Final Report of COOMET.T-K7:
Regional key comparison of water triple point cells
(COOMET theme No 395/BY/07)

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Introduction

Adoption of the International Arrangement on Mutual Recognition of National Standard, Calibration and Measurement Certificates, Issued by the National Metrology Institutes (hereinafter - NMI), 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 NMI 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 within COOMET in 2007. The theme is "Regional comparisons of the water triple point cells of the national standards of temperature", № 395/BY/07, registration in the KCDB "COOMET.T-K-7".

The purpose of the 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 NMI standards that take part in regional comparisons, is determined relative to the reference value of the CCT.T-K7 key comparison through the measurement results received in the linking NMI, which took part in both comparisons.

1 Organization of the comparisons

This section provides general principles and the comparisons scheme. The details and procedures for these comparisons are given in the Technical Protocol in Appendix 1.

1.1 Participants of the comparisons

7 national metrology institutes (NMI) took part in the COOMET regional comparisons:

VNIIM – D.I.Mendeleyev All-Russian Research Institute for Metrology, Moskovsky pr. 19, 198005, St. Petersburg, the Russian Federation, tel. +7812 315 52 07, fax: +7812 713 01 14, e-mail: A.I.Pokhodun@vniim.ru

BelGIM – Belarusian State Institute for Metrology, Starovilensky trakt 93, 220053, Minsk, the Republic of Belarus, tel. +375 117 2330421, fax. +375 17 2880938, e-mail: dikun@belgim.by

NNC IM – National Research Centre "Institute for Metrology", Mironositskaya str., 42, 61002, Kharkov, Ukraine, tel. +038 057 704 97 57, fax. +038 057 700 34 47, e-mail: Rymma.Sergiyenko@metrology.kharkov.ua .

NISM – National Institute for Standardization and Metrology, Kock str., 28, MD-2064, Kishinev, the Republic of Moldova, tel. +373 22 218 507, e-mail: metrologie@standard.md.

KazInMetr – The Republican State Enterprise SE "Kazakhstani Institute for Metrology", Levy Bereg str., 35, building 11, 010000, Astana, the Republic of Kazakhstan, tel. +7272 213 616, fax +7272 793 299, e-mail: metrology@nursat.kz.

GeoSTM – National Agency of Georgia for standards, technical regulations and metrology, Chargalskaya str. 67, 0141 Tbilisi, Georgia, tel. +380 57 04 97 57, fax +380 5700 34 47, e-mail: dep_mechanics@yahoo.com.

INIMET – National Research Institute for Metrology, Consulado 206, CP 10200, Havana, the Republic of Cuba, tel. +537 863 88 02, fax +537 867 69 66, e-mail: laboratorio@inimet.cu.

Of six participants national institute for metrology: VNIIM (RF) is a participant of CCT.T-K7 key comparisons. In COOMET comparisons it is the linking institute in terms of dissemination of the metrological equivalence to the BelGIM standards (the Republic of Belarus), NNC IM (Ukraine), NISM (the Republic of Moldova), KazInMetr (the Republic of Kazakhstan), GeoSTM (Georgia), INIMET (the Republic of Cuba).

BelGIM (the Republic of Belarus) has been appointed pilot NMI and coordinator of the regional comparisons.

1.2 Scheme of the comparisons

The Technical Protocol of comparisons, the forms of presentation of the measurement results and their uncertainties at the water triple point, the lists of the parameters for the cells and equipment applied were sent 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 CCT-K3, CCT-K4, CCT-K7 were performed according to different schemes and using different transfer standards. In the comparison CCT-K3 the use was made of standard platinum resistance thermometers as transfer standards, while in comparisons CCT-K4 and CCT-K7 – the cells for realization of the main ITS-90 fixed points. In the comparison CCT-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 CCT-K3 and CCT-K4 make it possible to estimate the temperature deviations of the fixed point realizations at the national institutes. In the comparison CCT.T-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. Hence, the differences of temperatures reproduced by the cells under the same conditions were obtained. Since the variations of the procedures for realization of the water triple point are insignificant in different laboratories, the discrepancies between reproduced temperature values depend mainly on the 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.

On this basis, it was decided to perform COOMET comparisons in accordance with the scheme of key comparisons CCT.T-K7.

In COOMET comparisons transfer cells have been forwarded to BelGIM where they have been compared with the reference BelGIM cell.

Peculiarity of these comparisons is the fact, that equivalence level is determined taking into account additive amendment, got using through the linking NMI – VNIIM, which participated in the key comparisons CCT.T–K7.

The scheme of comparisons is presented in Figure 1.

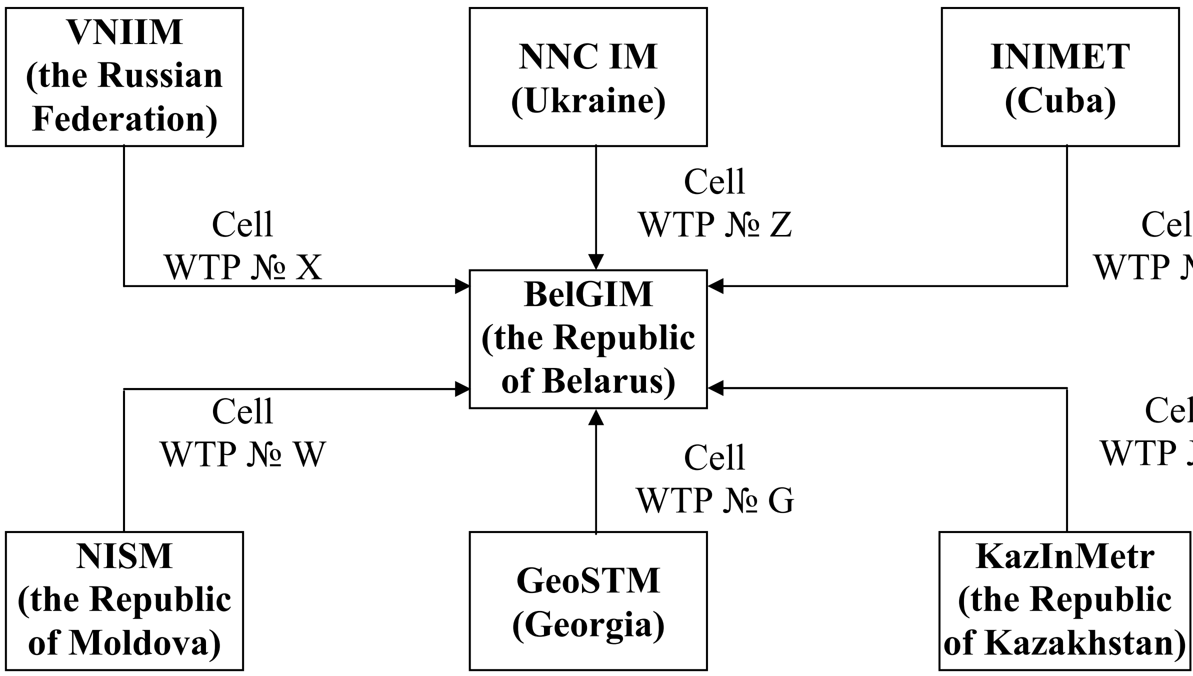

Figure 1

Comparisons were performed in three stages:

The first stage of comparison

Every laboratory-participant performed comparisons of the transfer cell with its national reference cell.

The second stage of comparison

Transfer cells have been presented together with the results of measurements in BelGIM, where all the transfer cells were compared with the reference BelGIM cell.

The third stage of comparison

Transfer cells were returned to the laboratories where they were again compared with the national reference cell in order to determine the stability of the transfer cell.

1.3 Time schedule of the comparisons

The first stage of comparisons:

Comparisons of transfer TPW cell with national reference cell conducted by the laboratories of national metrological institutes.

March 2008 – December 2009.

The second stage of comparisons:

Comparisons of the transfer cells with BelGIM reference cell.

January 2010 – October 2010.

The third stage of comparisons:

Repeated comparisons of transfer TPW cell with national reference cell conducted by the laboratories of national metrological institutes.

November 2010 – November 2011.

2 Comparisons of cells in national metrology institutes

At the first stage NMIs, participating in comparisons, have performed measurements on the basis of their laboratories. They have selected transfer TPW cells, performed measurements of temperature difference of transfer and national TPW cells, evaluation of temperature realization of the transfer cell, measurement of temperature field profile. Measurements have been performed by means of SPRT.

Technical and metrological characteristics of TPW cells (of transfer cells and national reference), measurement instruments and auxiliary equipment, used by NMI for measurements, are presented in Attachment 2.

2.1 Results of measurement of the temperature difference between the transfer cell and the cell of the national standard

Measurement of the temperature difference has been performed with two ice mantles frozen separately. For every ice mantle there have been conducted direct comparisons with the national reference cell within one week, one measurement per day.

Calculation of the temperature difference by every NMI has been performed on the basis of the following formula

$$T_T - T_{NMI} = (R_{T_i} - R_{NMI_i})/(dR/dT)_T \qquad (1)$$

where T_T – temperature value in the transfer cell, K;

$T_{НМИ}$ – temperature value in the national standard cell, K;

R_{T_i} – i-e value of SPRT resistance, measured in the transfer cell, Ohm;

R_{NMI_i} – i-e value of SPRT resistance, measured in the national standard cell, Ohm;

$(dR/dT)_T$ – sensitivity index of SPRT at the water triple point, Ohm /K.

