REPORT to the CCT on Comparison COOMET. T-K3
(COOMET theme No. 285/RU-a/03)
Final Report

REGIONAL COMPARISONS
OF THE NATIONAL STANDARDS OF TEMPERATURE
IN THE RANGE FROM THE TRIPLE POINT OF WATER
TO THE FREEZING TEMPERATURE OF ZINC

Prepared by

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1. Introduction

The decision about the necessity to perform regional comparisons within COOMET was taken after finishing key comparisons CCT-K3 and CCT-K4, which had been carried out under the direction of the Consultative Committee on Thermometry. Fourteen national metrology institutes joining the different metrological associations: EUROMET, COOMET, SIM took part in the comparisons.

Adoption of the international *Arrangement on Mutual Recognition of the National Standard, Calibration and Measurement Certificates Issued by the National Metrology Institutes*, which was signed by the majority of countries joining COOMET, was an incitement to perform regional comparisons within COOMET. The process of formation of the integrated international website on measurement capabilities of calibration of measuring instruments assumes confirmation of their claimed metrological characteristics on the basis of the results of regional comparisons and their link with the results of key comparisons.

Technical Committee TC1-10 took the decision about performance of regional comparisons of COOMET in 2001. The theme is "Comparison of the ITS-90 realizations in the range from 234.3156 K to 429.7485 ^{o}C", No. 227/RU/01, 229/UA/01, registration in the KCDB "COOMET.T-K3", supported CMC items: 1.1.1, 1.3.1, 1.3.2, 2.2.2, 2.3.1. During the COOMET TC1-10 meeting (Protocol of February 13, 2007) the name of the theme was corrected, the temperature range was changed, and the participants were specified. The new name of the theme reads "Regional comparisons of the national standards of temperature in the range from the triple point of water to the freezing point of zinc", No. 285/RU-a/03.

The purpose of regional key comparisons is dissemination of the metrological equivalence to the standards of the national metrology institutes, which did not participate in the BIPM key comparisons. The degree of equivalence of the measurement standard of the national metrology institutes participating in the regional comparisons is determined relative to the reference value of the BIPM key comparisons through the measurement results received in the linking national metrology institutes, which took part in both comparisons.

2. Organization of the comparisons

The general principles and the scheme of comparisons are presented in this Section. The details and procedures for these comparisons are given in the Technical Protocol in Appendix 1.

2.1. Participants of the comparisons

Four national metrology institutes (NMI's) took part in the COOMET regional comparisons:
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SMU – Slovak Institute of Metrology, Karloveska 63, 842 55 Bratislava, Slovakia
Phone: 42 17 60294277, fax: 42 17 65429592,
E-mail: duris@smu.gov.sk.
BelGIM – Belarusian State Institute for Metrology, 93, Starovilensky trakt, 220053, Minsk, Republic of Belarus
Phone: 375 117 2330421, fax: 375 17 2880938,
E-mail: coomet@belgim.by.
NNC IM – National Research Center "Institute for Metrology", 42, Mironositskaya str., 61002, Kharkov, Ukraine
Phone: 8 10 380 57 04 97 57, fax: 8 10 380 57 00 34 47,
E-mail: vsl@metrologia.kharkov.ua.

The two of four participants: VNIIM (RF) and SMU (Slovakia) also participated in the key comparisons K3 and K4. They play the role of linking institutes in the COOMET comparison to disseminate the metrological equivalence to the measurement standards of the NNC IM (Ukraine) and BelGIM (Republic of Belarus).
The pilot NMI and coordinator of the regional comparisons is VNIIM (RF).

2.2. Scheme of the comparisons

The Technical Protocol of comparisons, the forms of presentation of the measurement results and their uncertainties at the fixed points, the lists of the parameters for the cells and equipment applied were sent out to the participants of the comparisons. All the participants without any comments accepted the Technical Protocol and appendixes.

The scheme of the COOMET regional comparisons was chosen after the analysis of the schemes of the preceding key comparisons. The key comparisons K3, K4, K7 were performed according to different schemes and using different transfer standards. In the comparisons K3 the use was made of standard platinum resistance thermometers as transfer standards, while in the comparisons K4 and K7 the cells for realization of the main ITS-90 fixed points were applied. In the comparison K4 the transfer cell was compared to the cell of the national metrology institute using the apparatus of this national standard. One may say that the schemes of the comparisons K3 and K4 make it possible to estimate the temperature deviations of the fixed point realizations at the national institutes.

In the comparison K7 the transfer cells of all the participants of the comparison were brought to the BIPM laboratory and were compared with its two cells under the conditions of this laboratory without taking into account the peculiarities of the national realization procedures. The differences of temperatures reproduced by the cells under the same conditions were obtained. Since the variations of the procedures for realization of the triple point of water are insignificant in different laboratories, the discrepancies between reproduced temperature values depend mainly on isotopic composition and water purity in cells. One can accept that the obtained results correspond to the discrepancy of the realizations at the national institutes. However, this scheme of comparisons for the other fixed points cannot give us reliable results due to the differences in the procedures for their realization and the equipment applied.

Application of cells of the fixed points as transfer standards has a noticeable advantage because cells are much more stable than platinum resistance thermometers. However, this scheme is only possible if the dimensions of furnaces of all participants correspond to the overall dimensions of the cell. The standard equipment of the participants of the given comparison does not satisfy this condition. So, a decision was taken to perform the COOMET comparison in two stages.

At the first stage, which scheme is shown in Fig.1, the cells of fixed points of the national metrology institutes were used as transfer standards. They were compared with the VNIIM cells by means of standard platinum resistance thermometers using the VNIIM standard setups and equipment. Comparison of cells under similar conditions of realization of the fixed points makes it possible to estimate the influence of the impurities in metal on the results.

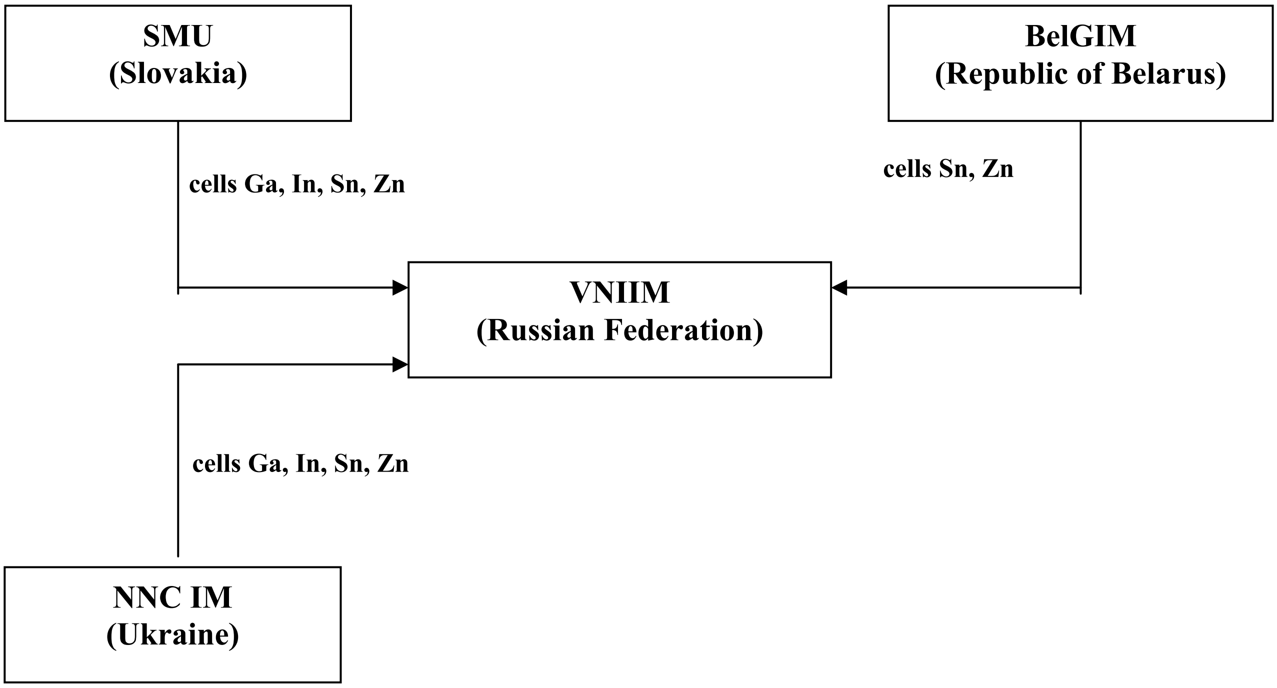

Figure 1. Scheme of the first stage of comparisons

At the second stage the equivalence of realization of the fixed points at the national institutes was estimated. Standard platinum resistance thermometer SPRT No. 25-02-03, manufactured at VNIIM, was used as a transfer standard. SPRT No. 25-02-03 was calibrated at VNIIM before the comparisons; its stability was controlled at VNIIM after making measurements at each NMI.

The equivalence of the standards and their link with the key comparisons CCT-K3 was established on the results of the second stage. Comparison of the results of the first and second stages makes it possible to come to a conclusion about the relationship between the basic uncertainty components: influence of impurities, procedure of realization and electrical measurements. The scheme of the second stage of the comparisons is shown in Fig.2.

