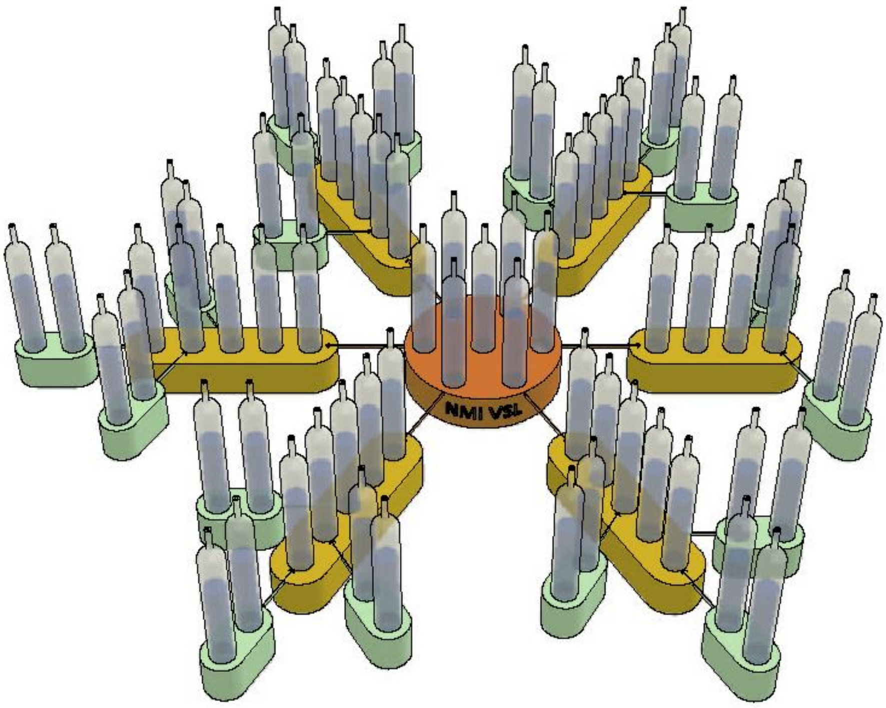

Report to the CCT on Key Comparison EUROMET.T-K7

(EUROMET Project 899)

Key comparison of water triple point cells

Prepared by
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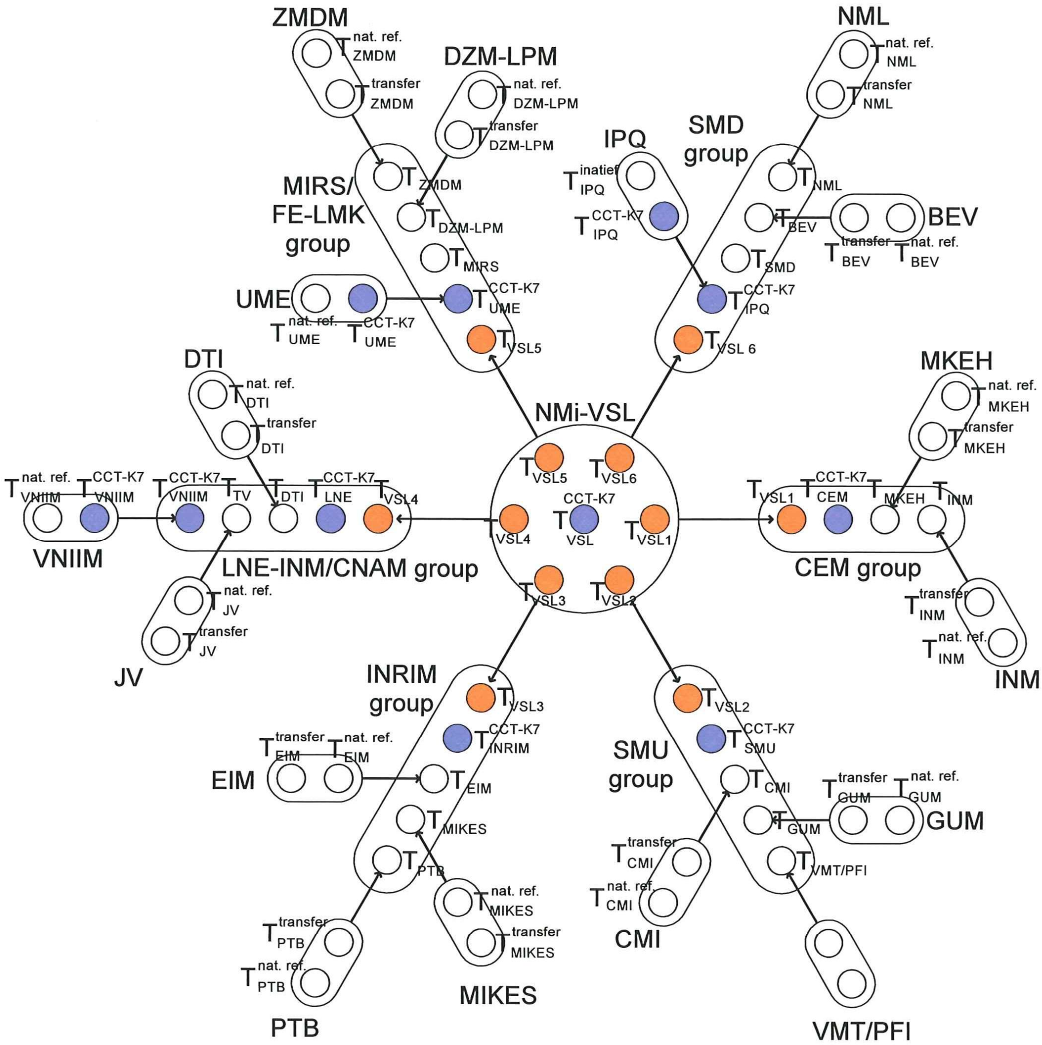
NMi van Swinden Laboratorium