Mean value of the temperature difference has been calculated on the basis of the formula

$$T_T - T_{NMI} = \sum_{i=1}^{n} (T_T - T_{NMI})_i / n \qquad (2)$$

where $(T_T - T_{NMI})_i$ – i-e value of temperature difference, obtained by NMI for two ice mantles, mK;

n – number of measurements of temperature difference.

The results of pair comparisons of cells, mean values of temperature difference and their total uncertainties are presented in Tables 1 – 5.

Table 1

The results of cells comparisons in NISM			
The first ice mantle		The second ice mantle	
Date	$(T_T - T_{NMI})_i$, mK	Date	$(T_T - T_{NMI})_i$, mK
1	2	3	4
16.03.2009	-0,024	30.03.2009	-0,016
17.03.2009	-0,049	31.03.2009	-0,025
18.03.2009	-0,016	01.04.2009	-0,022
19.03.2009	-0,034	02.04.2009	-0,039
20.03.2009	-0,017	03.04.2009	-0,029
$T_T - T_{NMI}$, mK	-0,027	–	–

Table 2

The results of cells comparisons in INIMET			
The first ice mantle		The second ice mantle	
Date	$(T_T - T_{NMI})_i$, mK	Date	$(T_T - T_{NMI})_i$, mK
01.02.2010	0,042	01.03.2010	0,047
02.02.2010	0,065	02.03.2010	0,044
03.02.2010	0,072	03.03.2010	0,067
04.02.2010	0,041	04.03.2010	0,053
05.02.2010	0,064	05.03.2010	0,069
08.02.2010	0,068	08.03.2010	0,068
09.02.2010	0,060	09.03.2010	0,054
10.02.2010	0,044	10.03.2010	0,050
11.02.2010	0,047	11.03.2010	0,042
12.02.2010	0,050	12.03.2010	0,065
15.02.2010	0,065	15.03.2010	0,067
16.02.2010	0,053	16.03.2010	0,044
17.02.2010	0,044	17.03.2010	0,042
18.02.2010	0,050	18.03.2010	0,062
19.02.2010	0,048	19.03.2010	0,066
$T_T - T_{NMI}$, mK	0,055	–	–

Table 3

The results of cells comparisons in VNIIM			
The first ice mantle		The second ice mantle	
Date	$(T_T - T_{NMI})_i$, mK	Date	$(T_T - T_{NMI})_i$, mK
1	2	3	4
23.10.2008	0,011	21.11.2008	0,013
24.10.2008	0,014	24.11.2008	0,012
27.10.2008	0,029	25.11.2008	0,024
28.10.2008	0,017	26.11.2008	0,016
29.10.2008	0,012	27.11.2008	0,011
30.10.2008	0,024	28.11.2008	0,012
31.10.2008	0,019	01.12.2008	0,023
03.11.2008	0,020	02.12.2008	0,019

Continuation of the table 3

1	2	3	4
05.11.2008	0,023	03.12.2008	0,018
06.11.2008	0,014	04.12.2008	0,024
07.11.2008	0,016	05.12.2008	0,012
10.11.2008	0,017	08.12.2008	0,016
11.11.2008	0,022	09.12.2008	0,014
12.11.2008	0,012	10.12.2008	0,029
13.11.2008	0,013	11.12.2008	0,011
$T_T - T_{NMI}$, mK	0,018	–	–

Table 4

The results of cells comparisons in NNC IM			
The first ice mantle		The second ice mantle	
Date	$(T_T - T_{NMI})_i$, mK	Date	$(T_T - T_{NMI})_i$, mK
07.11.2011	0,05	21.11.2011	0,04
08.11.2011	0,05	22.11.2011	0,04
09.11.2011	0,03	23.11.2011	0,03
10.11.2011	0,03	24.11.2011	0,03
11.11.2011	0,03	25.11.2011	0,03
$T_T - T_{NMI}$, mK	0,036	–	–

Table 5

The results of cells comparisons in KazInMetr			
The first ice mantle		The second ice mantle	
Date	$(T_T - T_{NMI})_i$, mK	Date	$(T_T - T_{NMI})_i$, mK
08.11.2010	0,157	29.11.2010	0,145
09.11.2010	0,109	30.11.2010	0,119
10.11.2010	0,149	01.12.2010	0,149
11.11.2010	0,122	02.12.2010	0,127
12.11.2010	0,152	03.12.2010	0,142
15.11.2010	0,135	06.12.2010	0,155
16.11.2010	0,141	07.12.2010	0,131
17.11.2010	0,154	08.12.2010	0,134
18.11.2010	0,138	09.12.2010	0,138
19.11.2010	0,112	10.12.2010	0,152
$T_T - T_{NMI}$, mK	0,139	–	–

Transfer TPW cell GeoSTM has also served as a national reference in comparisons.

2.2 Uncertainty budget

NMI has performed evaluation of temperature difference measurement uncertainty of the transfer and national cells. Uncertainty budget included uncertainty of the national reference cell (realization uncertainty) and direct comparisons of the transfer as well as national cells. Uncertainty budgets are presented in Appendix 3.

2.3 Results of measurement of the immersion profile

For every transfer cell there have been performed measurements of the immersion profile in order to guarantee that the measurements really depend on the temperature of phase division ice/water. Measurements have been conducted successively upward with the step 1 cm up to the level 5-10 cm below water surface.

In order to draw up theoretic curve the factor of hydrostatic pressure for water, provided in MTS-90 was used.

The measurement results are presented in figures 2 – 7.