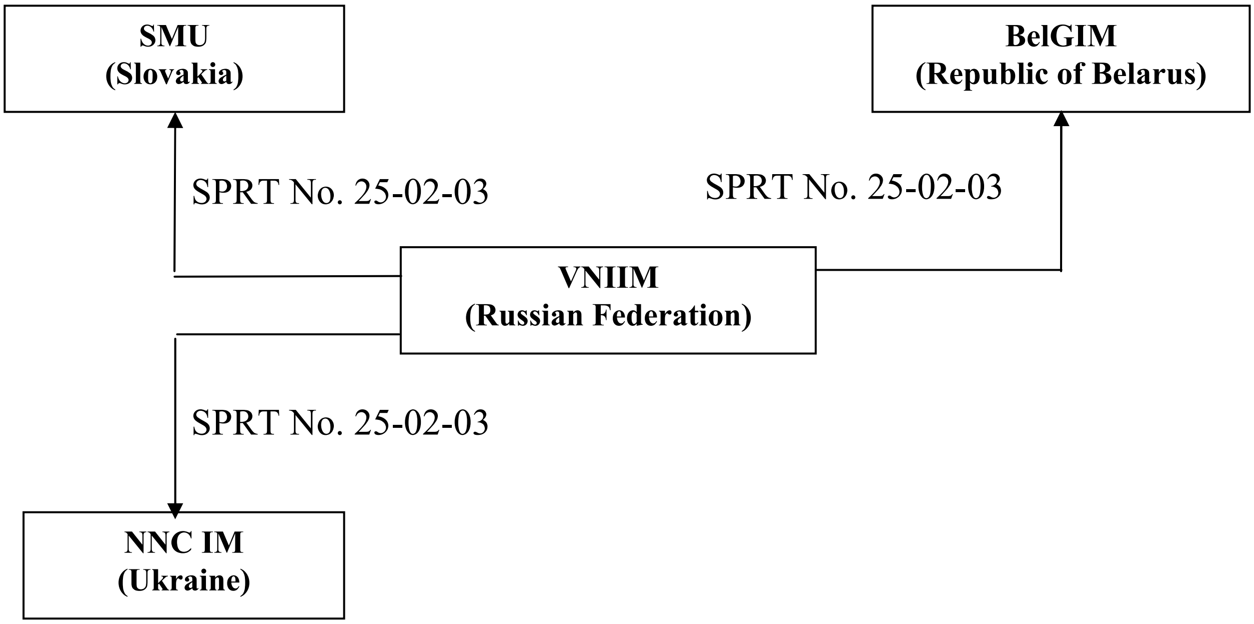

Figure 2. Scheme of the second stage of comparisons

2.3. Time schedule of the comparisons

The first stage of the comparisons of cells:
NNC IM – VNIIM July – August, 2005;
BelGIM – VNIIM August, 2005
SMU – VNIIM September – October, 2005.

The second stage of the comparisons:
SMU – March – April, 2006;
NNC IM – October – December, 2006;
BelGIM – February, 2007.

3. Results of the first stage of the comparisons

The cells of the fixed points of all the participants were compared with the corresponding VNIIM cells. The measurements were taken by means of two standard platinum resistance thermometers PRT No. 25-9-97 and PRT No. 25-00-04 using the measuring instruments and equipment of the State standard of temperature of the Russian Federation at VNIIM.

Each value of temperature difference between the cells was measuring during a day to avoid the influence of instability of the thermometers. Three measurement series were performed each time. The temperature difference was calculated using the following ratio:

$$\Delta T = (W_i - W_{VNIIM}) \cdot (\partial T/\partial W),$$

where $W = R_t/R_{TPW}$ is the relative resistance of the thermometer; R_t and R_{TPW} are the measurement results at the fixed point and the triple point of water, respectively; $(\partial T/\partial W)$ is the sensitivity coefficient specified in the ITS-90.

The uncertainty of the average temperature difference value between the cells $u_{\nabla t}$ was calculated as follows:

$$u^2_{\nabla t} = u_A^2 + 2\, u_B^2,$$

where u_A is the standard uncertainty (Type A) of the temperature difference; $u_B^2 = \sum u_{B\,i}^2$ is the sum of squares of the Type B components of the uncertainty budget of the fixed point of VNIIM (Appendix 3) except two components connected with metal purity and isotopic composition of water.

The uncertainty component $u_B(k=1)$ is equal to 0.024 mK, 0.034 mK, 0.035 mK and 0.085 mK for the points of Ga, In, Sn and Zn, respectively.

The results of the comparison of the cells, the average temperature difference values and the uncertainties of those values are presented in Tables 1 – 10.

3.1. Comparisons of cells for realization of the melting point of gallium

Table 1. Comparison results of the Ga cells of NNC IM and VNIIM

Thermometer number	*W* (Ga)		NNC IM – VNIIM		
	VNIIM	NNC IM	ΔT, mK	ΔTaver, mK	$u_{\nabla t}$.(k=2), mK
PRT 25-9-97	1.11810537	1.11810544	0.018		
	1.11810528	1.11810528	0.000	0.020	0.08
	1.11810530	1.11810547	0.043		

Table 2. Comparison results of the Ga cells of SMU and VNIIM

Thermometer number	*W* (Ga)		SMU - VNIIM		
	VNIIM	SMU	ΔT, mK	ΔTaver, mK	$u_{\nabla t}$.(k=2), mK
PRT 25-9-97	1.11810480	1.11810464	-0.040		
	1.11810478	1.11810483	0.013	-0.019	0.08
	1.11810492	1.11810480	-0.030		

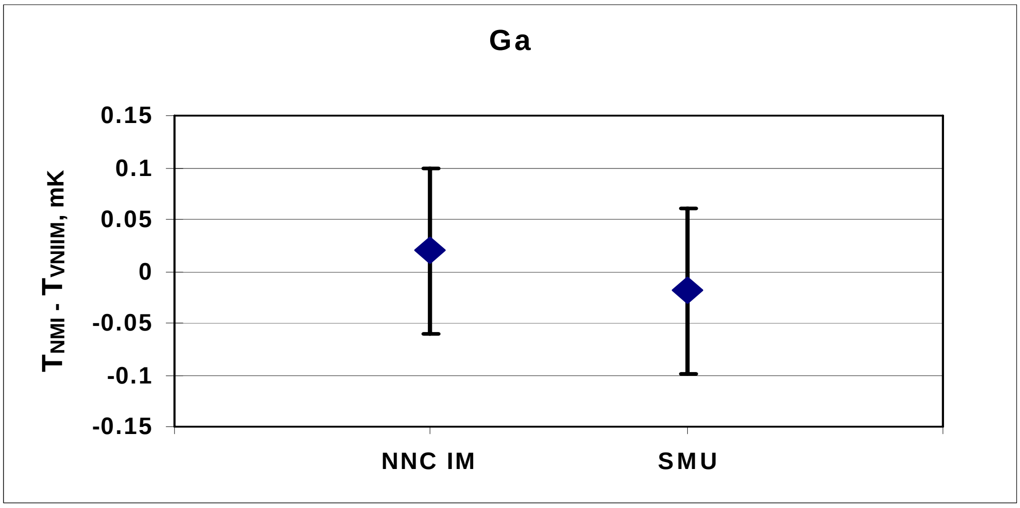

Figure 3. Comparison results of the Ga cells

3.2. Comparisons cells for realization of the freezing point of indium

Table 3. Comparison results of the In cells of NNC IM and VNIIM

Thermometer number	*W* (In)		NNC IM – VNIIM		
	VNIIM	NNC IM	Δ*T*, mK	Δ*T*aver, mK	$u_{\nabla t}$(*k*=2), mK
PRT 25-9-97	1.6096283	1.6096191	-2.421		
	1.6096276	1.6096186	-2.368	-2.447	0.21
	1.6096284	1.6096187	-2.553		

Table 4. Comparison results of the In cells of SMU and VNIIM

Thermometer number	*W* (In)		SMU - VNIIM		
	VNNIM	SMU	Δ*T*, mK	Δ*T*aver, mK	$u_{\nabla t}$(*k*=2), mK
PRT 25-9-97	1.6096271	1.6096266	-0.132		
	1.6096271	1.6096270	-0.026	-0.140	0.26
	1.6096278	1.6096268	-0.263		

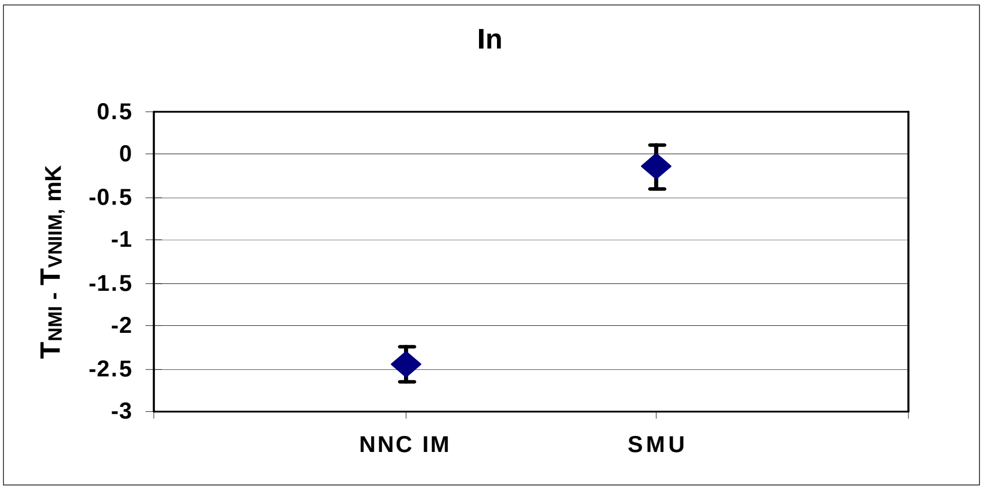

Figure 4. Comparison results of the In cells

3.3. Comparisons of cells for realization of the freezing point of tin

Table 5. Comparison results of the Sn cells of NNC IM and VNIIM

Thermometer number	*W* (Sn)		NNC IM – VNIIM		
	VNIIM	NNC IM	Δ*T*, mK	Δ*T*aver, mK	$u_{\nabla t}$.(*k*=2), mK
PRT 25-00-04	1.8924800	1.8924810	0.270		
	1.8924809	1.8924820	0.297	0.297	0.11
	1.8924796	1.8924808	0.324		

Table 6. Comparison results of the Sn cells of BelGIM and VNIIM

Thermometer number	*W* (Sn)		BelGIM - VNIIM		
	VNIIM	BelGIM	Δ*T*, mK	Δ*T*aver, mK	$u_{\nabla t}$.(*k*=2), mK
PRT 25-00-04	1.8924801	1.8924838	0.997		
	1.8924808	1.8924848	1.078	1.033	0.11
	1.8924811	1.8924849	1.024		