Final Report (November 2008)



CCT-K7 transfer cell

NMi-VSL transfer cell

non-co-pilot transfer cell

1. ORGANIZATION OF THE COMPARISON

INTRODUCTION

This is the report of EUROMET.T-K7 comparison of water triple point cells, regional extension of CIPM key comparison CCT-K7.

The decision to initiate this comparison was taken during the 2005 meeting of EUROMET Thermometry Technical Committee (Vienna, April 2005). In the same occasion, NMi VSL was charged with organizing the comparison, with support from co-pilot insitutes CEM (Spain), INRIM (Italy), LNE-INM/CNAM (France), MIRS/FE-LMK (Slovenia), SMD (Belgium) and SMU (Slovakia).

The final version of the corresponding protocol (see Appendix 1) was submitted to CCT WG7 for approval in May 2006 and declared approved by WG7 in June 2006.

The measurements were started in July 2006 and finalized in November 2007. All participants reports were delivered before the end of December 2007.

1.2 PARTICIPANTS, ROLES AND GROUPS

A total of 24 institutes took part in the comparison (see the list of participants and corresponding contact persons details in Appendix 2).

With the exception of the pilot (NMi VSL), the participants were divided in 6 groups, each one of them including one co-pilot as follows (bold characters for co-pilots):

1. **CEM**, MKEH, INM
2. CMI, GUM, **SMU**, VMT/PFI
3. EIM, **INRIM**, MIKES, PTB
4. DTI, JV, **LNE-INM/CNAM**, VNIIM
5. DZM-LPM, **MIRS/FE-LMK**, UME, ZMDM
6. BEV, IPQ, NML, **SMD**

Only one technically-based constraint was imposed on the group composition: to have at least one CCT-K7 participant within each group.

1.3 COMPARISON METHOD

The comparison was divided into two parts:

- **Part 1** (see following points 1.1 to 1.7) in which the link to CCT-K7 was re-established for the pilot and co-pilot participants by using the CCT-K7 transfer cells in combination with the NMi-VSL transfer cells.
- **Part 2** (see following points 2.1 to 2.6) in which the link to CCT-K7 was established for all the participants.

Part 1

1.1 NMi-VSL selected a set of 6 transfer cells of known isotopic composition (which in the following will be designated as *NMi-VSL transfer cells*).

