---|---|---|---|---|---|---|
| **Temperature** | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1. | SPRT, PRT using Thermal Equilibrium States defined on ITS-90 | Techniques for approximating ITS -90 | Using fixed point method | √ | X | X |
| 2 | RTD sensors with or without indicator, Temperature Transmitter with or without indicator | DAkkS DKD-R-5-1 | Comparison Method | √ | √ | √ |
| 3. | Thermocouple with or without Indicator | ASTM E220-13/ EURAMET cg-8 | Comparison Method | √ | √ | √ |
| 4. | Liquid-In-Glass Thermometer, Dial Temperature Gauge | IS 6274, IS 2480, OIML R 133 | Comparison Method | √ | √ | √ |
| 5. | Temperature Indicator with sensor of Liquid bath, Furnace, Oven, Freezer, Dry block Bath, Cold Room, Chamber | DAkkS DKD-R5-7 | Single Position Calibration Method (At a specified location in DUC) | √ | √ | X |
| 6. | Liquid bath, Furnace, Oven, | IEC 60068 (Part 3-6), | Multi Position | √ | √ | X |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Freezer, Cold Room, Environmental Chamber | Part 11, DAkkS DKD- R5-7 | Calibration | | | |
| 7. | Dry block Bath | EURAMET cg - 13 | Comparison Method | √ | √ | X |
| 8. | Infrared radiation thermometer/ Pyrometer | MSL technical guide 22, VDI/VDE 355 Part 4.3 | Comparison Method | √ | √ | √ |
| 9. | Temperature Indicator with sensor of Black Body Source | --- | Comparison Method | √ | √ | √ |
| 10. | IR Thermometer for human body temperature | ASTME1965-98(2016) | Comparison Method | √ | X | X |
| **Relative Humidity** | | | | | | |
| 1. | Humidity Sensor/ Transducer/Transmitter with Indicator | --- | Comparison Method | √ | √ | √ |
| 2. | Humidity Indicator with sensor of Chamber, Environmental Chamber | DAkkS DKD – R5-7 | Single Position Calibration Method (At a specified location in DUC) | √ | √ | X |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3. | Humidity Chamber, Environmental Chamber | DAkkS DKD-R5-7 | Multi Position Calibration | √ | √ | X |

Note: This technical requirement is based on above referred standard taking into account only the salient features required during calibration. Lab may follow any relevant standard; however, care shall be taken to follow the requirements in totality.

| **S. No.** | **Effective Volume of Chamber** | **No. of Sensor(s) used** | **Reference standard** |
|---|---|---|---|
| 1. | ≤2000 lm3 | Minimum 9 | DAkkS DKD R5-7/IEC60068-3-5 |
| 2. | >2000 lm3 | Minimum 15 | DAkkS DKD R5-7/IEC60068-3-5 |

## 5. Selection of Reference Standards/Equipment Used

| **S. No.** | Description of Device under Calibration (DUC) / Equipment | Reference Standard/ Standard Used for Calibration | Apparatus/ Source Used for Calibration | Standard can be used at | | |
|---|---|---|---|---|---|---|
| | | | | Lab | Site | Mobile |
| | | | **Temperature** | | | |
| 1. | SPRT, PRT using Thermal Equilibrium States defined on ITS | SPRT& Resistance Thermometry | Fixed Point Realization Apparatus | √ | X | X |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 90 | Bridge | | | | |
| 2. | RTD sensors with or without indicator, Temperature Transmitter with or without indicator | SPRT/PRT (4wire) & Digital Multimeter or PRT with Temperature Indicator | Low /High Temperature Liquid Baths, Dry Block Calibrators | √ | √ | √ |
| 3. | Thermocouple with or without Indicator | Noble Metal Thermocouple (Type S, R or B) & Digital Multimeter or TC with temperature Indicator | Low /High Temperature Liquid Bath, Dry Block Calibrator/ Calibration Furnace | √ | √ | √ |
| 4. | Liquid-In-Glass Thermometer, Dial Temperature Gauge | SPRT/PRT (4wire) & Digital Multimeter or PRT with Temperature Indicator | Low/ High Temperature Liquid Baths | √ | √ | √ |
| 5. | Temperature Indicator with sensor of Liquid bath, Furnace, Oven, Freezer, Dry block Bath, Cold Room, Chamber | PRT (4wire) / TC & Digital Multimeter or PRT/TC with Temperature Indicator | DUC is Source also | √ | √ | X |
| 6. | Liquid bath, Furnace, Oven, Freezer, Cold Room, Environmental Chamber | PRT/Type K/N TC (Minimum 9) with Datalogger | DUC is Source also | √ | √ | X |

