Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

Quality and Standards Authority of Ethiopia
QSAE

CENTROCAL
Beratungs-, Prüf- und Kalibrierzentrum
für Temperaturmesstechnik GmbH

East African Community

Final Technical Report

2^{nd} EAC – IC in Temperature Metrology

Industrial Platinum Resistance Thermometers

Pilot Laboratory: Quality and Standards Authority of Ethiopia
QSAE, Addis Ababa, Ethiopia

Reference Laboratory: CENTOCAL, Werne, Germany

Within the framework of the PTB-EAC project
"Establishment of a regional SQMT-architecture in the EAC"

Messgröße
DKD-K-09701
Temperatur

CENTROCAL GmbH
Lohstraße 2, D-59368 Werne
Postfach 1461, D-59357 Werne
Tel.: +49 (0) 23 89 - 409 - 02
Fax: +49 (0) 23 89 - 409 - 80
E-mail: info@roesseltemp.de
www.roesseltemp.de

Stadtsparkasse Werne
Kto. 1420 (BLZ 410 516 05)
IBAN DE65 4105 1605 0000 0014 20
Postbank Dortmund
Kto. 55 52-467 (BLZ 440 100 46)
Steuer-Nr. 333 598 801 93
USt-IdNr.: DE 170848458

Eingetragen unter
HRB 1468 Lünen
Geschäftsführer:
Dipl.-Ing. Reinhard Klemm

CENTROCAL
Ein Unternehmen
der RÖSSEL-Gruppe

Content

East African Community - Interlab Comparison

Final Technical Report of the 2nd EAC - IC in Temperature Metrology

1. INTRODUCTION

This report describes the results of the second interlab ring comparison with Industrial Platinum Resistance Thermometer in the range of -250 to 200 deg. Cent (°C).

The participating laboratories were (names in first-/last-name):

QSAE	Addis Ababa, Ethiopia	Wondwosen Fisseha, Fistum Tesfaye
KEBS	Nairobi , Kenya (Ref. Lab.)	Joel Kioko, Wilson Egadwa
TBS	Dar es Salaam, Tanzania	Alphonce Morris Kagoma / Adam Ziagi / Joseph Kadenge
UNBS	Kampala, Uganda	Yasin Lemeriga, Simon Rwashana,
RBS	Kigali, Rwanda	Cyprien Muzungu, Patrice Ntiyamira

Special thanks are directed to the pilot lab (QSAE, Mr. Wondwosen Fisseha and Mrs. Fistum Tesfaye) for their organization, logistics and accomplishment in doing this 2nd interlab ring comparison with industrial platinum resistance thermometers.

The German PTB (Mr. Stefan Wallerath & his team) and the technical consultant, Mr. Reinhard Klemm (Centrocal GmbH, Werne, Germany) thank all participated laboratories and persons for their cooperation.

The 2nd EAC-Interlab Comparison circle was also not started as a contest between the participating labs. No award will be presented to the “winner” because all participants are winners. The above given order of labs is a list only and reflects no any other relevancy.

The results are presented in an open form rather than to make them anonymous. Any of the participants will get all detailed informations from any other lab.

During a workshop, held at Tanzania Bureau of Standards (TBS) in Dar Es Salaam, Tanzania from June 6th to June 10th, 2009 the results were presented and discussed.

The German PTB as well as the consultant thanks TBS for the organization of the workshop and the hospitality to the participants.

2. ABSTRACT

The 2nd EAC-IC was done within a reasonable amount of time. The two returned Industrial Platinum Resistance Thermometers (IPRT's) were in a very good condition. No damage occurred and stability of the artifacts was achieved. The recalibration at the original lab in Germany produced expected results without any surprise.

The results given by the labs were in the form of calibration certificates. The formal layout was acceptable. All labs added a detailed uncertainty budget as requested.

An example or guide for a detailed uncertainty budget was developed by the consultant and sent to the labs. By return detailed budgets were made available in an acceptable form. Guide and individual budgets are given as appendices to this report.

The final elaboration, done by the consultant, is added to this report in both tabulary and graphical form. The report is written in " Word® ", graphics and tables in " Excel® " and the PDF - documents are made by using " Acrobat 8 Prof.® ".

Most of the labs achieved at all temperatures an E_n – value of 1,0 or below. Some lab showed results which are partly not consistently within the queue of the related measurements.

The workshop held in Dar Es Salaam is the "toolkit" for the following 3rd interlab comparison circles with electrical thermometers – i.e. thermocouples type N (NiCrSi – NiSi).

Word & Excel are registered trademarks of Microsoft Corp.; Acrobat is a registered trademark of Adobe Systems Inc.

3. RESULTS

3.1 Overview

Two Industrial Platinum Resistance Thermometers were calibrated by a German DKD - lab named "CENTROCAL" – further abbreviated as CC – before and after EAC-IC. The thermometers have no mark for the immersion depth. Due to the fact, that all labs in the EAC-IC have calibrated the artifacts at immersion depth of 100 to 160 mm, the final calibration at CC was performed in both depths – 100 mm and 160 mm. No difference was found. Therefore the results were not split for different immersion depths.
QSAE was the leading pilot lab for the EAC-IC and did the first and final calibration and stated the routines for the calibrations in the consecutive labs.

To have a clear understanding and give a good support to the labs for further interlab comparisons all results are referenced to QSAE as well as to CC.

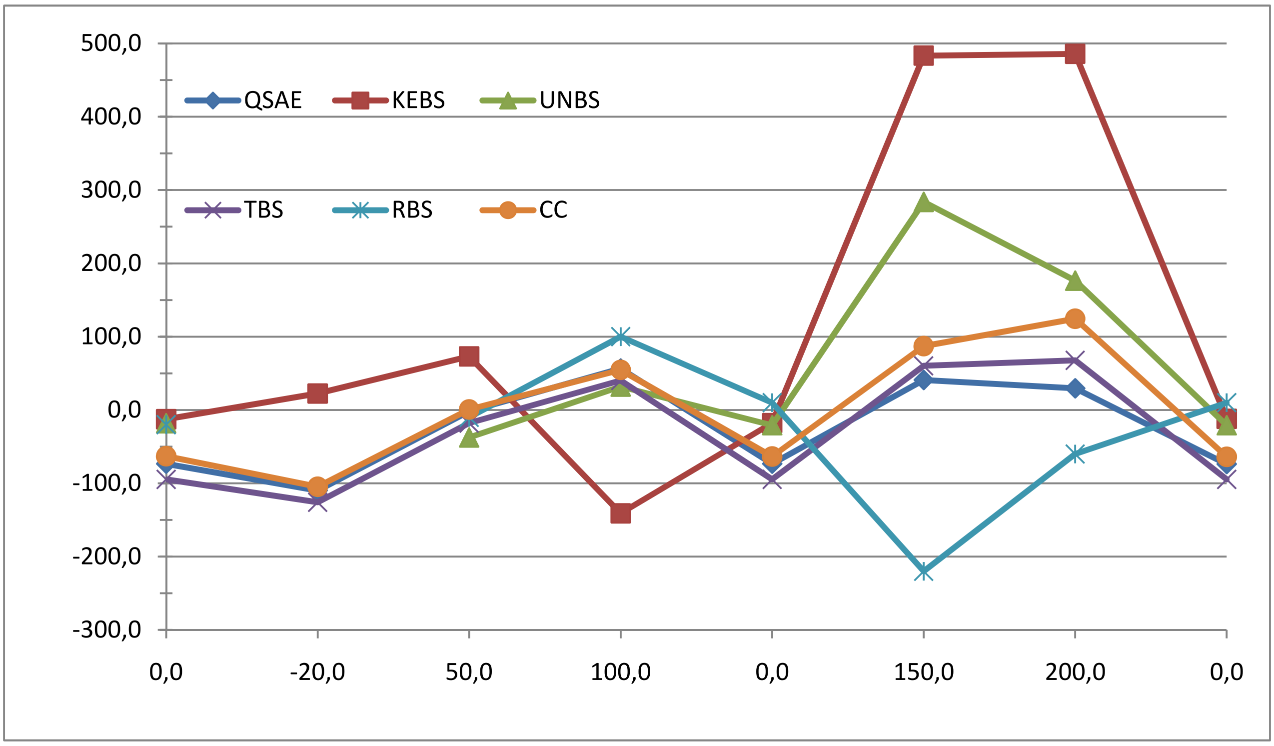
Lab Name	Immersion	Target Temp. In °C	Standard Temp. In °C	IPRT Value in Ohm	IPRT Value in °C	Deviation in mK	Uncert. (k=2) in mK	LV-QSAE in mK	En LV-QSAE	LV-CC in mK	En LV-CC	Uncert.	En LV-CC	En LV-QSAE
QSAE	100	0,0	0,003	99,9726	-0,070	-73,4	29	0,0	0,0	-10,4	-0,272			
		-20,0	-20,109	92,0738	-20,219	-109,8	29	0,0	0,0	-5,2	-0,135			
		50,0	50,293	119,5106	50,295	-1,9	36	0,0	0,0	-2,6	-0,059			
		100,0	99,884	138,4831	99,941	56,6	310	0,0	0,0	1,8	0,006			
		0,0	0,003	99,9726	-0,070	-73,4	29	0,0	0,0	-10,0	-0,261			
		150,0	149,965	157,3274	150,006	40,9	310	0,0	0,0	-46,3	-0,149			
		200,0	199,913	175,8347	199,942	29,5	310	0,0	0,0	-95,1	-0,306			
		0,0	0,003	99,9724	-0,071	-73,8	29	0,0	0,0	-9,9	-0,259			
KEBS	140	0,0	0,002	99,9685	-0,011	-12,5	200	60,9	0,301	50,5	0,251			
		-20,0	-19,697	92,2626	-19,675	22,5	300	132,3	0,439	127,1	0,422			
		50,0	50,030	119,4040	50,103	73,1	200	75,0	0,369	72,4	0,359			
		100,0	99,860	138,3610	99,719	-141,0	200	-197,6	-0,536	-195,8	-0,971			
		0,0	0,008	99,9687	-0,010	-17,9	200	55,5	0,275	45,5	0,226			
		150,0	149,937	157,4390	150,420	483,4	500	442,5	0,752	396,2	0,791			
		200,0	199,988	175,9820	200,474	485,8	500	456,3	0,776	361,2	0,722			
		0,0	0,003	99,9689	-0,009	-12,0	200	61,8	0,306	51,9	0,257			
UNBS	??	0,0	-0,019	99,9855	-0,037	-18,1	11	55,3	1,783	44,9	1,644	200	0,223	0,274
													0,000	0,000
		50,0	50,180	119,4520	50,143	-37,5	11	-35,6	-0,946	-38,2	-1,399	100	-0,371	-0,335
		100,0	100,067	138,5430	100,099	31,9	11	-24,7	-0,080	-22,9	-0,837	200	-0,113	-0,067
		0,0	-0,016	99,9856	-0,037	-20,8	11	52,6	1,696	42,6	1,560	100	0,413	0,505
		150,0	150,712	157,6970	150,996	283,8	11	242,9	0,783	196,6	7,199	200	0,975	0,658
		200,0	200,509	176,1080	200,685	176,4	11	146,9	0,474	51,8	1,898	200	0,257	0,398
		0,0	-0,016	99,9856	-0,037	-20,8	11	53,0	1,709	43,1	1,578	100	0,418	0,509