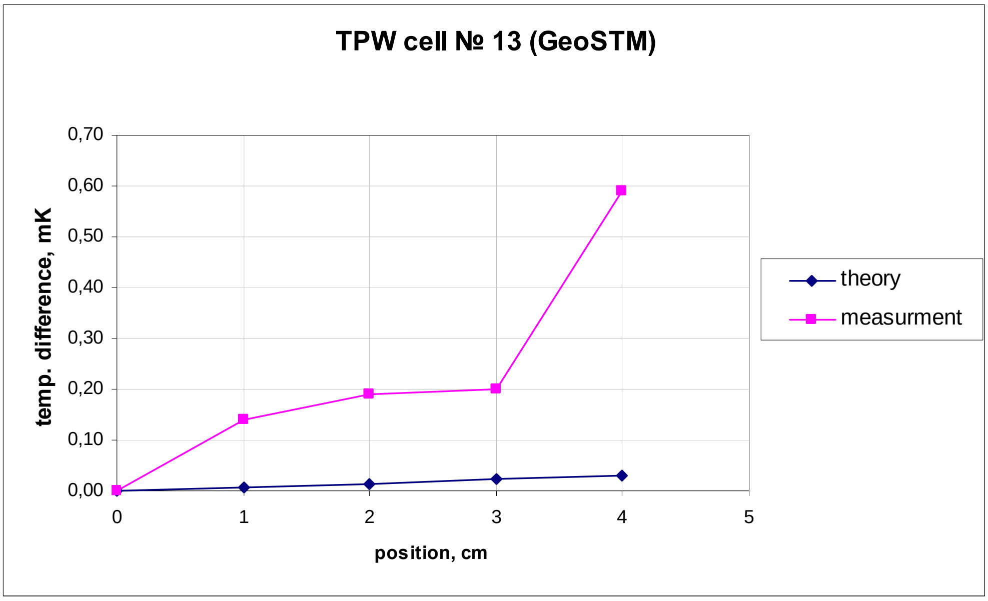

Figure 2

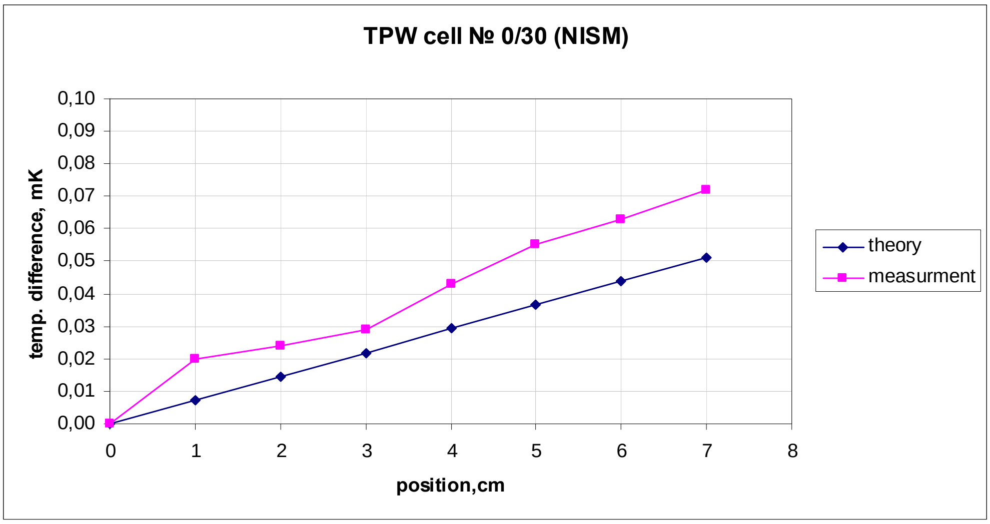

Figure 3

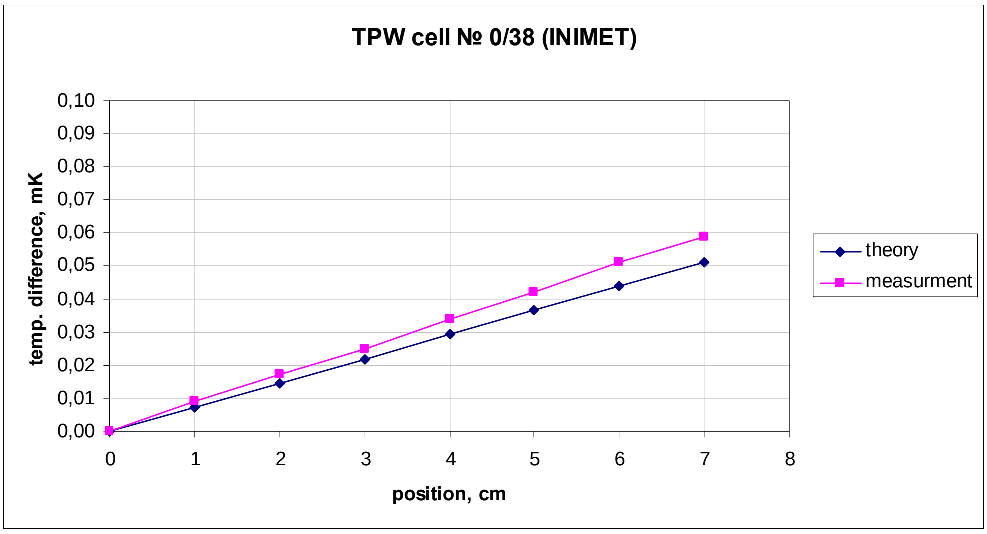

Figure 4

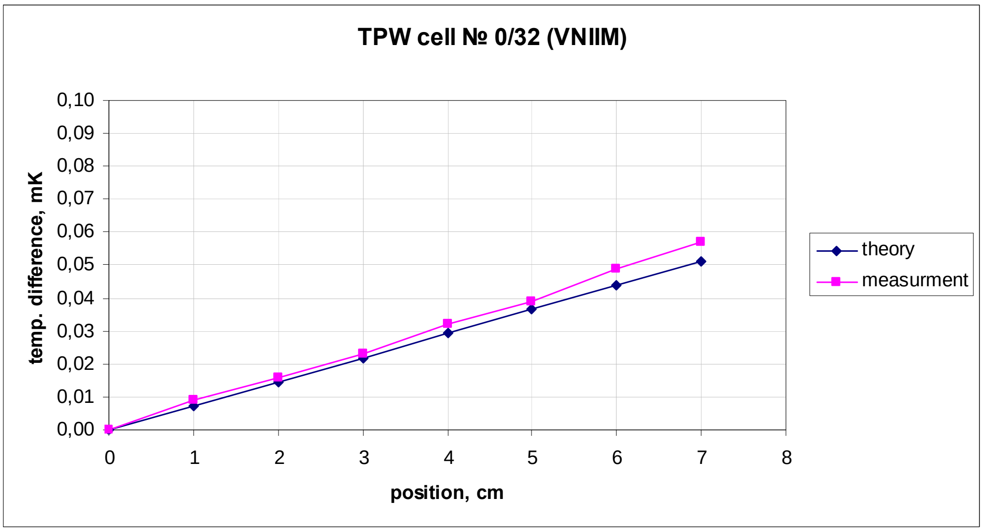

Figure 5

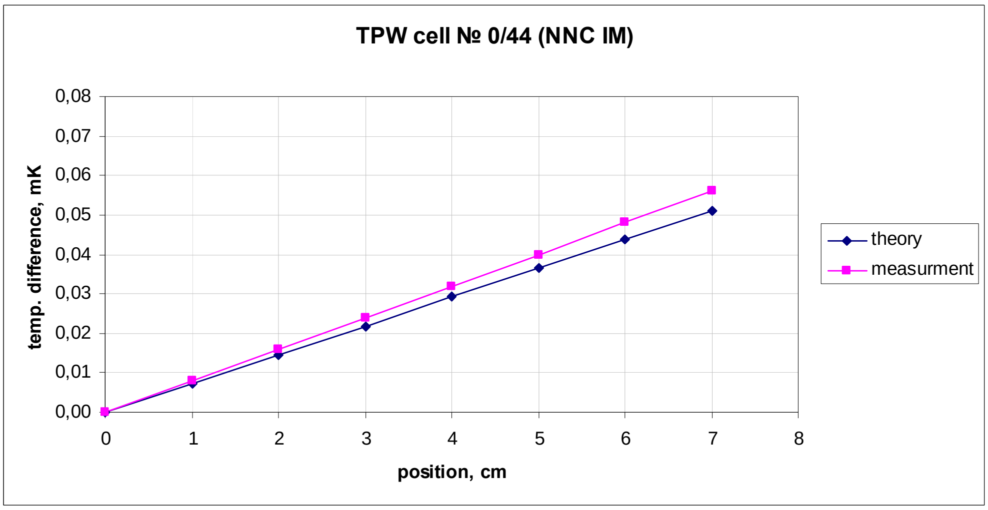

Figure 6

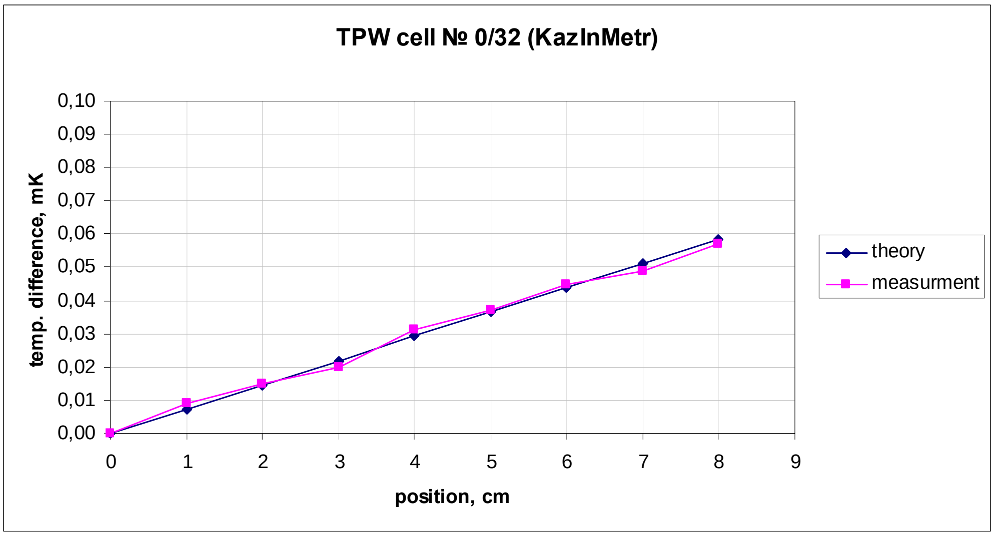

Figure 7

3 Comparisons of cells in BelGIM

3.1 BelGIM thermometry laboratory

At the second stage of comparisons transfer cells have been presented in BelGIM where they have been compared with the reference BelGIM cell.

For these comparisons BelGIM has chosen a TPW cell № 0/22 produced by VNIIM. Cell characteristics are presented in Table 6.

Table 6

Reference BelGIM TPW cell	
Production date	2007
Outer diameter	50 mm
Thermometer well diameter	15 mm
Depth of the thermometer well	250 mm
Immersion depth of the middle of the SPRT sensing element	235 mm

Figure 8 shows the scheme of equipment used for comparisons of TPW cells in BelGIM laboratory.

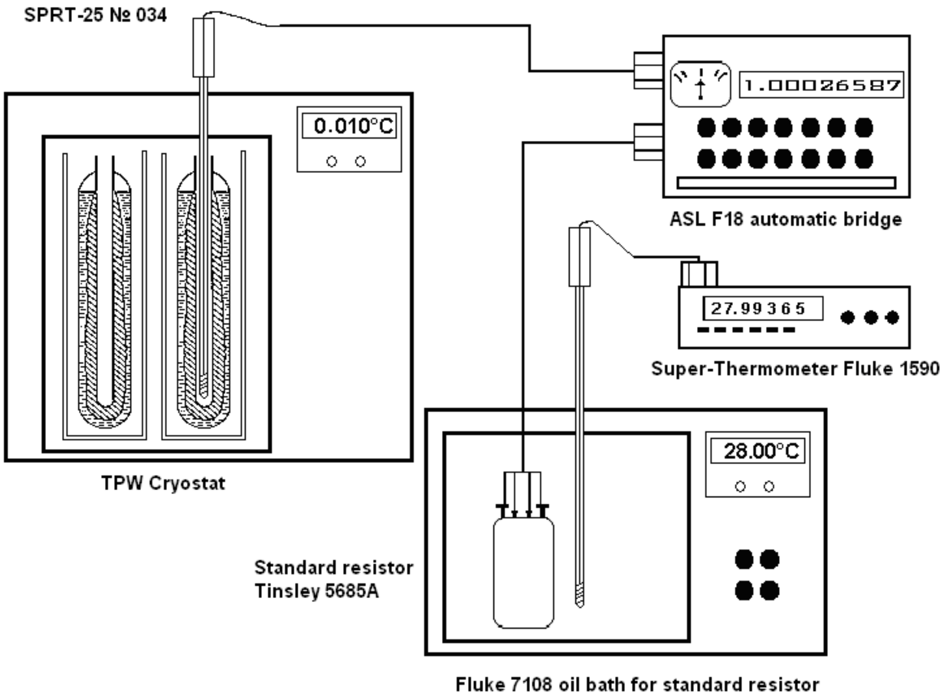

Figure 8

Cells were held in the thermostat "TPW Cryostat" that made it possible to place two cells simultaneously. Cryostat working medium is ethyl alcohol. Set temperature was 1-2 mK lower that the temperature of the TPW fixed point. Temperature measurement in the standard and transfer cells were performed with the help of standard platinum resistance thermometer SPRT-25 № 034 produced by Vladimir plant "Etalon" (Russia). By means of precision thermometric bridge ASL F18 there was measured thermometer resistance in relation to electrical resistance measure Tinsley 5685A with the nominal value 100 Ohm, immersed into temperature-controlled oil bath Fluke 7108. Thermostat temperature was controlled with the help of high-precision temperature gauge Super-Thermometer Fluke 1590 in combination with the standard resistance thermometer. Ambient temperature in the laboratory was supported with the deviation ± 1 °C .