| | | | | | | |
|---|---|---|---|---|---|---|
| 7. | Dry Block Bath | PRTs (4wire) / TCs & Digital Multimeter or PRTs/ TCs with Temperature Indicator | DUC is Source also | √ | √ | X |
| 8. | Infrared Radiation Thermometer/ Pyrometer | PRT(4wire) / TC & Digital Multimeter or PRT/ TC with Temperature Indicator<br>Or Infra- Red Thermometer | Black Body Furnace as Source | √ | √ | √ |
| 9. | Temperature Indicator with Sensor of Black Body Source | Infra-Red Thermometer | DUC is Source also | √ | √ | √ |
| 10. | IR Thermometer for human body temperature | Standard Radiation Pyrometer or PRT with indicator | Black body source. | √ | X | X |
| **Relative Humidity** | | | | | | |
| 1. | Humidity Sensor/ Transducer/Transmitter with Indicator, Thermo- hygrometer | Temperature & Humidity Indicator Or Thermo- hygrometer Or Certified | Temperature & Humidity Generator with Chamber | √ | √ | √ |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Humidity salt Solutions | | | | |
| 2. | Humidity Indicator with sensor of Chamber, Environmental Chamber | Temperature & Humidity Indicator Or Thermo-hygrometer | DUC is Source also | √ | √ | X |
| 3. | Humidity Chamber, Environmental Chamber | Wireless Thermo-hygrometers (Minimum Nine) | DUC is Source also | √ | √ | X |

Note1: Thermo-hygrometer may be calibrated in terms of Temperature and Humidity.

Note2: Base metal thermocouples are not used as reference standard for thermal calibrations, except for multi position calibration.

## 6. Recommendations for Accommodation and Environmental Conditions

| S. No. | General Requirements | At Lab/Mobile facility | At Site facility |
|---|---|---|---|
| 1. | Temperature | 25°C± 4°C or better * | 15°C to 40°C |
| 2. | Humidity | 30%RH to70%RH * | 30%RH to 80%RH |
| 3. | Vibration level | Calibration area should be adequately free from vibrations. | Calibration area should be adequately free from vibrations. |
| 4. | Illumination level | 250 to 500 Lux | 250 to 500 Lux |
| 5. | Acoustic Noise | < 60dBA | < 60dBA |
| 6. | Power Supply regulation | ±2 % or Better on Calibration Bench | ±2 % or Better on Calibration Bench |
| 7. | Total Harmonic Distortion | <5% (Ref. Std: IS:13875, IS: 4722) | <5% (Ref. Std: IS:13875, IS: 4722) |
| 8. | Earth Resistance | < 1Ω (Shall be measured and recorded | < 1Ω (Shall be measured and |

| | | | |
|---|---|---|---|
| | | at least once in a year.) | recorded at least once in a year.) |
| 9. | Neutral-Earth Voltage | < 1 V | < 1 V |
| 10. | Frequency | 50 Hz ±1 Hz. | 50 Hz ± 1 Hz. |

* Temperature: 25°C±2°C & Humidity: 45%RH to 65%RH (For Fixed Point Calibration Laboratory)

Note: Laboratory using fluids (oil/alcohol used in the calibration bath) may produce noxious or toxic fumes under certain circumstances. Fluid manufacturer’s MSDS (Material Safety Data Sheet) may be referred. Exhaust hood of sufficient capacity should be provided to pull oil fumes away from the operator. Also where the liquid nitrogen is used as calibration medium, proper arrangements should be made to remove the excess nitrogen vapours from the laboratory environments.

### 6.1 Traceability Requirements

As per the EAS policy in traceability.

## 7. Calibration Interval of Reference Standards

| **Reference Standard** | **Recommended Interval** |
|---|---|
| Triple Point of Water (Fixed Point Cell) | 1 year |
| SPRT, PRT with/without Indicator | 1 year |
| Thermocouple with/without Indicator | 1 year |
| Optical Pyrometer, IR Thermometer | 1 year |
| Humidity Indicator with Sensor | 1 year |

Note - The calibration interval of measuring instruments may be ascertained based upon the uncertainty, drift, in service checks etc. However, laboratory may refer ISO 10012 and ILAC G24 for deciding the periodicity of calibration other than above recommendations.

## 8. Legal Aspects

Calibration of liquid in Glass thermometer done by any accredited laboratories is meant for scientific and industrial purpose only. However, if used for commercial trading, additional recognition/ approval shall be complied as required by Dept. of Legal Metrology, Regulatory Bodies, etc. The recommendations of construction, manufacture, accuracy classifications, ranges and permissible errors, calibration and use of liquid in glass thermometers are specified in OMIL R 133.2002(E).