Table 7. Comparison results of the Sn cells of SMU and VNIIM

Thermometer number	*W* (Sn)		SMU - VNIIM		
	VNIIM	SMU	Δ*T*, mK	Δ*T*aver, mK	$u_{\nabla t}$.(*k*=2), mK
PRT 25-00-04	1.8924821	1.8924821	0.000		
	1.8924823	1.8924832	0.243	0.153	0.27
	1.8924810	1.8924818	0.216		

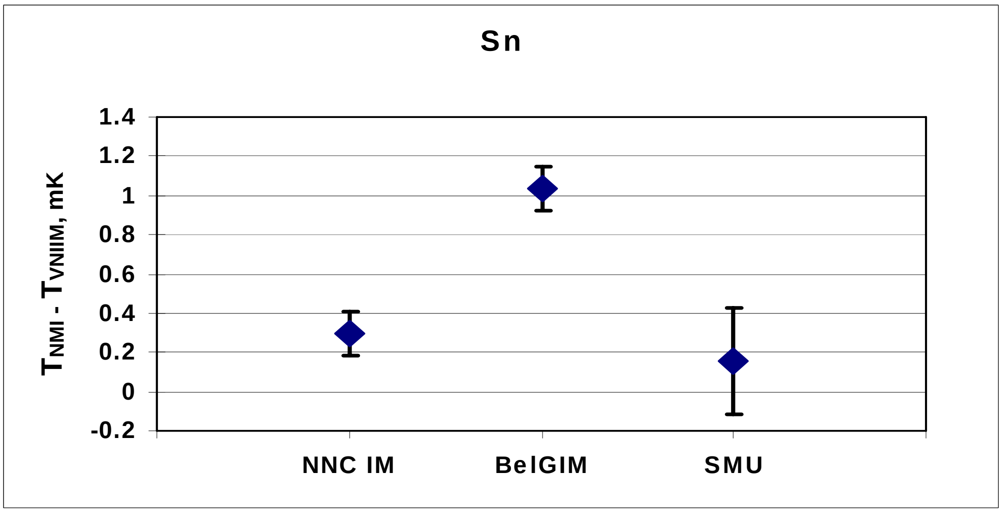

Figure 5. Comparison results of the Sn cells

3.4. Comparisons of cells for realization of the freezing point of zinc

Table 8. Comparison results of the Zn cells of NNC IM and VNIIM

Thermometer number	*W* (Zn)		NNC IM – VNIIM		
	VNIIM	NNC IM	Δ*T*, mK	Δ*T*aver, mK	$u_{\nabla t}$.(*k*=2), mK
PRT 25-00-04	2.5683539	2.5683534	-0.143		
	2.5683544	2.5683529	-0.428	-0.209	0.46
	2.5683546	2.5683544	-0.057		

Table 9. Comparison results of the Zn cells of BelGIM and VNIIM

Thermometer number	*W* (Zn)		BelGIM - VNIIM		
	VNIIM	BelGIM	Δ*T*, mK	Δ*T*aver, mK	$u_{\nabla t}$.(*k*=2), mK
PRT 25-00-04	2.5683545	2.5683505	-1.143		
	2.5683549	2.5683509	-1.143	-0.914	0.83
	2.5683534	2.5683518	-0.457		

Table 10. Comparison results of the Zn cells of SMU and VNIIM

Thermometer number	*W* (Zn)		SMU - VNIIM		
	VNIIM	SMU	Δ*T*, mK	Δ*T*aver, mK	$u_{\nabla t}$.(*k*=2), mK
PRT 25-00-04	2.5683546	2.5683539	-0.200		
	2.5683551	2.5683549	-0.057	-0.257	0.52
	2.5683554	2.5683536	-0.514		

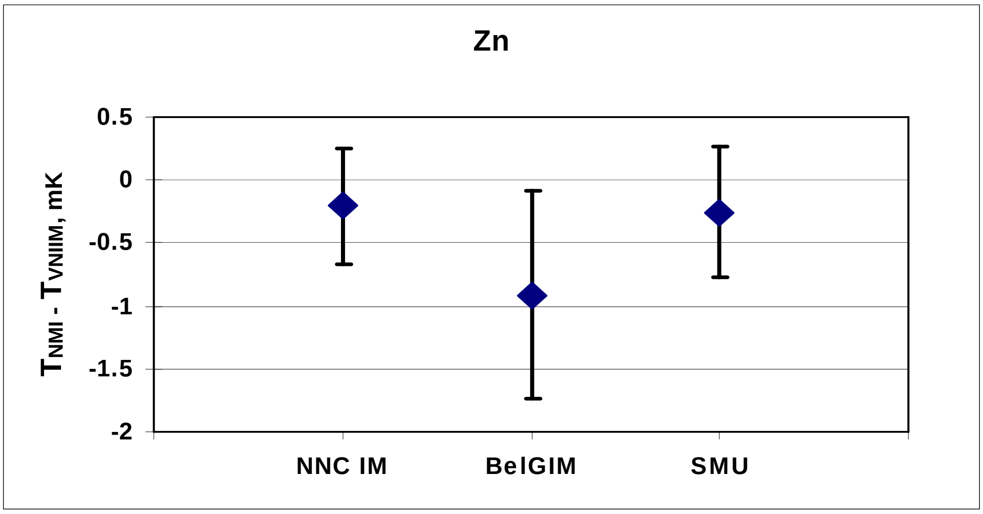

Figure 6. Comparison results of the Zn cells

4. Results of the second stage of the comparisons

4.1. Results of the comparisons of the fixed points realizations of the national metrology institutes

The fixed point temperature values of the national metrology institutes participating in the comparisons were measured by means of a transfer standard – platinum resistance thermometer SPRT No. 25-02-03. The measurement results W_i, their uncertainties $U(W_i)(k=1)$, presented by the institutes, differences $\Delta W_i = (W_{NMI} - W_{VNIIM})$, and corresponding differences $\Delta T = (T_{NMI} - T_{VNIIM})$ are shown in Tables 11 – 14.

NNC IM withdrew its measurement results of the second stage of comparisons (the e-mail of September 19, 2007).

The present Draft B Report presents the results of the second stage of the three participants: VNIIM, SMU and BelGIM.

Table 11. Differences in realizations of the Ga melting point at the national institutes

NMI	W_{Ga}	$U(W_{Ga})$ mK	$W_{NMI} - W_{VNIIM}$	$T_{NMI} - T_{VNIIM}$ mK
VNIIM	1.118 108 03	0.06	0	0
SMU	1.118 108 19	0.12	0.000 000 16	0.040

Table 12. Differences in realizations of the In freezing point at the national institutes

NMI	W_{In}	$U(W_{In})$ mK	$W_{NMI} - W_{VNIIM}$	$T_{NMI} - T_{VNIIM}$ mK
VNIIM	1.609 678 87	0.17	0	0
SMU	1.609 678 46	0.46	-0.000 000 41	- 0.108

Table 13. Differences in realizations of the Sn freezing point at the national institutes

NMI	W_{Sn}	$U(W_{Sn})$ mK	$W_{NMI}-W_{VNIIM}$	$T_{NMI}-T_{VNIIM}$ mK
VNIIM	1.892 601 03	0.24	0	0
SMU	1.892 601 66	0.42	0.000 000 63	0.170
BelGIM	1.892 601 26	0.47	0.000 000 23	0.062

Table 14. Differences in realizations of the Zn freezing point at the national institutes

NMI	W_{Zn}	$U(W_{Zn})$ mK	$W_{NMI}-W_{VNIIM}$	$T_{NMI}-T_{VNIIM}$ mK
VNIIM	2.568 544 72	0.28	0	0
SMU	2.568 543 45	0.40	- 0.000 001 27	- 0.363
BelGIM	2.568 543 40	0.54	-0.000 001 32	- 0.377

4.2. Estimation of the stability of the transfer SPRT No. 25-02-03

The estimation of the uncertainty of measurement result due to instability of the transfer SPRT No.25-02-03, u_{PRT}(k=1), was calculated using the assumption of a rectangular not symmetrical distribution of the thermometer resistance drift :

$$u_{PRT} = [(W_{VNIIM})_{end} - (W_{VNIIM})_{begin}]*(\partial T/\partial W)*1/\sqrt{3}$$

Table 15. Stability of the transfer SPRT No.25-02-03 and the associated uncertainty

Fixed point	$(W_{VNIIM})_{begin}$	$(W_{VNIIM})_{end}$	$(W_{VNIIM})_{end} - (W_{VNIIM})_{begin}$	ΔT, mK	u_{PRT} mK (k=1)
Ga	1.11810814	1.11810789	0.00000025	0.06	0.04
In	1.60967923	1.60967842	0.00000081	0.21	0.12
Sn	1.89260211	1.89260105	0.00000106	0.28	0.16
Zn	2.56854543	2.56854411	0.00000132	0.38	0.21

5. Comparison of the results of the first and second stages of the comparisons

The results of the first stage of the comparisons present deviations of the temperature values reproduced by the fixed point cells of the national standards of NMI under the VNIIM laboratory conditions from the value reproduced by the VNIIM cell. The main reason for the deviations during this comparison is different purity of metals in the cells. The metrologists consider the influence of metal purity on measurement result to be the main influencing factor, which is presented in the uncertainty budget of the results of one of the most significant components. So, the deviations received at the first stage of the comparisons are interesting for evaluation of the correctness of the approach for estimating the above component.

The results of the second stage of the comparisons present differences of the temperature values of the fixed point realized by the national standards of NMIs using the transfer SPRT. In this case there are many reasons for the differences: metal purity influence, procedures for realization of phase transitions at the NMI's, conditions for reaching the thermal equilibrium during measurements, electrical measurements, and instability of the transfer standard.

The comparison of the results of the first and second stages is demonstrated in the table 16.

