# GULFMET.T-K9 Regional Key Comparison
# ITS-90 SPRT Calibration from the Hg TP to the Zn FP

# Final Report

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November 2nd, 2026

## Table of Contents


1. Introduction ..... 3
2. Organization ..... 3
   2.1. Participants ..... 3
   2.2. Method ..... 3
   2.3. Participants' details ..... 4
   2.4. Comparison timeline ..... 4
3. Protocol ..... 5
4. Devices used in the comparison ..... 6
5. Measurements and Uncertainty ..... 6
6. Calculation of the Comparison Results ..... 8
7. Linking the Gulfmet Results with KCRV ..... 11
8. Linking with KCRV Results ..... 12
9. Degrees of equivalence (DoE) ..... 15
10. References ..... 16

Appendix I. Result Report of Emirates Metrology Institute (EMI) ..... 17

Appendix II. Result Report of Saudi Arabia Standards Organization National Metrology and Calibration Center (SASO-NMCC) ..... 20

Appendix III. Result Report of Ulusal Metroloji Enstitüsü (UME) ..... 23

Appendix IV. GULFMET. T-K9 Protocol ..... 26

List of Figures ..... 36

List of Tables ..... 37

## 1. Introduction

This is a report of the GULFMET.T-K9 comparison on the calibration of Standard Platinum Resistance Thermometers (SPRTs) from the Triple Point of Mercury (234.3156 K) to the Freezing Point of Zinc (692.677 K), according to the International Temperature Scale of 1990 (ITS-90) [1]. The participants of the comparison were TÜBITAK UME (Pilot), Emirates Metrology Institute (EMI) and Saudi Arabia National Measurements Calibration Center (SASO-NMCC). This project is a Gulfmet RMO Key comparison corresponding to EURAMET.T-K9 and CCT-K9.

The comparison was designed to compare the realization of the ITS-90 through the calibration of SPRTs. The transfer standards used were long-stem SPRTs and they were provided by each participant based on their criteria of selection.

The measurement protocol matched closely to the corresponding EURAMET.T-K9 key comparison. TÜBITAK UME temperature laboratory was the pilot of the comparison, and they were responsible for monitoring the stability performance of the thermometers during the circulation and for evaluating and reporting of the comparison results. The linking of the comparison data to the CCT-K9 reference values (KCRV) was performed using the TÜBITAK UME data. Linking report was prepared by EMI.

## 2. Organization

### 2.1. *Participants*

This Regional key comparison (GULFMET.T-K9) was planned by TUBİTAK UME, SASO NMCC and EMI. TÜBİTAK UME temperature laboratory was the pilot of the comparison.

### 2.2. *Method*

Since the number of participants was very small (three, including the pilot), the comparison had a star structure with two arms as shown in Figure 1:

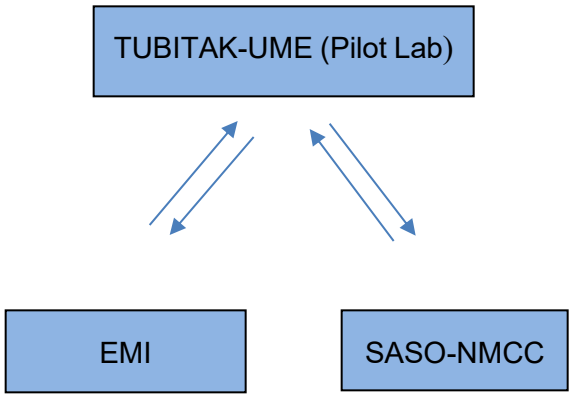



*Figure 1. The scheme of the comparison*

### 2.3. *Participants' details*

The contact details of the participants are given below:

*Table 1. List of participant laboratories and their contact details.*

| | | | |
|---|---|---|---|
| Türkiye | UME | Dr. Kalemci, Murat<br>murat.kalemci@tubitak.gov.tr | Uytun, Ali<br>ali.uytun@tubitak.gov.tr |
| Ulusal Metroloji Enstitüsü (UME), Barış Mah. Dr. Zeki Acar Cad. No:1 TR-41470 Gebze, Kocaeli | | | |

| | | | |
|---|---|---|---|
| United Arab Emirates | EMI | Dr. Anagnostou Miltiadis<br>miltiadis.anagnostou@qcc.gov.ae<br>Mob: +971 568746630<br>Tel.: +971 24035981 | Mr. Al Breiki, Ahmed<br>ahmed.albreiki@qcc.gov.ae |
| Emirates Metrology Institute (EMI), Krypto Labs Building, Masdar City, PO Box 853, Abu Dhabi | | | |

| | | | |
|---|---|---|---|
| Kingdom of Saudi Arabia | SASO-NMCC | Mr. Oqab AlOtaibi<br>o.otaibi@saso.gov.sa<br>Mob: +966 502799711 | Dr. Ismail A. Alfaleh<br>i.faleh@saso.gov.sa<br>Mob: +966 553295328 |
| National Measurements Calibration Center (SASO-NMCC), Temperature Measurement Department, Riyadh Al Muhammadiyah - in front of King Saud University, P.O.B. 3437, Riyadh 11471 | | | |

### 2.4. *Comparison timeline*

The timeline of the comparison is given in Table 2.

*Table 2. Comparison timeline.*

| | |
|---|---|
| Protocol agreement: | November, 2016 |
| Comparison protocol was approved by CCT-WG-KC: | May, 2017 |
| Participating labs calibrated their SPRTs: | October, 2017 |

| | |
|---|---|
| Transfer SPRTs were sent to the pilot: | November, 2017 |
| Transfer SPRTs returned to the NMIs: | April, 2018 |
| Transfer SPRTs re-calibrated by the NMIs: | June, 2018 |
| EMI Report was sent to pilot: | August, 2018 |
| SASO-NMCC report was sent to pilot: | January, 2019 |
| Draft A report was circulated: | April, 2019 |
| Draft B report was circulated and submitted to the CCT-WG-KC for review: | January, 2022 |
| Comments of the CCT-WG-KC for the Draft B report were submitted to pilot: | March, 2022 |
| Comparison results were linked to CCT-KCRV, and the revised Draft B report was submitted to the CCT-WG-KC for review: | May, 2026 |
| CCT-WG-KC Comments for the revised Draft B report were submitted to pilot: | July, 2026 |
| Answers to the comments for the revised Draft B report were submitted to the CCT-WG-KC: | September, 2026 |
| Draft B report was approved by the CCT-WG-KC: | October, 2026 |

The Draft B report of the comparison was submitted to CCT-WG-KC for approval in January 2022. One of the comments made by the working group was that as the linkage to CCT-K9 is not performed yet, the participants could not claim CMCs until the final reports of EURAMET.T-K9 and CCT-K9 are published. Finally, this linkage was made possible in May 2026, after the final report of CCT-K9 [2] was published in March 2023 and EURAMET.T-K9 [3] was published in October 2024. The approval cycle from the CCT-WG-KC was repeated for the revised Draft B report containing the CCT-K9 linkage. The Draft B report was finally approved by the CCT-WG-KC in October 2026.

## 3. Protocol

The protocol of the GULFMET.T-K9 comparison was first approved by all participants and then sent to the CCT-WG-KC working group for review. It was finalized after making the amendments suggested by the working group, before the beginning of the measurements. It matches closely the corresponding Euramet.T-K9 protocol and it is given in Appendix IV of this report.

Each participant selected two of their own SPRTs based on their own criteria for suitability and notified the pilot laboratory. Participants calibrated their two SPRTs from the Triple Point of Mercury (234.3156 K) to the Freezing Point of Zinc (692.677 K), according to the International Temperature Scale of 1990 (ITS-90) and their own procedures. Then hand-delivered one of them to the pilot laboratory to be used as their transfer standard. The second SPRT remained in the participant lab, to be used in case the transfer standard was not stable or damaged during the procedure. Upon the receipt of the SPRT by the pilot laboratory, it was calibrated in the same temperature range. The SPRT then hand carried back to the participant lab and it was calibrated again. If the results were considered acceptable and the transfer standard was stable enough, the results of the participants were communicated to the pilot laboratory using the forms specified in the protocol Appendices A, B, C.

## 4. Devices used in the comparison

The list of the selected SPRTs by the participants as transfer standards is given in Table 3 below.

*Table 3. Selected SPRTs by the participants to be used in this comparison.*

| | **SASO-NMCC** | **EMI** |
|---|---|---|
| **Manufacturer** | Isotech | Fluke/Hart Scientific |
| **Model** | 909 | 5681 |
| **Serial number** | 768 | 1783 |

Also, in Appendix I, Appendix II and Appendix III, of this report, the details of the devices used by EMI, SASO-NMCC and UME respectively are given. For UME the devices used match closely the ones used in EURAMET.T-K9 comparison and this makes possible the linking between this comparison and the EURAMET one.

## 5. Measurements and Uncertainty

The temperature range covered by this comparison is from the triple point of Hg (234.3156 K) to the freezing point of Zn (692.677 K).

The comparison was carried out with the two participant laboratories and the pilot laboratory in the scheme described in section 2.2. Tables 4 to 6 present the $W$ values given by each participant, and the pilot lab, obtained at the different fixed points. These values are the average of three plateau realizations for each fixed point. The $W$ values are corrected for the hydrostatic pressure of the cells

and the self-heating of the thermometers, therefore are equivalent to the ITS-90 assigned temperature values for 0 mA.

The values of the uncertainties reported in Tables 4 to 6 correspond to the combined expanded uncertainties $U$ given by the participants and the pilot, with a coverage factor of k=2. For the participant labs, the declared uncertainties were the same for the measurements done before sending the SPRTs to the pilot and on the return of these SPRTs. All the information about the uncertainty budgets is given in the form suggested by Appendix C of the protocol.