TBS	100	0,0	0,000	99,9630	-0,095	-94,7	30	-21,3	-0,510	-31,7	-0,811	25	-0,896	-0,555
		-20,0	-20,001	92,1100	-20,127	-125,9	30	-16,1	-0,386	-21,3	-0,545	25	-0,602	-0,420
		50,0	50,002	119,3910	49,984	-17,9	40	-16,0	-0,297	-18,6	-0,395	25	-0,526	-0,365
		100,0	99,998	138,5200	100,038	40,2	40	-16,4	-0,052	-14,5	-0,308	25	-0,411	-0,053
		0,0	0,000	99,9630	-0,095	-94,7	30	-21,3	-0,510	-31,3	-0,801	25	-0,884	-0,555
		150,0	150,001	157,3480	150,061	60,2	40	19,3	0,062	-26,9	-0,571	30	-0,690	0,062
		200,0	200,003	175,8820	200,071	67,7	40	38,2	0,122	-56,9	-1,205	50	-1,017	0,122
		0,0	0,000	99,9630	-0,095	-94,7	30	-20,9	-0,500	-30,8	-0,788	25	-0,870	-0,545

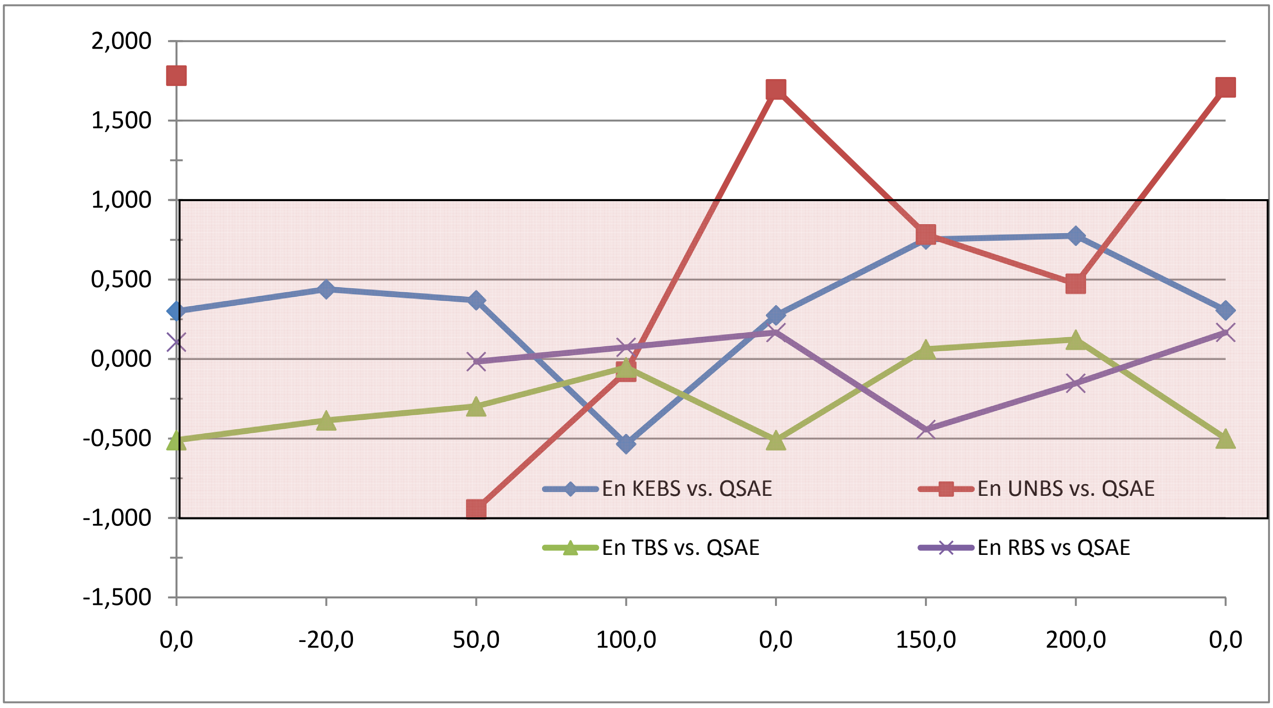
RBS	??	0,0	-0,004	99,9920	-0,020	-20,0	500	53,4	0,107	43,0	0,086
		50,0	50,670	119,6590	50,680	-10,0	500	-8,1	-0,016	-10,7	-0,021
		100,0	99,830	138,4030	99,730	100,0	500	43,4	0,074	45,2	0,090
		0,0	-702,000	99,9880	-0,030	10,0	500	83,4	0,167	73,4	0,147
		150,0	149,860	157,3550	150,080	-220,0	500	-260,9	-0,443	-307,2	-0,614
		200,0	200,050	175,8960	1200,110	-60,0	500	-89,5	-0,152	-184,6	-0,369
		0,0	-0,030	99,9840	-0,040	10,0	500	83,8	0,167	73,9	0,148

CC Value in °C	CC Dev. In mK	Uncert. CC in mK
0,049	-63,0	25,0
-19,891	-104,6	25,0
49,959	0,7	25,0
100,123	54,8	25,0
0,004	-63,4	25,0
150,13	87,2	25,0
200,054	124,6	25,0
-0,054	-63,9	25,0

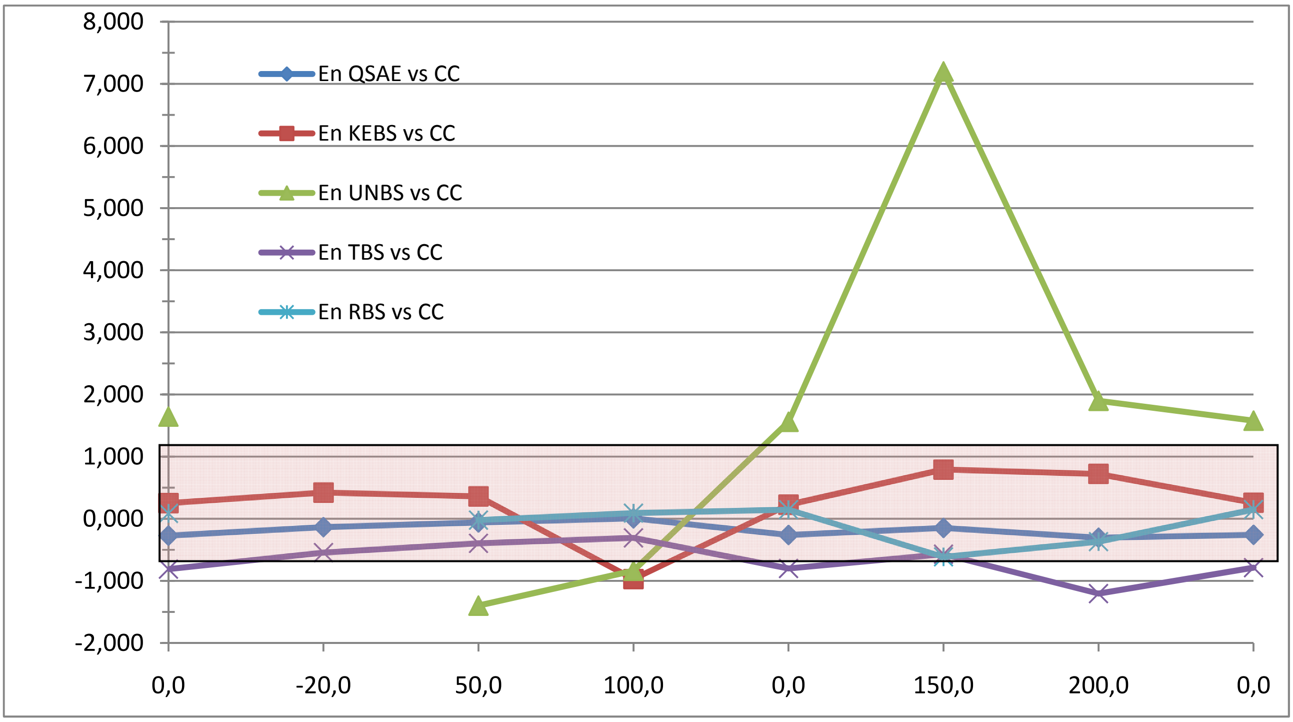
3.3 Fig. 1: Graphical display of deviation from all labs vs. temperature



3.4 Fig. 2: Graphical display of E_n vs temp., pilot-lab.: QSAE



3.5 Fig. 3: Graphical display of E_n vs temp., ref.-lab.: CC



3.6 First conclusion

As to be seen in the above graphical displays acc. to fig. 1 ... 3, the reported results are mostly inside the ± 1 range of the E_n-value. That means that nearly all labs have calculated their uncertainty on a very realistic level. One lab stated in his calibration certificate a measurement uncertainty lower than their accredited best measurement capability (BMC). This is not acceptable for a DKD-accredit lab. The consultant used the BMC for the calculations.

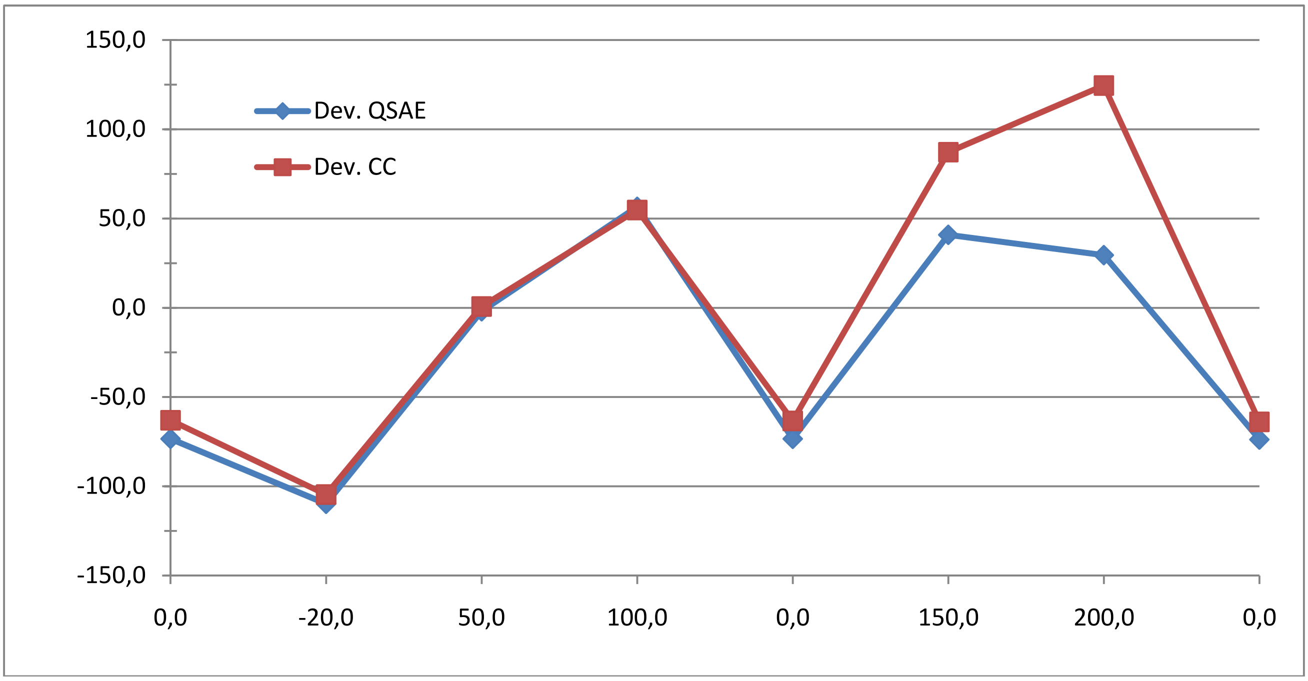
One lab made developed a correct uncertainty budget, but the figures are unrealistic low. The consultant knows what instruments and temperature sources are available. Taking this in consideration, the BMC of that lab could under any circumstances not be lower than 200 mK.