## 9. Calibration Methods

### i) Fixed Point Calibration:

Thermal equilibrium states are set up as defining fixed points and are assigned temperatures depending upon the reference values or published experimental data. The thermometer to be calibrated is brought into equilibrium with this temperature and measurement of thermometric parameters like resistance or e.m.f etc. is made. Generally fixed-point calibration gives most precise and accurate calibration but only a limited number of good fixed points are available. This method is used for the realisation of the International Temperature Scale, ITS-90. The thermometer is calibrated by measurements at series of temperature fixed points at triple, freezing/melting, vapor pressure points. These thermal equilibrium states known as fixed points are realised as described in “Supplementary Information for ITS-90” [CCT (1990)]

### ii) Comparison Calibration: Temperature

Temperature cannot be measured without error, so it is necessary to quantify these errors by calibration of the probe with or without display. Calibration is necessary where traceability to a national standard or compliance to industrial audit or ISO-9000 is required. Main technique of comparison calibration is to maintain the temperature standard and instrument under calibration at the same temperature within the required uncertainty. But apart from SPRTs, which are designed solely for calibration purposes, the design of the most of the IPRTs / RTDs is not suitable for calibration. Ideally for best results in comparison calibration the reference standard and the probe under calibration should as near as possible, immersed at the same depth in the source and both the probes should be identical.

A reference thermometer and the thermometer/PRT/thermocouple to be calibrated are immersed in a suitable, stirred liquid bath (organic liquid, water, oil or salt) or put in a suitable laboratory furnace and the readings of the both thermometers are compared. The choice of calibration temperature points should cover the range which is used in the temperature measurement. Metal blocks which have drilled holes for thermocouples, or other sensing elements, can be used in furnaces for homogenizing the temperature during calibration. If two thermocouples are compared in calibration, it is important to use a stable reference junction temperature.

All the Thermal sources shall be studied/known for their stability and uniformity data periodically at least once in a year, in order to use this data to evaluate uncertainty in the measurement.

### iii) Comparison Calibration: Humidity

For calibration of humidity meter, the humidity probe / sensor should be placed in the chamber of the humidity generator and the chamber should be maintained at a stable temperature and measurements of standard and device under calibration are made when thermal and water vapor pressure equilibrium conditions are reached. For psychrometer calibration, distilled water should be used in the reservoir of the sensor head. In case of calibration of thermo hygrometer, the humidity range is calibrated at a temperature of ~25°C and temperature range is calibrated at a humidity of ~50%RH. However, if temperature and humidity meter is required to be used at any humidity at any temperature and vice versa, then its humidity range needs to be calibrated at minimum three temperature points. For estimating the stability and uniformity of the chamber used in calibration, Standard DAkkS DKD R5-7 should be referred.

### iv) Non-Contact Thermometry:

Infrared thermometers are radiation thermometers. These devices measure infrared radiation and display a temperature based on the radiation measured by the infrared thermometer and the emissivity setting of the infrared thermometer. The term infrared thermometer generally refers to handheld devices with a thermopile detector. Some other names used for infrared thermometers are IR guns, point and shoot thermometers, spot pyrometers, laser thermometers.

The laboratories involved in the facility of calibration for infrared radiation thermometer /pyrometers shall satisfy the following conditions/ guidelines.

The thermal source used for the calibration should satisfy the condition of blackbody having a known emissivity in order to confirm suitable temperature as measured by standard IR-radiation thermometer. The two components of uncertainty i) uncertainty due to tolerance in emissivity of black body source and ii) uncertainty due to size of the source effect or distance to spot ratio are two important factors in the estimation of uncertainty in measurement in calibration of IR Thermometers.

It should be preferred to calibrate a radiation thermometer against a standard radiation thermometer using a black body radiation source and not using an ordinary furnace/thermal heating source. Lab may follow any other relevant standard however care shall be taken to follow the requirements in totality.

The thermal uniformity and stability shall be evaluated by non-contact technique in order to confirm accuracy in temperature measurement.

### v) Calibration of Thermal Sources:

The calibration of Baths, Furnace, Blackbody Source, Dry block Calibrators etc used as thermal sources by calibration laboratory is not required to be performed. The stability and uniformity are two major and specific components which should be estimated by the laboratory. These are two important components required to be considered for the evaluation of uncertainty in measurement.

For the estimation of stability and uniformity, some national /international guidelines should be followed. Calibration of set temperature and digital display value of thermal source shall also be calibrated for the effective operation of the source.