*Table 4. Measurement results obtained by EMI with SPRT No 1783.*

| Fixed Points | Before sending SPRTs to Pilot Laboratory | On return to participating NMI | |
|---|---|---|---|
| | $W$ | $W$ | $U$ (k=2) / mK |
| **Zn** | 2.56875393 | 2.56875367 | 1.743 |
| **Sn** | 1.89271203 | 1.89271272 | 1.268 |
| **In** | 1.60974378 | 1.60974373 | 1.700 |
| **Ga** | 1.11812781 | 1.11812796 | 0.513 |
| **Hg** | 0.84415120 | 0.84415116 | 0.571 |

*Table 5. Measurement results obtained by SASO-NMCC with SPRT No 768.*

| Fixed Points | Before sending SPRTs to Pilot Laboratory | On return to participating NMI | |
|---|---|---|---|
| | $W$ | $W$ | $U$ (k=2) / mK |
| **Zn** | 2.56853644 | 2.56853346 | 3.181 |
| **Sn** | 1.89258354 | 1.89258181 | 2.243 |
| **In** | 1.60964365 | 1.60965000 | 2.036 |
| **Ga** | 1.11811271 | 1.11811238 | 1.252 |
| **Hg** | 0.84417404 | 0.84417366 | 0.967 |

The SASO-NMCC uncertainty was modified from the initial submission, due to comments from the reviewers of the comparison, related to the water triple point stability of their thermometer.

*Table 6. Measurement results obtained by TUBİTAK UME for both SPRTs.*

| Fixed Points | Pilot Results of SPRT No 1783 | | Pilot Results of SPRT No 768 | |
|---|---|---|---|---|
| | $W$ | $U$ (k=2) / mK | $W$ | $U$ (k=2) / mK |
| **Zn** | 2.56875897 | 1.561 | 2.568535353 | 1.501 |
| **Sn** | 1.89271206 | 1.092 | 1.89258217 | 1.084 |
| **In** | 1.60974297 | 1.176 | 1.60965374 | 1.120 |
| **Ga** | 1.11812826 | 0.403 | 1.11811069 | 0.435 |
| **Hg** | 0.84415336 | 0.426 | 0.84417647 | 0.448 |

## 6. Calculation of the Comparison Results

Initially, in the draft reports of the comparison, the calculation of a reference value for every fixed point was attempted, using the weighted mean of the measurements reported by the participating laboratories and the pilot. This approach has been abandoned, following a comment from a reviewer of the draft report, that the RMO key comparisons are not generating reference values. This also became apparent from the final report of EURAMET.T-K9 [3], where the participating labs are linked directly to the CCT-K9 key comparison reference value (KCRV). We will follow this approach too, and link directly our results to the CCT-K9 results. This will be done via TUBITAK-UME who participated in the Gulfmet comparison and in the Euramet comparison. In the Euramet comparison the link of the TUBITAK-UME to the CCT-K9 KCRV is already given in Table 4.30 (of EURAMET.T-K9).

Each participating NMI measured their SPRT before and after the pilot lab, for this reason we are using the average W values to compare with the pilot, these average W values for each lab are calculated by:

$$\bar{W}_{lab} = \frac{1}{2} * \left(W_{lab\ before} + W_{lab\ after}\right) \quad (1)$$

The temperature difference for the realization of each fixed point between the participating NMIs and the pilot is calculated as:

$$\Delta T_{(lab-pilot)} = \frac{\left(\bar{W}_{lab} - W_{pilot}\right)}{\frac{dW_r}{dT}} + \Delta T_{lab} \quad (2)$$

where $\frac{dW_r}{dT}$ represents the sensitivity of the reference function Wr defined in the ITS-90, and the term $\Delta T_{lab}$ is related to the stability of the SPRT before and after travelling to the pilot lab. It is considered to have an average value of zero, with uncertainty which is calculated from the difference of the measurements of the lab before and after the traveling of the transfer standard.

The uncertainty of $\overline{W}_{lab}$ in Equation (1) is calculated from the uncertainties of $W_{lab\ before}$ and $W_{lab\ after}$ declared by the labs. In fact, the two participating labs provided a single uncertainty budget that applies for both measurements, “before” and “after”. In these uncertainty budgets, there was no information on whether an uncertainty contribution was strongly correlated between the initial and final measurements (systematic) or fluctuated randomly (random). This was because this information was not asked for by the protocol of the comparison. Therefore, it was decided that we will follow the reasoning of the Euramet.T-K9 final report and classify the uncertainty components related to the phase transition realization repeatability, the propagated TPW, the SPRT self-heating and the heat flux as random, while the others are classified as systematic. The numerical values of the combined expanded uncertainty are given in Tables 4, 5, 6.

Following the Euramet.T-K9 final report, the uncertainty in $\overline{W}_{lab}$, derived from the combined "before" and "after" travelling measurement sets, is evaluated using the uncertainty values provided by the NMIs for each set. Random components were assumed to be entirely uncorrelated and were combined in accordance with GUM [4], Section 5.1.2. Conversely, systematic components were considered correlated and were combined in accordance with GUM [4], Section 5.2.2. As a result, the overall combined uncertainty is:

$$u^2(\overline{W}_{lab}) = \frac{1}{4} * \left(\frac{u_R^2(W_{lab\ before})}{n_{before}} + \frac{u_R^2(W_{lab\ after})}{n_{after}}\right) + \left(\frac{u_S(W_{lab\ before})}{2} + \frac{u_S(W_{lab\ after})}{2}\right)^2 \quad (3)$$

Where $u_R(W_{lab\ before})$ and $u_R(W_{lab\ after})$ represent the random terms of the uncertainty budget, before and after, which have identical values in this comparison, $u_S(W_{lab\ before})$ and $u_S(W_{lab\ after})$ are the systematic terms before and after, again identical in this comparison, $n_{before}$ and $n_{after}$ is the number of the plateaus realized by each lab for the fixed point cells before and after, in this comparison this number is equal to three for all labs.

The shift of the W values of each SPRT, before and after their transfer to the pilot, is used to determine the uncertainty of $\Delta T_{lab}$ as:

$$u(\Delta T_{lab}) = \frac{1}{2*\sqrt{3}} * \frac{|W_{lab\ before} - W_{lab\ after}|}{\frac{dW_r}{dT}} \quad (4)$$

Combining the uncertainty terms of Equation 3, Equation 4, and the $u(W_{pilot})$, given in Table 6 in the form of expanded uncertainty, we can determine the uncertainty of $\Delta T_{(lab-pilot)}$ as:

$$u^2(\Delta T_{(lab-pilot)}) = \left(\frac{1}{\frac{dW_r}{dT}}\right)^2 * u^2(\bar{W}_{lab}) + \left(\frac{1}{\frac{dW_r}{dT}}\right)^2 * u^2(W_{pilot}) + u^2(\Delta T_{lab}) \qquad (5)$$

The results for each lab are given in Tables 7 and 8 respectively.

*Table 7. Average W values obtained by EMI and its expanded uncertainty converted to temperature, W values obtained by UME for EMI's SPRT and its expanded uncertainty converted to temperature, and temperature difference between EMI and UME and its expanded uncertainty.*

| Fixed Point | $\bar{W}_{EMI}$ | $U(\bar{W}_{EMI})$ / mK | $W_{UME}$ | $U(W_{UME})$ / mK | $\bar{W}_{EMI}$-$W_{UME}$ | $\Delta T_{(EMI-UME)}$ / mK | $U(\Delta T_{(EMI-UME)})$ / mK |
|---|---|---|---|---|---|---|---|
| Zn | 2.56875380 | 1.52 | 2.56875897 | 1.56 | -0.00000517 | -1.48 | 2.18 |
| Sn | 1.89271238 | 1.09 | 1.89271206 | 1.09 | 0.00000031 | 0.08 | 1.54 |
| In | 1.60974376 | 1.64 | 1.60974297 | 1.18 | 0.00000078 | 0.21 | 2.02 |
| Ga | 1.11812789 | 0.44 | 1.11812826 | 0.40 | -0.00000037 | -0.09 | 0.60 |
| Hg | 0.84415118 | 0.53 | 0.84415336 | 0.43 | -0.00000218 | -0.54 | 0.68 |

*Table 8. Average W values obtained by SASO-NMCC and its expanded uncertainty converted to temperature, W values obtained by UME for SASO-NMCC's SPRT and its expanded uncertainty converted to temperature, temperature difference between SASO-NMCC and UME and its expanded uncertainty.*

| Fixed Point | $\bar{W}_{SASO-NMCC}$ | $U(\bar{W}_{SASO-NMCC})$ / mK | $W_{UME}$ | $U(W_{UME})$ / mK | $\bar{W}_{SASO-NMCC}$ - $W_{UME}$ | $\Delta T_{(SASO-NMCC-UME)}$ / mK | $U(\Delta T_{(SASO-NMCC-UME)})$ / mK |
|---|---|---|---|---|---|---|---|
| Zn | 2.56853495 | 1.50 | 2.56853535 | 1.50 | -0.00000040 | -0.12 | 2.18 |
| Sn | 1.89258268 | 1.06 | 1.89258217 | 1.08 | 0.00000050 | 0.14 | 1.54 |
| In | 1.60964683 | 1.19 | 1.60965374 | 1.12 | -0.00000691 | -1.82 | 1.90 |
| Ga | 1.11811255 | 0.56 | 1.11811069 | 0.44 | 0.00000185 | 0.47 | 0.71 |
| Hg | 0.84417385 | 0.49 | 0.84417647 | 0.45 | -0.00000262 | -0.65 | 0.67 |

## 7. Linking the Gulfmet Results with KCRV

The temperature difference of the labs from the CCT-KCRV is calculated as:

$$\Delta T_{(lab-KCRV)} = \Delta T_{(lab-pilot)} + \Delta T_{(pilot-P_i)} + \Delta T_{(P_i-KCRV)} \quad (6)$$

Where $P_i$ is the star pilot of the EURAMET.T-K9, who also participated in CCT-K9, and is related to our pilot lab in GULFMET.T-K9 (UME). From the EURAMET final report, we know that $P_i$ is PTB (Germany's National Metrology Institute). Equation 6 can be expressed equivalently as:

$$\Delta T_{(lab-KCRV)} = \Delta T_{(lab-pilot)} + \Delta T_{(pilot-KCRV)} \quad (7)$$