Using the a corrected level for the calculation of the E_n-value, than all measurements are inside the ± 1 range!

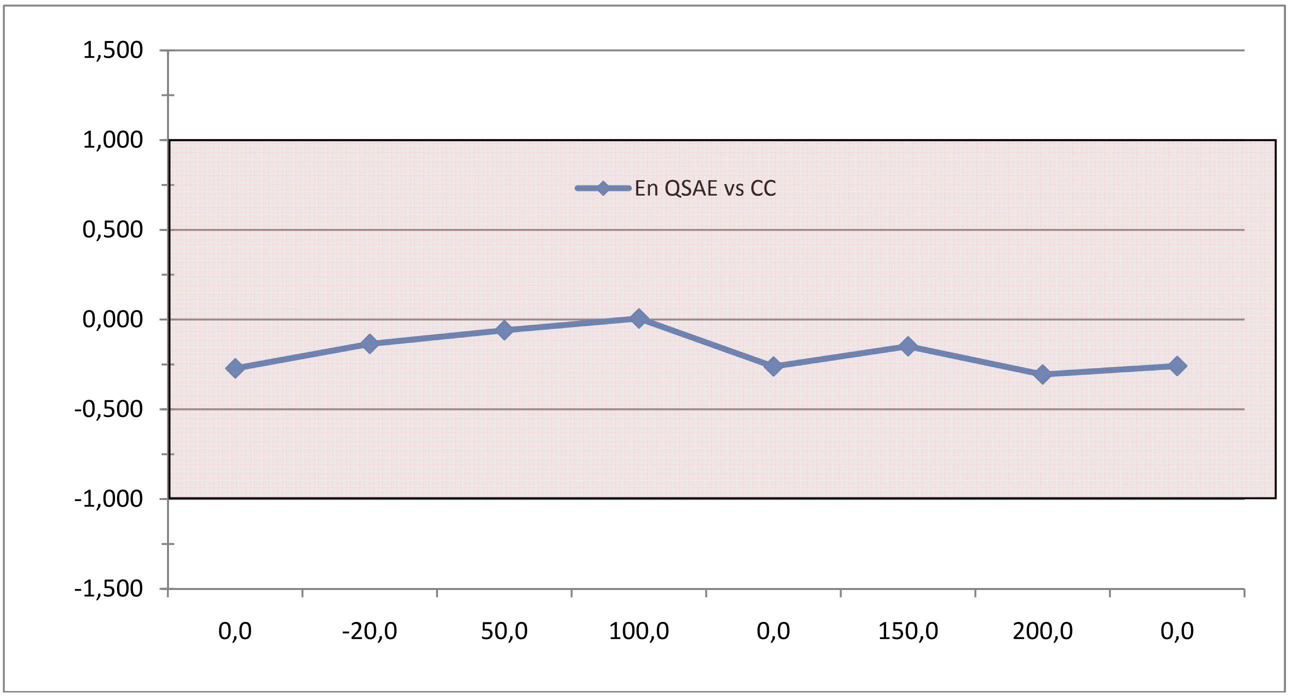
4. DETAILED RESULTS PER PARTICIPATED LABORATORY

4.1 QSAE, Addis Ababa, Ethiopia – pilot lab

4.1.1 Fig. 4: Deviation Value in °C versus Temperature in °C



4.1.2 Fig. 5: En - Value versus Temperature in °C, QSAE vs. ref. lab Centrocal



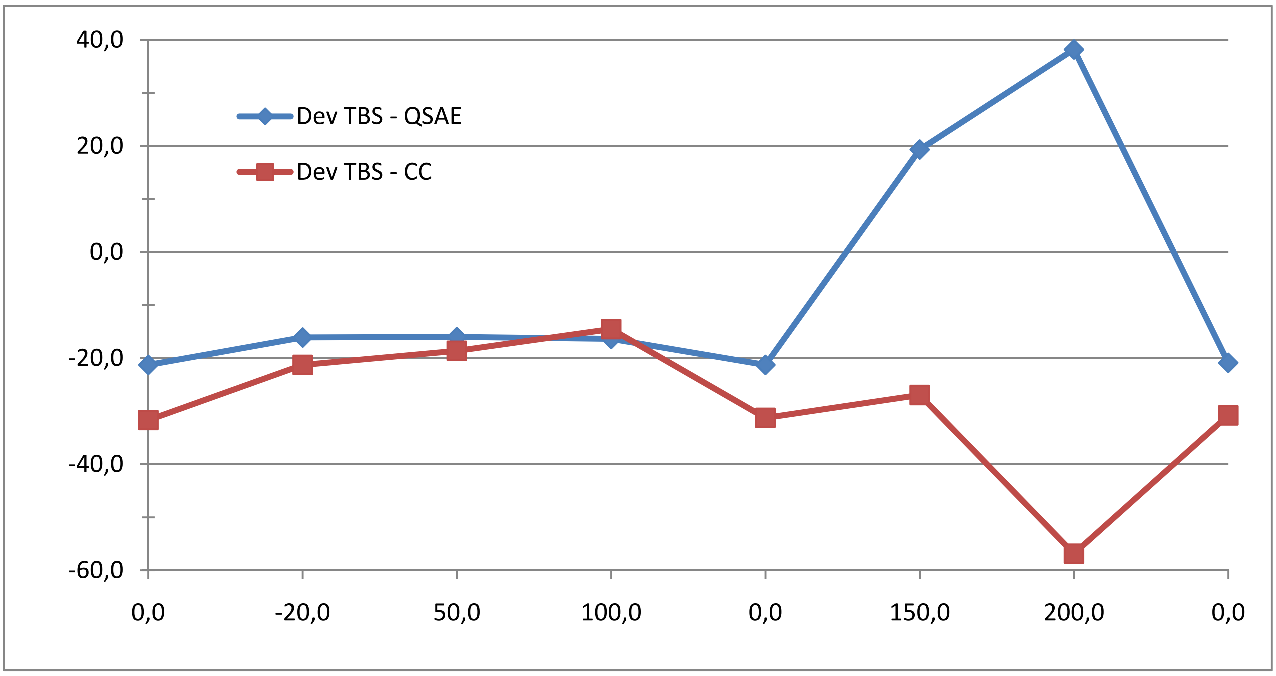
4.1.4 Comments

The graphic of the reported deviations look not so bad. The trend is exactly the same as of CC. It seems to the consultant, that there are no major deficiencies in handling, hardware and calibration procedures.

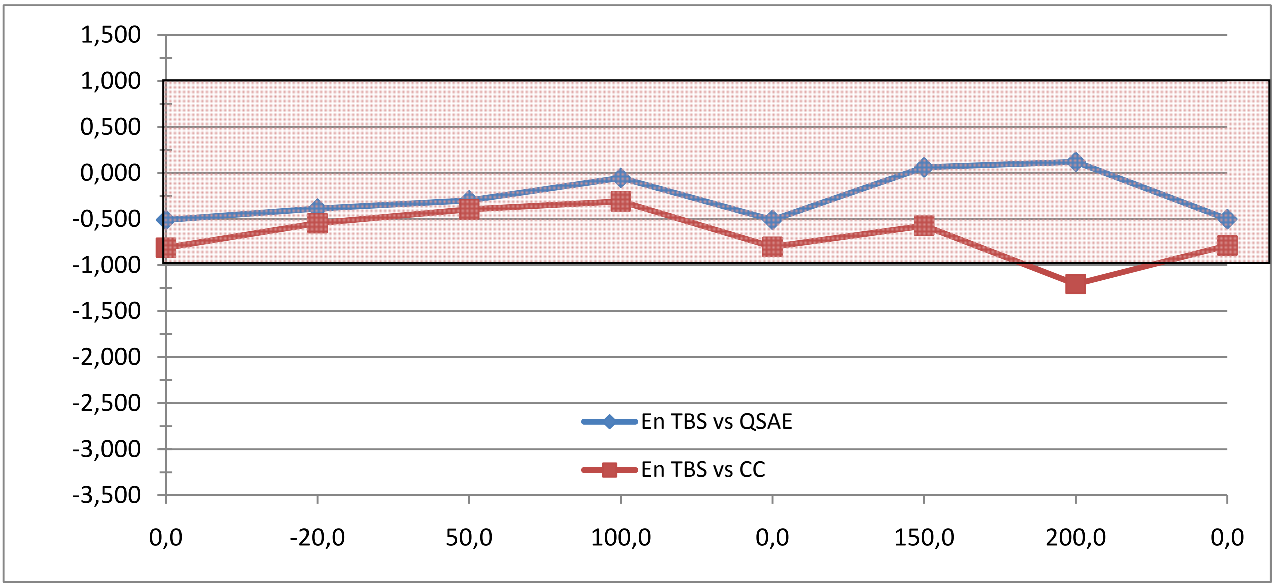
It seems on the other hand, that the estimation of the uncertainty is quite realistic. Some more adder for security in the estimation of accompanying parameters may lead to better results. The measurements are partly better than the estimated uncertainty.