### vi) Calibration of Liquid-in-Glass Thermometers:

There are specific international and national documented standards available for calibration of glass thermometers. These are two different types of liquid-in-glass thermometers. One the solid stem and the other enclosed scale stem type of glass thermometers. Similarly, according to the practical use, there are further three different categories known as Total Immersion or Full Immersion thermometers (TI), the Partial Immersion thermometers (PI) and the Complete Immersion (CI) thermometers.

- Calibration of LIG Thermometers shall not be calibrated in dry well calibrator sources.
- Only liquid temperature baths are employed for glass thermometers.
- For calibration of total immersion thermometers, Liquid baths of high depth (~450mm to 500mm) are required. These cannot be calibrated on shallow depth baths.
- Partial Immersion LIG thermometers are required to be calibrated at specified immersion depth of thermometer stem as marked or mentioned over the stem.
- In the calibration of glass thermometers, readings shall be observed by using a Reading Telescope with minimum 10 x magnification, focusing length 100 cm and not by a magnifying glass. This avoids the parallax error giving faulty reading while reading the thermometer.

i) Calibration of IR thermometer for body temperature measurement

In present times, there is a lot of interest in measuring human body temperature using non - contact or infrared (IR) temperature measurements. Infrared measurements are ideal for the fever screening, because making the measurement takes few milliseconds and you do not have to touch the person or object you are measuring, which helps prevent further spread of disease.

Industrial IR thermometers are not designed for measuring human forehead temperature should be accurate within ± 0.3°C (±0.54°F) and IR thermometer for measuring ear canal temperature measurements should be within ± 0.2°C (±0.36°F) as per ASTM E1965-98(2016).

When calibrating a forehead IR thermometer, it is important to apply best practices involving emissivity, wavelength and geometry. Useful temperature range such thermometer should be 35 °C to 45°C. It can be calibrated using a black body source designed for calibration of forehead IR thermometer against a calibrated IR thermometer or contact type thermometer at atleast three temperature calibration points i.e minimum, mid-range and maximum of the range or at 37°C. Emissivity of DUC should be set as that of source ( preferably at 0.98) and distance from the front of DUC to target should be kept as per D:S ratio as given for that particular DUC thermometer. While calibrating IR thermometer should be kept perpendicular to the target.

Emissivity, D:S ratio, Diameter of the source at which calibration has been performed should be mentioned on the calibration report issued to the customer.

## 10. Recommended Components of Measurement Uncertainty

| S. No. | Description of Device Under Calibration | Uncertainty Components/ Type/ Distribution |
|---|---|---|

| | | |
|---|---|---|
| 1. | SPRT, PRT, Thermocouples using Fixed Point Cell (Thermal Equilibrium States) | Uncertainty in measurement repeatability of DUC, Type A<br>Uncertainty of Standard Resistance used, Type B, Normal<br>Uncertainty due to resistance measuring unit (Bridge/DVM) Type B, Normal<br>Uncertainty due to heating effect measurement, Type B, Rectangular.<br>Uncertainty due to heat flex immersion error, Type B, Rectangular<br>Uncertainty due to choice of fixed point value from realization plateau, Type B, Rectangular<br>Uncertainty due to chemical purity of material in fixed point cell<br>Uncertainty due to propagation due to change in TPW value Type B, Rectangular<br>Uncertainty due to error in gas pressure in the fixed-point cell, Type B, Rectangular<br>Uncertainty due to hydrostatic head correction in fixed point cell, Type B, Rectangular |
| 2. | RTDs with or without Temperature Indicator, Temperature Transmitter with or without Indicator | Uncertainty in measurement repeatability, Type A<br>Uncertainty of reference standards used Type B, Normal<br>Uncertainty of readout unit in case of RTD probe calibration only, type B, Normal<br>Uncertainty due to drift in reference standard(s), Type B, Rectangular<br>Uncertainty due to resolution of readout, Type B, Rectangular<br>Uncertainty due to stability of temperature source, Type B, Rectangular |

| | | |
|---|---|---|
| | | Uncertainty due to uniformity of temperature source, Type B, Rectangular<br>Uncertainty due to self-heating effect error, Type B, Rectangular<br>Uncertainty due to Immersion error, Type B, Rectangular |
| 3. | Thermocouple with or without Temperature Indicator | Uncertainty in measurement repeatability, Type A<br>Uncertainty of reference standards used Type B, Normal.<br>Uncertainty of readout unit in case of T/C probe calibration only, type B, Normal.<br>Uncertainty due to drift in reference standard(s), Type B, Rectangular<br>Uncertainty due to resolution of readout, Type B, Rectangular<br>Uncertainty due to stability of temperature source, Type B, Rectangular<br>Uncertainty due to uniformity of temperature source, Type B, Rectangular<br>Uncertainty due to stability of ice point for reference junction, Type B, Rectangular<br>Uncertainty due to in-homogeneity of thermocouple, Type B, Rectangular |
| 4. | Liquid-In-Glass Thermometer, Dial Temperature Gauge | Uncertainty in measurement repeatability, Type A<br>Uncertainty of reference standards used Type B, Normal<br>Uncertainty due to drift in reference standard(s), Type B, Rectangular<br>Uncertainty due to resolution of liquid-in-glass thermometer/dial gauge , Type B, Rectangular<br>Uncertainty due to stability of temperature source, |