The first term of the right-hand side of Equation 7 and its expanded uncertainty is already given for the two participating labs in Tables 7 and 8. In this comparison the pilot lab is UME, and the second term of the right hand side of Equation 7 as well as its combined expanded uncertainty, can be taken directly from Table 4.30 of the final report of the EURAMET.T-K9 [2]. This table is given below:

4.30 UME – results

| | $\Delta T_{(Lij-KCRV)}$ mK | $U_{(Lij-KCRV)}$ mK |
|---|---|---|
| Zn | 1.42 | 1.69 |
| Sn | 0.20 | 1.01 |
| In | -0.19 | 1.12 |
| Ga | -0.24 | 0.40 |
| Hg | 0.55 | 0.57 |
| Ar | 0.42 | 1.05 |

*Table 4.30 Deviation $\Delta T_{(Lij-KCRV)}$ at each fixed-point measured at UME. Uncertainties are displayed at the k = 2 level.*

To determine the uncertainty of $u\big(\Delta T(lab-KCRV)\big)$ we must go back to Equation 6 and combine the uncertainty of the three terms shown there as:

$$u^2\big(\Delta T_{(lab-KCRV)}\big) = u^2\big(\Delta T_{(lab-pilot)}\big) + u^2\big(\Delta T_{(pilot-P_i)}\big) + u^2\big(\Delta T_{(P_i-KCRV)}\big) + 2 * u\big[\Delta T_{(pilot-P_i)}, \Delta T_{(P_i-KCRV)}\big] + 2 * u\big[\Delta T_{(lab-pilot)}, \Delta T_{(pilot-P_i)}\big] + 2 * u\big[\Delta T_{(lab-pilot)}, \Delta T_{(P_i-KCRV)}\big] \quad (8)$$

Where $u\left[\Delta T_{(lab-pilot)},\ \Delta T_{(pilot-P_i)}\right]$ is the covariance associated to $\Delta T_{(lab-pilot)}$ and $\Delta T_{(pilot-P_i)}$, namely $u\left[\Delta T_{(lab-pilot)},\ \Delta T_{(pilot-P_i)}\right] = cov\left(\Delta T_{(lab-pilot)},\ \Delta T_{(pilot-P_i)}\right)$. Similarly, $u\left[\Delta T_{(lab-pilot)},\ \Delta T_{(P_i-KCRV)}\right]$ and $u\left[\Delta T_{(pilot-P_i)},\ \Delta T_{(P_i-KCRV)}\right]$ are the covariances associated to the combinations of the other terms of Equation 6.

The term: $2 * u\left[\Delta T_{(lab-pilot)},\ \Delta T_{(P_i-KCRV)}\right]$ is zero because refers to unrelated measurements, and the sum of terms: $u^2\left(\Delta T_{(pilot-P_i)}\right) + u^2\left(\Delta T_{(P_i-KCRV)}\right) + 2 * u\left[\Delta T_{(pilot-P_i)},\ \Delta T_{(P_i-KCRV)}\right] \equiv u^2\left(\Delta T_{(pilot-KCRV)}\right)$, is the square of the standard uncertainty of the difference $\Delta T_{(pilot-KCRV)}$ calculated in EURAMET.T-K9 for UME, and it is given in Table 4.30 above in the form of expanded uncertainty.

So finally, Equation 8 becomes:

$$u^2\left(\Delta T_{(lab-KCRV)}\right) = u^2\left(\Delta T_{(lab-pilot)}\right) + u^2\left(\Delta T_{(pilot-KCRV)}\right) + 2 * u\left[\Delta T_{(lab-pilot)},\ \Delta T_{(pilot-P_i)}\right] \quad (9)$$

For the evaluation of the term $2 * u\left[\Delta T_{(lab-pilot)},\ \Delta T_{(pilot-P_i)}\right]$ we can follow the same logic explained in the final report of EURAMET.T-K9 paragraph 2.4. According to this paragraph the systematic terms of the uncertainty are strongly correlated between the measurements of the pilot (UME) in the two regional comparisons GULFMET and EURAMET, because they are using the same equipment, same fixed-point cells, and the uncertainty terms have similar values. So, this term is equal to

$$2 * u\left[\Delta T_{(lab-pilot)},\ \Delta T_{(pilot-P_i)}\right] = -2 * u_S^2 \quad (10)$$

Where the $u_S^2$ represents the sum of the squares of the standard uncertainty systematic terms of the pilot lab (UME) in either the GULFMET or the EURAMET comparison.

We have used the EURAMET.T-K9 comparison uncertainty budget, provided by UME, and found in Table II.24 “UME (Turkey) – detailed uncertainties” of the final report, to calculate the term: $-2 * u_S^2$ .

## 8. Linking with KCRV Results

Using the reasoning explained in paragraph 7, the results of the GULFMET.T-K9 are linked to the CCT K9 comparison and they are presented in the following Table 9, Table 10, Figure 2 and Figure 3.

*Table 9. Deviation of EMI from the KCRV value in the measured fixed points and its expanded uncertainty.*

| *Fixed Point* | $\Delta T_{(EMI-KCRV)}$ / mK | $U(\Delta T_{(EMI-KCRV)})$ / mK |
|---|---|---|
| Zn | -0.06 | 2.16 |
| Sn | 0.28 | 1.52 |
| In | 0.02 | 1.91 |
| Ga | -0.33 | 0.67 |
| Hg | 0.01 | 0.77 |

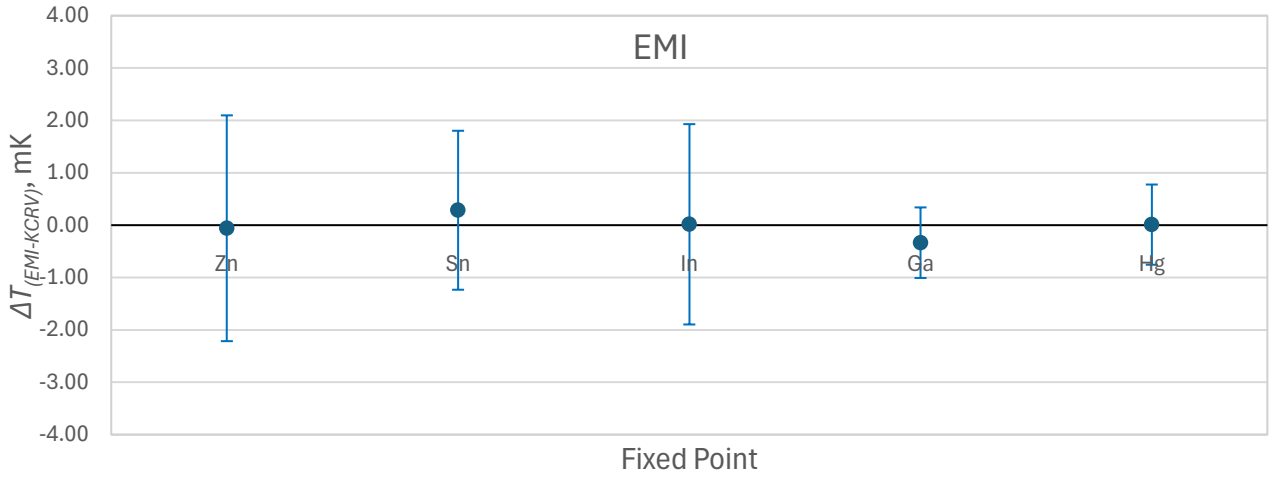



*Figure 2. EMI deviation from KCRV and its expanded uncertainty.*

*Table 10. Deviation of SASO-NMCC from the KCRV value in the measured fixed points and its expanded uncertainty.*

| *Fixed Point* | $\Delta T_{(SASO\ NMCC-KCRV)}$ / mK | $U(\Delta T_{(SASO\ NMCC-KCRV)})$ / mK |
|---|---|---|
| Zn | 1.30 | 2.15 |
| Sn | 0.34 | 1.51 |
| In | -2.01 | 1.78 |
| Ga | 0.23 | 0.78 |
| Hg | -0.10 | 0.76 |

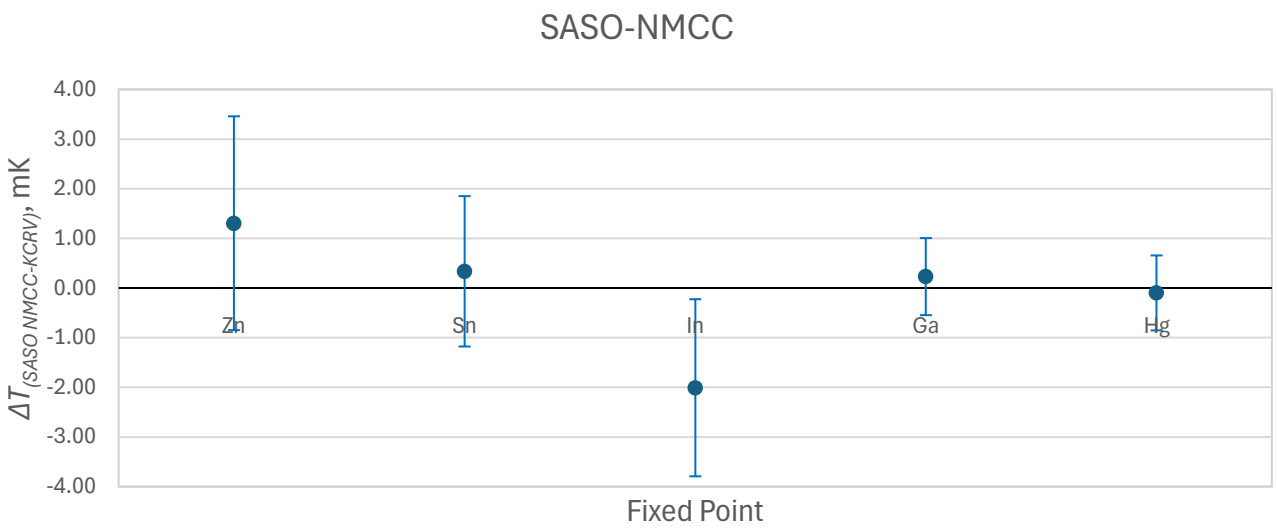



*Figure 3. SASO-NMCC deviation from KCRV and its expanded uncertainty.*

The results for all labs at all fixed points are summarized in Figure 4. The results related to UME are taken from the EURAMET.T K9 final report.