4.2 TBS , Dar Es Salaam, Tanzania

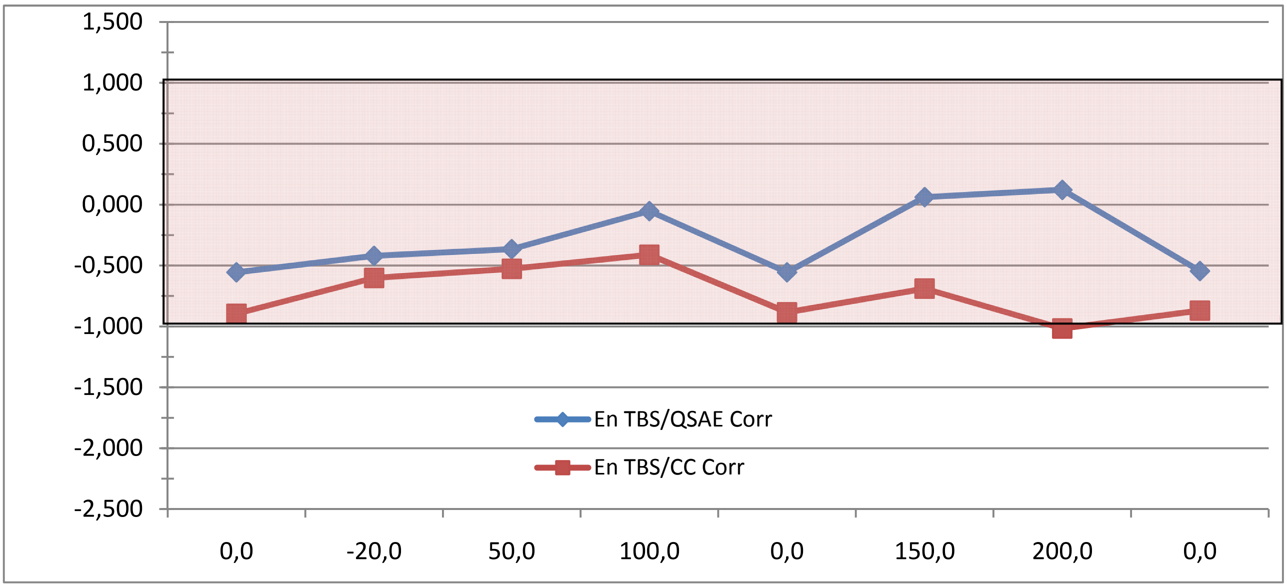
4.2.1 Fig. 6: Deviation Value in °C versus Temperature in °C



4.2.2 Fig. 7: E_n - Value versus Temperature in °C



4.2.2 Fig. 7a: E_n - Value versus Temperature in °C, corrected uncertainty



4.2.5 Comments

The graphic of the absolute results looks quite good. The trend is widely the same except in only one point. It seems to the consultant, that there are no deficiencies in handling, hardware and calibration procedures.

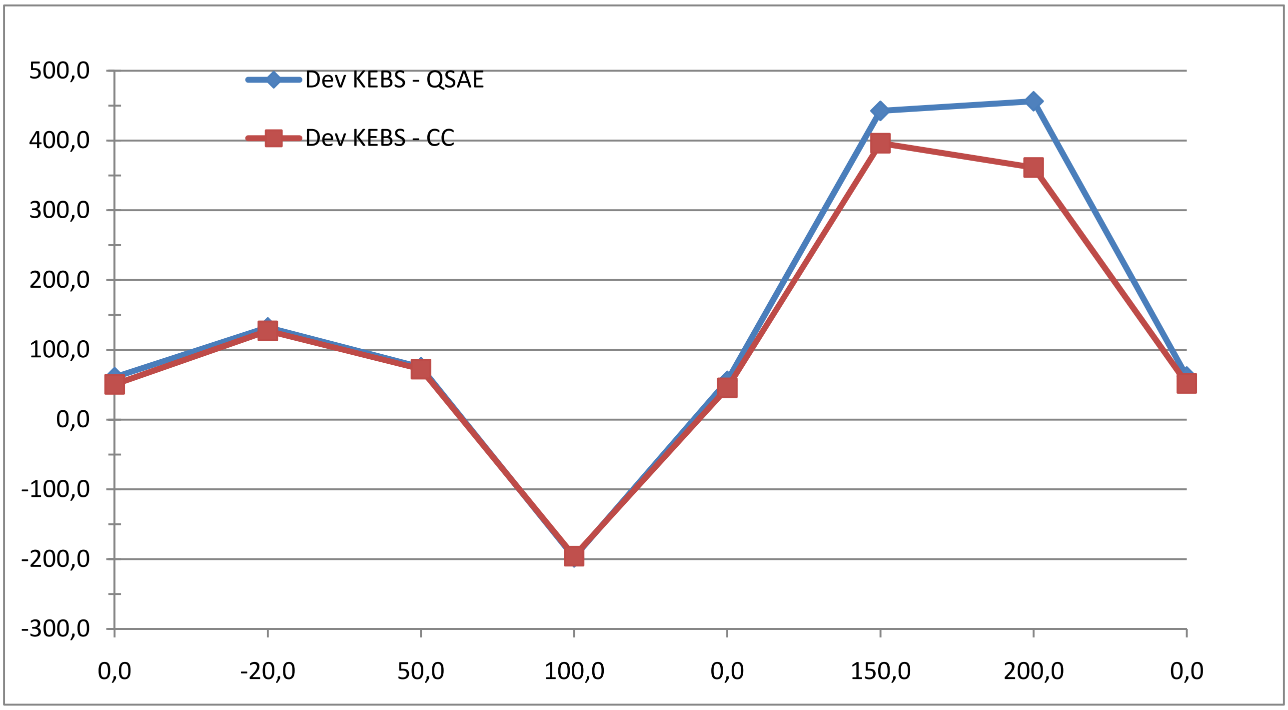
It seems on the other hand, that the estimation of the uncertainty compared with CC is a little bit too progressive.

It's hard to understand, that the E_n – values at positive temperatures are inside ± 1,0 – but are outside at zero and below. One possible explanation could be that the waiting time for thermal stabilization of the temperature source was too short – but other influences are also possible.

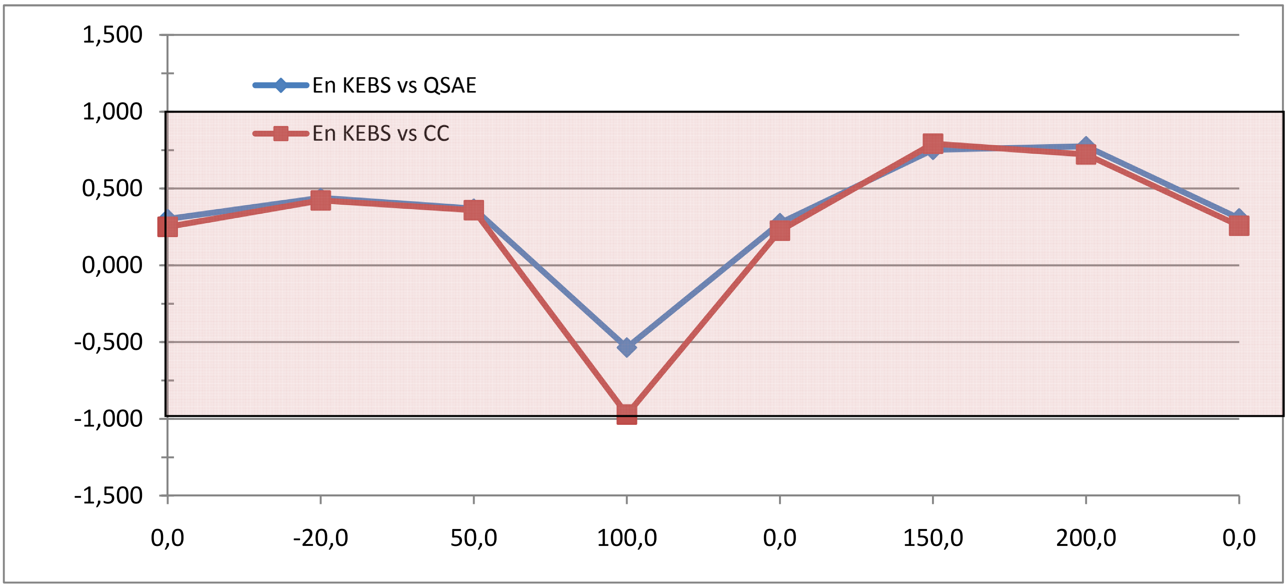
Compared with the reference lab (CC) the results shows quite good consistency.

4.3 KEBS; Nairobi, Kenya

4.3.1 Fig. 8: Deviation Value in °C versus Temperature in °C



4.3.2 Fig. 9: E_n - Values versus Temperature in °C



4.3.3 Comments

The graphic of the absolute results looks not so bad. The trend is quite comparable as of QSAE as well as CC.

It seems to the consultant, that there might be some little deficiencies in handling, hardware and/or calibration procedure or they misinterpreted the routines given by CC.

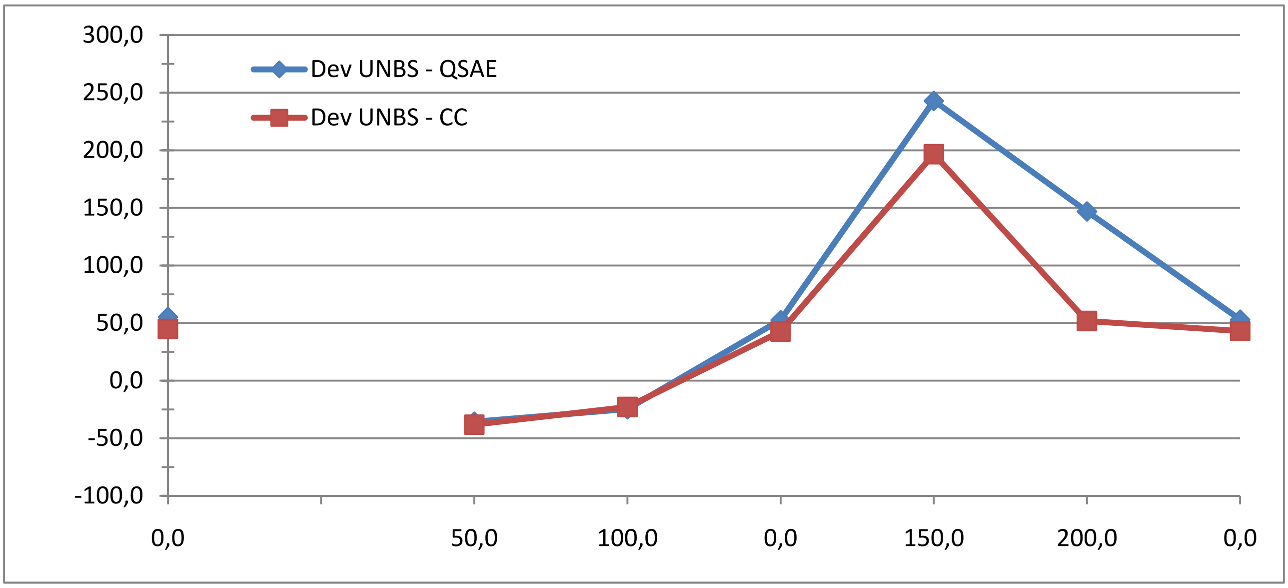
It is hardly to understand that the four three temperatures show an E_n – value close to zero while the next two temperatures are close to the ± 1,0 borderline.

Their estimation of uncertainty in the budget is far below their BMC. It is not allowed for a DKD-accredit lab to give uncertainties in the certificate below BMC!