1.2 NMi-VSL compared the 6 *NMi-VSL transfer cells* with its *national reference* and its *reference cell for the comparison* (the one that was used as transfer cell during CCT-K7).

1.3 One *NMi-VSL transfer cell* was transferred to each one of the 6 co-pilots laboratories.

1.4 Each participant laboratory selected one *transfer cell* for the comparison. The laboratories that had participated to CCT-K7 (except for PTB) adopted as *transfer cell* for this comparison the same cell that they used as transfer cell in CCT-K7.
1.5 The non-copilot laboratories that had participated to CCT-K7 (IPQ and UME) compared the selected *transfer cell* to their own national reference (cell or group of cells).
1.6 The non-copilot laboratories that had participated to CCT-K7 (IPQ and UME) delivered the selected *transfer cell* to the assigned co-pilot.
1.7 The copilot laboratories that had participated to CCT-K7 (CEM, INRIM, LNE-INM/CNAM and SMU) compared the received *NMi-VSL transfer cell* with the cell they had used as transfer cell in CCT-K7 and with their national reference. The copilot laboratories that had not participated to CCT-K7 (MIRS/FE-LMK and SMD) compared the following cells: the received *NMi-VSL transfer cell*, the transfer cell of the non-copilot laboratory that had participated to CCT-K7, the local transfer cell and the local national reference.

Part 2
2.1 Each non-copilot laboratory that had not participated to CCT-K7 compared its selected *transfer cell* to its own national reference (single cell or group of cells).
2.2 Each non-co-pilot laboratory that had not participated to CCT-K7 delivered the selected transfer cell to the assigned co-pilot.
2.3 Each co-pilot measured the group of cells formed by: its own *transfer cell*, the *NMi-VSL transfer cell* and the assigned non-co-pilot's *transfer cells* (with a maximum of three non-copilot transfer cells).
2.4 The co-pilot delivered the *NMi-VSL transfer cell* back to NMi-VSL and the non-copilot labs retrieved their respective transfer cells.
2.5 Each non-co-pilot participant laboratory re-compared the received cells to its national reference.
2.6 NMi-VSL re-compared the *NMi-VSL transfer cells* to its national reference.

1.4 TRANSFER CELLS

The transfer cells selected by each participant are presented in Table I. The designations adopted in this report differ in many cases from those used by the laboratories because a uniform labelling system was adopted here for convenience. Each cell is identified here by the acronym of the laboratory owning the cell, followed by a serial number.

The protocol required the transfer cells to be carefully selected by the owning participant on the basis of a number of selection criteria, and allowed the co-pilot laboratories to reserve the right to reject transfer cells not meeting the selection criteria.

The co-pilot laboratories accepted all the submitted transfer cells. In one case, the owning laboratory (EIM), after having delivered its transfer cell to the copilot laboratory, decided to withdraw it and replace it with another one because EIM found it to be 0.3 mK lower than the national reference. This deviation from the protocol was accepted because the co-pilot laboratory had not started measuring the cells yet.

Each participant was asked to provide an immersion profile of its transfer cell. In addition, the pilot and the co-pilots were asked to provide an immersion profile of the measured NMi-VSL transfer cells. The measured profiles are reported in Appendix 3.