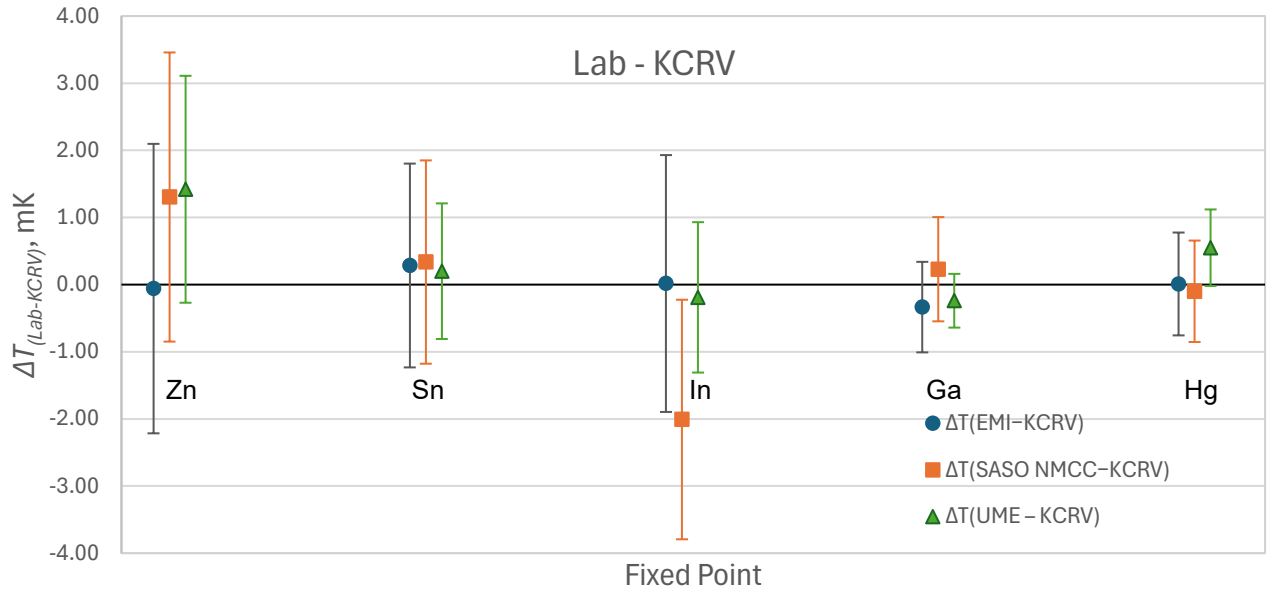



*Figure 4. Labs' deviation from KCRV and its expanded uncertainty at all fixed points. The results for UME were taken from the EURAMET.T K9 final report.*

## 9. Degrees of equivalence (DoE)

The bilateral equivalence matrices for each fixed point are presented in the tables below. In these tables, the entries above the diagonal represent the pairwise differences between the labs (calculated as row minus column) in millikelvin (mK), along with their corresponding expanded uncertainties (k=2), also expressed in mK. The differences between EMI and UME: $\Delta T_{(EMI-UME)}$ and SASO and UME: $\Delta T_{(SASO\text{-}NMCC\text{-}UME)}$, with their expanded uncertainty, are already given in Tables 7 and 8 respectively. The difference between EMI and SASO are calculated as: $\Delta T_{(EMI\ -\ SASO\text{-}NMCC)} = \Delta T_{(EMI-UME)} - \Delta T_{(SASO\text{-}NMCC\text{-}UME)}$. The expanded uncertainty of this difference is calculated by combining the uncertainties of the two terms in quadrature, assuming they are uncorrelated.
Below the diagonal, we left the table empty, because the respective differences would be the opposite of the differences given above the diagonal, with the same expanded uncertainty.

*Table 11. DoE at the Zink fixed point*

| Zn (row-column) | EMI | SASO | UME |
|---|---|---|---|
| **EMI** | - | -1.36 ±3.08 | -1.48 ±2.18 |
| **SASO** | | - | -0.12 ±2.18 |
| **UME** | | | - |

*Table 12. DoE at the Tin fixed point.*

| Sn (row-column) | EMI | SASO | UME |
|---|---|---|---|
| **EMI** | - | -0.05 ±2.18 | 0.08 ±1.54 |
| **SASO** | | - | 0.14 ±1.54 |
| **UME** | | | - |

*Table 13. DoE at the Indium fixed point.*

| In (row-column) | EMI | SASO | UME |
|---|---|---|---|
| **EMI** | - | 2.03 ±2.77 | 0.21 ±2.02 |
| **SASO** | | - | -1.82 ±1.90 |
| **UME** | | | - |

*Table 14. DoE at the Gallium fixed point.*

| Ga (row-column) | EMI | SASO | UME |
|---|---|---|---|
| **EMI** | - | -0.56 ±0.93 | -0.09 ±0.60 |
| **SASO** | | - | 0.47 ±0.71 |
| **UME** | | | - |

*Table 15. DoE at the Mercury fixed point.*

| Hg (row-column) | EMI | SASO | UME |
|---|---|---|---|
| **EMI** | - | 0.11 ±0.95 | -0.54 ±0.68 |
| **SASO** | | - | -0.65 ±0.67 |
| **UME** | | | - |

## 10. References


[1] The International Temperature Scale of 1990 (ITS-90), H Preston-Thomas 1990 Metrologia 27 3, https://www.bipm.org/utils/common/pdf/ITS-90/ITS-90_metrologia.pdf

[2] CCT Key Comparison 9 Final Report, ITS-90 SPRT Calibration from the Ar TP to the Zn FP, 2023 Metrologia 60 03001, https://doi.org/10.1088/0026-1394/60/1A/03001

[3] EURAMET.T-K9 regional key comparison ITS-90 SPRT calibration from the Ar TP to the Zn FP, 2024 Metrologia 61 03005, https://doi.org/10.1088/0026-1394/61/1A/03005

[4] JCGM 100:2008, Evaluation of measurement data — Guide to the expression of uncertainty in measurement, https://www.bipm.org/documents/20126/2071204/JCGM_100_2008_E.pdf

## Appendix I. Result Report of Emirates Metrology Institute (EMI)

Appendix A (Protocol): Measurement Reporting Worksheet of EMI

| **Participating NMI/DI** | **Emirates Metrology Institute (EMI)** | | | |
|---|---|---|---|---|
| | Before sending SPRTs to Pilot Laboratory | | | |
| Initial R(TPW), after annealing | 25.362591 | | | |
| | $\overline{W}(FP)$ | $u[\overline{W}(FP)], mK$ | n (*) | Comments (if any) |
| Zinc | 2.56875393 | 0.87 | 3 | 0.095 mK, full width spread of W |
| Tin | 1.89271203 | 0.63 | 3 | 0.397 mK, full width spread of W |
| Indium | 1.60974378 | 0.85 | 3 | 0.192 mK, full width spread of W |
| Gallium | 1.11812781 | 0.26 | 3 | 0.152 mK, full width spread of W |
| Mercury | 0.84415120 | 0.29 | 3 | 0.017 mK, full width spread of W |
| (*) *n, Number of equilibria realized* | | | | |
| Final *R* (TPW) | 25.362643 | | | |
| **On return to participating NMI** | | | | |
| On Receipt *R* (TPW), after annealing | 25.362617 | | | |
| | $\overline{W}(FP)$ | $u[\overline{W}(FP)], mK$ | n (*) | Comments (if any) |
| Zinc | 2.56875367 | 0.87 | 3 | 0.389 mK, full width spread of W |
| Tin | 1.89271272 | 0.63 | 3 | 0.475 mK, full width spread of W |
| Indium | 1.60974373 | 0.85 | 3 | 0.092 mK, full width spread of W |
| Gallium | 1.11812796 | 0.26 | 3 | 0.024 mK, full width spread of W |
| Mercury | 0.84415116 | 0.29 | 3 | 0.052 mK, full width spread of W |
| (*) *n, Number of equilibria realized* | | | | |
| Final *R* (TPW) | 25.362663 | | | |
| **Fixed-Point Cell Information** | | | | |
| | Manufacturer/Type/Serial Number | | L (cm) (*) | |
| Zinc | Fluke/5906/Zn06110 | | 19.5 | |
| Tin | Fluke/5905/Sn05095 | | 19.5 | |
| Indium | Fluke/5904/In04051 | | 19.5 | |
| Gallium | Fluke/5943/Ga43134 | | 16.8 | |
| H2O TP | Fluke/TPW 5901-Q/AQ5074 | | 28 | |
| Mercury | Fluke/5900E/Hg44 | | 21 | |
| (*)*Maximum thermometer Immersion depth into the substance, cm.* *Report the distance between the surface of the metal and the bottom of the thermometer well of the cell.* | | | | |
| **Measurement System** | | | | |
| Resistance Ratio Bridge Model | Measurements International/MI-6015T/1102596 | | | |
| Reference Resistor Model | Tinsley/5685A, 25 Ω/17894/09 and IET/SRX-100, 100 Ω/HI1311914 | | | |
| Resistor Enclosure Stability, mK | Measurements International/9300A/1103442, Stability 10 mK | | | |
| **R(WTP) values during the calibration process:** All the R(WTP) values and the moment when they are measured, according to the measurements at the other fixed points (Zinc, Tin, Indium, Gallium, Mercury), are requested, in a table. | | | | |

## Appendix B (Protocol): Example of an SPRT measurement of EMI

To obtain the value of W(FP) at the ITS-90 fixed point, corrections must be applied to the measured values, Wmeas(FP), as follows.