| | | |
|---|---|---|
| | | Type B, Rectangular<br>Uncertainty due to uniformity of temperature source, Type B, Rectangular |
| 5. | Temperature Indicator with Sensor of Liquid bath, Furnace, Oven, Freezer, Dry block Bath, Cold Room, Environmental Chamber | Uncertainty in measurement repeatability, Type A<br>Uncertainty of reference standards used Type B, Normal<br>Uncertainty due to drift in reference standard(s), Type B, Rectangular<br>Uncertainty due to (Stability of Source) i.e. Temperature Gradient, Type B, Rectangular<br>Uncertainty due to resolution of Temperature Indicator of DUC, Type B, Rectangular |
| 6. | Liquid bath, Furnace, Oven, Freezer, Cold Room, Environmental Chamber | Uncertainty in measurement repeatability, Type A<br>Uncertainty of reference standards used Type B, Normal<br>Uncertainty due to drift in reference standard(s), Type B, Rectangular<br>Uncertainty due to (Stability of Source) i.e. Temperature Gradient, Type B, Rectangular.<br>Uncertainty due to uniformity of DUC, Type B, Rectangular<br>Uncertainty due to resolution of Temperature Indicator of DUC, Type B, Rectangular.<br>Uncertainty due to wall radiation effect on sensors of temperature measurements, Type B, Rectangular<br>Uncertainty due to loading effect due to standards and accessories used, Type B, Rectangular |
| 7. | Infrared Radiation Thermometer/ Pyrometer | Uncertainty in measurement repeatability, Type A<br>Uncertainty of reference standard pyrometer, |

| | | |
|---|---|---|
| | | Type B, Normal (For Non-Contact Standard)<br>Uncertainty of reference standard PRT/TC with Indicator, Type B, Normal (For Contact Standard)<br>Uncertainty due to drift in reference standards used, Type B, Rectangular<br>Uncertainty due to resolution of pyrometer under calibration, Type B, Rectangular<br>Uncertainty due to stability of black body source, Type B, Rectangular<br>Uncertainty due to uniformity of black body source, Type B, Rectangular (For Contact to Non-Contact Calibration)<br>Uncertainty due to tolerance in emissivity of the source, Type B, Rectangular<br>Uncertainty due to size of source effect, Type B, Rectangular |
| 8. | Temperature Indicator with sensor of Black Body Source | Uncertainty in measurement repeatability, Type A<br>Uncertainty of reference standard pyrometer, Type B, Normal<br>Uncertainty due to drift in reference standard used, Type B, Rectangular<br>Uncertainty due to resolution of black body source under calibration, Type B, Rectangular.<br>Uncertainty due to stability of black body source, Type B, Rectangular<br>Uncertainty due to uniformity of black body source, Type B, Rectangular<br>Uncertainty due to tolerance in emissivity of the source, Type B, Rectangular<br>Uncertainty due to size of source effect, Type B, Rectangular |

| | | |
|---|---|---|
| 9. | Humidity Sensor with Indicator, Humidity Transducer/Transmitter with Indicator | Uncertainty in measurement repeatability, Type A<br>Uncertainty of reference standard Thermo-hygrometer used Type B, Normal<br>Uncertainty due to drift in reference standard(s), Type B, Rectangular<br>Uncertainty due to resolution of DUC, Type B, Rectangular<br>Uncertainty due to stability of humidity chamber, Type B, Rectangular<br>Uncertainty due to uniformity of humidity chamber, Type B, Rectangular |
| 10. | Humidity Indicator of Humidity Chamber, Environmental Chamber | Uncertainty in measurement repeatability, Type A<br>Uncertainty of reference standard Thermo-hygrometer used Type B, Normal<br>Uncertainty due to drift in reference standard(s), Type B, Rectangular<br>Uncertainty due to resolution of DUC, Type B, Rectangular<br>Uncertainty due to stability of humidity chamber, Type B, Rectangular |
| 11. | Humidity Chamber, Environmental Chamber | Uncertainty in measurement repeatability, Type A<br>Uncertainty of reference standard Thermo hygrometer used Type B, Normal<br>Uncertainty due to drift in reference standard(s), Type B, Rectangular<br>Uncertainty due to Stability of Chamber, Type B, Rectangular<br>Uncertainty due to Uniformity of Chamber, Type B, Rectangular<br>Uncertainty due to resolution of Temperature Indicator of Chamber, Type B, Rectangular |