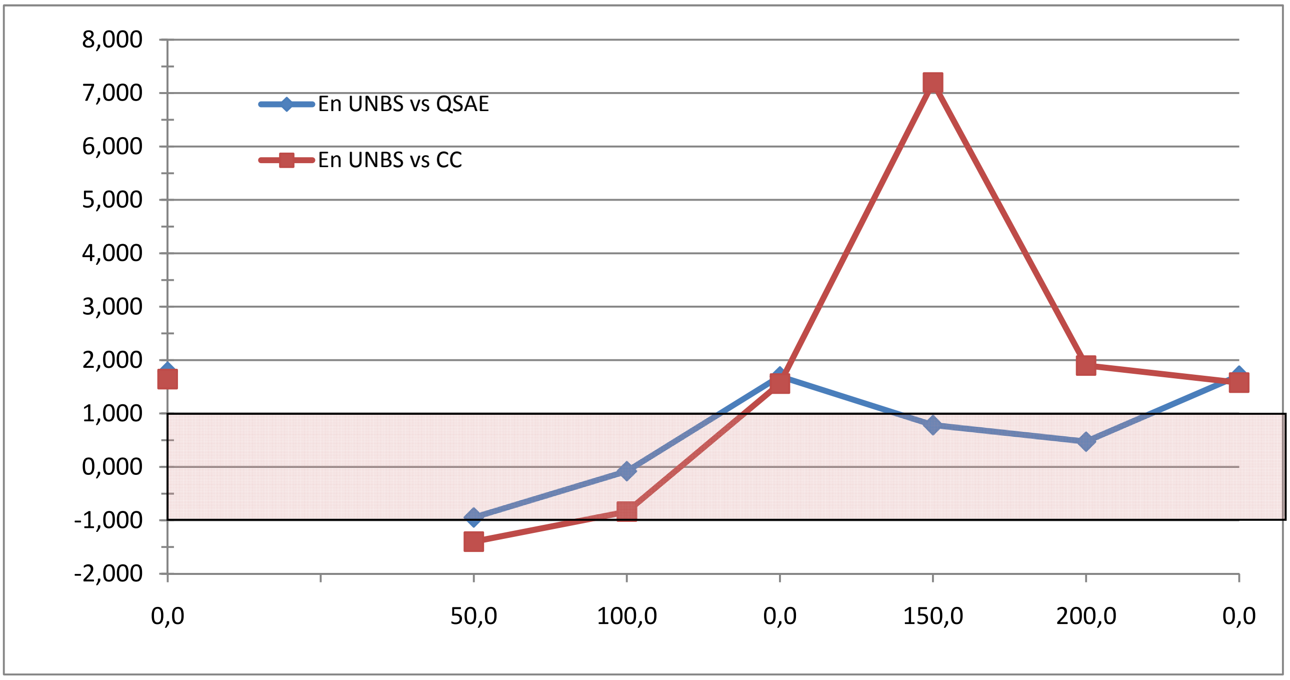
Nevertheless, the consultant took the BMC-figures into consideration. While doing this the E_n-values are just inside the ± 1,0 borderline.

4.4 UNBS, Kampala, Uganda

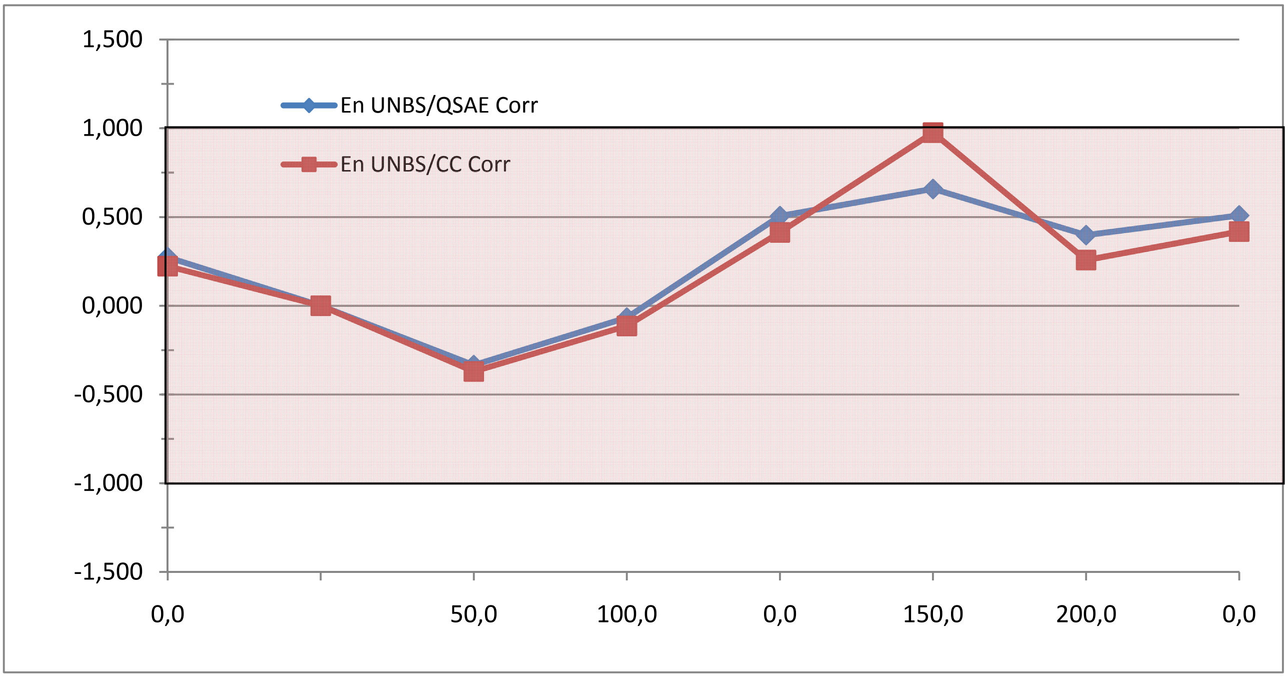
4.4.1 Fig. 10: Deviation Values in °C versus Temperature in °C



4.4.2 Fig 11: E_n - Values versus Temperature in °C



4.4.3 Fig 12: E_n - Values versus Temperature in °C, corrected to uncertainty = 200 mK



4.4.4 Comments

The graphic of the absolute results as per table 13 above looks not so bad. The trend is quite comparable as of QSAE.

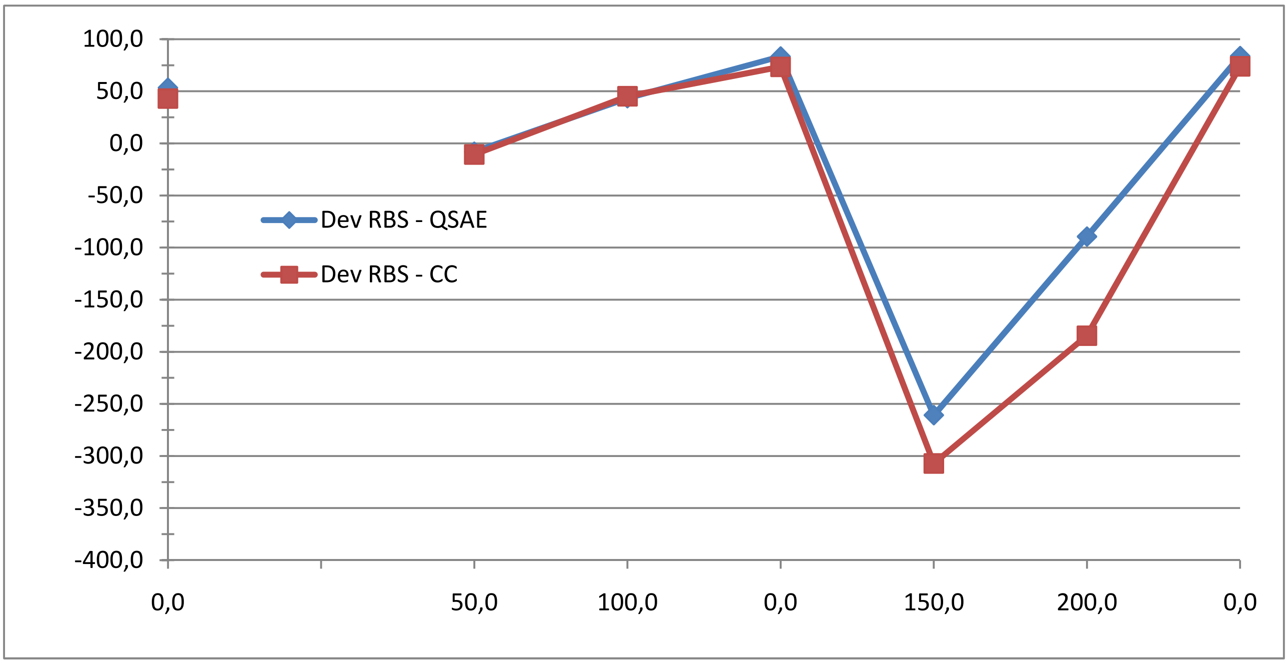
It seems to the consultant, that there might be some little deficiencies in handling and/or calibration procedures or they misinterpreted the routines given by QSAE.

It is hard to understand why the upper temperatures are so far away from reference lab. The consultant assumes that the waiting time for stabilization of the tempering device was too short. Other effects like misconnecting the artifact (two/three-wire instead of four-wire) or mishandling/miscalibration of the used DMM are thinkable.

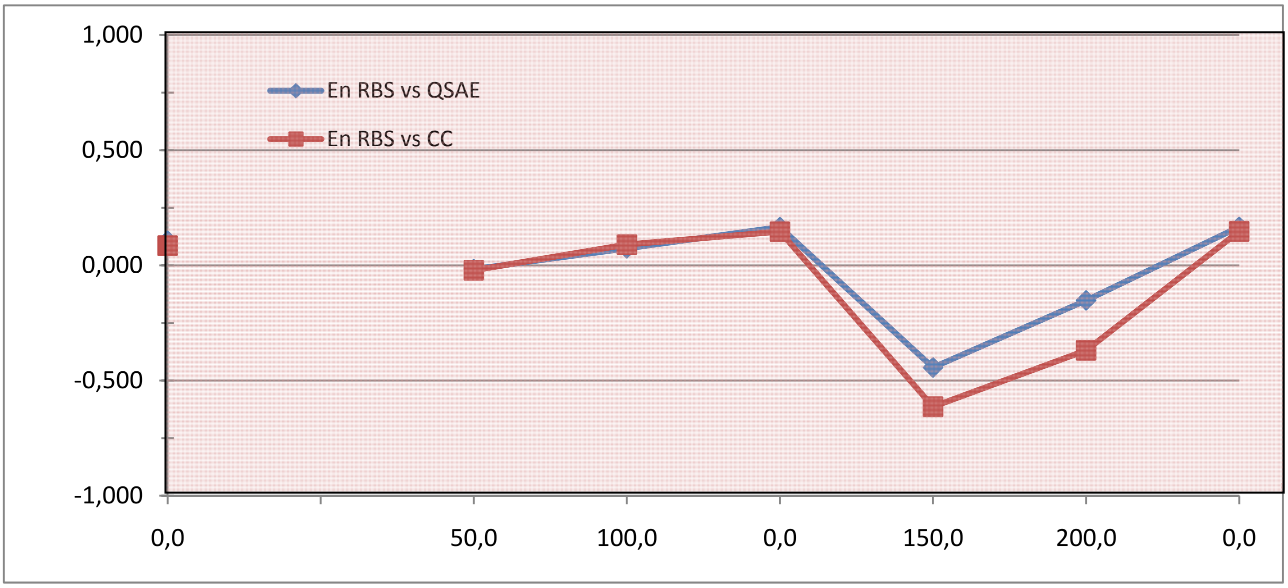
The consultant strongly recommends to review the calibration procedures.