Table 16. Results of the first and second stages of the comparison

Fixed point	**NMI**	**1st stage** **ΔT, mK**	**2nd stage** **ΔT, mK**
Ga	**SMU - VNIIM**	- 0.019	0.040
In	**SMU - VNIIM**	-0.140	-0.108
Sn	**SMU - VNIIM**	0.153	0.170
	BelGIM - VNIIM	1.033	0.062
Zn	**SMU - VNIIM**	-0.257	-0.363
	BelGIM - VNIIM	-0.914	-0.377

As is seen from the Table 16, the temperature differences between the cells and the SMU – VNIIM and BelGIM – VNIIM national realizations are basically within the limits of the claimed uncertainties of the results. It is not possible to come to an unambiguous conclusion about the prevailing influence of metal purity on differences of results on the basis of the given results.

6. Results of the COOMET regional comparisons

The results of the COOMET key comparisons were estimated in accordance with the document "*Guide on Estimation of the COOMET Key Comparison Data*", COOMET, R/GM/14:2006.
This document allows to link of the results of the regional COOMET comparisons with the results of key comparison CIPM, in this case with results of CCT comparison КС3.
Results of CCT comparison К3 in the protocol of WG8 " Inter-RMO CMC review committee 3-6-03 " represented as differences [T_{NMI} - ARV (K3)] with evaluations of their uncertainty for each reference point and NMI.

6.1. Evaluations of the weighted mean values ($T_{wm} - T_{VNIIM}$) and their uncertainties for the fixed points

The results of the comparison of the fixed points are deviations of the results of NMIs from the weighted mean value of the deviations.
The weighted mean value of the comparison result, $\Delta T_{wm} = (T_{wm} - T_{VNIIM})$, for each fixed point and its standard uncertainty, $u_{wm}(\Delta T_{wm})$ are calculated by the formulas:

$$\Delta T_{wm} = (T_{wm} - T_{VNIIM}) = \frac{\sum_{1}^{n} \frac{(T_{NMI} - T_{VNIIM})}{U^2(T_{NMI} - T_{VNIIM})}}{\sum_{1}^{n} \frac{1}{U^2(T_{NMI} - T_{VNIIM})}}, \qquad u_{wm}{}^2 = \frac{1}{\sum_{1}^{n} \frac{1}{U^2(T_{NMI} - T_{VNIIM})}}$$

where $(T_{NMI} - T_{VNIIM})$ are the differences shown in Tables 11 – 14,
$U^2(T_{NMI} - T_{VNIIM}) = U^2(W_i) + u^2_{PRT} + u^2(VNNIM$ component A);
the values of $U(W_i)$ are shown in Tables 11 – 14, those for u_{PRT} – in Table 15, and those for $u(VNNIM$ component A) in Appendix 3.
$u_{wm}(\Delta T_{wm})$ is the standard uncertainty of the weighted mean value ΔT_{wm}..

The calculation results of ΔT_{wm} and u_{wm} of the fixed points are presented in Tables 17 – 20.

6.2. Deviations of NMI results from the weighted mean values $(T_{NMI} - T_{wm})$ and their uncertainties

After determination of ΔT_{wm} the measurement result deviations of the participants from the weighted mean value were calculated, i.e.

$$(T_{NMI} - T_{wm}) = (T_{NMI} - T_{VNIIM}) - (T_{wm} - T_{VNIIM}).$$

The uncertainty of the deviations of the participants from the weighted mean value $U(T_{NMI} - T_{wm})$ was calculated by the formula:

$$U^2(T_{NMI} - T_{wm}) = U^2(T_{NMI} - T_{VNIIM}) + u^2_{wm} ,$$

The calculation results of $(T_{NMI} - T_{wm})$ and $U(T_{NMI} - T_{wm})$ for all fixed points are given in Tables 17 – 20 and Figures 7 – 10.

Table 17. Fixed melting point of gallium
ΔT_{wm} = 0.009 mK, u_{wm} = 0.060 mK.

NMI	$T_{NMI} - T_{VNIIM}$ mK	$T_{NMI} - T_{wm}$ mK	$U(T_{NMI} - T_{wm})$ mK (k=1)
VNIIM	0	-0.009	0.09
SMU	0.040	0.031	0.14

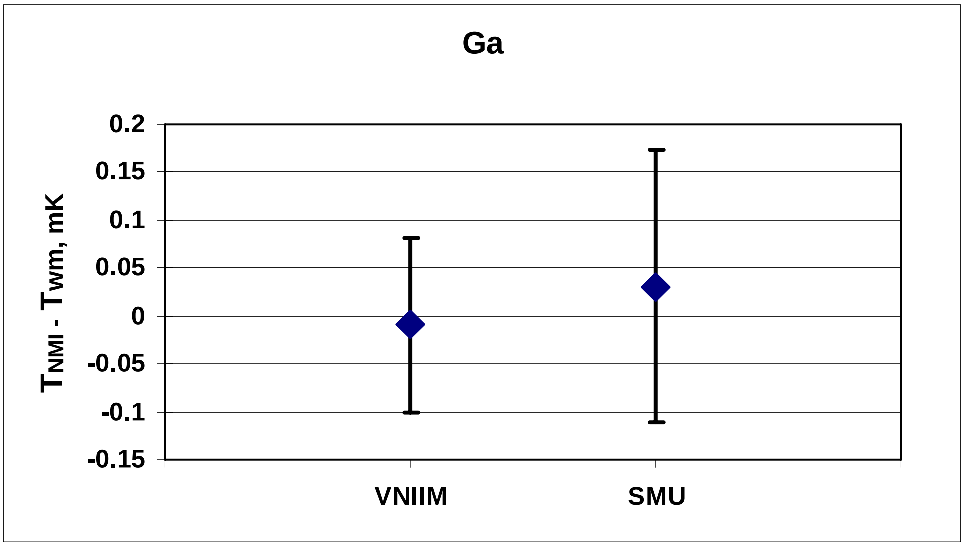

Figure 7. Deviations of the NMI results from the weighted mean value for the Ga melting point

Table 18. Fixed freezing point of indium

$\Delta \boldsymbol{T}_{wm}$= -0.016 mK, $\boldsymbol{u}_{wm}$ = 0.189 mK

NMI	$T_{NMI} - T_{VNIIM}$ mK	$T_{NMI} - T_{wm}$ mK	$U(T_{NMI} - T_{wm})$ mK (k=1)
VNIIM	0	0.016	0.25
SMU	- 0.108	-0.092	0.52

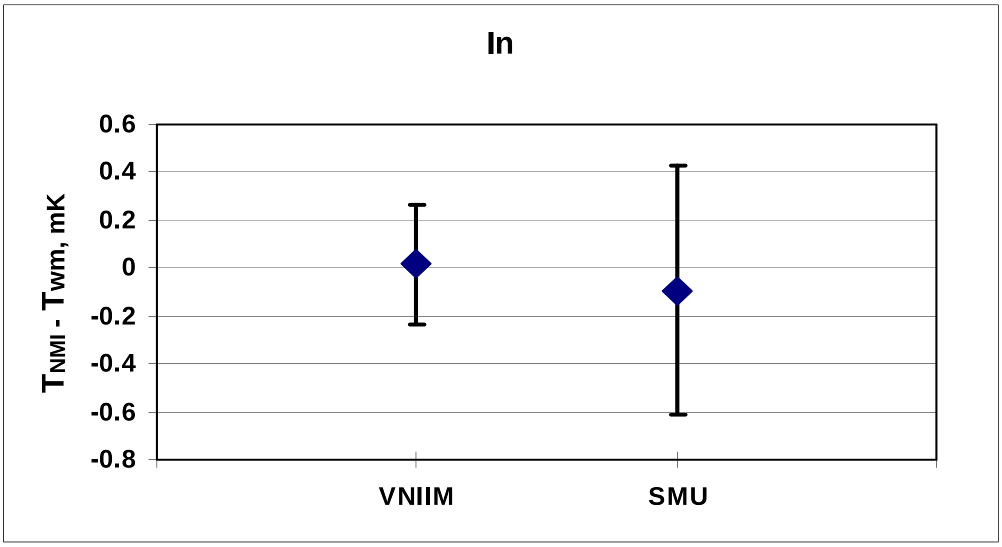

Figure 8. Deviations of the NMI results from the weighted mean value for In freezing point

Table 19. Fixed freezing point of tin

$\Delta \boldsymbol{T}_{wm}$ = 0.046 mK, $\boldsymbol{u}_{wm}$ = 0.224 mK

NMI	$T_{NMI} - T_{VNIIM}$ mK	$T_{NMI} - T_{wm}$ mK	$U(T_{NMI} - T_{wm})$ mK (k=1)
VNIIM	0	-0.046	0.36
SMU	0.170	0.124	0.54
BelGIM	0.062	0.016	0.58

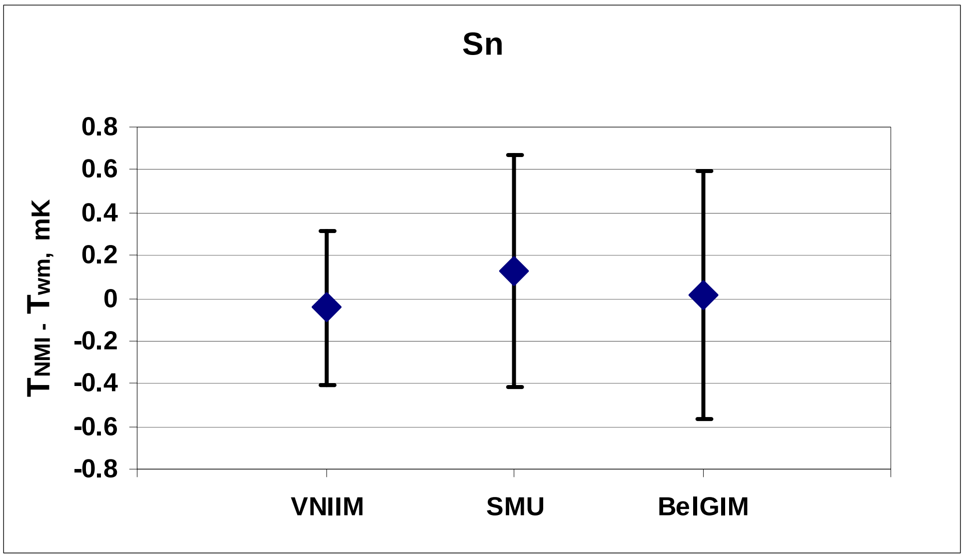

Figure 9. Deviations of the NMI results from the weighted mean value for Sn freezing point