W(FP) = Wmeas(FP) + Cp + Ci,

where

Cp is the gas pressure correction multiplied by (dT/dp)(dW/dT),
Ci is the immersion depth correction multiplied by (dT/dh)(dW/dT)

**Before sending SPRTs to Pilot Laboratory**

| | Pressure | | Immersion | |
|---|---|---|---|---|
| | correction mK | $u_{correction}$ mK | correction mK | $u_{correction}$ mK |
| *W(Zn)* | 0.693 | 0.043 | -0.470 | 0.016 |
| *W(Sn)* | 0.526 | 0.033 | -0.383 | 0.013 |
| *W(In)* | 0.800 | 0.049 | -0.574 | 0.019 |
| *W(Ga)* | 0 | 0 | 0.176 | 0.007 |
| *W(Hg)* | 0 | 0 | -1.342 | 0.041 |
| *W(H2O)* | 0 | 0 | 0.189 | 0.004 |

**After sending SPRT to Pilot Laboratory**

| | Pressure | | Immersion | |
|---|---|---|---|---|
| | correction mK | $u_{correction}$ mK | correction mK | $u_{correction}$ mK |
| *W(Zn)* | 0.693 | 0.043 | -0.470 | 0.016 |
| *W(Sn)* | 0.526 | 0.033 | -0.383 | 0.013 |
| *W(In)* | 0.800 | 0.049 | -0.574 | 0.019 |
| *W(Ga)* | 0 | 0 | 0.176 | 0.007 |
| *W(Hg)* | 0 | 0 | -1.342 | 0.041 |
| *W(H2O)* | 0 | 0 | 0.189 | 0.004 |

# Appendix C (Protocol): Uncertainty Budget for EMI Measurements

The Wt ratio of the thermometer at the fixed points is calculated by:

Wt = Xt/X0.01°C + Ct *[CXt/1+ CXt/2 + CXt/3 + CXt/4 + CXt/5 + CXt/6 + CXt/7 + CXt/8] + C0*[CX0.01°C/1+ CX0.01°C/2 + CX0.01°C/3 + CX0.01°C/4 + CX0.01°C/5 + CX0.01°C/6 + CX0.01°C/7 + CX0.01°C/8 + CX0.01°C/9] + Cr*[DRs/1+DRs/2] + SWt

Where:

Xt is the ratio of the thermometer resistance at the fixed point to the standard resistor Rs, measured by the bridge

X0.01 °C is the ratio of the thermometer resistance at the triple point of water to the standard resistor Rs, measured by the bridge

Ct = δWt/δXt = 1/X0.01°C

C0 = δWt/δX(0.01°C) = [- Xt / (X0.01°C)^2]

Cr = δWt/δ(DRs) = Wt

| | | Hg | Ga | In | Sn | Zn | | | |
|---|---|---|---|---|---|---|---|---|---|
| Quantity Qi | Components | Uncertainty, ui in mK | Uncertainty, ui in mK | Uncertainty, ui in mK | Uncertainty, ui in mK | Uncertainty, ui in mK | Degrees of freedom, Vi | Type A or B | Characterized: |
| Xt | Repeatability of readings | 0.005 | 0.015 | 0.010 | 0.004 | 0.007 | 35 | A | Random |
| C Xt/1 | Repeatability of temperature realized by cell (mK) | 0.100 | 0.100 | 0.200 | 0.300 | 0.400 | infinite | B | Random |
| C Xt/2 | Uncertainty linked with purity of fixed point cell (mK) | 0.250 | 0.200 | 0.800 | 0.500 | 0.700 | infinite | B | Systematic |
| C Xt/3 | Uncertainty linked Hydrostatic pressure correction (mK) | 0.041 | 0.007 | 0.019 | 0.013 | 0.016 | infinite | B | Systematic |
| C Xt/4 | Uncertainty linked with perturbing heat exchanges (mK) | 0.021 | 0.029 | 0.007 | 0.026 | 0.079 | infinite | B | Random |
| C Xt/5 | Uncertainty linked with self-heating correction (mK) | 0.014 | 0.029 | 0.029 | 0.029 | 0.058 | infinite | B | Systematic |
| C Xt/6 | Uncertainty linked with bridge linearity | 0.005 | 0.006 | 0.023 | 0.024 | 0.025 | infinite | B | Systematic |
| C Xt/7 | Uncertainty linked with AC/DC current (mK) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | infinite | B | Systematic |
| C Xt/8 | Uncertainty linked with gas pressure (mK) | 0.010 | 0.010 | 0.100 | 0.080 | 0.120 | infinite | B | Systematic |
| X0.01 °C | Repeatability of readings | 0.003 | 0.007 | 0.006 | 0.011 | 0.014 | 35 | A | Random |
| C X0.01°C/1 | Repeatability of temperature realized by cell (mK) | 0.042 | 0.056 | 0.084 | 0.102 | 0.147 | infinite | B | Random |
| C X0.01°C/2 | Short repeatability of calibrated SPRT (mK) | 0.048 | 0.065 | 0.098 | 0.117 | 0.169 | infinite | B | Random |
| C X0.01°C/3 | Uncertainty linked with purity and isotopic composition (mK) | 0.042 | 0.056 | 0.084 | 0.102 | 0.147 | infinite | B | Systematic |
| C X0.01°C/4 | Uncertainty linked Hydrostatic pressure correction (mK) | 0.002 | 0.002 | 0.004 | 0.004 | 0.006 | infinite | B | Systematic |
| C X0.01°C/5 | Uncertainty linked with perturbing heat exchanges (mK) | 0.005 | 0.007 | 0.010 | 0.012 | 0.017 | infinite | B | Random |
| C X0.01°C/6 | Uncertainty linked with self-heating correction (mK) | 0.024 | 0.033 | 0.049 | 0.059 | 0.085 | infinite | B | Systematic |
| C X0.01°C/7 | Uncertainty linked with bridge linearity | 0.005 | 0.006 | 0.037 | 0.045 | 0.065 | infinite | B | Systematic |
| C X0.01°C/8 | Uncertainty linked with AC/DC current (mK) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | infinite | B | Systematic |
| C X0.01°C/9 | Uncertainty linked with internal insulation leakage (mK) | 0.006 | 0.008 | 0.012 | 0.015 | 0.021 | infinite | B | Systematic |
| DRS/1 | Uncertainty linked with stability of $R_S$ (reference resistor) between TPW and FP | 0.002 | 0.003 | 0.004 | 0.005 | 0.007 | infinite | B | Random |
| DRS/2 | Uncertainty linked with temperature variation of $R_S$ between TPW and FP | 0.005 | 0.007 | 0.005 | 0.006 | 0.008 | infinite | B | Random |
| SWt | Wt scatter | 0.005 | 0.044 | 0.056 | 0.115 | 0.027 | infinite | B | Random |
| **Combined standard uncertainty** | | 0.29 | 0.26 | 0.85 | 0.63 | 0.87 | | | |
| **k factor** | | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | | | |
| **Expanded uncertainty** | | 0.57 | 0.51 | 1.70 | 1.27 | 1.74 | | | |

## Appendix II. Result Report of Saudi Arabia Standards Organization-National Metrology and Calibration Center (SASO-NMCC)

Appendix A (Protocol): Measurement Reporting Worksheet of SASO-NMCC

| **Participating NMI/DI** | **SASO NMCC** | | | |
|---|---|---|---|---|
| **Before sending SPRTs to Pilot Laboratory** | | | | |
| Initial R(TPW) | 25.416393 | | | |
| | $\overline{W}(FP)$ | $u[\overline{W}(FP)], mK$ | n (*) | Comments (if any) |
| Zinc | 2.56853644 | 1.739 | 3 | |
| Tin | 1.89258354 | 1.769 | 3 | |
| Indium | 1.60964365 | 2.515 | 3 | |
| Gallium | 1.11811271 | 0.894 | 3 | |
| Mercury | 0.84417404 | 1.554 | 3 | |
| (*) *n, Number of equilibria realized* | | | | |
| Final $R$(TPW) | 25.416610 | | | |
| **On return to participating NMI** | | | | |
| On Receipt $R$(TPW), | 25.41658784 | | | |
| | $\overline{W}(FP)$ | $u[\overline{W}(FP)], mK$ | n (*) | Comments (if any) |
| Zinc | 2.56853346 | 1.739 | 3 | |
| Tin | 1.89258181 | 1.769 | 3 | |
| Indium | 1.60965000 | 2.515 | 3 | |
| Gallium | 1.11811238 | 0.894 | 3 | |
| Mercury | 0.84417366 | 1.554 | 3 | |
| (*) n, Number of equilibria realized | | | | |
| Final $R$(TPW) | 25.41674941 | | | |

**Fixed-Point Cell Information**

| **Fixed-Point Cell Information** | | L(mm) | | |
|---|---|---|---|---|
| | Type /manufacturer/serial number | | Open or sea | Traceability |
| Zinc | Sealed/UME/17-01 | 196 | Seal | |
| Tin | Sealed/UME/2015/02 | 196 | Seal | |
| Induim | 5904/ Hart Scientific /04037 | 195 | Seal | |
| Gallium | 17401 YSI 197 | 230 | Seal | |
| Mercury | 17724/ISOTECH/Hg-268 | 200 | Seal | |

(*) *Maximum thermometer Immersion depth into the substance measured to the thermal centre of the SPRT sensing element, cm*

| **Measurement System** | |
|---|---|
| Resistance Ratio Bridge Model | F18 |
| Reference Resistor Model | 5685A |
| Resistor Enclosure Stability, mK | 0.1 |