Laboratory	**Cell designation in this report**	**Manufacturer or type**	**Model**	**Year of fabrication or purchase**	**Accessories or comments on special use**	**Inner diameter of well /mm**	**Cell diameter /mm**	**Depth of well below water surface /mm**
BEV	BEV-332	Isotech	B11	2004	-	11	64	262
CEM	**CEM-2030**	Isotech	A11	1999	foam	11	50	270
CMI	CMI-1038	NPL	32	1999	-	11	50	272
DZM-LPM	DZM-4	Isotech	E11	2003	-	13	50	260
DTI	DTI-0199	Jarret	A11	1987	1 mm foam	11	51	298
EIM	EIM-997	NPL	32	1999	-	12	40	220
GUM	GUM-957	NPL	32	1998		12	40	220
INM	INM-5016	Hart Scientific	5901A-Q	2006	-	12	50	252
INRIM	**INRIM-1322**	Hart Scientific	5901	2002	bushing and sponge	12	60	260
IPQ	**IPQ-2114**	Jarret	A11	2000	-	11	50	270
JV	JV-1026	Hart Scientific	5901D-Q	2006	-	12	60	265
LNE-INM/CNAM	**LNE-6**	UME	-	1996	-	11	41	260
MIKES	MIKES-1449	Hart Scientific	5901	2005	-	12.7	60	310
MIRS/FE-LMK	MIRS-002	NMi-VSL	Quartz 3	2006	bushing	9	56	280
MKEH	MKEH-092	NMi-VSL	Borosilicate	2000	-	9	56	250
NMi-VSL	**NMi-094**	NMi-VSL	Borosilicate 3	1998	foam	9	56	248
NMi-VSL	NMi-029	NMi-VSL	Borosilicate 3	2004	foam	9	56	266
NMi-VSL	NMi-030	NMi-VSL	Borosilicate 3	2004	foam	9	56	280
NMi-VSL	NMi-032	NMi-VSL	Borosilicate 3	2006	foam	9	56	266
NMi-VSL	NMi-001	NMi-VSL	Quartz 3	2006	foam	9	56	254
NMi-VSL	NMi-003	NMi VSL	Quartz 3	2006	foam	9	56	276
NMi-VSL	NMi-004	NMi-VSL	Quartz 3	2006	foam	9	56	283
NML	NML-1011	Hart Scientific	5901D-Q	2006	-	12	60	265
PTB	PTB-627	L.S. Messtechnik	2940	2004	-	10	40	220
SMD	SMD-5017	Hart Scientific	5901A-Q	2006	foam	12	50	270
SMU	**SMU-1**	VNIIM		2000	-	11	50	266
UME	**UME-92**	UME	Large size	2002	-	9	56	244
VMT/PFI	VMT-2005	Hart Scientific	5901C-G	2006	-	14	60	245
VNIIM	**VNIIM-03**	VNIIM	Silica glass	2000	-	11	50	257
ZMDM	ZMDM-182	PTB	Z (or B)	1987	-	15	50	210

Table I Overview of information available on the transfer cells selected by the participating laboratory.

2. EQUIPMENT, TECHNIQUES AND UNCERTAINTIES

2.1 LABORATORY EQUIPMENT AND TECHNIQUES

The equipment, the techniques and the measuring conditions at each participating laboratory are summarized in Table II.
Regarding the technique for the preparation of the ice mantle, the participants were left free to use the procedure normally applied in their laboratory (see last column of table II).

2.2 UNCERTAINTIES

Each participant laboratory submitted a detailed uncertainty budget using the appropriate Excel sheet attached to the protocol.
The uncertainty components related to the comparison of a pair of cells were separated from the components related to the national reference, thus allowing the necessary flexibility in the analysis of the results.
The uncertainty budgets submitted by all participants are reported in Table III.