Table 20. Fixed freezing point of zinc
ΔT_{wm} = -0.160 mK, u_{wm} = 0.250 mK

NMI	$T_{NMI} - T_{VNIIM}$ mK	$T_{NMI} - T_{wm}$ mK	$U(T_{NMI} - T_{wm})$ mK (k=1)
VNIIM	0	0.160	0.43
SMU	- 0.363	-0.203	0.55
BelGIM	- 0.377	-0.217	0.66

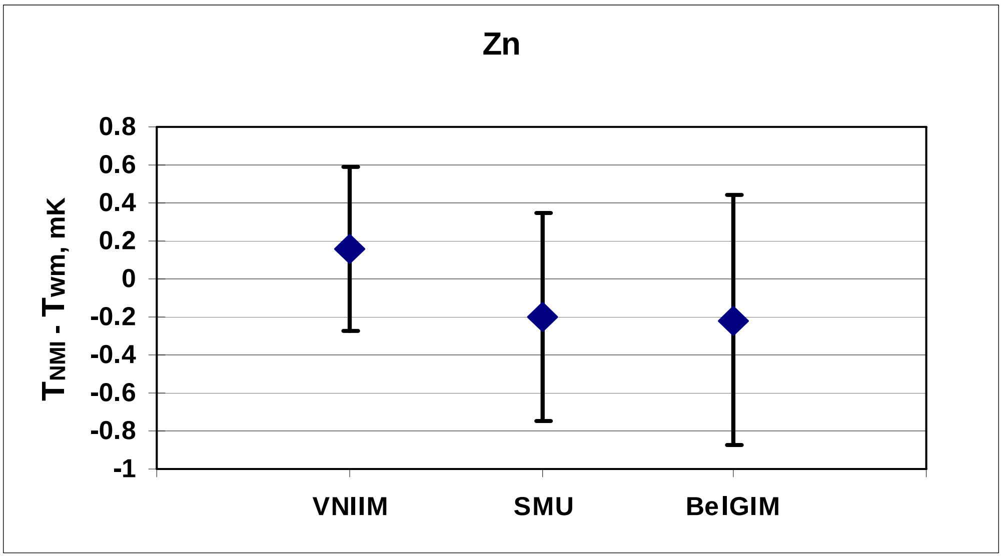

Figure 10. Deviations of the NMI results from the weighted mean value for Zn freezing point

7. Calculation of the additive corrections and the degrees of equivalence of the SMU and BelGIM standards of the fixed points relative to the Key comparisons K3

Two linking institutes: VNIIM and SMU participated in the comparisons for the fixed point of gallium and freezing points of tin and zinc. VNIIM was the only linking institute for the freezing point of indium.
The additive corrections and the degrees of equivalence of the measurement standards were calculated by the following formulas:

$$\Delta = \frac{\sum_{i=1}^{L} \frac{\Delta_i}{S_i^2}}{\sum_{i=1}^{L} S_i^{-2}}, \qquad u^2(\Delta) = \frac{2}{\sum_{i=1}^{L} S_i^{-2}}$$

where $\Delta_i = (T_{linkNMI} - T_{K3ARV}) - (T_{linkNMI} - T_{wm})$;
S is the standard deviation of the measurement results received by the linking NMI;
L is the number of the linking NMI's;
u(Δ) is the standard uncertainty.
The transformed result of the NMI measurement is equal to the sum of a result of NMI in COOMET comparison and additive correction. As the results of Key comparison K3 represented as differences [T_{NMI} - ARV (K3)], also degree of equivalence "***d***" of the NMI result is calculated by the formulas:
$d_i = (T_{NMI} - T_{wm}) + \Delta_i$,
its standard uncertainty $u^2 = U^2[(T_{NMI} - T_{wm})] + u^2(\Delta_i)$.

The results of K3 used in the calculations are given in Table 21.

Table 21. Results of K3

NMI	**Fixed points**	**T_{NMI} – ARV, mK**	**U(ARV) (k=2) mK**	**U(T_{NMI}-ARV) (k=2) mK**
VNIIM	Ga	0.05	0.08	0.25
	In	0.54	0.59	1.11
	Sn	0.59	0.37	0.99
	Zn	0.52	0.32	1.85
SMU	Ga	0.08	0.08	0.23
	Sn	0.26	0.37	1.12
	Zn	0.03	0.32	1.05

7.1. Fixed melting point of gallium

When the NNC IM withdrew its measurement results of the second stage of the comparison, for the fixed melting point of gallium the results of the two linking institutes: VNIIM and SMU were left. The temperature difference between the realizations of the melting point of gallium of the two national institutes, [*T*(SMU) – *T*(VNIIM)], in the COOMET comparison is 0.04 mK, while in the K3 comparisons this difference was equal to 0.03 mK. These results practically agree with the temperature differences obtained by VNIIM and SMU in K3.

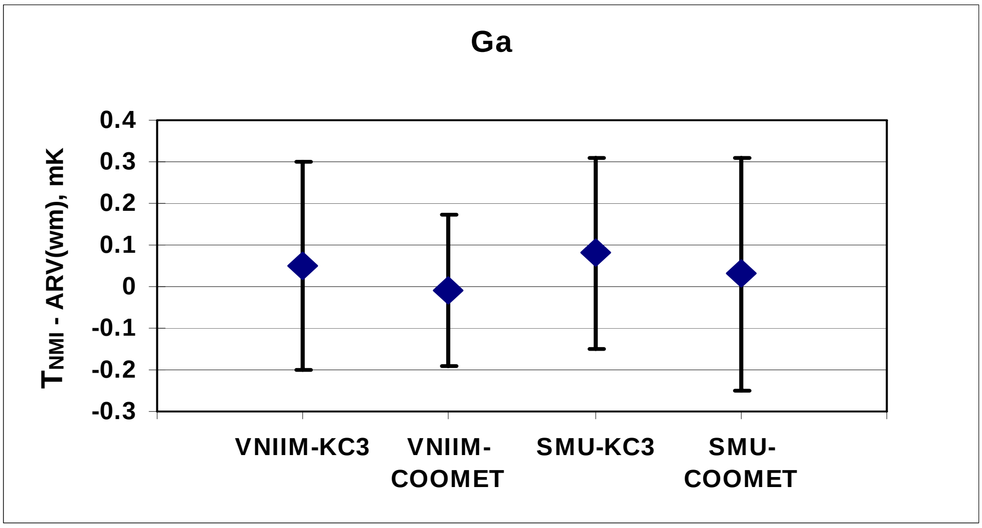

Fig.11. Results VNIIM and SMU on comparisons COOMET ***(T_{NMI}- T_{wm})*** and CCT-K3 (***T_{NMI}***- ARV).

7.2. Fixed freezing point of indium

VNIIM was a linking institute for the fixed freezing point of indium.

VNNIM: result of K3 $T_{VNIIM} - T_{ARVK3}$ = 0.54 mK;

of COOMET $T_{VNIIM} - T_{wm}$= -0.016 mK.

As a result, the additive correction to SMU result for the freezing point of indium is:

Δ= 0.556 mK, its uncertainty ***u(Δ)*** = 0.16 mK.

The transformed measurement result is equal to the sum NMI result at COOMET comparison and the additive correction. The transformed measurement result of SMU is 0.464 mK.

As the results of Key comparison K3 represented as differences [T_{NMI} - ARV (K3)], also degree of equivalence "***d***" of the result of SMU rather K3 is equal 0.464 мK, [T_{SMU} – ARV(K3)] = 0.464 мK.

The uncertainty ***u(d)*** is equal 0.46 mK.

The differences [$\boldsymbol{T_{NMI}}$ – ARV(K3)] and their uncertainties (k=2) for the freezing point of indium are shown on fig.12.

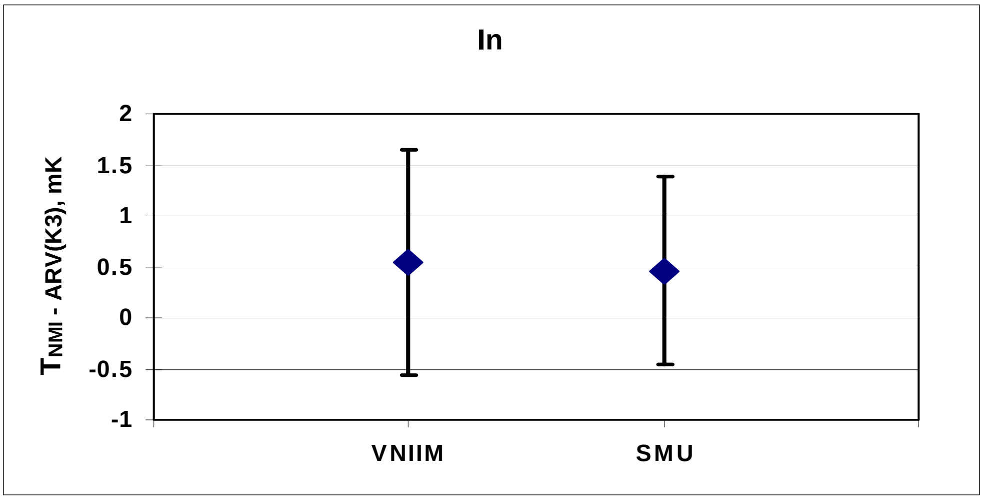

Fig.12. The differences [$\boldsymbol{T_{NMI}}$ – ARV(K3)] for the freezing point of indium

7.3. Fixed freezing point of tin

VNIIM and SMU were two linking institutes for the comparison of the fixed freezing point of tin.