4.5 RBS, Kigali, Rwanda

4.4.1 Fig. 13: Deviation Values in °C versus Temperature in °C



4.4.2 Fig. 14: E_n – Values versus Temperature in °C



4.4.5 Comments

The graphic of the deviation values above look quite good. The trend is close to QSAE and CC. The down peak at 150 and 200 °C is hard to understand. It seems to the consultant, that there are some deficiencies in handling, hardware and calibration procedures.

It seems on the other hand, that the estimation of the uncertainty is a little bit too conservative. Some more progressive estimation of accompanying parameters may lead to better results.

The results show a good degree of professionalism in performing calibrations. On the other hand, the given deviation value at 150 and 200 °C is not understandable. An unexpected high heat dissipation may be one possible declaration of that fact. Some investigations at RBS may clarify this circumstances.

5. FINAL CONCLUSION

It has to be mentioned that the consultant sees some points where difficulties appeared:

The direct and fast communication within the participating labs needs no further improvement.

Transportation of the artifacts from one lab to the next might cause problems.

The tracebility status of the instruments used in the labs should be clear.

The given uncertainty budgets seen overall are quite o.k., but some need to be more realistic.

The calibration procedures seen overall are quite o.k.

In general, the results under the above and the premise of the second EAC-IC are truly very satisfactionary. Most of them are acceptable; partly some "fine tuning" is needed. But all labs did a professional work and demonstrated a very high degree of engagement.

The initial sense while choosing industrial platinum thermometers (IPRT's) for the second EAC-IC was to get a better appraisal of capabilities from the participating labs. Beside the rather high robustness the calibration is quite easy and might be a part of the daily or future work.

The next EAC-IC will be done with two times two thermocouples (TC's) type N (NiCrSi vs. NiSi). The TC's are in the accuracy class 1 according to IEC 584. Due to the basically high robustness handling and transportation will be much easier.

The consultant provides the two pairs of calibrated artifacts as well as detailed calibration procedures. See appendix 3 of this report.

The pilot lab will be TBS Tanzania Bureau of Standards in Dar Es Salaam, Tanzania.

Head of temperature lab: Ingram Kisamo ijkisamo@yahoo.com

Most likely, based on the experiences of the actual finished EAC-IC the next IC will provide better results and a further step onward in terms of personnel skills, lab procedures, uncertainty budget and communication.

Werne (Germany) July 15, 2009

R. Klemm, Consultant

APPENDIX 1: 3rd EAC-IC with Thermocouples Uncertainty - Budged

Analysis of measurement uncertainty in calibration of thermocouples type N

The following analysis for the comparative calibration of a TC type N is given as an example for the determination of measurement uncertainty. It must be clearly stated, that this document is a guideline rather than a "cooking book". Special circumstances like measurement ensemble, available hardware equipment, ambient conditions, personnel, …….. have to be taken in consideration while estimating the individual uncertainty budget.

The TC's in this particular ring comparison (EAC - Interlab Comparison **->** EAC - IC) were originally calibrated with an immersion depth of approx. 500 mm a in a horizontal tube-type furnace. After its return to Germany recalibration will be done at the same immersion depth in the same furnace. In any case, it is useful to spend some words into the evaluation of a measurement uncertainty budget. Basically, only four steps are to be done in a systematical order as following:

1st step: Estimation of the uncertainty associated with the temperature of the tempering device.

2nd step: Estimation of the uncertainty associated with the artifact under test

3rd step: Combination of the different uncertainties and parameters

4th step: Result of the calibration together with uncertainty, probability level & expansion factor.

It is strongly recommended to do the a.m. steps in a tabular form - either by hand on paper or (better) in a PC - based worksheets - i.e. Microsoft® EXCEL® or equivalent.

An example for an uncertainty budget is given on the next two pages. It describes a calibration using the comparison method between a standard TC type S (Pt10%Rh vs. Pt) and the artifact type N (NiCrSi vs. NiSi). Please keep in mind, that it is an example only! All figures need to be adjusted to the capabilities and hardware of the participating labs.

1st step: Estimation of the uncertainty associated with the temperature of the tempering device

Determination of "true" temperature in the tempering device

Standard - TC: Type S

$t_x = t_S (Vi_S + C_S \cdot \delta V_{iS1} + C_S \cdot \delta V_{iS2} + C_S \cdot \delta V_R - C_S / C_{SO} \cdot \delta t_{0S} + \delta t_D + \delta t_F + \delta_{WA})$

Dimension	Item	Estimate	UOM	Uncert.	UOM	Distribution	Divisor	Sensit.	UOM	u_i (t)	UOM	$(u_i (t))^2$
t_S	Temperature of normal TC	500	°C	0,50	K	normal	2	1,000	1	0,250	K	0,062500
δV_{iS1}	Correction: Uncertainty Of DMM		---	3,00	µV	normal	2	0,101	K/µV	0,151	K	0,022946
δV_{iS2}	Correction: Resolution of DMM		---	0,02	µV	rectangular	1,732	0,101	K/µV	0,001	K	0,000001
δV_R	Correction: Multipoint switch		---	1,00	µV	rectangular	1,732	0,101	K/µV	0,058	K	0,003399
δt_{0S}	Correction: CJC of normal TC		---	0,05	K	rectangular	1,732	2,70	µV/K	0,078	K	0,006096
δ_{WA}	Correction: Heat dissipation of the normal TC		---	0,20	K	rectangular	1,732	1,000	1	0,115	K	0,013333
δ_{tD}	Correction: Drift of normal TC		---	0,10	K	rectangular	1,732	1,000	1	0,058	K	0,003333
δ_{tF}	Correction: Profile of the heat source		---	0,20	K	rectangular	1,732	1,000	1	0,115	K	0,013333
t_X	Temperature of furnace ts +/- u_i(t)	500	°C							0,353	K	

Numeric values given either by certificate or best available estimation are to be inserted into the green column named “Uncert.”
The sensitivity has to be calculated in accordance to the UOM (Units Of Measure **->** mK, °C, mΩ or ......) given by uncertainty’s UOM.

5.2 Determination of uncertainty of artifact at measuring temperature

Artifact: **Type** **N** Max. Meas - Temp. **1300 °C**

$V_x = V_{iX} + \delta V_{iX1} + \delta V_{iX2} + \delta V_R + \delta V_{LX} + \Delta t_{CX} - \delta t_{OX} / C_{XO} + \delta_{WA}$

Dimension	Item	Estimate	UOM	Uncert.	UOM	Distribution	Divisor	Sensit.	UOM	u_i (t)	UOM	$(u_i (t))^2$
X_i	Measure of artifact at temperature t_s	16747,86	µV	0,35	K	normal	1	38,28	µV/K	13,531	µV	183,079147
δV_{iX1}	Correction: Uncertainty of µV-used indicator (DMM or equiv.)			16,00	µV	normal	2	1	1	8,000	µV	64,000000
δV_{iX2}	Correction: resolution of used µV-indicator			5,00	µV	rectangular	1,732	1	1	2,887	µV	8,333333
δV_R	Correction: Multipoint switch			0,00	µV	rectangular	1,732	1	1	0,000	µV	0,000000
δV_{LX}	Correction for ext. /comp. Cable			1,00	µV	rectangular	1,732	1	1	0,577	µV	0,333333
δ_{WA}	Correction: Heat dissipation artifact			0,50	K	rectangular	1,732	38,28	µV/K	11,050	µV	122,108426
δ_{Hom}	Correction: Inhomogenities			0,10	K	normal	2	38,28	µV/K	1,914	µV	3,663253
δt_{OX}	Correction: CJC of artifact			0,50	K	rectangular	1,732	12,97	µV/K	3,744	µV	14,015448
V_X	Thermal EMF V_x of artifact at furnace temperature +/- u_i(t)	16747,86	µV							19,888	µV	

5.3 **Table of result**

BMC in K	BMC in K	u_i (t)	UOM	Exp.F. k	Expanded uncert.	UOM	Type N	UOM
Noblem.???	Basem.???	19,89	µV	2	39,78	µV	1,03	K

Purple column: Result = This is the expanded uncertainty with an expansion factor **k = 2 → probability level ~ 95 %**
Yellow column: Best measurement capability of the participating lab.

4th step: Result of the calibration together with uncertainty, probability level & expansion factor

In the 4th and final step the complete measuring result is stated for the calibration certificate. It should be given in the following form:

At the calibration temperature of XX,XX °C, the reduced correction C_R for the thermometer [Serial Number] is

$$C_R = (X,XX \pm \text{uncertainty})\ °C$$

Denoted is the expanded uncertainty, which is calculated from the standard uncertainty by multiplication with the expansion factor k = 2.

This is equivalent to a normal distribution with a probability level of approx. 95 %.

The calibration was done in the a.m. sequence and temperature range. To achieve the stability of the instrument, the indicated temperature range should in no case over- or under stepped. The uncertainty given is calculated at the time and under the procedures of the calibration stated in this document. It contains no fractions for the long term stability.

Addendum 1:

Here following are some recommendations and / or guidelines for a realistic estimation of the particular uncertainties to be inserted into the a.m. tables or equitation. Please keep in mind, that each laboratory has its own "specialties", personnel, equipment and experiences. Therefore a global valid algorithm for the calculation of uncertainty is basically impossible. But some points of interest may be valid to put the focus onto:

Calibrated SPRT's mostly have an uncertainty of 3 .... 5 mK including k = 2
Normal distribution may be estimated **->** $u(t_N)$ is in the range of 1,5 to 2,5 K *

Uncertainties of the electric measuring equipment (DMM's, drift, ...) used for CJC-calculations may be estimated to be in sum 50 to 150 mk and rectangular distributed
→ 50 mK / SQRT 3 = 29 mK; → **1**50 mK / SQRT 3 = 87 mK *

Uncertainty due to the inhomogeniety of the low-temperature liquid bath without any equalizing block or other facilities may be estimated to be at best not lower than 10 mK and rectangular distributed → 10 mK / SQRT 3 = 5,9 mK *

Uncertainty due to the stability of the high temperature liquid bath without any equalizing block or other facilities may be estimated to be at best not lower than 15 mK and rectangular distributed
→ 15 mK / SQRT 3 = 8,7 mK *

Uncertainty due to the inhomogeniety of a dry-block calibrator with equalizing block or other facilities may be estimated to be at best not lower than 150 mK and rectangular distributed
→ 150 mK / SQRT 3 = 87 mK *

Uncertainty due to the stability of the liquid bath without any equalizing block or other facilities may be estimated to be at best not lower than 50 mK and rectangular distributed
→ 50 mK / SQRT 3 = 29 mK *

Uncertainty due to the inhomogeniety of a horizontal tube-type furnace with equalizing block or other facilities may be estimated to be at best not lower than 250 mK and rectangular distributed
→ 250 mK / SQRT 3 = 145 mK *

Uncertainty of a Precision Standard Thermocouple Type S (Pt10%Rh-Pt) or R (Pt13%Rh-Pz) calibrated at freezing-points of the ITS 90 may be estimated to be at best not lower than 500 mK and normal distributed → 500 / 2 = 250 mK *

*All above mentioned parameters may be even better depending on the hardware used. Uncertainties based on calibration certificates are in most cases normal distributed → divisor = 2 instead of SQRT 3

The ice-point may be realized by using demineralized water in a quite clean ambient. It is known from earlier experiments that the temperature while using this procedure differs from 0 °C by approx. -5 to -10 mK If it is not possible to follow a.m. procedure (trap water, no stainless container, no latex gloves, dusty environment, ...) the deviation may be higher by factor 2 to 3. The uncertainty is estimated to be in the range of 3 to 17 mK (rectangular distribution).
Please keep in mind that the sensitivity of a type N at 0 °C is only 39 mK per µV or 26 µV per K Even 30 mK/SQRT 3 = 17 mK gives a nearly invisible impact on the total result of uncertainty.