Laboratory	Resistance ratio bridge	Measurement current (frequency)	Number of repeated measure ments	Frequenc y of repeated measure ments	Reference resistor	Temp. control of reference resistor	SPRT and lenght of the sensor	Storage container for WTP cells	Technique ice mantle preparation
BEV	Isotech 6010 B	1 mA (DC)	50	0.1 Hz	100 Ω Fluke 742A-100	no control	Hart 5699 (50 mm)	Hart Scientific 7012	LN-cooled bar
CEM	ASL900	1 mA (75 Hz)	10	1/45 Hz	25 Ω Tinsley AC/DC Wilkins	± 10 mK	Tinsley 5187 SA (40 mm)	YSI 18233	Dry ice
CMI	ASL F900	1 mA (75 Hz)	15	1/60 Hz	25 Ω Tinsley 5685A	± 10 mK	Hart Scientific 5681 (28 mm)	Isotech 18233	LN-cooled bar and ethanol bath
DZM-LPM	ASL F18	1 mA	32	1/15 Hz	25 Ω Tinsley 5685A	± 10 mK	Hart Scientific 5681 (40 mm)	Crushed ice	Immersion cooler
DTI	ASL F18	1 mA (25 Hz)	60	0.1 Hz	Sullivan Ltd.	± 0.1 K	L&N 8163-Q (45 mm)	Crushed ice	Solid CO_2 and ethanol
EIM	MI6010	1 mA (DC)	36	1/8 Hz	25 Ω Tinsley 5685A	± 20 mK	Isotech 909 (80 mm)	Hart Scientific 7012	LN-cooled bar
GUM	ASL F18	1 mA (75 Hz)	24	0.02 Hz	25 Ω Tinsley 5685A	± 20 mK	YSI 8167-25 (50 mm)	Hart Scientific 7312	Solid CO_2
INM	ASL F18	1 mA (25 Hz)	10	1/15 Hz	25 Ω Tinsley	± 10 mK	Tinsley (54 mm)	Crushed ice	Solid CO_2
INRIM	ASL F18	2 mA (25 Hz)	16		25 Ω Tinsley 5685A	± 0.1 K	L&N 8167-25 (25 mm)	Isotech	LN-cooled bar
IPQ	ASL F18	1 mA (75 Hz)	100	1/10 Hz	25 Ω Tinsley	± 5 mK	Hart Scientific 5681 (50 mm)	Hart Scientific 7312	Solid CO_2
JV	MI6010	1 mA	120	1/15 Hz	100 Ω Tinsley	± 1.5 mK	L&N (50 mm)	Isotech 18233	Dry ice
LNE-INM/CNAM	ASL F900	1 mA (75 Hz)	30-50	1/60 Hz	25 Ω Tinsley 5649	± 5 mK	L&N, (25 mm)	Isotech	LN-cooled bar
MIKES		1 mA	20	0.1 Hz	25 Ω Tinsley 5648	± 15 mK	Tinsley 5187 SA (22 mm)	Hart Scientific 7012	Solid CO_2
MIRS/FE-LMK	ASL F900	1 mA	20 - 40	1/15 Hz	25 Ω Tinsley 5685A	± 3 mK	Hart Scientific 5681 (40 mm)	Isotech	LN-cooled bar
MKEH	ASL F18	1 mA (75 Hz)	50	0.2 Hz	25 Ω Tinsley 5685A	± 50 mK	Tinsley 5187 SA	Hart Scientific 7012	Solid CO_2
NMi-VSL	MI6015, ASL F-18	1 mA and 2 mA (25 Hz)	30	0.1 Hz	25 Ω Tinsley 5684S	± 1 mK	L&N, Cat. 8167-25 (33 mm)	Isotech 18233	LN flow-through cooling
NML	ASL F18	1 mA	25	0.5 Hz	25 Ω Tinsley 5685A	± 10 mK	Hart Scientific 5681 (40 mm)	Hart Scientific 7312	Solid CO_2
PTB	ASL F18	1 mA (25 Hz)			25 Ω Tinsley 5685	± 10 mK	YSI 8167-256 (35 mm)	Isotech 18233	Immersion cooler
SMD	ASL F18	1 mA (75 Hz)	20	0.1 Hz	25 Ω Tinsley 5685A	± 10 mK	Hart Scientific 5681 (30 mm)	Isotech	Immersion cooler and crushed CO_2
SMU	ASL F900	1 mA (75 Hz)	25	0.1 Hz	100 Ω Tinsley AC/DC 5686A	± 0.8 mK	Tinsley 5178 SA (50 mm)	Isotech 18233	LN-cooled bar
UME	MI6015	1 mA	30	1/30 Hz	25 Ω Tinsley AC/DC Wilkins	± 10 mK	Hart Scientific 5681 (38 mm)	Hart Scientific 4072	LN
VMT/PFI	MI6010	1 mA	15	0.1 Hz	25 Ω Tinsley 5685 A	± 20 mK	Tinsley 5187 SA (40 mm)	Hart Scientific 7012	LN-cooled bar
VNIIM	Guildline 9975	1 mA (DC)	15		MC3020	± 5 mK	VNIIM (58 mm)	Ice bath	LN
ZMDM	ASL F18	1 mA	60	0.2 Hz	100 Ω Tinsley 56885A	± 10 mK	Isotech 670 (30 mm)	Ice bath	LN-cooled ice mantle maker

Table II Overview of the equipment and measuring conditions at each participating laboratory.