Appendix B (Protocol): Example of an SPRT measurement of SASO-NMCC

| | self-heating | | hydrostatic | | pressure | | Imertion | |
|---|---|---|---|---|---|---|---|---|
| | correction mK | $u_{correction}$ mK | correction mK | $u_{correction}$ mK | correction mK | $u_{correction}$ mK | correction mK | $u_{correction}$ mK |
| $\overline{R}$ (Zn) | | 0.0967305 | 0.393600524 | 0.0135 | 0 | | | 0.80400323 |
| $\overline{R}$ (Sn) | | 0.1021902 | 0.340346939 | 0.011 | 0 | | | 2.20033086 |
| $\overline{R}$ (In) | | 0.1115800 | 0.519938213 | 0.033 | 0 | | | 3.71832585 |
| $\overline{R}$ (Ga) | | 0.1035524 | -0.238873518 | -0.012 | 0 | | | -0.979332716 |
| $\overline{R}$ (Hg) | | 0.0970368 | 1.223804479 | 0.071 | 0 | | | 3.35233258 |

Appendix C (Protocol): Uncertainty Budget for SASO-NMCC Measurements, submitted initially.

| **Participating NMI** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **SASO-NMCC Budget** | mK | mK | mK | mK | mK | | |
| | **Hg** | **Ga** | **In** | **Sn** | **Zn** | **Type A or B** | **Characterized:** |
| Phase Transition Realization Repeatability | 0.014 | 0.007 | 0.008 | 0.010 | 0.006 | A | Random |
| Bridge (repeatability, nonlinearity, AC quadrature) | 0.026 | 0.026 | 0.026 | 0.026 | 0.026 | A | Systematic |
| Reference resistor stability | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | A | Systematic |
| Chemical Impurities | 0.144 | 0.116 | 0.462 | 0.289 | 0.404 | B | Systematic |
| Hydrostatic-head | 0.041 | -0.007 | 0.019 | 0.006 | 0.008 | B | Systematic |
| Propagated TPW | 0.240 | 0.318 | 0.458 | 0.539 | 0.731 | A | Random |
| SPRT self-heating | 0.056 | 0.060 | 0.064 | 0.059 | 0.056 | B | Random |
| Heat Flux | 0.720 | -0.283 | 1.073 | 0.635 | 0.232 | B | Random |
| Insulation leakage | | | | | | B | Systematic |
| SPRT Pt Oxydation | | | | | | B | Systematic |
| Gas pressure | | | | | | B | Systematic |
| | | | | | | | |
| Combined Standard Uncertainty | 0.7768 | 0.4468 | 1.2576 | 0.8843 | 0.8696 | | |
| Expanded Uncertainty (k=2) | 1.554 | 0.894 | 2.515 | 1.769 | 1.739 | | |

Appendix C (Protocol): Final Uncertainty Budget for SASO-NMCC Measurements. It was submitted by the lab, after the comments of the CCT WG-KC reviewers of the Draft B report, related to the TPW instability of their transfer SPRT.

| **SASO-NMCC Budget** | mK | mK | mK | mK | mK | | |
|---|---|---|---|---|---|---|---|
| | **Hg** | **Ga** | **In** | **Sn** | **Zn** | **Type A or B** | **Characterized:** |
| Phase Transition Realization Repeatability | 0.014 | 0.007 | 0.008 | 0.010 | 0.006 | A | Random |
| Bridge (repeatability, nonlinearity, AC quadrature) | 0.026 | 0.026 | 0.026 | 0.026 | 0.026 | A | Systematic |
| Reference resistor stability | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | A | Systematic |
| Chemical Impurities | 0.144 | 0.116 | 0.462 | 0.289 | 0.404 | B | Systematic |
| Hydrostatic-head | 0.041 | -0.007 | 0.019 | 0.006 | 0.008 | B | Systematic |
| TPW measurement uncertainty, propagated to the fixed points | 0.240 | 0.318 | 0.458 | 0.539 | 0.731 | A | Random |
| SPRT self-heating | 0.056 | 0.060 | 0.064 | 0.059 | 0.056 | B | Random |
| Heat Flux | 0.029 | 0.044 | 0.056 | 0.068 | 0.092 | B | Random |
| SPRT TPW Instability | 0.383 | 0.518 | 0.776 | 0.935 | 1.347 | B | Random |
| Insulation leakage | | | | | | B | Systematic |
| SPRT Pt Oxydation | | | | | | B | Systematic |
| Gas pressure | 0.032 | 0.035 | 0.039 | 0.039 | 0.056 | B | Systematic |
| | | | | | | | |
| Combined Standard Uncertainty | 0.48 | 0.63 | 1.02 | 1.12 | 1.59 | | |
| Expanded Uncertainty (k=2) | 0.97 | 1.25 | 2.04 | 2.24 | 3.18 | | |

## Appendix III. Result Report of Ulusal Metroloji Enstitüsü (UME)

Appendix A (Protocol): Measurement Reporting Worksheet of TUBITAK-UME

**Participating NMI/DI** | Pilot (UME) Results for SPRT No 1783 of EMI

Pilot Laboratory

Initial R(TPW), after annealing

| | $\overline{W}(FP)$ | $u[\overline{W}(FP)], mK$ | n (*) | Comments (if any) |
|---|---|---|---|---|
| Zinc | 2.56875897 | 0.780 | 3 | |
| Tin | 1.89271206 | 0.546 | 3 | |
| Indium | 1.60974297 | 0.588 | 3 | |
| Gallium | 1.11812826 | 0.201 | 3 | |
| Mercury | 0.84415336 | 0.213 | 3 | |

*(*)n, Number of equilibria realized*

Final $R$(TPW)

**Participating NMI/DI** | Pilot (UME) Results for SPRT No 768 of SASO-NMCC

Pilot Laboratory

Initial R(TPW), after annealing

| | $\overline{W}(FP)$ | $u[\overline{W}(FP)], mK$ | n (*) | Comments (if any) |
|---|---|---|---|---|
| Zinc | 2.568535353 | 0.750 | 3 | |
| Tin | 1.89258217 | 0.542 | 3 | |
| Indium | 1.60965374 | 0.560 | 3 | |
| Gallium | 1.11811069 | 0.217 | 3 | |
| Mercury | 0.84417647 | 0.224 | 3 | |

*(*)n, Number of equilibria realized*

Final $R$(TPW)

**Fixed-Point Cell Information**

| | Type /manufacturer/serial number | L (cm) (*) | Open or sealed cell | Traceability |
|---|---|---|---|---|
| Zinc | TÜBİTAK UME, BSA,Zn 13/01 | 175 | Open | EUROMET.T-K3 |
| Tin | TÜBİTAK UME, BSA,Sn 13/01 | 171 | Open | EUROMET.T-K3 |
| Indium | NPL, In 7/95 | 149 | Sealed | EUROMET.T-K3 |
| Gallium | ISOTECH, 17401, Ga068 | 205 | Sealed | EUROMET.T-K3 |
| Mercury | TÜBİTAK UME, SS-38, Hg09-01 | 175 | Sealed | EUROMET.T-K3 |
| | | | | |

*(*) Maximum thermometer Immersion depth into the substance measured to the thermal centre of the SPRT sensing element, cm*

**Measurement System**

| | |
|---|---|
| Resistance Ratio Bridge Model | DC MI 6015T |
| Reference Resistor Model | TINSLEY, 5685A |
| Resistor Enclosure Stability, mK | < 5 |

Appendix C (Protocol): TUBITAK-UME Uncertainty Budget for the calibration of EMI Thermometer.

| Participating NMI | EMI | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hg | | Ga | | In | | Sn | | Zn | | | |
| | mK | df | mK | df | mK | df | mK | df | mK | df | Type A or B (*) | |
| Phase Transition Realization Repeatability | 0.090 | infinite | 0.070 | infinite | 0.170 | infinite | 0.245 | infinite | 0.340 | infinite | B | Random |
| Bridge (repeatability, non-linearity, AC quadrature) | 0.040 | 40 | 0.040 | 40 | 0.060 | 40 | 0.075 | 40 | 0.080 | 40 | A | Systematic |
| Reference resistor stability | 0.020 | infinite | 0.020 | infinite | 0.020 | infinite | 0.020 | infinite | 0.020 | infinite | B | Systematic |
| Chemical Impurities | 0.140 | infinite | 0.100 | infinite | 0.500 | infinite | 0.400 | infinite | 0.600 | infinite | B | Systematic |
| Hydrostatic-head | 0.035 | infinite | 0.015 | infinite | 0.034 | infinite | 0.022 | infinite | 0.027 | infinite | B | Systematic |
| Propagated TPW | 0.109 | infinite | 0.146 | infinite | 0.208 | infinite | 0.247 | infinite | 0.334 | infinite | B | Random |
| SPRT self-heating | 0.030 | infinite | 0.030 | infinite | 0.050 | infinite | 0.050 | infinite | 0.060 | infinite | B | Random |
| Heat Flux | 0.028 | infinite | 0.030 | infinite | 0.120 | infinite | 0.080 | infinite | 0.090 | infinite | B | Random |
| Insulation leakage | | | | | | | | | | | | |
| SPRT Pt Oxydation | | | | | | | | | | | | |
| Gas pressure | 0.030 | infinite | 0.020 | infinite | 0.040 | infinite | 0.040 | infinite | 0.050 | infinite | B | Systematic |
| | | | | | | | | | | | | |
| Combined Standard Uncertainty | 0.213 | | 0.201 | | 0.588 | | 0.546 | | 0.780 | | | |
| Expanded Uncertainty ($k$ =2 level, using effective df) | 0.426 | | 0.403 | | 1.176 | | 1.092 | | 1.561 | | | |