Every laboratory is an individual with its individual equipment, routines, personnel, environment etc. and, of course, individual requirements of its customers.
The purpose of this document is to give a common valid recommendation for the estimation of uncertainty in measurement with TC's.

It is not in the status of a directive.

It shall guide every laboratory to investigate its own capabilities - for the customer's benefits.
The calibration certificates which came back to Germany are o.k. The informations therein are basically satisfactionary from our side of view.

Conclusion

The success of this intercomparison provides a motivation to organize a regional comparison to compare the BMC's of the labs over a wider range. Industrial mineral insulated metal sheathed TC's may be best suitable to be a travelling thermometer (they are even more robust than IPRT's and can generally be used over a much wider temperature range). It is important to note that PTB together with TBS and CC has organized a workshop for all participating labs before we embark on the third intercomparison. This will enable the labs own the document as well as harmonize the measurement procedures.

APPENDIX 2: 3rd EAC-IC with Type N TCs

A. Artifacts:

Four off MI-TC's type N with 3 mm sheath diameter by 500 mm immersion length.

a) Two TCs are furnished with firmly connected extension cable type N in 2 m length. A proper kind of cool joint compensation for using in an ice-bath, dry-block calibrator, water-triple-point-cell or equivalent must be added by each lab.
b) Two TCs are furnished with a Pt 100 in class A in the transition sleeve and a firmly connected extension 6-conductor copper cable with 2 m in length. This construction acts as a proper kind of cool joint compensation. Four conductors are used for the measuring resistor; two are for the thermal EMF.

Tables and polynomial calculation for the TCs according to item a above: IEC 584 (EN 60584)

Tables for the TCs according to item b above are added as appendix 3.

The artifacts are of a rather rugged construction. Therefore transport from lab to lab by a parcel service (UPS, FedEx or whatever is available) or post-parcel is not a problem if proper packed. For reliability, the shipping in two different parcels is strongly recommended.

CAUTION: Although the artifacts are MI-TC's, bending is truly possible but not desired. Especially 20 mm starting at the tip and the first 50 mm downwards the transition sleeve may be in no case bended. The transition sleeve is **not** a handle!

B. Minimum immersion depth

For MI-TC's the min. required immersion depth is 50 times outer diameter **->**50 * 3mm = 150 mm
An immersion depth of 160 mm is recommended, the max. depth may not exceed 500 mm

C. Incoming procedure

Upon receipt of the artifacts an annealing procedure as following has to be done by **every** of the participating laboratories:

1. Measuring at a stable temperature - for example 250 °C or what is in the capability of the lab. The temperature level is not critical - only stability is important
2. Ramp of 100 to 150 K/h up to 550 °C
3. Soak for min. 2 hours, max. 5 h at 550 °C
4. Switch off the furnace and cool down with inserted TCs
5. Measuring at a stable temperature - see item 1.
6. Repeat steps 2 to 5 until stability is achieved

The comparison of values as per item 1 and 5 above shows any damage occurred during transport, comparison of values as per item 5 and 9 above shows the 1st figure for stability. Repeat steps 6 to 9 until stability is inside the estimated uncertainty of each laboratory - but not more than 3 times. Take the final value for the further calibration steps.

D. Measuring Sequence

The measuring sequence for each of the two different constructed TC's is as following:

1. Measuring at a stable temperature – for example 250 °C or what is in the capability of the lab. The temperature level is not critical – only stability is important. This value may be taken from the sequence C above
2. Start at 100 °C
3. Next step 200 °C followed by 300 °C, 400 °C and 500 °C. The highest temperature should not exceed 550 °C.
4. If a lab is due to its hardware not able to able to reach 500 °C than finish sequence at the highest possible temperature. In that case steps in 50 °c are recommended.
5. Slowly cool down room to temperature
6. Same as step 1 above
7. Repeat steps 2 to 6
8. Result is the averaged value in each step from the two sequences.

E. Report and calibration certificate

Please provide any written report or comment in form of a Word® document, any table with values in form of an Excel® worksheet and the certificate in form of a PDF-document or JPG-picture.
The report of results from any lab is requested with following documentation:

1. Initial and final value as per item C above.
2. Values as per Item D above in the order mentioned.
3. Complete traceable calibration certificates for any of the instruments used.
4. Complete and detailed description of the calibration procedure used, hardware included. Parts and/or chapters from the working instruction(s) included in the QMS may be added for information – if available in English language.
5. Complete and detailed uncertainty budget similar to the guide as per appendix 1. Estimated values on the base of best available knowledge, experience and/or former measurements
6. Calibration certificate

The queue or circulation order will be stated by the pilot lab. Every lab is requested to do its measurement in a reasonable amount of time. The max. timeframe for each lab is given by the pilot lab. All participating labs are asked to take care, that the complete cycle may be finished by latest February 2010 to make sure that the workshop for presentation of results could take place in roughly one year from now.

The last lab in the queue (TBS) please returns the artifacts to one of the following the addresses.

Physikalisch Technische Bundesanstalt PTB
Attn. Mr. Tobias Diergardt
Q.52 Technical Cooperation
Bundesallee 100
D – 38116 Braunschweig / Germany

Alternatively send to:

CENTROCAL GmbH
Attn. Reinhard Klemm
Managing Director
Lohstrasse 2
D – 59368 Werne / Germany

Each lab please sends all the a.m. paperwork as a sampler per mail to following addresses:

Tanzania Bureau of Standards, Mr. Alphonce M. Kagoma or his substitute, as the pilot lab:

silikag@yhoo.com or alphonce.kagoma@tbstz.org

TBS is asked to prepare the final report and send it per mail to:

tobias.diergrath@ptb.de **and** reinhard.klemm@centrocal.de

or alternatively in paper, CD, USB-stick or equivalent to the postal addresses as mentioned abhove.

We thank you very much for your cooperation!

APPENDIX 3: Tables for use with the TC including CJC in the transition sleeve.

Table 1: Resistance in Ohm to temperature in °C for Pt 100/0

Ω to °C Pt 100	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
100	0,00	0,26	0,51	0,77	1,02	1,28	1,54	1,79	2,05	2,30
101	2,56	2,82	3,07	3,33	3,58	3,84	4,10	4,35	4,61	4,86
102	5,12	5,38	5,63	5,89	6,15	6,40	6,66	6,92	7,17	7,43
103	7,68	7,94	8,20	8,45	8,71	8,97	9,22	9,48	9,74	9,99
104	10,25	10,51	10,76	11,02	11,28	11,53	11,79	12,05	12,30	12,56
105	12,82	13,07	13,33	13,59	13,85	14,10	14,36	14,62	14,87	15,13
106	15,39	15,64	15,90	16,16	16,42	16,67	16,93	17,19	17,44	17,70
107	17,96	18,22	18,47	18,73	18,99	19,24	19,50	19,76	20,02	20,27
108	20,53	20,79	21,05	21,30	21,56	21,82	22,08	22,33	22,59	22,85
109	23,11	23,36	23,62	23,88	24,14	24,40	24,65	24,91	25,17	25,43
110	25,68	25,94	26,20	26,46	26,72	26,97	27,23	27,49	27,75	28,01
111	28,26	28,52	28,78	29,04	29,30	29,55	29,81	30,07	30,33	30,59
112	30,84	31,10	31,36	31,62	31,88	32,14	32,39	32,65	32,91	33,17
113	33,43	33,69	33,94	34,20	34,46	34,72	34,98	35,24	35,50	35,75
114	36,01	36,27	36,53	36,79	37,05	37,31	37,56	37,82	38,08	38,34
115	38,60	38,86	39,12	39,38	39,64	39,89	40,15	40,41	40,67	40,93
116	41,19	41,45	41,71	41,97	42,23	42,48	42,74	43,00	43,26	43,52
117	43,78	44,04	44,30	44,56	44,82	45,08	45,34	45,60	45,85	46,11
118	46,37	46,63	46,89	47,15	47,41	47,67	47,93	48,19	48,45	48,71
119	48,97	49,23	49,49	49,75	50,01	50,27	50,53	50,79	51,05	51,31
120	51,57	51,83	52,09	52,35	52,61	52,87	53,13	53,39	53,65	53,91
121	54,17	54,43	54,69	54,95	55,21	55,47	55,73	55,99	56,25	56,51
122	56,77	57,03	57,29	57,55	57,81	58,07	58,33	58,59	58,85	59,11
123	59,37	59,63	59,89	60,15	60,41	60,67	60,93	61,19	61,45	61,71
124	61,98	62,24	62,50	62,76	63,02	63,28	63,54	63,80	64,06	64,32
125	64,58	64,84	65,10	65,37	65,63	65,89	66,15	66,41	66,67	66,93
126	67,19	67,45	67,71	67,98	68,24	68,50	68,76	69,02	69,28	69,54
127	69,80	70,06	70,33	70,59	70,85	71,11	71,37	71,63	71,89	72,16
128	72,42	72,68	72,94	73,20	73,46	73,72	73,99	74,25	74,51	74,77
129	75,03	75,29	75,56	75,82	76,08	76,34	76,60	76,87	77,13	77,39
130	77,65	77,91	78,17	78,44	78,70	78,96	79,22	79,48	79,75	80,01