Origin	BEV	CEM	CMI	DZM-LPM	DTI	EIM	GUM	INM	INRIM	IPQ	JV	LNE-INM/ CNAM
Components related to the comparison of a pair of cell												
Repeatability for a single ice mantle (including bridge noise)	70	6	16	15	7	10	15	8	11	36	10	7
Reproducibility for different ice mantles	70	3	5	10	14	16	21	12	1	10	110	10
Reproducibility for different types of SPRTs	0	10	6	10	0	17	0	5	0	-	60	25
Hydrostatic head (from both cells)	6	6	4	7	5	10	9	5	4	2	10	14
SPRT self-heating (from both cells)	50	6	10	5	0	25	7	10	6	21	0	13
Perturbing heat exchanges	30	10	20	10	11	20	15	20	1	8	0	5
Standard resistor short-term drift		7				3						
Moisture									1			
SPRT instability										51		
Total uncertainty (k=1) for the comparison of a pair of cells	**115**	**19**	**29**	**24**	**20**	**42**	**32**	**27**	**13**	**67**	**126**	**34**
Components related to properties of the national reference												
Chemical impurities	50	29	20	20	10	71	60		6	21	100	30
Isotopic composition	35	16	35	10	35	71		50	2			10
Residual gas pressure in the cell	0	4	8	4	10	5	5		1	3	-	*
Reproducibility	80	12	20	30	32	20	14	10	14	31	110	25
Others	80											
Total uncertainty (k=1) for the comparison of the transfer cell to the national reference	**173**	**40**	**54**	**45**	**53**	**111**	**70**	**58**	**23**	**77**	**195**	**53**

Table III Uncertainty budgets of the participant laboratories. All components expressed in μK and k=1.

Origin	MIKES	MIRS/FE-LMK	MKEH	NMi-VSL	NML	PTB	SMD	SMU	UME	VMT/PFI	VNIIM	ZMDM
Components related to the comparison of a pair of cell												
Repeatability for a single ice mantle (including bridge noise)	5	2	5	11	13	5	4	10	14	20	3	13
Reproducibility for different ice mantles	32	2			62	10	4	15	11	15	20	50
Reproducibility for different types of SPRTs	32	5	9	8	0	10	7	-	10	10	15	37
Hydrostatic head (from both cells)	7	7	1	5	14	6	7	6	3	4	1	17
SPRT self-heating (from both cells)	1	6	14	7	60	10	6	0		22	3	28
Perturbing heat exchanges	2	7	10	5	20	5	3	12		12	0	32
Standard resistor stability												2
Differential bridge non-linearities				6								30
others									9			
Combined standard uncertainty for the comparison of a pair of cells	**46**	**13**	**20**	**18**	**91**	**20**	**12**	**22**	**22**	**37**	**25**	**84**
Components related to properties of the national reference												
Chemical impurities	3	5		20	40	10	25	20	70	100	-	
Isotopic composition	3	2	60	2	8	10	2	35			0.4	60
Residual gas pressure in the cell	5	5		3	-	5	5	-		5	1	
Reproducibility	39	10		5	30	10	7	30	7	45	25	60
Drift						10						
Combined standard uncertainty for the comparison of the transfer cell to the national reference	**61**	**18**	**63**	**28**	**104**	**29**	**30**	**55**	**74**	**116**	**36**	**120**

* Included in chemical impurities uncertainty component.

Table III Uncertainty budgets of the participant laboratories. All components expressed in μK and k=1.