VNIIM: result of K3 of COOMET — $T_{VNIIM} - T_{ARVK3} = 0.59$ mK; $T_{VNIIM} - T_{wm} = -0.046$ mK.

As a result, the VNNIM additive correction is Δ_B = 0,636 mK.

SMU: result of K3 of COOMET — $T_{SMU} - T_{ARVK3} = 0.26$ mK; $T_{SMU} - T_{wm} = 0.124$ mK.

As a result, the SMU additive correction is Δ_s = 0.136 mK.

The summary additive correction of the two lining institutes is:

Δ = 0.360 mK, uncertainty $u(\Delta)$ = 0.13 mK.

The transformed BelGIM measurement result is 0.376 мК, its uncertainty is equal to 0.60 мК.

The degree of equivalence "*d*" of the result of BelGIM rather K3 is equal 0.376 мК, [T_{BelGIM} – ARV(K3)] = 0.376 мК.

The uncertainty $u(d)$ is equal 0.60 mK.

The differences [$\boldsymbol{T_{NMI}}$ – ARV(K3)] and their uncertainties (k=2) for the freezing point of tin are shown on fig.13.

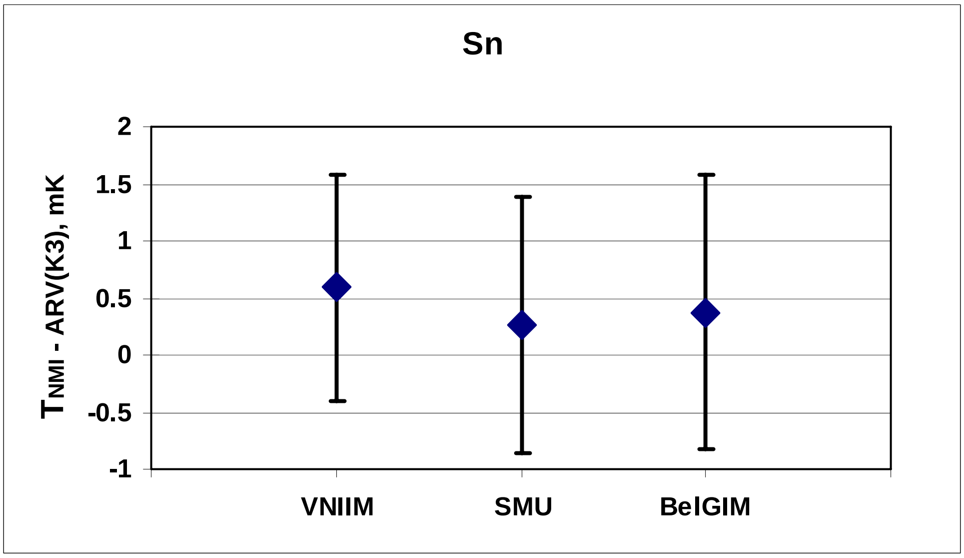

Fig.13. The differences [T_{NMI} – ARV(K3)] for the freezing point of tin

7.4. Fixed freezing point of zinc

VNIIM and SMU were two linking institutes for the comparison of the fixed freezing point of zinc.

VNIIM: result of K3 $T_{VNIIM} - T_{ARVK3}$ = 0.52 mK,
of COOMET $T_{VNIIM} - T_{wm}$ = 0.160 mK,

As a result, the VNNIM additive correction is $\Delta_в$ = 0.360 mK,

SMU: result of K3 $T_{SMU} - T_{ARVK3}$ = 0.03 mK,
of COOMET $T_{SMU} - T_{wm}$ = -0.203 мK,
As a result, Δ_s = 0.233 mK.
The summary additive correction of the two lining institutes is:
Δ= 0.310 мK, uncertainty $u(\Delta)$ = 0.13 mK.

The transformed BelGIM measurement result is 0.093 mK, its uncertainty is equal to 0.67 mK.
The degree of equivalence "*d*" of the result of BelGIM rather K3 is equal 0.093 мK, [T_{BelGIM} – ARV(K3)] = 0.093 мK.
Its uncertainty ***u(d)*** is equal 0.67 mK.

The differences [T_{NMI} – ARV(K3)] and their uncertainties (k=2) for the freezing point of zinc are shown on fig.14.

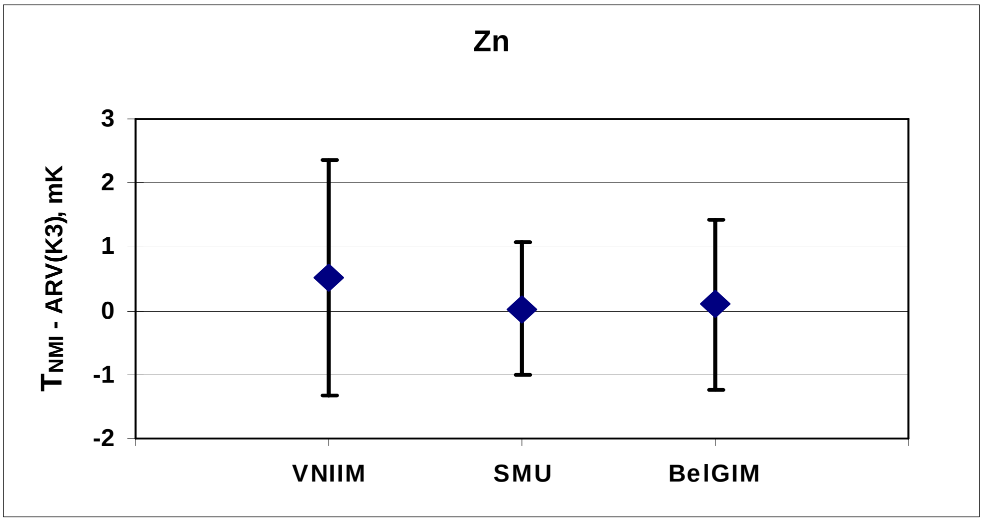

Fig.14. The differences [T_{NMI} – ARV(K3)] for the freezing point of zinc

8. Conclusion

The uncertainty claimed by NMIs for CMC website are considered as confirmed by the results of the regional comparison, if the degree of equivalence "***d***" of the NMI result in the comparison is less than the double value of its uncertainty, i.e. the following inequality is held ("*Guide on Evaluation of the COOMET Key Comparison Data*", COOMET.R/GM/14:2006):

$$|d| < 2u(d)$$

This inequality corresponds to the criterions of the recognition of uncertainties CMC, claimed by NMI, determined by the protocol of WG8 CCT " Inter-RMO CMC review committee 3-26-03 ".

The analysis of the COOMET regional comparison results makes it possible to come to the following conclusions:

1. The uncertainty of the fixed freezing point of indium, claimed by the SMU, is confirmed by the COOMET comparison results. The comparison result is the confirmation the appropriate CMC lines.
2. The uncertainties of the fixed freezing points of tin and zinc, claimed by BelGIM, are confirmed by the COOMET comparison results. The comparison results are the confirmation the appropriate CMC lines.

Appendix 1

Technical Protocol

REGIONAL COMPARISONS OF THE NATIONAL STANDARDS OF TEMPERATURE IN THE RANGE FROM THE TRIPLE POINT OF WATER TO THE FREEZING TEMPERATURE OF ZINC

Introduction

The decision about the necessity to perform regional comparisons within COOMET was taken after finishing key comparisons K3 and K 4, which had been carried out under the direction of the Consultative Committee on Thermometry. Fourteen national metrology institutes joining the different metrological associations: EUROMET, COOMET, SIM took part in the comparisons.

Adoption of the international *Arrangement on Mutual Recognition of the National Standard, Calibration and Measurement Certificates Issued by the National Metrology Institutes*, which was signed by the majority of countries joining COOMET, as well as formation of the international website on measurement capabilities of calibration of measuring instruments of various national metrology institutes was an incitement to perform regional comparisons within COOMET.

Two national metrology institutes: VNIIM (RF) and SMU (Slovakia) joining the CIPM key comparisons K3 and K4, as well as two national metrology institutes: NNC IM (Ukraine) and BelGIM (Republic of Belarus) take part in the COOMET regional comparisons.

All the participants of the comparisons shall act according to the instruction given below. Each laboratory during the comparisons shall apply the adopted realization of the ITS-90. The instruction is written in compliance with the Appendix 1 to the Report on the CCR Key Comparisons K3. The comparisons carefully follow the protocols given in the Guidance for the CIPM key comparisons, in Appendix F to the document "*Arrangement on Mutual Recognition of the National Standard, Calibration and Measurement Certificates Issued by the National Metrology Institutes*" [ ].

VNIIM (RF) as a participant of the key comparisons K3 and K4 is a coordinator of the regional comparisons.

1. The comparisons are performed in two stages.
The scheme of comparisons is shown in the Draft B Report, p.4.

Thermometers are extremely fragile objects and must be only transported by courier with a great care. Each laboratory is responsible for transportation of the thermometers to another laboratory.
Each laboratory calibrates the transported thermometers at the fixed points and draws up a report on the measurement results. This report is sent directly to VNIIM during one month after completion of measurements. VNIIM calculates deviations of the results between the cells at VNIIM and deviations of the results between the laboratories, as well as uncertainties due to the deviations of the results.

2. Time schedule of the comparisons

See Draft B Report, p.4.
The transfer of the thermometers between the laboratories with an intermediate stability check of the Standard platinum resistance thermometers (SPRT) at VNIIM is estimated during three weeks.

3. Procedures

All the participants of the comparisons shall act according to the instruction given below. Each laboratory shall apply the accepted practice for realization of the ITS-90 during the comparisons.
The instruction is written in compliance with Appendix 1 of the CCT Report on key comparisons K3 [ ]. The comparisons strictly follow the protocols given in the CIPM Guidance for key comparisons and in Appendix F to the document "On Mutual Recognition…" [ ].