3.2 Equipment characteristics evaluation

Before the performance of comparisons in BelGIM laboratory there has been conducted research of equipment used in measurements.

3.2.1 Evaluation of non-stability of the cryostat TPW

With the help of standard platinum thermometers SPRT-10 there were conducted measurements in the thermostat in order to support triple point water cells. Measurement results maintenance non-stability of the set temperature and temperature gradients horizontally and vertically are presented in Table 7.

Table 7

Non-stability of maintenance of the set temperature, °C	Horizontal temperature gradient, °C/cm	Vertical temperature gradient, °C/cm
0,002	0,00019	0,00024

3.2.2 Fluke 7108 thermostat temperature non-stability

A measure of electrical resistance used with the bridge F 18 was maintained in the oil thermostat at the temperature 28,00 °C. According to technical documentation of the manufacturer, non-stability of thermostat temperature maintenance makes ±0,004 °C. By means of high-precision temperature gauge Super-Thermometer Fluke 1590 in combination with the standard platinum thermometer, there was performed research of non-stability of thermostat temperature maintenance for several days. As a result, maximum temperature deviation from the set value made 0,002 °C.

3.2.3 Accuracy and linearity of thermometric bridge F 18

Before the beginning and in the process of comparisons there has been conducted examination of bridge F 18 with the help of two standard resistors with the nominal value 100 Ohm, which are component parts of the bridge. Deviation of measurement results didn't exceed tolerable values given in technical documentation for the bridge.

3.3 Results of cell measurements in BelGIM

Ice mantles have been frozen with the use of technology applied in BelGIM laboratory which is based on immersion into the thermometer well, filled with alcohol, of the rods cooled in liquid nitrogen. Direct comparisons for every mantle were performed at least in 4 days from the moment of freezing.

Before the beginning of each measurement a metal rod of room temperature was placed into the thermometer well. At the moment when the mantle started rotating freely round the thermometer well the core was removed.

Measurement of the temperature difference has been performed with two ice mantles frozen separately. In order to exclude the influence of thermometer non-stability, measurement of every temperature difference value between the cells was performed within the day.

In the process of conducting measurements the operator reads the data from F 18 bridge visually. Measurements have started in 20 minutes after installation of SRT into the cell thermometer well in order to secure temperature balance.

For every cell there was performed 3 cycles of measurements, each of which consisted of 10 measurements at the current of 1 mA, then 10 measurements at the current of 1,414 mA and again 10 measurements at 1 mA. Interval between every measurement made approximately 15 seconds. After changing the current operator was waiting for two minutes before making the first measurement record. All the readings of F 18 bridge were recorded in the protocol. Temperature in the oil thermostat was fixed at the beginning and at the end of every measurement cycle in order to maintain the temperature of the electrical resistance gauge.

Calculation of the temperature deviation for every NMI has been performed on the basis of the following formula

$$\left(T_T - T_{BelGIM}\right)_i = \left(R_{T_i} - R_{BelGIM_i}\right)/(dR/dT)_T \text{, mK} \tag{4}$$

where R_{T_i} – *i*-e resistance value of SPRT, measured in the transfer cell taking into account allowance for hydrostatic-head and self-heating effect, Ohm;

R_{BelGIM_i} – *i*-e resistance value of SPRT, measured in the reference BelGIM cell taking into account allowance for pressure and hydrostatic-head effect, Ohm;

$(dR/dT)_T$ – sensitivity index of SPRT at the water triple point, Ohm /K.

The average values of temperature deviations at two mantles have been calculated on the basis of the following formula

$$T_T - T_{BelGIM} = \sum_{i=1}^{n} \left(T_T - T_{BelGIM}\right)_i / n \tag{5}$$

where T_T – temperature in the transfer NMI cell;

T_{BelGIM} – temperature in the reference BelGIM cell;

n – number of measurements of temperature difference.

Evaluation of the total standard uncertainty of the obtained temperature mean deviations between the transfer and BelGIM reference cell for every NMI was calculated on the basis of the formula

$$u^2(T_T - T_{BelGIM}) = u^2{}_A + 2u^2{}_B \tag{6}$$

where u_A – standard uncertainty of the obtained mean value of temperature difference, evaluated according to type A;

u_B^2 – the sum of squares that constitute uncertainty, evaluated according to type B of uncertainty budget of cells measurement in BelGIM (Appendix 4)

The results of pair comparisons of cells, mean values of temperature difference and their total uncertainties are presented in Table 8.

Table 8

Measurement number	GeoSTM	NISM	INIMET	VNIIM	NNC IM	KazInMetr
The results of measurements of temperature deviations in BelGIM, $(T_T - T_{BelGIM})_i$, mK						
1	-0,14	-0,03	-0,05	-0,04	-0,03	-0,02
2	-0,15	-0,02	-0,03	-0,03	-0,02	-0,01
3	-0,15	-0,03	-0,04	-0,03	-0,04	-0,03
4	-0,16	-0,02	-0,02	-0,04	-0,03	-0,02
5	-0,12	-0,04	-0,03	-0,02	-0,05	-0,01
6	-0,15	-0,02	-0,04	-0,05	-0,03	-0,02
7	-0,15	-0,03	-0,02	-0,04	-0,04	-0,01
8	-0,14	-0,03	-0,05	-0,04	-0,04	-0,03
9	-0,11	-0,02	-0,03	-0,02	-0,02	-0,01
10	-0,15	-0,03	-0,04	-0,04	-0,04	-0,02
$T_T - T_{BelGIM}$, mK	-0,145	-0,030	-0,038	-0,032	-0,033	-0,013
u_A, mK	0,005	0,002	0,003	0,003	0,003	0,002
u_B, mK	0,030	0,030	0,030	0,030	0,030	0,030
$u(T_T - T_{BelGIM})$, mK	0,043	0,043	0,042	0,043	0,043	0,043

Calculation of the mean value between obtained deviations is performed according to the following formula

$$\Delta T_{mean} = \sum_{i=1}^{n} (T_T - T_{BelGIM})_i / n \qquad (7)$$

Deviations of the measurement results of each NMI from ΔT_{mean} were calculated on the basis of the formula

$$T_T - T_{mean} = (T_T - T_{BelGIM}) - \Delta T_{mean} \qquad (8)$$

Evaluation of standard uncertainties of the obtained temperature deviation values were calculated on the basis of the following formula

$$u^2(T_T - T_{mean}) = u^2(T_T - T_{BelGIM}) + u^2(T_T - T_{NMI}) \qquad (9)$$

where $u(T_T - T_{BelGIM})$ – total standard uncertainty of the obtained mean value of the temperature difference between the transferred and reference BelGIM cell;

$u(T_T - T_{NMI})$ – total standard uncertainty, presented by NMI (k=1), mK (Appendix 2).

The results are presented in Table 9 and figure 9.

Table 9

NMI	BelGIM	GeoSTM	NISM	INIMET	VNIIM	NNC IM	KazInMetr
ΔT_{mean}, mK	-0,042	-	-	-	-	-	-
$T_T - T_{mean}$, mK	0,042	-0,103	0,012	0,004	0,010	0,009	0,029
$u(T_T - T_{mean})$, mK	0,055	0,119	0,081	0,062	0,056	0,084	0,071

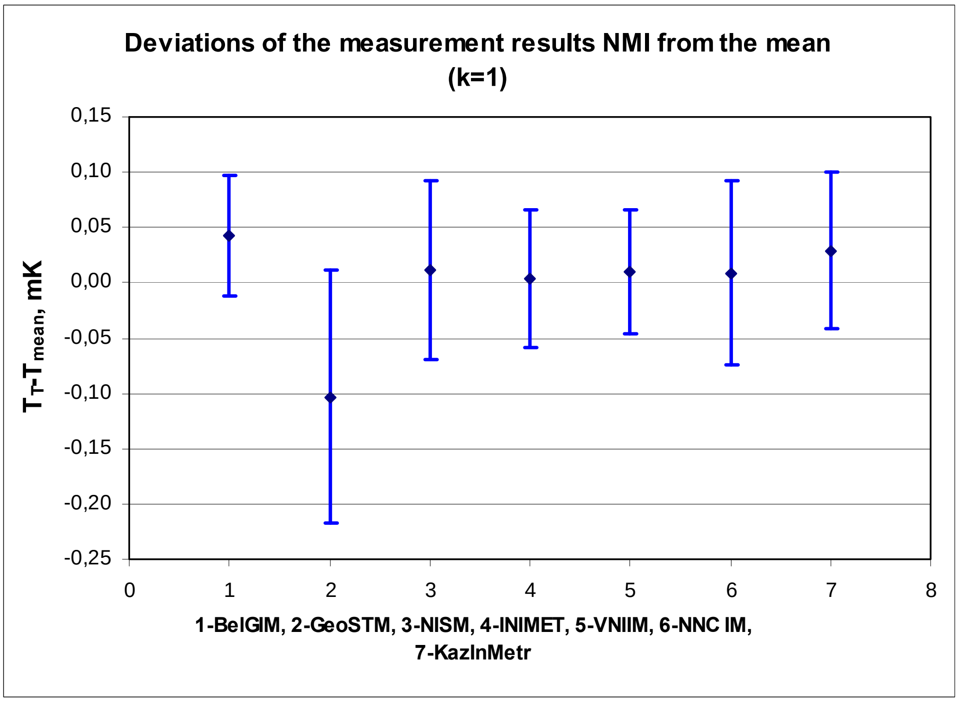

Figure 9

4 Determination of stability of the transfer cells

After the cells return from BelGIM, the laboratories performed measurements of stability of their cells by means of additional direct comparisons with national reference, using the same method as previously.