| | | |
|---|---|---|
| 12. | IR Thermometer for human body/forehead temperature measurement | Uncertainty in measurement repeatability, Type A<br>Uncertainty of reference standard pyrometer, Type B, Normal (For Non-Contact Standard)<br>Uncertainty of reference standard PRT/TC with Indicator, Type B, Normal (For Contact Standard)<br>Uncertainty due to drift in reference standards used, Type B, Rectangular<br>Uncertainty due to resolution of pyrometer under calibration, Type B, Rectangular<br>Uncertainty due to stability of black body source, Type B, Rectangular<br>Uncertainty due to uniformity of black body source, Type B, Rectangular<br>Uncertainty due to tolerance in emissivity of the source, Type B, Rectangular<br>Uncertainty due to size of source effect, Type B, Rectangular<br>Uncertainty due to ambient temperature and ambient conditions, Type B, Rectangular |

## Example of Uncertainty Calculation

### Calibration of Type N Thermocouple at 1000 ºC

A type N thermocouple is calibrated by comparison with type R reference thermocouple in a horizontal furnace at a temperature of 1000 ºC. The emfs generated by the standard and under calibration thermocouples are measured with a digital microvoltmeter keeping their reference junction at 0ºC. The test thermocouple is connected to the reference point i.e. ice point using compensating leads.

This exercise deals with the calculation of uncertainty in measurements associated with the emf value of under calibration thermocouple i.e type N thermocouple. The emf of the standard thermocouple i.e Type R thermocouple is also measured at the temperature of the furnace at 1000ºC & actual temperature is calculated from the tables of the calibration report.

**10.1** The mathematical model is given as under:

$V_x$ the emf to be assigned to under calibration type N thermocouple at ≅ 1000ºC is

$$\mathbf{V_x \cong V_n + t_s . C_n + \delta V_d + \delta V_r + \delta V_l + \delta t_j . C_{n0} + \delta t_u . C_n + \delta V_R}$$

Where

**$V_n$** : Measured emf of under calibration T/C at 1000ºC.
**$V_s$** : Measured emf of reference type R thermocouple T/C at 1000ºC.
$t_s$ : Actual temperature calculated from calibration report of reference standard T/C by measuring emf $V_s$ by reference type R T/C at the temperature of approx. 1000ºC.
**$\delta V_d$** : Contribution from the calibration of digital microvoltmeter
**$\delta V_r$** : Contribution due to resolution of digital microvoltmeter
**$\delta t_j$** : Contribution due to stability of reference junction temperature (ice point)
**$\delta V_l$**: Contribution due to compensating leads of under calibration T/C
**$\delta t_u$** : Contribution due to non-uniformity of the furnace
**$\delta V_R$** : Repeatability of measurement of under calibration T/C
**$C_n$** : Sensitivity Coefficient of under calibration type N T/C at 1000ºC (38.5µV/ ºC)
**$C_{n0}$**: Sensitivity Coefficient of under calibration type N T/C at 0ºC (-25.4µV/ ºC)

The actual temperature is deduced from the calibration report corresponding to the average value emf measured by reference thermocouple. The deviation in temperature $\Delta t$ from 1000ºC is calculated and emf measured by under calibration type N T/C is corrected for this deviation $\Delta t$ multiplied by $C_n$, the sensitivity coefficient of under calibration type N T/C.

### 10.2 Type B Evaluation

### 10.2.1 Uncertainty contribution due to the standard used i.e. Type R T/C at temperature ($t_s$):

The type R reference T/C is used for the calibration of under calibration type N thermocouple and the reference T/C is a calibrated thermocouple, traceable to national standards. The calibration certificate of this thermocouple gives the expanded uncertainty associated by with the temperature of 1000.5ºC value as U = ±1ºC at approximately 95 % confidence level with coverage factor '*k*'=2 for normal distribution. So the standard uncertainty is obtained by dividing the expanded uncertainty by coverage factor.

The standard uncertainty $u(t_s) = 1/2 = 0.5$ºC, sensitivity coefficient $c_1 = 38.5\mu V/$ ºC & degree of freedom $\nu_1 = \propto$.