Appendix C (Protocol): TUBITAK-UME Uncertainty Budget for the calibration of SASO-NMCC Thermometer

| Participating NMI | SASO | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hg | | Ga | | In | | Sn | | Zn | | | |
| | mK | df | mK | df | mK | df | mK | df | mK | df | Type A or B (*) | |
| Phase Transition Realization Repeatability | 0.110 | infinite | 0.100 | infinite | 0.080 | infinite | 0.230 | infinite | 0.270 | infinite | B | Random |
| Bridge (repeatability, non-linearity, AC quadrature) | 0.040 | 40 | 0.040 | 40 | 0.060 | 40 | 0.075 | 40 | 0.080 | 40 | A | Systematic |
| Reference resistor stability | 0.020 | infinite | 0.020 | infinite | 0.020 | infinite | 0.020 | infinite | 0.020 | infinite | B | Systematic |
| Chemical Impurities | 0.140 | infinite | 0.100 | infinite | 0.500 | infinite | 0.400 | infinite | 0.600 | infinite | B | Systematic |
| Hydrostatic-head | 0.035 | infinite | 0.015 | infinite | 0.034 | infinite | 0.022 | infinite | 0.027 | infinite | B | Systematic |
| Propagated TPW | 0.109 | infinite | 0.146 | infinite | 0.208 | infinite | 0.247 | infinite | 0.334 | infinite | B | Random |
| SPRT self-heating | 0.030 | infinite | 0.030 | infinite | 0.045 | infinite | 0.060 | infinite | 0.060 | infinite | B | Random |
| Heat Flux | 0.040 | infinite | 0.050 | infinite | 0.070 | infinite | 0.090 | infinite | 0.071 | infinite | B | Random |
| Insulation leakage | | | | | | | | | | | | |
| SPRT Pt Oxydation | | | | | | | | | | | | |
| Gas pressure | 0.030 | infinite | 0.020 | infinite | 0.040 | infinite | 0.040 | infinite | 0.050 | infinite | B | Systematic |
| | | | | | | | | | | | | |
| Combined Standard Uncertainty | 0.224 | | 0.217 | | 0.560 | | 0.542 | | 0.750 | | | |
| Expanded Uncertainty ($k$ =2 level, using effective df) | 0.448 | | 0.435 | | 1.120 | | 1.084 | | 1.501 | | | |

Uncertainty Budget for TUBITAK-UME in EURAMET.T-K9, found in Table II.24 “UME (Turkey) – detailed uncertainties” of the final report.

| | Ar | | Hg | | Ga | | In | | Sn | | Zn | | Type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mK | df | mK | df | mK | df | mK | df | mK | df | mK | df | |
| Phase Transition Realization Repeatability | 0.098 | | 0.102 | | 0.092 | | 0.044 | | 0.210 | | 0.256 | | B (R) |
| Bridge (repeatability, non-linearity, AC quadrature) | 0.070 | | 0.050 | | 0.045 | | 0.055 | | 0.075 | | 0.080 | | B (S) |
| Reference resistor stability | 0.020 | | 0.020 | | 0.020 | | 0.020 | | 0.020 | | 0.020 | | B (S) |
| Chemical Impurities | 0.300 | | 0.140 | | 0.070 | | 0.450 | | 0.360 | | 0.600 | | B (S) |
| Hydrostatic-head | 0.034 | | 0.035 | | 0.015 | | 0.034 | | 0.022 | | 0.027 | | B (S) |
| Propagated TPW | 0.029 | | 0.109 | | 0.146 | | 0.208 | | 0.247 | | 0.334 | | B (R) |
| SPRT self-heating | 0.020 | | 0.030 | | 0.030 | | 0.050 | | 0.050 | | 0.050 | | B (R) |
| Heat Flux | 0.200 | | 0.025 | | 0.038 | | 0.030 | | 0.052 | | 0.066 | | B (R) |
| Insulation leakage | | | | | | | | | | | | | |
| SPRT Pt Oxydation | | | | | | | | | | | | | |
| Gas pressure | | | 0.030 | | 0.020 | | 0.040 | | 0.040 | | 0.050 | | B (S) |
| | | | | | | | | | | | | | |
| Combined Standard Uncertainty | 0.38 | | 0.22 | | 0.20 | | 0.51 | | 0.50 | | 0.74 | | |
| | | | | | | | | | | | | | |
| Expanded Uncertainty ($k$=2, using effective df) | 0.77 | | 0.44 | | 0.40 | | 1.01 | | 1.00 | | 1.49 | | |

**Appendix IV. GULFMET. T-K9 Protocol**

# GULFMET. T-K9 Protocol

## Regional key comparison

***ITS-90 SPRT Calibration from the Hg TP to the Zn FP***

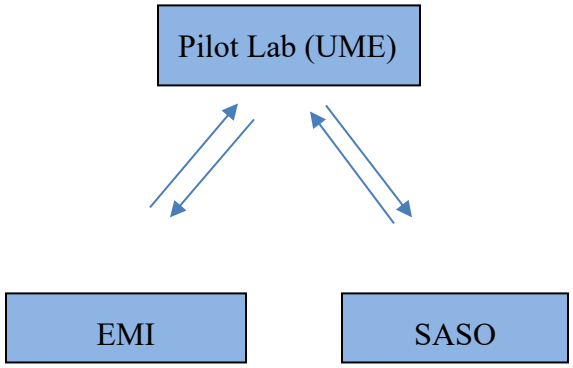
**Objective:**

This comparison is designed to compare the realization of the ITS-90 through the calibration of SPRTs. The range of temperature covered in this comparison is from the triple point of Hg (234.3156 K) to the freezing point of Zn (692.677 K). The transfer standards used will be long-stem SPRTs.

This protocol matches closely the corresponding CCT-K9 key comparison.

**Method:**

Since the number of the participants is very small (three including the pilot), the comparison will have a star structure with two arms. See the sketch below:




Pilot Lab: UME (Turkey)

Participants: EMI (United Arab Emirates), SASO (Saudi Arabia)

**Coordinator:**

Kalemci, Murat (UME)

The name, postal and e-mail addresses of the participants are given in appendix D

**Projected Timeline:**

| | |
|---|---|
| Protocol Agreement: | November, 2016 |
| Transfer Standards Sent to the pilot: | May, 2017 |
| Transfer Standards Returned to NMIs: | July, 2017 |
| Transfer Standards Re-Measured by NMIs: | September, 2017 |
| Draft A Report Completed: | December, 2017 |

**Participants will supply the following information:**

- 2 ITS-90 calibrated SPRTs
    - NMI participant will select their own SPRTs based on their own criteria for suitability and will convey the selection criteria to the Pilot Laboratory.
    - Two SPRTs must be calibrated by NMI participant before measurements are made by the Pilot Laboratory.
    - One SPRT will be carried to the Pilot Laboratory for calibration.

*(Here is the slight difference with the CCT-K9 protocol. A second thermometer is prepared and immediately kept at disposal in case of trouble with the transfer standard, particularly in case of carrier problems)*

    - Each participant will repossess their thermometer and will make a re-calibration.
    - SPRTs are to be measured at every available fixed-point over the range of the comparison including the In FP and Ga MP
- Prior to calibration an annealing procedure for both thermometers has to be performed as follows:
    - Determine the $R_{TPW}$ value of the thermometer before annealing.
    - Carefully insert the SPRT into a furnace at 480 °C.
    - Anneal the SPRT for two hours at 480 °C.
    - Carefully remove the SPRT from the furnace directly to the room environment.
    - Re-determine the value of $R_{TPW.}$
    - If the resistance at TPW increases after annealing, consider using another thermometer for the comparison.
    - If the resistance at TPW of the SPRT is decreasing by an equivalent of 0.5 mK or greater, proceed to a second annealing procedure.
    - If the resistance decrease is less than an equivalent of 0.5 mK, proceed with the calibration.

- Calibration results supplied in $\overline{W}(FP)$ for each Fixed Point (FP) with all corrections applied by the NMI such that the $\overline{W}(FP)$ values are equivalent to the ITS-90 assigned temperature values for 0 mA. Uncertainties, $u(\overline{W})$, may be specific to each SPRT.

    - Appendix A gives a reporting worksheet

- The measurement equation used to compute each calibration result with an indication of which inputs vary randomly for each realized equilibrium and which inputs are systematic across all equilibria for each fixed point within this comparison
    - Any quantities in the measurement equation that are a mixture of random and systematic effects for each SPRT should be broken into constituent parts that are either purely random or purely systematic within this comparison.
        - An example of an SPRT measurement is given in Appendix B

- Uncertainty budget compliant with CCT WG3 that includes degrees of freedom associated to each component

    - A template for the uncertainty budget is given in Appendix C
        - Sources of uncertainty may be added or deleted as needed
        - An NMI/DI may choose to supply their own uncertainty budget (CMC and WG3 compliant) that includes degrees of freedom for each source of uncertainty
        - Please identify which components of the uncertainty budget are associated with random effects in $\overline{W}(FP)$ and which are associated with systematic effects in $\overline{W}(FP)$ within this comparison.

    (NMI/DI are encouraged to use the template, but if it prefers it may supply its own, taking care to not forget any uncertainty components (for this point, the suggested budget can be a help).

    For information about uncertainties in the calibration of SPRTs, you could refer to the document “Uncertainties in the Realisation of the SPRT Subranges of the ITS-90”, prepared by CCT-WG3, which can be downloaded from the following internet link:
    http://www.bipm.org/cc/CCT/Allowed/24/D19_rev_WG3_Doc_rev_10July2009.pdf

- Heat Flux (Immersion) profile for each fixed-point cell using the SPRTs of this comparison

    - [*R*(FP), 0 mA] and corresponding [immersion depth (sensor midpoint), cm]

- All results and required information will be e-mailed to the pilot and to the coordinator.

*If you have questions about any aspect of the protocol or if you are not sure how to report something that is requested, please contact the coordinator prior to submitting your report. After reviewing all*

*submitted reports, the pilot /coordinator will contact you if there is anything that is unclear or if any additional information is needed to complete the analysis of the data.*

Note:

The thermometer number is assigned to the NMI SPRT by arrival date. L1 will be the thermometer first arrived to the pilot and L2 will be the second. In case the second thermometer is needed from some lab, the letter S will be added to the initial code (i.e. L1S).