3. RE-ESTABLISHING THE LINK TO CCT-K7

3.1 INTRODUCTION

This comparison is based on measurements performed at pilot's laboratory, co-pilots' laboratories and non-co-pilots' laboratories.
The measurements performed are always reported as observed temperature differences between pairs of cells.
When writing the temperature difference measured between two cells, subscripts and superscripts are added to emphasize the role of both cells in the comparison.
Moreover the measured differences are enclosed within brackets and a subscript is added to the bracket indicating the role of the performer in the comparison (pilot, co-pilot, non-co-pilot).
So, for example, $T_{VSLi}^{\ EU\text{-}K7}$ refers to NMi-VSL transfer cell *i* of this comparison, while $T_{VSL}^{\ CCT\text{-}K7}$ refers to the transfer cell that NMi VSL used during CCT-K7. If the temperature difference between these two cells is measured by the pilot's laboratory, this difference is written as $(T_i^{\ EU\text{-}K7} - T_{VSL}^{\ CCT\text{-}K7})_{pilot}$.
In this chapter we are only concerned with the differences between the temperatures realized in practice by the cells, therefore no isotopic correction is applied to the cells, not even when the isotopic composition is known.

3.2 MEASUREMENTS AT PILOT'S LABORATORY

The 6 NMi-VSL transfer cells to be sent to the 6 co-pilots (one to each co-pilot) were preliminary compared at NMi-VSL with the cell that NMi-VSL had used as transfer cell in CCT-K7 (VSL-094).
The results of these measurements are summarized in Table IV and Figure 1.
As the measurements were repeated on two separately prepared ice mantles (see the protocol in Appendix 1), the resulting temperature difference between a pair of cells is expressed as the average of all the temperature differences measured for the pair of cells in both the prepared mantles.

NMi VSL transfer cell	**Assigned to co-pilot**	**$(T_{VSLi}^{\ EU\text{-}K7} - T_{VSL}^{\ CCT\text{-}K7})_{pilot}$ /µK**			**$u(T_{VSLi}^{\ EU\text{-}K7} - T_{VSL}^{\ CCT\text{-}K7})_{pilot}$ /µK (k = 1)**
		First mantle	**Second mantle**	**Average**	
VSL-030	CEM	-30.7	-43.3	-37.0	18
VSL-003	INRIM	-11.1	13.4	1.2	18
VSL-001	LNE-INM/CNAM	-15.2	-22.2	-18.7	18
VSL-004	MIRS/FE-LMK	0.2	-7.7	-3.8	18
VSL-029	SMD	-38.2	-28.0	-33.1	18
VSL-032	SMU	-42.2	-43.3	-42.8	18

Table IV: Temperature differences measured at NMi VSL between the NMi-VSL transfer cells of this comparison and the NMi VSL CCT-K7 transfer cell (k = 1 for the combined standard uncertainty). The assignement of the NMi-VSL transfer cells to the co-pilots is also shown.