### 10.2.2 Uncertainty due to the calibration of digital microvoltmeter ($\delta V_d$):

The calibration certificate of the of the digital microvoltmeter stated the expanded uncertainty U = ±2 μV at a coverage factor of '*k'* =2 for normal distribution for voltages below 50 mV. So the standard uncertainty due to the calibration of digital micerovoltmeter,

$u(\delta V_d) = 2/2 = 1\mu V$, sensitivity coefficient $c_2 = 1$ & degree of freedom $\nu_2 = \propto$.

### 10.2.3 Correction due to resolution of the digital microvoltmeter ($\delta t_r$):

The resolution of the $4^{1/2}$ digit digital micrometer in the 10 mV is 1μV. This gives a temperature resolution limit of ±0.5μV. Assuming Rectangular Probability Distribution, the standard uncertainty of resolution

$u(\delta t_r) = 0.5/\sqrt{3} = 0.29\ \mu V$, Sensitivity coefficient $c_3=1$, Degree of freedom $\nu_3 = \propto$.

### 10.2.4 Uncertainty due to stability of reference junction temperature (ice point) ($\delta t_j$):

The stability of ice point bath (reference junction temperature depending upon the study & experimental data is known to be 0 ºC ±0.1 ºC, so assuming Rectangular Probability Distribution with these limits, the standard uncertainty of reference junction temperature

$u(\delta t_j)= 0.1 / \sqrt{3} = 0.058$ °C, Sensitivity coefficient $c_4= - 25.4 \mu V/ {}^oC$, Degree of freedom $\nu_4 = \infty$.

### 10.2.5 Uncertainty due to compensating leads of under calibration T/C ($\delta t_l$):

The compensating leads have been tested in the range 0 °C to 40 °C and voltage difference between leads and thermocouple wires are estimated to be less than 5$\mu$V. Considering the limits as 5 $\mu$V and assuming Rectangular Probability Distribution with these limits, the standard uncertainty

$u(\delta t_l) = 5 / \sqrt{3} = 2.90 \mu V$, Sensitivity coefficient $c_5= 1$, Degree of freedom $\nu_5 = \infty$.

### 10.2.6 Uncertainty due to temperature gradients in the furnace ($\delta t_u$):

The temperature gradients in the furnace have been measured at a temperature of 1000°C. The non-uniformity of temperature in the working zone has been estimated to be within ±0.1°C, so assuming Rectangular Probability Distribution, the standard uncertainty

$u(\delta t_u) = 0.1 / \sqrt{3} = 0.58$ °C, Sensitivity coefficient $c_6= 38.5 \mu V/ {}^oC$, Degree of freedom $\nu_6 = \infty$.

## 10.3 Type A Evaluation:

### 10.3.1 Uncertainty due to the repeatability of observations of under calibration type N T/C with digital microvoltmeter ($\delta V_R$)

The under calibration type N T/C and standard T/C were kept in a furnace allowing half an hour stabilization time at a temperature of approximately 1000 °C, the readings of DUC and reference standard T/C as read by the digital microvoltmeter noted and average was calculated. The average emf of reference T/C was 10503$\mu$V and converted to temperature by means of voltage and temperature relations given in the calibration certificate of the reference standard T/C. This mean value emf, 10503$\mu$V gives the temperature as 1000.5°C.

The readings and average of standard T/C and DUC are shown in Table 8

| S. | Referenc | DUC | Deviation | ($q_i$ – q |
|---|---|---|---|---|

| No. | e Reading s In µV | reading ($q_i$) in µV | from average ($q_i – q_{ave}$) µV | $_{ave})^2$ in µV |
|---|---|---|---|---|
| 1. | 10502 | 36245 | 3 | 9 |
| 2. | 10503 | 36248 | 0 | 0 |
| 3. | 10503 | 36248 | 0 | 0 |
| 4. | 10504 | 36251 | 3 | 9 |
| 5. | 10503 | 36248 | 1 | 0 |
| 6. | 10503 | 36247 | 1 | 1 |
| 7. | 10504 | 36249 | 1 | 1 |
| 8. | 10503 | 36250 | 2 | 4 |
| 9. | 10503 | 36246 | 2 | 4 |
| 10. | 10503 | 36248 | 0 | 0 |
| Average | 10503 | 36248 | | |

n=10 & n-1 =9

Standard Uncertainty in value of µV measured with DUC T/C

$u(\delta V_R)$ = ESDM = SQRT $\{\sum (q_i – q_{ave})^2 /(n(n-1))\}$

$u(\delta V_R)$ = 0.558 µV and Degree of freedom $\nu_7 = 9$

### 10.4 Combined standard uncertainty, $u_c$ ($V_x$):

The combined uncertainty $u_c$ (y) in output estimate is equal to root sum square of all contributions ci $u_i$(xi) discussed above i.e.,