Non-stability of the transfer cell was calculated on the basis of the following formula

$$\Delta T_{non-st} = (T_T - T_{NMI})_1 - (T_T - T_{NMI})_2 \quad (3)$$

where $(T_T - T_{NMI})_1$ – mean value of temperature difference, obtained by NMI on the 1-2 mantles, mK;

where $(T_T - T_{NMI})_2$ – mean value of temperature difference, obtained by NMI on the 3 (4) mantle, mK;

Non-stability value shouldn't exceed 0,1 mK.

Measurement results presented by NMI are shown in Tables 10 – 14.

Table 10

The results of cells comparisons in NISM			
The third ice mantle		The fourth ice mantle	
Date	$(T_T - T_{NMI})_i$, mK	Date	$(T_T - T_{NMI})_i$, mK
01.11.2010	-0,036	15.11.2010	-0,044
02.11.2010	-0,018	16.11.2010	-0,022
03.11.2010	-0,050	17.11.2010	-0,034
04.11.2010	-0,021	18.11.2010	-0,024
05.11.2010	-0,027	19.11.2010	-0,042
$T_T - T_{NMI}$, mK	-0,032	-	-
ΔT_{non-st}, mK	0,005	-	-

Table 11

The results of cells comparisons in INIMET			
The third ice mantle		The fourth ice mantle	
Date	$(T_T - T_{NMI})_i$, mK	Date	$(T_T - T_{NMI})_i$, mK
26.10.2011	0,043	03.11.2011	0,057
27.10.2011	0,064	04.11.2011	0,044
28.10.2011	0,041	05.11.2011	0,062
29.10.2011	0,065	06.11.2011	0,054
30.10.2011	0,053	07.11.2011	0,051
$T_T - T_{NMI}$, mK	0,053	-	-
ΔT_{non-st}, mK	0,002		

Table 12

The results of cells comparisons in VNIIM			
The third ice mantle		The fourth ice mantle	
Date	$(T_T - T_{NMI})_i$, mK	Date	$(T_T - T_{NMI})_i$, mK
26.09.2011	0,024	03.10.2011	0,017
27.09.2011	0,012	04.10.2011	0,012
28.09.2011	0,027	05.10.2011	0,024
29.09.2011	0,017	06.10.2011	0,016
30.09.2011	0,012	07.10.2011	0,019
$T_T - T_{NMI}$, mK	0,018	-	-
ΔT_{non-st}, mK	0,000		

Table 13

The results of cells comparisons in NNC IM			
The third ice mantle		The fourth ice mantle	
Date	$(T_T - T_{NMI})_i$, mK	Date	$(T_T - T_{НМИ})_i$, мK
1	2	3	4
12.12.2011	0,040	19.12.2011	0,033
13.12.2011	0,031	20.12.2011	0,031
14.12.2011	0,032	21.12.2011	0,031
16.12.2011	0,029	22.12.2011	0,030
16.12.2011	0,031	23.12.2011	0,030
$T_T - T_{NMI}$, mK	0,032	-	-
ΔT_{non-st}, mK	0,004	-	-

Table 14

The results of cells comparisons in KazInMetr			
The third ice mantle		The fourth ice mantle	
Date	$(T_T - T_{NMI})_i$, mK	Date	$(T_T - T_{NMI})_i$, mK
15.08.2011	0,144	15.08.2011	0,134
16.08.2011	0,104	16.08.2011	0,121
17.08.2011	0,144	17.08.2011	0,147
18.08.2011	0,116	18.08.2011	0,136
19.08.2011	0,146	19.08.2011	0,124
$T_T - T_{NMI}$, mK	0,132	-	-
ΔT_{non-st}, mK	0,007	-	-

5 Results of regional comparisons of COOMET

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 the results of the regional COOMET comparisons with the results of key comparison CIPM; in this case with results of comparisons of the Consultative Committee on Thermometry CCT.T-K7.

5.1 Evaluation of the deviation of the weighed mean values (T_{wm}- T_{BelGIM}) and its uncertainty

The deviation of the weighed mean values $\Delta T_{wm}=T_{wm}-T_{BelGIM}$ and its standard uncertainty $u_{wm}(\Delta T_{wm})$ were calculated on the basis of the following formulas:

$$\Delta T_{wm} = \left(T_{wm} - T_{BelGIM}\right) = \frac{\sum_1^n \frac{\left(T_T - T_{BelGIM}\right)}{u^2\left(T_T - T_{BelGIM}\right)}}{\sum_1^n \frac{1}{u^2\left(T_T - T_{BelGIM}\right)}}, \quad u_{wm}{}^2 = \frac{1}{\sum_1^n \frac{1}{u^2\left(T_T - T_{BelGIM}\right)}} \tag{10}$$

Obtained results are presented in Table 15.

Table 15

NMI	$u(T_T\text{-}T_{BelGIM})$, mK	$\Delta T_{wm}=(T_{wm}\text{-}T_{BelGIM})$, mK	u_{wm}, mK
BelGIM	0,055	**-0,029**	**0,026**
GeoSTM	0,111		
NISM	0,081		
INIMET	0,062		
VNIIM	0,056		
NNC IM	0,084		
KazInMetr	0,071		

5.2 Deviations of NMI results from the weighed mean values ($T_{NMI} - T_{wm}$) and evaluation of their uncertainties

Upon determination of ΔT_{wm} calculation of deviation of standard NMI cells from the weighed mean value was performed. Taking into account deviations, presented by the participants, deviations of the results from the weighed mean value take the form

$$T_{NMI}-T_{wm}=(T_T-T_{BelGIM}) - (T_{wm} - T_{BelGIM})-(T_T-T_{NMI}) \tag{11}$$

Uncertainty of deviations of the measurement results performed by the participants from the weight mean value $u(T_{NMI} - T_{wm})$ was evaluated by the following formula

$$u^2(T_{NMI} - T_{wm}) =[u^2(T_T - T_{BelGIM}) + u^2(T_T - T_{NMI}) + u^2{}_{wm}] \tag{12}$$

The results of the obtained values $(T_{NMI} - T_{wm})$ and $u(T_{NMI} - T_{wm})$ are presented in Table 16 and Figure 10. Two continuous horizontal lines in the Figure reflect standard uncertainty $u_{wm}(\Delta T_{wm})$ of the weighed mean value.

Table 16

NMI	BelGIM	GeoSTM	NISM	INIMET	VNIIM	NNC IM	KazInMetr
$T_{NMI}\text{-}T_{wm}$, mK	0,029	-0,116	0,026	-0,064	-0,021	-0,040	-0,123
$u(T_{NMI}\text{-}T_{wm})$, mK	0,069	0,165	0,110	0,081	0,071	0,113	0,095
$U(T_{NMI}\text{-}T_{wm})$, mK	0,138	0,330	0,220	0,162	0,142	0,226	0,190

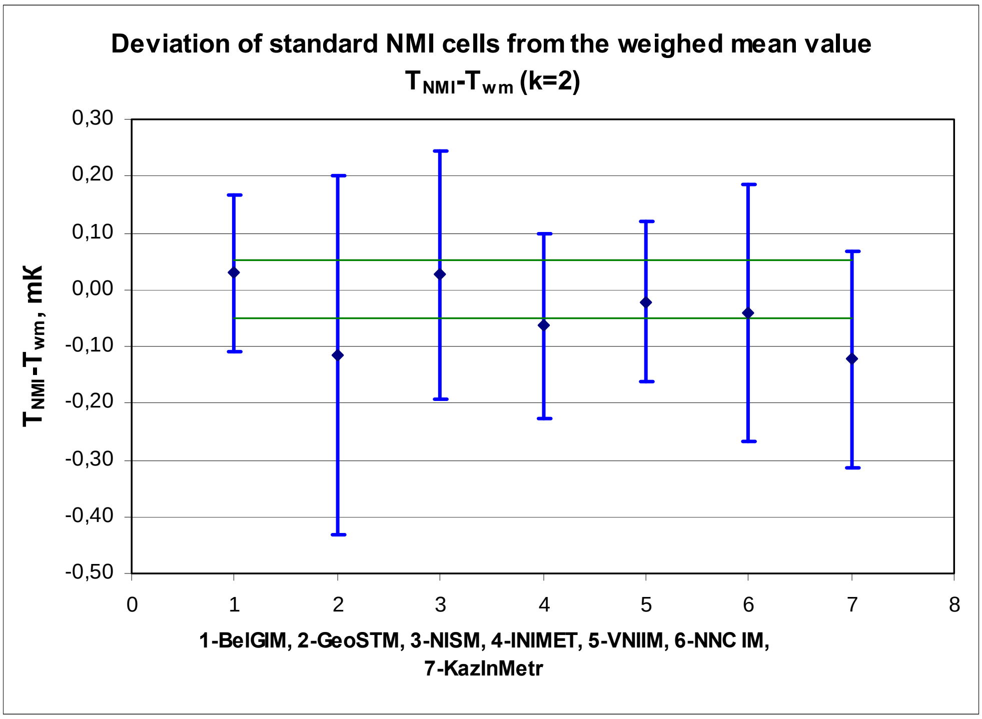

Figure 10

6 Calculation of the additive corrections and the degrees of equivalence of the triple point water cells standards in relation to the results of CCT.T-K7 key comparisons

One linking institute took part in comparisons – VNIIM.