3. 1. Actions of VNIIM as a coordinating laboratory

The coordinating laboratory VNIIM prepares and calibrates the SPRT's. At the first stage it compares cells of the fixed points from the participating laboratories with its own cells using the SPRT's in accordance with the practice accepted at VNIIM.
At the second stage the coordinating laboratory VNIIM transfers the calibrated the SPRT to the laboratories for their calibrations in accordance with the practice accepted at the participating laboratories, and checks the SPRT stability between calibrations at the laboratories.
The coordinator collects reports on calibration of the SPRT from the participating laboratories and carries out the analysis of the results.

3.2. Actions of the participating laboratories

At the first stage the participating laboratories pass their cells of the fixed points to the coordinator.
At the second stage, after receiving the cells and calibrated SPRT from the coordinator, they perform the following procedures:
1. Measurement of the SPRT resistance at the triple point of water.
2. Annealing of the SPRT in a certain sequence:
   a) The SPRT is inserted in the furnace at the temperature 500 °C;
   b) The temperature in the furnace is raised to 600 °C;
   c) The SPRT is kept in the furnace during two hours;
   d) The temperature in the furnace is reduced to 450 °C during 2,5 hours;
   e) The SPRT is quickly removed from the furnace to the air and cools down to room temperature.
3. Measurement of the SPRT resistance at the triple point of water.

If the SPRT resistance at the triple point of water after annealing is changed by less than 0,5 mK in the temperature equivalent, it is possible to start its calibration at the fixed points.
If the SPRT resistance at the triple point of water after annealing is changed by 0,5 mK or more in the temperature equivalent, annealing should be repeated.
If after the second annealing the SPRT resistance at the triple point of water is changed by more than 0,5 mK in the temperature equivalent, the SPRT should be replaced.
The SPRT is calibrated in the following order: TPW, Zn, TPW, Sn, TPW, In, TPW, Ga, TPW.
The practice accepted in the laboratory is used for each fixed point. On the basis of measurement results for each fixed point the relative resistance value of the SPRT is calculated: $W = R_t/R_{TPW}$, where R_{TPW} is the SPRT resistance at the triple point of water obtained directly after measuring R_t. The values of R_t and R_{TPW} shall be corrected for overheating with measuring current, for hydrostatic pressure and pressure in the cell.
The calibration cycle shown above shall be repeated minimum three times.
The values of W received in three cycles of measurement and their average value for each fixed point are passed over to the coordinator. On completion of measurements the SPRT is returned to the coordinator for stability check.

4. Submission of the results

All the laboratories participating in the comparisons shall send the following information to the coordinator:

a) Parameters of the cells of the fixed points, furnaces, measuring instruments used by the participating laboratories in the comparisons according to Table 2 in the Appendix;

b) Measurement results $W = R_t/R_{TPW}$, where R_t is the resistance of the SPRT at each fixed point; R_{TPW} is the SPRT resistance at the triple point of water obtained after measuring R_t. The values of R_t and R_{TPW} shall be corrected for overheating with measuring current, for hydrostatic pressure and pressure in the cell according to Appendix A of the Protocol;
c) Examples of the experimental freezing curves for the fixed points of In, Sn, Zn and the melting curves for the fixed point of Ga;
d) Experimental curves of dependence of fixed point temperature on depth of immersion of the SPRT applied;
e) Uncertainty budget for each fixed point calculated in accordance with Appendix B of the Protocol.

Appendix A

Measurement results						
COOMET						
Name of the laboratory:						
W(t) = *R*(t)/*R*(TPW), where *R*(TPW) is the resistance at the TPW after measuring *R*(t)						
Correction for pressure in the cell						
Point to be measured:						
Thermometer number:						
Point to be measured:	R measured at 1mA	Overheat	Hydrostatics	Pressure	Corrected R	W
	ohm	ohm	ohm	ohm	ohm	
Average W						

Appendix B

Explanation and proposals for estimation of the uncertainty components

1. Reproducibility of the W_t values. The type A uncertainty component – r.m.s. deviation of the measured "*n*" values of *W*. The number of the degrees of freedom is (*n*–1).

2. The uncertainty component due to the influence of metal purity on the fixed point temperature value (Type B).

At present, the CCT Working Group 1 has prepared the document [ ] on the recommended methods for estimation of this component. The first method called "*Sum of individual estimates*" (SIE) is more preferable. This method assumes calculation of the correction for the influence of impurities, which should be applied to the measurement result. The correction is calculated by the following formula:

$$T_{\text{liq}} - T_{\text{pure}} = \Sigma_i c_{11,I} \times \partial T/\partial c_{1,i} = \Sigma_i c_{11,I} \times m_{1,i},$$

where T_{liq} is the "liquidus" temperature of the substance used;

T_{pure} is the temperature of the phase transition of pure substance;

$c_{11,i}$ is the concentration (mole fraction) for the i-impurity;

$\partial T/\partial c_{1,i} = m_{1,i}$ is the initial inclination of the liquidus line in the binary phase diagram for the i-impurity.

In this case the uncertainty component due to the influence of purity of metal is the uncertainty of the applied correction. It can be calculated by the following formula:

$$u^2_{\text{sie}} = \Sigma_i[u^2(c_{11,i}) \times m^2_{1,I} + u^2(m_{1,i}) \times c^2_{11,i}],$$

where *u* is the uncertainty of the parameters used for calculation of the correction.

As is seen from the above ratios, for application of the SIE method it is necessary to know the concentration of all impurities from the certificate to the metal used, the uncertainty of its determination, the inclinations of the "liquidus" curves of the binary phase diagrams for each impurity and their uncertainty.

The second method for estimation of the uncertainty due to the influence of impurities called "*Overall maximum estimate*" (OME) can be applied in those cased where the data on concentration of individual impurities are absent, or the inclinations of the "liquidus" curves are not known. It is assumed in this case that no impurity forms solid solutions, and the following inequality is correct:

$$T_{\text{liq}} - T_{\text{pure}} < \Delta T_{\text{оме,мах}} = c_{11}/A,$$

where c_{11} is the sum of concentrations (mole fraction) of all impurities;
A is the cryoscopic constant.

If we accept that the "liquidus" temperature is within the range $T_{\text{liq}} - T_{\text{pure}}$, then the uncertainty component can be estimated as follows:

$$u^2_{\text{ome}} = (c_{11}/A)^2/3.$$

The third method for estimation of this uncertainty component presents a combination of the SIE and OME methods. It is allowed to apply the SIE method for impurities with the prevailing influence and the OME method for the other impurities.

3. Uncertainty of the correction for hydrostatic pressure (Type B)

The correction for hydrostatic pressure, which is applied to the measurement result, is equal to the product of the immersion depth of the sensing element middle of the thermometer relative to the metal surface in the cell "*h*" and the hydrostatic pressure ratio dT/dh for the given metal presented in the ITS-90. The uncertainty of the given correction is determined as follows:

$$u^2_{\text{h}} = (dT/dh)^2 \times u^2(h),$$

where $u^2(h)$ is the uncertainty estimate of the immersion depth determination h.

If $u(h)$ is the maximum uncertainty estimate of the immersion depth determination h, the standard deviation of the given uncertainty component is $u^2_{\text{h}}/3$.

4. Uncertainty component due to pressure in the cell

For open cells this component is determined by the uncertainty of gas pressure measurement above the metal and its maintenance in correspondence with the ITS-90 equal to 103 Pa, and is estimated as follows:

$$u^2_{\text{p}} = (dT/dp)^2 \times u^2(p),$$

where dT/dp is the ratio presented in the ITS-90, and $u(p)$ is the uncertainty estimate of measurement and maintenance of pressure in the period of phase transition.

If $u(p)$ is the maximum uncertainty estimate, the standard deviation of the given uncertainty component is $u^2_p/3$.

For closed cells it is necessary to know which pressure value is in the cell in the period of phase transition. This pressure value is determined by pressure and temperature at the moment of sealing the cell. If it differs from 103 Pa, it must be specified in the certificate to the cell for calculation of the corresponding correction for pressure.

The uncertainty component is estimated on the basis of the pressure measurement uncertainty at the moment of sealing the cell.

5. The uncertainty component of the correction for overheating with measuring current

In the existing practice the correction for overheating with measuring current is calculated on the basis of assumption of linear dependence of overheating on measuring current power generated in the thermometer. This assumption leads to calculation of the correction as follows:

$$\Delta R = 2R(1) - R(\sqrt{2}),$$

where $R(1)$ is the thermometer resistance with the measuring current 1 mA, and $R(\sqrt{2})$ is its resistance with the current $\sqrt{2}$ mA.

The uncertainty of the correction depends on validity of the assumption of the linear dependence of overheating on power for the given thermometer type, on uncertainty of measuring current values, and on resolution of a bridge used in measurements. The simplest way to estimate the uncertainty of the correction is estimation of the standard deviation of the obtained series of values ΔR_i.

6. The uncertainty component due to deviation of thermal equilibrium between the thermometer and the interface from ideal equilibrium.

This uncertainty component appears due to heat dissipation along the thermometer, due to thermal resistance of the walls and gaps between the thermometer and the metal interface. The presence of this uncertainty component is confirmed by deviation of the temperature dependence on the immersion depth of the thermometer from the expected hydrostatic dependence, variations of the thermometer indications when the heat exchange conditions between the thermometer and the crucible of the furnace elements are changed. The uncertainty component can be received from the results of the experimental studies carried out in the laboratory.

7. The uncertainty component due to non-linearity of the bridge

The estimate of the uncertainty component can be obtained from the parameter of the bridge used, and from the comparison of its indications with other bridges.

8. The uncertainty component due to direct or alternating measuring current

The estimate of the uncertainty component can be obtained by comparison of the results of measurement with d.c. and a.c. bridges.