**Role of the coordinator / pilot:**

- To prepare a protocol
- To send the protocol to all the participants for agreement
- To register the comparison and to keep contact with CCT and GULFMET at the different steps of the comparison.
- To be informed of the state of progress of the comparison and communicate with the participants in case of delays or any other issues.
- To liaise with NMIs participants regarding receipt and return of the SPRTs.
- To check their initial value of R (TPW), before and after annealing, against the final value reported by the participant. In the case of significant discrepancy, to consult with the participant before proceeding with the calibration.
- To receive all the results of measurements from the labs.
- To carry out the calibration of the SPRTs using the same equipment as was used in EURAMET.T-K9. It is necessary that one of the SPRTs used by the Pilot in EURAMET.T-K9 is also included in the calibration experiments.
- To prepare tables of results and uncertainties for the calibration of the Participants SPRTs in accordance with Appendices A, B and C, and to calculate the differences $\Delta T_{(Lj-P)}$ and uncertainties $u_{(Lj-P)}$ (see next paragraph)
- To write the draft A and draft B (using the entries of the labs)
- To exchange with the participants concerning draft A and draft B.

**Method of Analysis and link to the CCT-K9 KCRV value.**

For the GULFMET.T-K9 comparison, for each fixed point, and each NMI/DI, the fixed-point realization temperature differences from the CCT KCRV and the associated uncertainty will be calculated using the deviation of each lab from the pilot lab, the deviation of the pilot lab to EURAMET KCRV and the deviation of EURAMET KCRV to CCT KCRV, following equations:

For each laboratory *Lj* in the comparison

$$\Delta T_{(Lj-KCRV)} = \Delta T_{(Lj-P)} + \Delta T_{(P-EURAMET.KCRV)} + \Delta T_{(EURAMET.KCRV-CCT.KCRV)}$$

$$u^2_{(Lj-KCRV)} = u^2_{(Lj-P)} + u^2_{(P-EURAMET.KCRV)} + u^2_{(EURAMET.KCRV-CCT.KCRV)}$$

The four values, $\Delta T_{P-EURAMET.KCRV}$, $\Delta T_{EURAMET.KCRV-CCT.KCRV}$, $u_{P-EURAMET.KCRV}$ and $u_{EURAMET.KCRV-CCT.KCRV}$ will be available from the EURAMET-K9 report and:

$$\Delta T_{(Lj-P)} = \frac{[\overline{W}(FP)_{Lj} - \overline{W}(FP)_{Pi}]}{dW_r / dT} + C_{Lj}$$

$C_{Lj}$ is a term used to account for uncertainty associated with the travel, handling, or stability of the SPRT and is taken to have a value of $C_{Lj} = 0$ and a standard uncertainty, $u_{C_{Lj}}$, of

$$u_{C_{Lj}} = \frac{abs[\overline{W}(FP)_{Ljbefore} - \overline{W}(FP)_{Ljafter}]}{(dW_r / dT).\sqrt{12}}$$

## Appendix A: Measurement Reporting Worksheet

**Participating NMI/DI**

Before sending SPRTs to Pilot Laboratory

Initial R(TPW), after annealing

| | $\overline{W}(FP)$ | $u[\overline{W}(FP)], mK$ | n (*) | Comments (if any) |
|---|---|---|---|---|
| Zinc | | | | |
| Tin | | | | |
| Indium | | | | |
| Gallium | | | | |
| Mercury | | | | |

(*)*n, Number of equilibria realized*

Final *R*(TPW)

**On return to participating NMI**

On Receipt *R*(TPW), after annealing

| | $\overline{W}(FP)$ | $u[\overline{W}(FP)], mK$ | n (*) | Comments (if any) |
|---|---|---|---|---|
| Zinc | | | | |
| Tin | | | | |
| Indium | | | | |
| Gallium | | | | |
| Mercury | | | | |

(*)*n, Number of equilibria realized*

Final *R*(TPW)

**Fixed-Point Cell Information**

| | Type /manufacturer | L (cm) (*) |
|---|---|---|
| Zinc | | |
| Tin | | |
| Indium | | |
| Gallium | | |
| Mercury | | |

(*)*Maximum thermometer Immersion depth into the substance, cm. Report the distance between the surface of the metal and the bottom of the thermometer well of the cell.*

**Measurement System**

| | |
|---|---|
| Resistance Ratio Bridge Model | |
| Reference Resistor Model | |
| Resistor Enclosure Stability, mK | |

## Appendix B: Example of an SPRT measurement

To obtain the value of W(FP) at the ITS-90 fixed point, corrections must be applied to the measured values, Wmeas(FP), as follows.

W(FP) = Wmeas(FP) + Cp + Ci,

where

Cp is the gas pressure correction multiplied by (dT/dp)(dW/dT),
Ci is the immersion depth correction multiplied by (dT/dh)(dW/dT)

### Before sending SPRTs to Pilot Laboratory

| | pressure | | immersion | |
|---|---|---|---|---|
| | correction mK | $u_{correction}$ mK | correction mK | $u_{correction}$ mK |
| *W(Zn)* | | | | |
| *W(Sn)* | | | | |
| *W(In)* | | | | |
| *W(Ga)* | | | | |
| *W(Hg)* | | | | |

### After sending SPRT to Pilot Laboratory

| | pressure | | immersion | |
|---|---|---|---|---|
| | correction mK | $u_{correction}$ mK | correction mK | $u_{correction}$ mK |
| *W(Zn)* | | | | |
| *W(Sn)* | | | | |
| *W(In)* | | | | |
| *W(Ga)* | | | | |
| *W(Hg)* | | | | |

**Appendix C: Suggested Uncertainty Budget for the Determination of the *W*-Value of an SPRT**

**Participating NMI**

| | Hg | | Ga | | In | | Sn | | Zn | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **mK** | **df** | **mK** | **df** | **mK** | **df** | **mK** | **df** | **mK** | **df** | **Type A or B (*)** |
| Phase Transition Realization Repeatability | | | | | | | | | | | |
| Bridge (repeatability, non-linearity, AC quadrature) | | | | | | | | | | | |
| Reference resistor stability | | | | | | | | | | | |
| Chemical Impurities | | | | | | | | | | | |
| Hydrostatic-head | | | | | | | | | | | |
| Propagated TPW | | | | | | | | | | | |
| SPRT self-heating | | | | | | | | | | | |
| Heat Flux | | | | | | | | | | | |
| Moisture | | | | | | | | | | | |
| SPRT Pt Oxidation | | | | | | | | | | | |
| Gas pressure | | | | | | | | | | | |
| Slope of Plateau | | | | | | | | | | | |
| Combined Standard Uncertainty | | | | | | | | | | | |
| Expanded Uncertainty (*k*=2 level, using effective df) | | | | | | | | | | | |

**(*) write A or B depending on the method used**

***df: degree of freedom***

**Appendix D:**

Name, postal and e-mail addresses of the pilot and participants.

| | | | |
|---|---|---|---|
| Turkey | UME | Kalemci, Murat<br>murat.kalemci@tubitak.gov.tr | Uytun, Ali<br>ali.uytun@tubitak.gov.tr |
| Ulusal Metroloji Enstitüsü (UME)<br>Barış Mah. Dr. Zeki Acar Cad. No:1 TR-41470<br>Gebze, Kocaeli | | | |

| | | | |
|---|---|---|---|
| United Arab Emirates | EMI | Anagnostou Miltiadis<br>miltiadis.anagnostou@qcc.abudhabi.ae<br>Mob: +971 568746630<br>Tel.: +971 24035981 | Al Breiki, Ahmed<br>ahmed.albreiki@qcc.abudhabi.ae |
| Emirates Metrology Institute (EMI)<br>Block H, CERT Technology Park<br>881, Sultan Bin Zayed the First Street<br>PO Box 853, Abu Dhabi | | | |

| | | | |
|---|---|---|---|
| Kingdom of Saudi Arabia | SASO NMCC | Mr. Abdulaziz Mubarak AlZahrani<br>am.zahrani@saso.gov.sa<br>Mob: +966 598692311<br>Tel: +966 112529729 | Dr. Ismail A. Alfaleh<br>i.faleh@saso.gov.sa<br>Mob: +966 553295328 |
| National Measurements Calibration Center (SASO)<br>Temperature Measurement Department<br>Riyadh Al Muhammadiyah - in front of King Saud University<br>PO. B 3437 Riyadh 11471 | | | |

**List of Figures**

Figure 1. The scheme of the comparison ..... 3
Figure 2. EMI deviation from KCRV and its expanded uncertainty. ..... 13
Figure 3. SASO-NMCC deviation from KCRV and its expanded uncertainty. ..... 14
Figure 4. Labs' deviation from KCRV and its expanded uncertainty at all fixed points. The results for UME were taken from the EURAMET.T K9 final report. ..... 14

## List of Tables

Table 1. List of participant laboratories and their contact details. ..... 4
Table 2. Comparison timeline. ..... 4
Table 3. Selected SPRTs by the participants to be used in this comparison. ..... 6
Table 4. Measurement results obtained by EMI with SPRT No 1783. ..... 7
Table 5. Measurement results obtained by SASO-NMCC with SPRT No 768. ..... 7
Table 6. Measurement results obtained by TUBİTAK UME for both SPRTs. ..... 8
Table 7. Average W values obtained by EMI and its expanded uncertainty converted to temperature, W values obtained by UME for EMI's SPRT and its expanded uncertainty converted to temperature, and temperature difference between EMI and UME and its expanded uncertainty. ..... 10
Table 8. Average W values obtained by SASO-NMCC and its expanded uncertainty converted to temperature, W values obtained by UME for SASO-NMCC's SPRT and its expanded uncertainty converted to temperature, temperature difference between SASO-NMCC and UME and its expanded uncertainty. ..... 10
Table 9. Deviation of EMI from the KCRV value in the measured fixed points and its expanded uncertainty. ..... 13
Table 10. Deviation of SASO-NMCC from the KCRV value in the measured fixed points and its expanded uncertainty. ..... 13
Table 11. DoE at the Zink fixed point ..... 15
Table 12. DoE at the Tin fixed point. ..... 15
Table 13. DoE at the Indium fixed point. ..... 15
Table 14. DoE at the Gallium fixed point. ..... 16
Table 15. DoE at the Mercury fixed point. ..... 16