Calculation of the additive corrections and the degrees of equivalence of standards was performed on the basis of the following formulas

$$\Delta = \frac{\sum_{i=1}^{L} \frac{\Delta_i}{S_i^2}}{\sum_{i=1}^{L} S_i^{-2}}, \qquad u^2(\Delta) = \frac{2}{\sum_{i=1}^{L} S_i^{-2}} \tag{13}$$

where $\Delta_i = [T_{LINK.NMI} - KCRV(CCT.K7)] - (T_{LINK.NMI} - T_{wm})$, additive correction,

S_i – is the standard deviation of the measurement results received by the linking NMI,

L – number of the linking NMI's,

$u(\Delta)$ – standard uncertainty of the additive correction.

The transformed result of the NMI measurement is equal to the sum of a result in COOMET comparisons and additive correction. As the results of key comparison K7 are represented as differences $[T_{NMI} - KCRV(CCT.T\text{-}K7)]$, the degree of equivalence *"d"* of NMI results is evaluated on the basis of the following formula

$$d_i = [T_{NMI} - KCRV(K7)] = (T_{NMI} - T_{wm}) + \Delta_i \tag{14}$$

Standard uncertainty of the obtained values *"d"* is evaluated on the basis of the formula

$$u^2(d) = u^2[(T_{NMI} - T_{wm})] + u^2(\Delta) \tag{15}$$

VNIIM result in CCT.T-K7 T_{VNIIM}-KCRV(CCT.T-K7) = 0 mK.

As a result, additive correction to the results of NMI for WTP cells is Δ = 0,025 mK, its uncertainty u(Δ)(k=1) =0,051 mK.

The transformed measurement result is equal to the sum of NMI measurement results in COOMET comparisons and additive correction.

Measurement results and their uncertainties are presented in Table 15.

Table 15

NMI	BelGIM	GeoSTM	NISM	INIMET	VNIIM	NNC IM	KazInMetr
T_{NMI}-KCRV(CCT.T-K7), mK	0,050	-0,095	0,047	-0,043	0,000	-0,019	-0,102
U(d_i), mK (k=2)	0,172	0,345	0,242	0,191	0,175	0,249	0,215

The differences [T_{NMI} – KCRV(CCT.T-K7)] and their uncertainties (k=2) are presented in Figure 11.

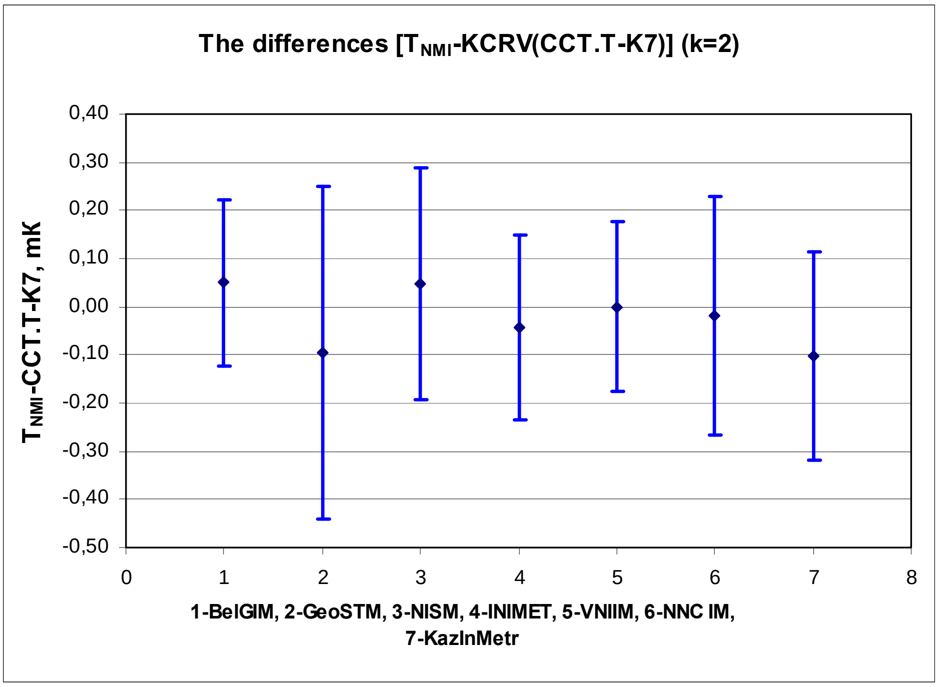

Figure 11

Conclusion

The uncertainties claimed by NMIs for CMC are considered as confirmed by the results of the regional comparisons, if the degree of equivalence "d" of the NMI result in comparison is less than the double value of its uncertainty ("Guide on evaluation of the COOMET key comparison data", COOMET.R/GM/14:2006)., i.e. the following inequation is realized: $|d| < 2u(d)$

This inequation meets the recognition criteria claimed by NMI uncertainties of CMC, stated in the protocol of the Working Group WG8 CCT "Inter-RMO CMC review committee 3-26-03".

As a result of analysis of the COOMET regional comparison results the following conclusions can be made:

1. Uncertainty of measurement assessments of TPW results, claimed by NMI, are confirmed by the results of COOMET comparisons.

2. Results of COOMET comparisons represent confirmation of uncertanties claimed by NMI for TPW while corresponding CMC row is provided.

Appendix 1

TECHNICAL PROTOCOL
on COOMET theme № 395/BY/07

"REGIONAL COMPARISONS OF THE TRIPLE POINT WATER CELLS OF THE NATIONAL STANDARDS OF TEMPERATURE"

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2010

CONTENTS

Introduction

Unit of measurement of the fundamental physical quantity, which is thermodynamic temperature, in the International System of Units (SI) is Kelvin (K) which is determined as 1/273,16 of water triple point temperature (TPW). TPW is also the main fixed point of the international temperature scale ITS–90 in which it is assigned the exact temperature value of 273,16 K, which secures coincidence of the thermodynamic and practical scales at this temperature. In ITS-90 scale the main value used for temperature calculation, measured with the help of the standard platinum resistance thermometer (SPRT) within the range from 13.8033 K to 1234.93 K is W(t) – the relation of its resistance at the measured temperature to the resistance at the TPW temperature. Consequently, accuracy and reproducibility of the temperature scale on the whole is determined by means of accuracy of reproduction of TPW temperature.

The decision about the performance of regional comparisons was caused by the necessity to evaluate the equivalence of national standards of COOMET members.

The following institutions participate in the COOMET comparisons: 1 national metrology institutes FSUE "VNIIM – D.I.Mendeleyev" (the Russian Federation), included ICWM into key comparisons CCT-K3, CCT-K4 and CCT-K7 as well as 6 national metrology institutes: RUE "Belarusian State Institute for Metrology" (the Republic of Belarus), National Research Centre "Institute for Metrology" (Ukraine), RSE "Kazakhstan Institute for Metrology" (the Republic of Kazakhstan), National Institute of Metrology and Standardization (the Repulic of Moldova), National Agency of Georgia for Standards, Technical Regulations and Metrology (Georgia), INIMET (Cuba).

All the participants of comparisons shall act in accordance with the instruction given below. Each laboratory during the comparisons shall apply the adopted realization practice of the ITS-90.

The instruction is compiled in compliance with Appendix 1 to the Report on the key comparisons CCT.T-K7. The comparisons carefully follow the protocols given in the Guidence 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”.

BelGIM (RB) is a coordinator of regional comparisons.

Regional comparisons within COOMET assume comparisons of ITS-90 realization at the triple point water with the use of standard platinum resistance thermometers.

The scheme of comparisons will be carried out with the use of transfer comparison standards – cells for realization of water triple point which will be presented to the coordinator and compared with the standard BelGIM cell on the basis of National Temperature Standard of the Republic of Belarus with the use of equipment of this national standard.

Comparisons include three stages:

The first stage

Each laboratory-participant selects one of the cells as a transfer one and compares it with its national reference cell.

The second stage

The transfer cell is sent together with the measurement results to BelGIM where all transfer cells are compared with the base cell.