9. The uncertainty component due to variation of reference resistance temperature

The estimate of the uncertainty component can be calculated on the basis of estimation of measured temperature instability of the reference resistor (temperature instability of the thermostat for the reference resistor), its temperature coefficient and uncertainty of the measurement results of the reference resistor temperature:

$$u^2_{sr} = u^2_t + u^2_n,$$

где u^2_t is the standard deviation of the temperature measurements of the reference resistor;

u^2_n is the standard deviation of the reference resistor due to temperature instability.

$$u^2_n = u^2_{\delta T} \times N^2 \times (\partial T/\partial R)^2,$$

where $u_{\delta T}$ is the standard deviation of the temperature during measurement of the reference resistor;

N is the temperature coefficient of the reference resistor;

$(\partial T/\partial R)$ is the thermometer sensitivity.

10. The uncertainty component due to temporary variation of resistance

This component is insignificant if measurements are taken during a short period of time.

Appendix 2

PARAMETERS OF THE CELLS OF FIXED POINTS, FURNACES AND MEASURING INSTURMENTS USED BY THE PARTICIPATING LAGORATORIES IN THE COMPARISONS

Laboratory	VNIIM	SMU	BelGIM	NNC IM
Bridge, potentiometer				Bridge
Manufacturer		ASL	ASL	Ukraine
Type	Guidline 9975	F18	F 18	CA-300
D.C. or A.C.	d.c.	a.c.	a.c.	a.c.
A.C. frequency		75 Hz	25 Hz	325 Hz
D.C. period	4 s			
Normal measurement current	1 mA	1 mA	1 mA	1 mA
Self-heating current	1,414 mA	1,414 mA	1,414 mA	1,414 mA
Resistance linearity				
Bridge (yes/no)		no	no	yes
Reference resistor				
Manufacturer	ZIP, RF	Tinsley	ZIP, RF	
Type	MC 3020	5685 A	P 331	M 3001
Reference resistor - temperature control (yes/no)	yes	yes	no	yes
TPW cell				
Manufactrurer	VNIIM		VNIIM	VNIIFTRI
Outer diameter	50 mm		48 mm	65 mm
Thermometer well diameter	11 mm		13 mm	20 mm
Immersion depth of the middle of the SPRT sensing element	260 mm	20,5 cm	212 mm	225 mm
Thermostat for maintaining the TPW	Thermostat with ice	ISOTECH	“Kryostat TTB”	

Zn fixed point cell				
Manufacturer	VNIIM		VNIIM	VNIIM
Open or closed	open	closed	closed	closed
Outer diameter	52 mm		53 mm	54 mm
Thermometer well diameter	14 mm		9,4 mm	9 mm
Metal purity	99,9999 %	99,9999 %	99,9999 %	99,999 %
Immersion depth of the middle of the SPRT sensing element	160 mm	17,5 cm	180 mm	175 mm
Furnace for the fixed point of Zn				
Manufacturer	VNIIM			NNC IM
Type (1, 2 or 3 zones)	3 zones	3 zones	3 zones	3 zones
Duration of melting plateau				56 min
Duration of freezing plateau	10 hours	12 hours	9 hours	45 min
Sn fixed point cell				
Manufacturer	VNIIM		VNIIM	VNIIM
Open or closed	open	closed	closed	closed
Outer diameter	52 mm		53,4 mm	54 mm
Thermometer well diameter	14 mm		9,3 mm	9 mm
Metal purity	99,9999 %	99,9999 %	99,9999 %	99,999 %
Immersion depth of the middle of the SPRT sensing element	160 mm	17,5 cm	180 mm	175 mm
Furnace for the fixed point of Sn				
Manufacturer	VNIIM		Belarus	NNC IM
Type (1, 2 or 3 zones)	3 zones	3 zones	heat pipe	3 zones
Duration of melting plateau				56 min
Duration of freezing plateau	11 hours	12 hours	9 hours	48 min
In fixed point cell				
Manufacturer	VNIIM			NNC IM

Open or closed	open	closed		open
Outer diameter	42 mm			50 mm
Thermometer well diameter	10 mm			9 mm
Metal purity	99,9999 %	99,9999 %		99,999 %
Immersion depth of the middle of the SPRT sensing element	173 mm	17 cm		155 mm
Furnace for the fixed point of In				
Manufacturer	VNIIM			NNC IM
Type (1, 2 or 3 zones)	3 zones	3 zones		1 zone
Duration of melting plateau				65 min
Duration of freezing plateau	12 hours	14 hours		76 min
Ga fixed point cell				
Manufacturer	VNIIM			NNC IM
Open or closed	open	closed		open
Outer diameter	42 mm			50 mm
Thermometer well diameter	10 mm			9 mm
Metal purity	99,99999 %	99,99999%		99,9999 %
Immersion depth of the middle of the SPRT sensing element	167 mm	17,5 cm		155 mm
Furnace for the fixed point of Ga				
Manufacturer	VNIIM			NNC IM
Type (1, 2 or 3 zones)	2 zones	Liquid thermostat		1 zone
Duration of melting plateau	17 hours	15 hours		652 min

Appendix 3

UNCERTAINTY BUDGET

Uncertainty Budget for the Melting Point of Gallium

Uncertainty component	mK	
	VNIIM	SMU
1. Reproducibility of the W_t values	0,041	0,031
2. Component due to metal purity	0,025	0,010
3. Component due to correction for hydrostatic pressure	0,003	0,006
4. Component due to correction for self heating	0,010	0,020
5. Component due to deviation from thermal equilibrium	0,020	0,025
6. Component due to accounting for pressure in the cell	0,0002	0,002
7. Component due to a.c. or d.c.	-	-
8. Component due to nonlinearity of the bridge	0,003	0,060
9. Component due to temperature of the reference resistance	0,0001	0,003
10. Component due to stability of the reference resistance	-	-
Components due to measurement in the TPW		
11. Component due to purity and isotopic composition of water	0,010	0,060
12. Component due to correction for hydrostatic pressure	0,001	0,002
13. Component due to correction for self heating	0,006	0,011
14. Component due to deviation from thermal equilibrium	0,006	0,020
15. Component due to a.c. or d.c.	-	-
16. Component due to nonlinearity of the bridge	0,003	0,060
Total uncertainty	0,055	0,116
Expanded uncertainty	0,110	0,232

Uncertainty Budget for the Freezing Point of Indium

Uncertainty component	**mK**	
	VNIIM	**SMU**
1. Reproducibility of the W_t values	0,110	0,170
2. Component due to metal purity	0,120	0,400
3. Component due to correction for hydrostatic pressure	0,005	0,016
4. Component due to correction for self heating	0,012	0,030
5. Component due to deviation from thermal equilibrium	0,030	0,070
6. Component due to accounting for pressure in the cell	0,0006	0,050
7. Component due to a.c. or d.c.	-	-
8. Component due to nonlinearity of the bridge	0,003	0,080
9. Component due to temperature of the reference resistance	0,0001	0,010
10. Component due to stability of the reference resistance	-	-
Components due to measurement in the TPW		
11. Component due to purity and isotopic composition of water	0,010	0,060
12. Component due to correction for hydrostatic pressure	0,001	0,002
13. Component due to correction for self heating	0,006	0,011
14. Component due to deviation from thermal equilibrium	0,006	0,020
15. Component due to a.c. or d.c.	-	-
16. Component due to nonlinearity of the bridge	0,003	0,060
Total uncertainty	0,167	0,460
Expanded uncertainty	0,334	0,920

Uncertainty Budget for the Freezing Point of Tin

Uncertainty component	mK		
	VNIIM	**SMU**	**BelGIM**
1. Reproducibility of the W_t values	0,200	0,180	0,136
2. Component due to metal purity	0,120	0,350	0,320
3. Component due to correction for hydrostatic pressure	0,003	0,011	0,010
4. Component due to correction for self heating	0,015	0,030	0,020
5. Component due to deviation from thermal equilibrium	0,030	0,050	0,023
6. Component due to accounting for pressure in the cell	0,0006	0,036	0,010
7. Component due to a.c. or d.c.	-	-	0,040
8. Component due to nonlinearity of the bridge	0,003	0,050	0,150
9. Component due to temperature of the reference resistance	0,0001	0,010	0,023
10. Component due to stability of the reference resistance	-	-	
Components due to measurement in the TPW			
11. Component due to purity and isotopic composition of water	0,010	0,090	0,110
12. Component due to correction for hydrostatic pressure	0,001	0,004	0,010
13. Component due to correction for self heating	0,006	0,020	0,020
14. Component due to deviation from thermal equilibrium	0,006	0,040	0,100
15. Component due to a.c. or d.c.	-	-	0,030
16. Component due to nonlinearity of the bridge	0,003	0,090	0,030
Total uncertainty	0,236	0,424	0,470
Expanded uncertainty	0,472	0,848	0,940

Uncertainty Budget for the Freezing Point of Zinc

Uncertainty component	**mK**		
	VNIIM	**SMU**	**BelGIM**
1. Reproducibility of the W_t values	0,170	0,210	0,160
2. Component due to metal purity	0,210	0,270	0,340
3. Component due to correction for hydrostatic pressure	0,010	0,013	0,010
4. Component due to correction for self heating	0,025	0,030	0,020
5. Component due to deviation from thermal equilibrium	0,080	0,050	0,320
6. Component due to accounting for pressure in the cell	0,0012	0,047	0,010
7. Component due to a.c. or d.c.	-	-	0,040
8. Component due to nonlinearity of the bridge	0,003	0,060	0,160
9. Component due to temperature of the reference resistance	0,0001	0,020	0,031
10. Component due to stability of the reference resistance	-	-	-
Components due to measurement in the TPW			
11. Component due to purity and isotopic composition of water	0,010	0,130	0,110
12. Component due to correction for hydrostatic pressure	0,001	0,005	0,010
13. Component due to correction for self heating	0,006	0,030	0,020
14. Component due to deviation from thermal equilibrium	0,006	0,050	0,100
15. Component due to a.c. or d.c.	-	-	0,030
16. Component due to nonlinearity of the bridge	0,003	0,130	0,030
Total uncertainty	0,283	0,405	0,545
Expanded uncertainty	0,566	0,810	1,090