Table 2: Resistance in Ohm (Pt 100/0) to EMF in µV for a TC type N										
Ω to µV Type N	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
100	0,0	6,6	13,3	19,9	26,6	33,2	39,9	46,5	53,2	59,8
101	66,5	73,1	79,8	86,5	93,1	99,8	106,5	113,2	119,8	126,5
102	133,2	139,9	146,6	153,3	160,0	166,7	173,4	180,1	186,8	193,5
103	200,2	206,9	213,6	220,4	227,1	233,8	240,5	247,3	254,0	260,7
104	267,5	274,2	281,0	287,7	294,5	301,2	308,0	314,7	321,5	328,3
105	335,0	341,8	348,6	355,3	362,1	368,9	375,7	382,5	389,3	396,0
106	402,8	409,6	416,4	423,2	430,0	436,9	443,7	450,5	457,3	464,1
107	470,9	477,8	484,6	491,4	498,3	505,1	511,9	518,8	525,6	532,5
108	539,3	546,2	553,0	559,9	566,8	573,6	580,5	587,4	594,2	601,1
109	608,0	614,9	621,8	628,7	635,6	642,5	649,4	656,3	663,2	670,1
110	677,0	683,9	690,8	697,7	704,6	711,6	718,5	725,4	732,4	739,3
111	746,2	753,2	760,1	767,1	774,0	781,0	787,9	794,9	801,9	808,8
112	815,8	822,8	829,7	836,7	843,7	850,7	857,7	864,7	871,7	878,7
113	885,7	892,7	899,7	906,7	913,7	920,7	927,7	934,7	941,8	948,8
114	955,8	962,9	969,9	976,9	984,0	991,0	998,1	1005,1	1012,2	1019,2
115	1026,3	1033,4	1040,4	1047,5	1054,6	1061,6	1068,7	1075,8	1082,9	1090,0
116	1097,1	1104,2	1111,3	1118,4	1125,5	1132,6	1139,7	1146,8	1153,9	1161,0
117	1168,2	1175,3	1182,4	1189,5	1196,7	1203,8	1211,0	1218,1	1225,3	1232,4
118	1239,6	1246,7	1253,9	1261,0	1268,2	1275,4	1282,5	1289,7	1296,9	1304,1
119	1311,3	1318,5	1325,6	1332,8	1340,0	1347,2	1354,4	1361,6	1368,9	1376,1
120	1383,3	1390,5	1397,7	1405,0	1412,2	1419,4	1426,7	1433,9	1441,1	1448,4
121	1455,6	1462,9	1470,1	1477,4	1484,7	1491,9	1499,2	1506,5	1513,7	1521,0
122	1528,3	1535,6	1542,9	1550,1	1557,4	1564,7	1572,0	1579,3	1586,6	1594,0
123	1601,3	1608,6	1615,9	1623,2	1630,5	1637,9	1645,2	1652,5	1659,9	1667,2
124	1674,6	1681,9	1689,3	1696,6	1704,0	1711,3	1718,7	1726,1	1733,4	1740,8
125	1748,2	1755,6	1762,9	1770,3	1777,7	1785,1	1792,5	1799,9	1807,3	1814,7
126	1822,1	1829,5	1836,9	1844,4	1851,8	1859,2	1866,6	1874,1	1881,5	1888,9
127	1896,4	1903,8	1911,3	1918,7	1926,2	1933,6	1941,1	1948,6	1956,0	1963,5
128	1971,0	1978,4	1985,9	1993,4	2000,9	2008,4	2015,9	2023,4	2030,9	2038,4
129	2045,9	2053,4	2060,9	2068,4	2075,9	2083,5	2091,0	2098,5	2106,0	2113,6
130	2121,1	2128,6	2136,2	2143,7	2151,3	2158,8	2166,4	2174,0	2181,5	2189,1

Table 3: EMF in µV to temperature in °C, ref. Junction at 0 °C										
µV to °C Type N	**0,00**	**50,00**	**100,00**	**150,00**	**200,00**	**250,00**	**300,00**	**350,00**	**400,00**	**450,00**
2500	90,68	92,39	94,09	95,79	97,48	99,17	100,86	102,54	104,22	105,90
3000	107,57	109,24	110,90	112,57	114,23	115,88	117,54	119,19	120,83	122,47
3500	124,11	125,75	127,38	129,02	130,64	132,27	133,89	135,51	137,12	138,74
4000	140,35	141,95	143,56	145,16	146,76	148,35	149,94	151,53	153,12	154,71
4500	156,29	157,87	159,44	161,02	162,59	164,16	165,73	167,29	168,85	170,41
5000	171,97	173,52	175,08	176,63	178,17	179,72	181,26	182,80	184,34	185,88
5500	187,41	188,94	190,47	192,00	193,52	195,05	196,57	198,09	199,60	201,12
6000	202,63	204,14	205,65	207,16	208,66	210,17	211,67	213,17	214,67	216,16
6500	217,66	219,15	220,64	222,13	223,61	225,10	226,58	228,06	229,54	231,02
7000	232,50	233,97	235,44	236,92	238,39	239,85	241,32	242,79	244,25	245,71
7500	247,17	248,63	250,09	251,54	253,00	254,45	255,90	257,35	258,80	260,25
8000	261,70	263,14	264,58	266,02	267,46	268,90	270,34	271,78	273,21	274,65
8500	276,08	277,51	278,94	280,37	281,80	283,22	284,65	286,07	287,49	288,91
9000	290,33	291,75	293,17	294,59	296,00	297,42	298,83	300,24	301,65	303,06
9500	304,47	305,88	307,28	308,69	310,09	311,50	312,90	314,30	315,70	317,10
10000	318,50	319,89	321,29	322,68	324,08	325,47	326,86	328,25	329,64	331,03
10500	332,42	333,81	335,19	336,58	337,96	339,34	340,73	342,11	343,49	344,87
11000	346,25	347,63	349,00	350,38	351,75	353,13	354,50	355,87	357,24	358,62
11500	359,99	361,35	362,72	364,09	365,46	366,82	368,19	369,55	370,92	372,28
12000	373,64	375,00	376,36	377,72	379,08	380,44	381,79	383,15	384,51	385,86
12500	387,22	388,57	389,92	391,27	392,62	393,97	395,32	396,67	398,02	399,37
13000	400,72	402,06	403,41	404,75	406,10	407,44	408,78	410,13	411,47	412,81
13500	414,15	415,49	416,83	418,16	419,50	420,84	422,17	423,51	424,85	426,18
14000	427,51	428,85	430,18	431,51	432,84	434,17	435,50	436,83	438,16	439,49
14500	440,82	442,15	443,47	444,80	446,12	447,45	448,77	450,10	451,42	452,74
15000	454,07	455,39	456,71	458,03	459,35	460,67	461,99	463,31	464,63	465,94
15500	467,26	468,58	469,90	471,21	472,53	473,84	475,16	476,47	477,78	479,10
16000	480,41	481,72	483,03	484,34	485,66	486,97	488,28	489,59	490,89	492,20
16500	493,51	494,82	496,13	497,43	498,74	500,05	501,35	502,66	503,96	505,27
17000	506,57	507,88	509,18	510,49	511,79	513,09	514,39	515,70	517,00	518,30
17500	519,60	520,90	522,20	523,50	524,80	526,10	527,40	528,70	530,00	531,29
18000	532,59	533,89	535,19	536,48	537,78	539,08	540,37	541,67	542,96	544,26
18500	545,55	546,85	548,14	549,43	550,73	552,02	553,31	554,61	555,90	557,19
19000	558,48	559,77	561,07	562,36	563,65	564,94	566,23	567,52	568,81	570,09
19500	571,38	572,67	573,96	575,25	576,54	577,82	579,11	580,40	581,68	582,97
20000	584,25	585,54	586,82	588,11	589,39	590,68	591,96	593,24	594,52	595,81
20500	597,09	598,37	599,65	600,95	602,23	603,51	604,79	606,08	607,36	608,64
21000	609,92	611,21	612,49	613,77	615,05	616,33	617,61	618,89	620,17	621,45

How to use the a.m. tables:

a) Measure the resistance of the CJ-resistor inside the transition sleeve.
b) Go to table 1 to make sure that the temp. at the transition sleeve does not exceed 80 °C!
c) Measure the thermal EMF directly after step a.
d) Repeat step **a** & b and average the values.
e) Go with the averaged value of step **a** into table 2 and find the µV value. Intermediate values may be linear interpolated.
f) Add the µV-value of step **c** to the µV-value of step **e** .
g) Take the resulting µV-value of step **f** and go into table 3 and find the temperature in °C. Intermediate values may be linear interpolated.
h) Repeat steps above for each temperature level requested in **appendix 2 item D.**

Polynomial Coefficients for a Thermocouple Type N (NiCrSi-NiSi)

$$E = \sum_{i=0}^{i} A_i \, (t_{90})^i \qquad\qquad t_{90} = \sum_{i=0}^{i} A_i * E^i$$

Calculation:
Temperature [°C] to EMF [µV]
Range: - 210 °C to 0 °C
A(0) = 0
A(1) = 26.159105962
A(2) = 0.010957484228
A(3) = -0.000093841111554
A(4) = -4.6412039759E-08
A(5) = -2.6303367716E-09
A(6) = -2.2653438003E-11
A(7) = -7.6089300791E-14
A(8) = -9.3419667835E-17
Range: 0 °C to 1300 °C
B(0) = 0
B(1) = 25.929394601
B(2) = 0.01571014188
B(3) = 0.000043825627237
B(4) = -2.5261169794E-07
B(5) = 6.4311819339E-10
B(6) = -1.0063471519E-12
B(7) = 9.9745338992E-16
B(8) = -6.0863245607E-19
B(9) = 2.0849229339E-22
B(10) = -3.0682196151E-26

Calculation:
EMF [µV] to Temperature [°C]
Range: - 3990 µV to 0 µV
A(0) = 0
A(1) = 0.038436847
A(2) = 0.0000011010485
A(3) = 5.2229312E-09
A(4) = 7.2060525E-12
A(5) = 5.8488586E-15
A(6) = 2.7754916E-18
A(7) = 7.7075166E-22
A(8) = 1.1582665E-25
A(9) = 7.3138868E-30
Range: 0 µV to 20613 µV
B(0) = 0
B(1) = 0.0386896
B(2) = -0.00000108267
B(3) = 4.70205E-11
B(4) = -2.12169E-18
B(5) = -1.17272E-19
B(6) = 5.3928E-24
B(7) = -7.98156E-29
Range: 20613 µV to 47513 µV
C(0) = 19.72485
C(1) = 0.03300943
C(2) = -0.0000003915159
C(3) = 9.855391E-12
C(4) = -1.274371E-16
C(5) = 7.767022E-22
Uncertainty: +0,021 / -0,039 °C

The following table is a draft for an EXCEL® worksheet, which may be used to present the final results of the calibration.

Target Temp.	Actual Temp.	Measured value in µV	CJC in Ohm	CJC in °C	CJC in µV	Corrected µV due to CJC	Calculated Temp. in °C	Deviation in K Col.H-Col.B
250	249,52	7525	---	---	---	---.	247,90	-1,62
250	249,52	6985	109,785	25,130	662,12	7647,12	251,46	1,94

The headline from left to right gives the consecutive steps for the calibration.

The medium line reflects as an example the calibration of the type N TC’s with the firmly connected extension cable. The color of the cable is **pink**. Plus-pole is pink too while the minus-pole is white. This artifacts need a physical (ice-bath) or electronic cool-joint-compensation CJC.

The bottom line reflects as an example the calibration of the type N TC’s with the firmly connected copper cable and a Pt 100 element built-in into the transition sleeve. The color of the cable is **white**. Wiring is printed on the TAG-plate. These artifacts need no physical (ice-bath) cool-joint-compensation CJC. The built-in resistance element is used for CJC.

As mentioned in the workshop, all participating labs please send their results in a tabular form – i.e. in form of an EXCEL® worksheet (if there is any possibility). It makes live easier for both parties – TBS and Centrocal to perform the reports.

Thank you again for your cooperation and Good Luck