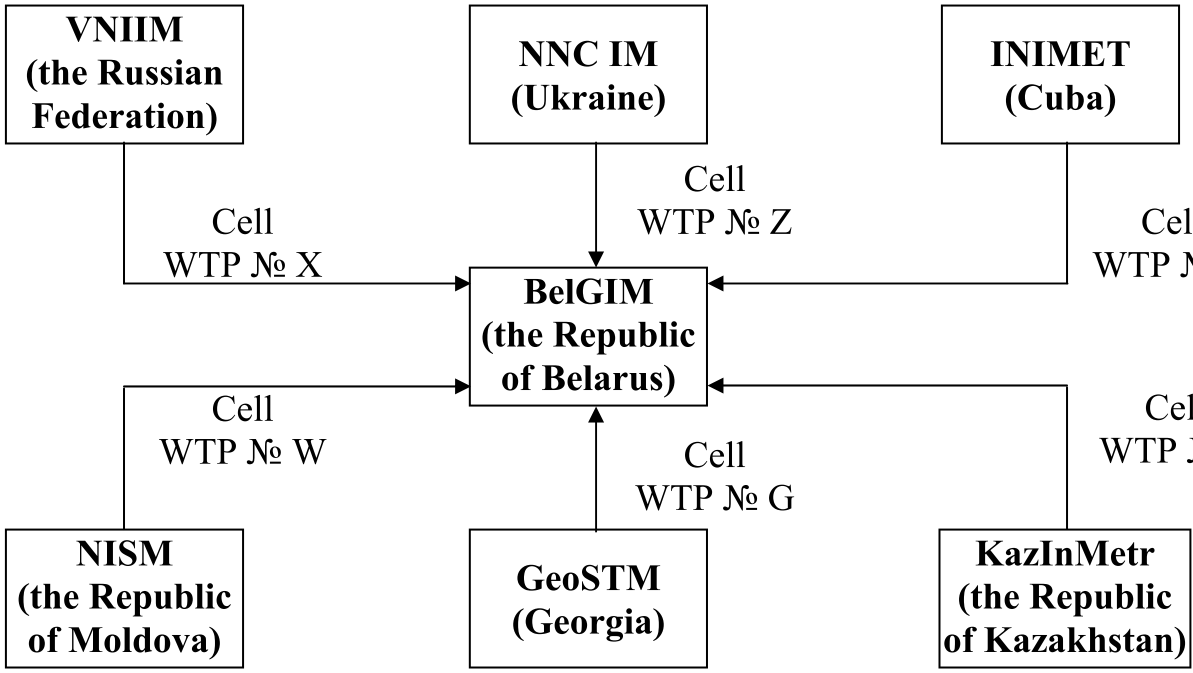
The third stage

Transfer cells were returned to the laboratories where they are again compared with the national reference cell in order to determine the stability of the transfer cell.

Each laboratory is responsible for submitting the cells to the coordinator.

BelGIM will calculate the difference in results of the laboratories as well as uncertainties, related to differences of results.

1 Scheme of the comparisons



2 Laboratories – participants of comparisons

The Republic of Belarus
Republican Unitary Enterprise
"Belarusian State Institute for Metrology"
(BelGIM)
Starovilensky trakt 93
220053, Minsk
The Republic of Belarus

The Russian Federation
FSUE "VNIIM – D.I.Mendeleyev"
(VNIIM)
Moskovsky pr., 19
190005, St. Petersburg
the Russian Federation

Ukraine
NNC IM – National Research Centre "Institute for Metrology",
Mironositskaya str., 42, 61002,
Kharkov, Ukraine.

The Republic of Moldova
National Institute for Metrology and Standardization
(NISM)
MD-2064, Kishinev, Kock str., 28
the Republic of Moldova

The Republic of Kazakhstan
The Republican State Enterprise SE "Kazakhstani Institute for Metrology", “KazInMetr”
010000, Astana, Levy Bereg, 35 str., building 11
the Republic of Kazakhstan

Georgia
National Agency of Georgia for standards, technical regulations and metrology, (GeoSTM)
Georgia, 0141 Tbilisi, Chargalskaya str., 67

Cuba
National Research Institute for Metrology (INIMET).
Consulado 206, CP 10200, Havana, the Republic of Cuba.

3 Time schedule of the comparisons

Table 1

Period	Task	Laboratory
June, 1-30 2009	Preparationof the base WTP cell	BelGIM
1 July - September, 2009	Comparison of the transfer WTP cells with national standards	VNIIM,NNC IM, "KazInMetr", NISM, GeoSTM, INIMET
October 01-30, 2009	Submittal of transfer cells into BelGIM	VNIIM,NNC IM, "KazInMetr", NISM, GeoSTM, INIMET
November 01, 2009 – April 30, 2010	Performance of comparisons of the transfer WTP cells with the base cell	BelGIM
January 01 - May 31, 2010	Submittal of the transfer cells into laboratories, perfoming comparison with national standards	VNIIM,NNC IM, "KazInMetr", NISM, GeoSTM, INIMET
December 01, 2009 – June 31, 2011	Processing the comparison results	BelGIM

4 Selection of the transfer cells

Cells, selected for these comparisons, should be thoroughly checked. Characteristics of the **transfer** cell shall not considerably differ from those of the base cell or the cells used in this National Metrological Institute. The cell, whose quality is doubtful and doesn’t meet the requirements of the test procedure, given below, shall not be used.

The cells undergo the following test which will be repeated in the process of acceptance of the cells in BelGIM:

- water should not contain visible floating substances;

– while leaning the cell smoothly there should be heard a sharp click which signifies a low level of air content.

BelGIM reserves the right to reject transfer cells that do not meet the minimal requirements of selection during their acceptance.

Laboratories that wish to send cells with nonstandard size, for example, with the length that exceeds 50 cm, should notify about it in advance.

5 Instructions on measurements

Before sending cells to BelGIM it is necessary to perform the following actions:

– the cell should be thoroughly selected in accordance with the criteris in c.4;

– the cell should be compared with the national standard cell.

Measurements shall be performed with two ice mantles, frozen separately. For every ice mantle there have been conducted direct comparisons with the base cell within one week, one measurement per day. Measurements should be started at least in 4 days upon freezing the ice mantle. For every mantle at least 5 measurements are performed, the results are recorded in a special form (Appendix A). Measurement procedure should correspond to practice applied by this laboratory.

– for every transfer cell it is necessary to perform measurements of the temperature pattern profile in order to guarantee that the measurements really depend on the temperature of phase division ice/water. Measurements are to be conducted successively upward with the step 1 cm up to the level 10 cm below water surface. For every position it is necessary to determine and apply the correction for self-heating with measuring current. It is also necessary to indicate the position of the sensitive element which was applied in the process of comparison with base cell (Appendix B). This information shall be presented graphically.

When the cell comes back from BelGIM, it is necessary to confirm the cell stability with the help of an additional comparison with the national reference cell.

6 Presenting results

Each participating laboratory shall submit their report on measurements to BelGIM together with the cell which includes:

– the results of daily measurements, obtained at two separately frozen mantles. Allowances for self-heating with measuring current (reducing to zero current) and hydrostatic-head effect shall be reflected in the measurement results, corrections for the transfer cell are also communicated separately. On the basis of this data set there shall be determined deviation of the transfer cell from the national standard cell;

– immersion profile of the transfer cell which reflects location of the sensitive element at the moment of calibration performance (chart) Appendix B;

– uncertainty budget of temperature realization of the transfer cell. This budget shall include uncertainty of the national standard (realization uncertainty) and direct comparisons of the transfer cell with the standard one. A model of uncertainty budget is presented in Appendix C;

– equipment used for graduation: the description of national standard, ice mantle freezing technique, the type of device for supporting WTP cell, thermometer type, type of bridge for resistance measurement (AC or DC), type of the standard resistance gauge and availability of temperature regulation, date of purchase or manufacturing of the standard cell and transfer cell, measuring currents, duration (age) of the mantle of the standard cell. If possible, isotopic composition or analysis of admixtures.

The Form for filling in this information is given in Appendix A.

After the cells return from BelGIM, the laboratories shall perform measurements of stability of their cells by means of additional direct comparisons with national reference, using the same method as previously. If the cell proves its stability, this information shall be submitted to BelGIM. Only in this case measurements performed before sending the cell to BelGIM will be used. If there was detected a slight but considerable drift, the laboratory shall send new results within 6 months to BelGIM, in the same form as previously and a new final cell temperature value will be determined on the basis of all measurements. If the cell non-stability is not detected ($\Delta T > 100$ μK, or criteria set by the participating laboratories before the beginning of comparisons), the laboratory shall inform BelGIM as soon as possible but not later than 3 months prior to the beginning. If additional measurements are not performed at the scheduled time, only the first result will be recorded for the information processing.

7 Measurements in BelGIM

All the cells, sent to BelGIM, will be compared with the national BelGIM cell. Ice mantle will be frozen with the use of technology applied in BelGIM laboratory which is based on immersion into the cell thermometer well, filled with alcohol, of the stems cooled in liquid nitrogen. Cells were held in the thermostat "WTP Cryostat" that makes it possible to place two cells simultaneously. For every cell there will be frozen two ice mantles separately. Direct comparisons for every ice mantle will be conducted within a week (5 working days), in 4 days from the moment of freezing the mantle.