$$u_c^2 (y) = \Sigma\, ci^2\, u_i^2(xi)$$

$$u_c (V_x) = (881.187)^{1/2} = 29.685\ \mu V$$

### 10.4.1 Effective Degree of Freedom

The effective degree of freedom of combined standard uncertainty is given by the following equation:

$$\nu_{eff} = \frac{u_c^4(V_x)}{\qquad} = 72086497 \cong \infty$$

$$\sum_{i=1}^{n} u_i^4 / \nu_i$$

### 10.4.2 Expanded Uncertainty, U:

For degree of freedom, $\nu_{eff} \cong \infty$ at approximately 95.45 % level of confidence, the ‘t’ factor from student′s ‘t’ table is 2. So the coverage factor ‘*k*’ =2.

The expanded uncertainty U is:

$U = k\, u_c(y) = k\, u_c(V_x) = 2 \times 29.685 = 59.37\ \mu V$

### 10.5 Uncertainty Budget:

| Qty | Estimated Value $x_i$ | Limits $\Delta x_i$ | Standard Uncertainty $u(x_i)$ | Probability Type A & B Divisor | Degree of freedom $\nu_i$ | Sensitivity Coefficient $C_i$ | Uncertainty Contribution $u_i(y)$ (µV) | $u_i^2(y)$ $(\mu V)^2$ |
|---|---|---|---|---|---|---|---|---|
| $t_s$ | 1000.5°C | 1.0°C | 0.5 | Normal, Type B, 2 | ∞ | 38.5µV/ °C | 19.25 | 370.563 |
| $\delta V_d$ | - | 2µV | 1 µV | Normal, Type B, 2 | ∞ | 1 | 1.0 | 1.000 |
| $\delta V_r$ | - | 0.5µV | 0.29 µV | Rectangular Type B, √3 | ∞ | 1 | 0.29 | 0.084 |
| $\delta t_j$ | - | 0.1°C | 0.058 °C | Rectangular Type B, √3 | ∞ | -25.4µV/°C | -1.48 | 2.190 |
| $\delta V_l$ | - | 5µV | 2.90 | Rectangular Type B, √3 | ∞ | 1 | 2.90 | 8.410 |
| $\delta t_u$ | - | 1.0 °C | 0.58°C | Rectangular Type B, √3 | ∞ | 38.5µV/ °C | 22.33 | 498.629 |
| $\delta V_R$ | 36248 µV | - | 0.558µV | Normal TypeA, √10 | 9 | 1 | 0.558 | 0.311 |

| | | | | | |
|---|---|---|---|---|---|
| Combined standard Uncertainty, $u_c$ ($V_x$) | - | - | - | - | √881.187 = 29.685μV |
| Expanded Uncertainty, U | | | | 'k' =2 | 29.685 x 2 = 59.37 μV |
| $V_x$ = 36248μV ± 59.37 μV | | | | | |

### 10.6 Reporting of Results:

The results are reported as: The type N thermocouple shows at the temperature of 1000.5°C with its cold junction at a temperature of 0°C, an emf of 36248μV ± 59.37 μV. The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor 'k' = 2 based on students′ 't' – distribution for effective degree of freedom $\nu_{eff} = \infty$ estimated at a confidence level of approximately 95 %.

## 11. Sample Scope

| Sl. No. | Product/ Device under Calibration Temperature At Lab & Site* | Standard/ Equipment Used | Range(s) | Calibration & Measurement Capability** | | | Remarks/ Method used |
|---|---|---|---|---|---|---|---|
| | | | | Claimed by Laboratory (±) | Observed by Assessor (±) | Recomended by Assessor (±) | |
| 1. | RTD with | PRT with | 0°C to | 0.25° | 0.20° | 0.25° | DAkkS |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Indicator | Temperature Indicator using Low Temperature Liquid Bath | 100°C | C | C | C | DKD R5-1:2010, Comparison |

** EAS (doc.no.) to be referred for recommendation of CMC.

* EAS (doc.no.) to be referred for site calibration scope recommendation.

| Revision No. | Date approved | Revision History |
|---|---|---|
| 1 | 2022-05-10 | • The document is revised due to the name ENAO change to EAS and new logo developed. |
| 1.1 | 2023-02-07 | • Correction done on page 1 that, this document was prepared by Meseret Tessema replaced by Zewdu Ayele (new quality manager).<br>• Former director general was resigned and replaced by Mrs. Meseret Tessema. |