COOMET measurements report form sheet № 395/BY/07

Laboratory:____

Contact person: ______________________________________

Contact address, e-mail: _________________________________

____

Ttransfer cell: № and type: ______________________________

Date of purchase or manufacture: __________________________

Measurement results of the first ice mantle

Date of first preparation of ice mantle: _________________________

Date of first preparation of ice mantle: _________________________

Technique for preparation: ______________________________

____

Age of mantle of reference cell: ____________________________

Date of measurement	Temperature difference from national reference	Hydrostatic head correction for transfer cell	Self-heating correction for transfer cell
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

The temperature differences should already be corrected for hydrostatic-head and self-heating effects. To allow comparison with our measurements, the corrections should also be given separately.

Measurement results on second ice mantle

Date of the second freezing of the ice mantle: ______________________________

Technique for preparation: ____

____

Age of mantle of reference cell: ____

Date of measurement	Temperature difference from national reference	Hydrostatic head correction for transfer cell	Self-heating correction for transfer cell
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

The temperature differences should already be corrected for hydrostatic-head and self-heating effects. To allow comparison with our measurements, the corrections should also be given separately.

Resulting temperature difference between transfer cell and national reference: _____

____

Equipment used for calibration

Description of the national standard (1 or several cells, date of purchase or manufacture): ____

Bridge type for measuring resistance, AC or DC: ______________________________

Measuring current: ____

Type of resistance standard gauges: ___________________________________

Temperature control of resistance gauges (yes, no), if yes, stability: ______________

Thermometer type, the length of the sensitive element: ________________________

A device for WTP cell support: ____

Field profile (only for the transfer cell)

Distance from the middle part of the sensitive element to the surface of water in the cell	Temperature changes

The above table is for reporting measurement of the hydrostatic head effect. Thermometer readings should be corrected for self-heating, measured at each position.

Uncertainty budget

Source	Input (k=2)
National reference	
(Uncertainties related only to properties of the reference cell)	
Chemical impurities	
Isotopic variation	
Residual gas pressure in cell	
Reproducibility [1]	
Comparison of transfer cell to national reference	
(Uncertainties related to the comparison of the two cells)	
Repeatability for a single ice mantel (incl. bridge noise) [2]	
Reproducibility for different ice mantles [3]	
Reproducibility for different types of SPRTs [4]	
Hydrostatic head of standard cell	
Hydrostatic head of reference cell	
Self-heating of standard cell and reference cell [5]	
Perturbing heat exchanges [6]	
others	
……………….	
Total uncertainty	

[1] It is possible to evaluate reproducibility of standard temperature taking into account changes of the following values:
- size of ice mantle;
- duration (age) of ice mantles;
- difference between separate mantles;
- treating cells before freezing mantles.

[2] Under the repeatability in the process of realization of one ice mantle one should understand standard deviation of daily experimentally obtained differences of temperatures between the transfer cell and the cell of national standard, divided by the square root of the number of daily measurements results (usually 5). This component is also used in calculating the stability of the standard resistance gauges (temperature effect).

[3] Reproducibility for different ice mantles is an additional component of uncertainty which is taken into account in the process of measurements at different separately frozen

ice mantles of the transfer cell (sometimes laboratories use one and the same ice mantle for all the measurements).

[4] Evaluation of temperature differences between the transfer cell and the national standard can also depend on the SPRT type. This component takes into consideration possible defects of SPRT internal insulation.

[5] These components are strongly correlated positively. All measurements contain allowance for self-heating with measuring current. If thermal resistance in the transfer cell and the cell of national standard has approximately the same value, difference between corrections for self-heating with measuring current is very small. At the same time, corrections for self-heating with measuring current in the transfer cell and the cell of national standard are strongly correlated. In this case, these components are negligible.

[6] This component of uncertainty arises due to heat removal on the thermometer, because of thermal resistance of walls and layers between the thermometer and phase ice/water boundary. Availability of this component of uncertainty is proved by the deviation of temperature dependence on the depth of thermometer immersion from expected hydrostatic dependence, change in thermometer readings in case of changing the conditions of thermometer heat exchange with the environment.
Evaluation of uncertainty can be obtained from the results of experimental tests, in case of changes of SPRT immersion depth per height of sensitive element ≈ 5 cm.

Appendix 2

Table 1

NMI	GeoSTM	NISM	VNIIM	NNC IM	KazInMetr	INIMET
1	2	3	4	5	6	7
Bridge for measuring resistance	Potentiometer					Comparator
Manufacturer	Krasnodar ZIP	Measurements International Inc.	ASL	Spetsavtomatika, Ukraine	ASL	Krasnodar ZIP
Type	P 3003	model 6010C	F 900	CA300-1	F 18	P 3017
Alternative Current or Direct Current (AC or DC)	DC	DC	AC	AC	AC	DC
Norm. Measur. Current	1 mA	1 mA	1 mA	1 mA	1 mA	1 mA
Overheat current	1 414 mA	1 414 mA	1 414 mA	1 414 mA	1 414 mA	1 414 mA
Standard resistance gauge						
Manufacturer	Krasnodar ZIP	Tinsley	ZIP «Nauchpribor» Russia	Tinsley	ZIP «Nauchpribor» Russia	ZIP «Nauchpribor» Russia
Type	P 3030	model 5685A, 100 Ohm	MC 3020	5685A 100 Ohm	P 321	MC 3020
Gauge temperature control (yes, no)	yes	yes	yes	yes	no	yes
Stability	–	± 0,005 °C	0,01 °C	0,01 °C	–	0,01 °C

Continuation of Table 1

1	2	3	4	5	6	7
Standard platinum resistance thermometer						
Manufacturer	3-d Etalon, Russia	Fluke	VNIIM	3-d Etalon, Russia	3-d Etalon, Russia	–
Type	PTS-25	model 5681	ETS	PTS-25	PTS-10	–
The length of the sensitive element	–	44 mm	36 mm	50 mm	40 mm	–
TPW cell«						
Transfer standard						
Manufacturer	VNIIM	VNIIM	VNIIM	VNIIM	VNIIM	VNIIM
Date of purchase or manufacture	1983	2008	2008	2011	2008	2010
Outer diameter	50 mm	50 mm	50 mm	50 mm	50 mm	50 mm
Diameter of the thermometer well	16 mm	15 mm	15 mm	16 mm	16 mm	15 mm
Depth of the thermometer well	167 mm	250 mm	250 mm	250 mm	250 mm	250 mm
National reference						
Manufacturer	–	Hart Scientific	VNIIM	–	Hart Scientific, VNIIM	–
Date of purchase or manufacture	–	2008	3 WTP cells, manufactured in 2006, 2007 and 2008.	1996	2 WTP cells, manufactured in 2008 and 2010.	2002
Freezing technology	CO2	CO2	rod, cooled in liquid nitrogen	rod, cooled in liquid nitrogen	LN2	rod, cooled in liquid nitrogen
Thermostat for TPW support	thermostat with ice	FLUKE, model 7312	FLUKE, model 7312	thermostat with ice	FLUKE, model 7312	Dewar flask with ice

Appendix 3

Budget of uncertainties of temperature difference measurement of the transfer and national cells

Table 1

NMI	BelGIM	GeoSTM	NISM	INIMET	VNIIM	NNC IM	KazInMetr
Source	**Input (k=2), mK**						
National reference							
(Uncertainties related only to properties of the reference cell)							
Chemical impurities							
Isotopic variation			0,010	0,001	0,001	0,050	0,007
Residual gas pressure in cell			0,005	0,002	0,002	–	0,002
Reproducibility			0,050	0,060	0,050	0,023	0,100
Comparison of transfer cell to national reference							
(Uncertainties related to the comparison of the two cells)							
Repeatability for a single ice mantel (incl. bridge noise)	0,012	0,203	0,010	0,011	0,006	0,010	0,009
Reproducibility for different ice mantles	0,040	0,030*	0,050	0,040	0,040	0,031	0,040
Reproducibility for different types of SPRTs	0,030		0,060	0,030	0,030	–	0,030
Correction for hydrostatic-head effect in the reference cell			0,005	0,002	0,002	0,002	0,002
Correction for hydrostatic-head effect in the transfer cell	0,004	0,004	0,005	0,002	0,002	0,002	0,002
SPRT self-heating in the transfer cell and reference cell	0,020	0,070*	0,010	0,010	0,006	0,012	0,017
Perturbing heat exchanges	0,040	0,048	0,100	0,040	0,002	0,03	0,002
other						0,006	
Total uncertainty	0,068	0,222	0,137	0,089	0,071	0,072	0,114

*evaluations are achieved on the basis of measurement protocols, provided by GeoSTM

Appendix 4

Budget of uncertainties of TPW cells measurements in BelGIM

Table 1

NMI	**GeoSTM**	**NISM**	**INIMET**	**VNIIM**	**NNC IM**	**KazInMetr**
Source	**Input (k=1) mK**					
Reproducibility of values	0,005	0,002	0,003	0,003	0,003	0,002
Component due to correction for hydrostatic-head effect	0,002	0,002	0,002	0,002	0,002	0,002
Component due to correction for self heating	0,011	0,006	0,011	0,008	0,006	0,011
Component due to deviation from thermal equilibrium	0,024	0,021	0,021	0,020	0,019	0,018
Component due to nonlinearity of the bridge	0,014	0,014	0,014	0,014	0,014	0,014
Component due to the value of reference resistance taking into account temperature instability	0,016	0,016	0,016	0,016	0,016	0,016
Total uncertainty	0,034	0,031	0,032	0,030	0,030	0,031
Expanded uncertainty (k=2)	0,069	0,062	0,064	0,061	0,059	0,061