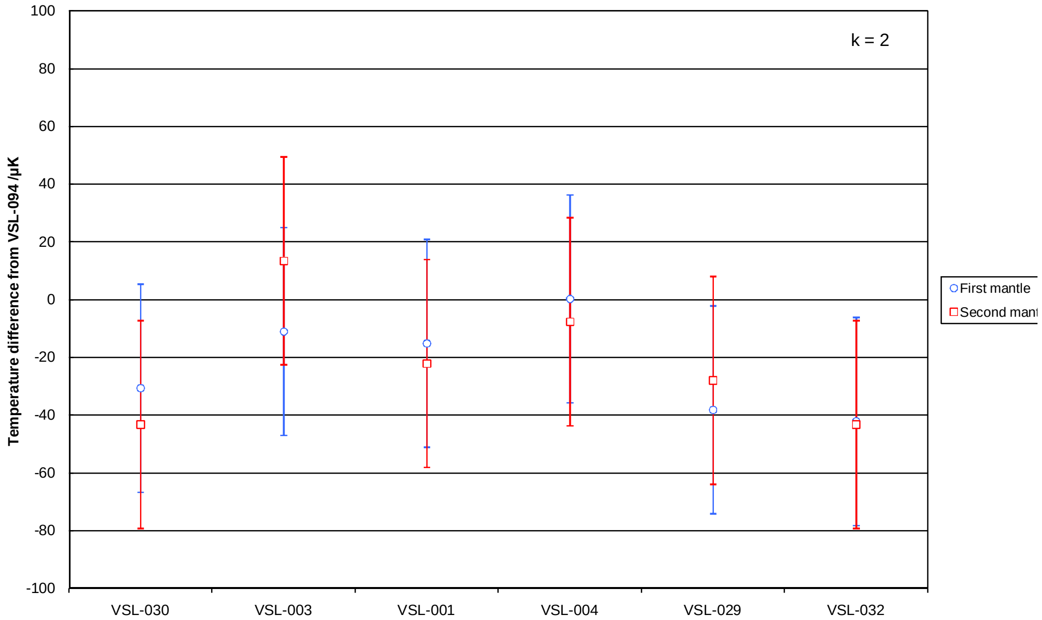


Figure 1: Temperature differences, measured at NMi-VSL, between the NMi-VSL transfer cells of this comparison and the NMi-VSL CCT-K7 transfer cell (uncertainty bars at k = 2).

3.3 MEASUREMENTS AT CO-PILOTS' LABORATORIES (PART 1)

During part 1 of the comparison, the NMi-VSL transfer cell received by each co-pilot was compared directly against the CCT-K7 transfer cell, available at the co-pilot laboratory.
The results of these measurements are shown in Table V and Figure 2. Notice that the CCT-K7 transfer cells available at MIRS/FE-LMK and SMD are respectively the cells that UME and IPQ used as transfer cell in CCT-K7 comparison.

Co-pilot laboratory	**CCT-K7 transfer cell available at co-pilot lab *i***	$(T_{VSLi}^{EU\text{-}K7} - T_i^{CCT\text{-}K7})_{co\text{-}pilot}$ /µK			$u(T_{VSLi}^{EU\text{-}K7} - T_i^{CCT\text{-}K7})_{co\text{-}pilot}$ /µK (k = 1)
		First mantle	**Second mantle**	**Average**	
CEM	CEM-2030	-33.2	-29.7	-31.5	19
INRIM	INRIM-1322	11.9	26.3	19.1	13
LNE-INM/CNAM	LNE-6	106.7	101.0	103.9	34
MIRS/FE-LMK	UME-92	86.8	86.0	86.4	13
SMD	IPQ-2214	-65.9	-72.5	-69.2	12
SMU	SMU-1	23.0	19.3	21.2	22

Table V: Temperature difference, measured during part 1 at each co-pilot laboratory, between the NMi-VSL transfer cell and the CCT-K7 transfer cell available at the co-pilot laboratory and associated combined standard uncertainty.

3.4 MEASUREMENTS AT CO-PILOTS' LABORATORIES (PART 2)

During part 2 of the comparison, the NMi-VSL transfer cell was compared again to the CCT-K7 transfer cells available at each co-pilot laboratory.
The results of these measurements are shown in Table VI and figure 2. Notice that, during part 2, at LNE-INM/CNAM also the CCT-K7 transfer cell of VNIIM was available.

Co-pilot laboratory	CCT-K7 transfer cell available at co-pilot lab	$(T_{VSLi}{}^{EU\text{-}K7} - T_i{}^{CCT\text{-}K7})_{co\text{-}pilot}$ /µK			$u(T_{VSLi}{}^{EU\text{-}K7} - T_i{}^{CCT\text{-}K7})_{co\text{-}pilot}$ /µK (k = 1)
		First mantle	Second mantle	Average	
CEM	CEM-2030	-32.3	-31.6	-31.9	21
INRIM	INRIM-1322	43.9	10.2	27.0	13
LNE-INM/CNAM	LNE-6	106.8	94.6	100.7	35
MIRS/FE-LMK	UME-92	80.3	80.8	80.6	13
SMD	IPQ-2214	-69.5	-57.4	-63.5	12
SMU	SMU-1	21.3	30.8	26.0	22
LNE-INM/CNAM	VNIIM-03	4.3	-	4.3	33

Table VI: Temperature difference, measured during part 2 at each co-pilot laboratory, between the NMi-VSL transfer cell and the CCT-K7 transfer cell available at the copilot laboratory and associated combined standard uncertainty.

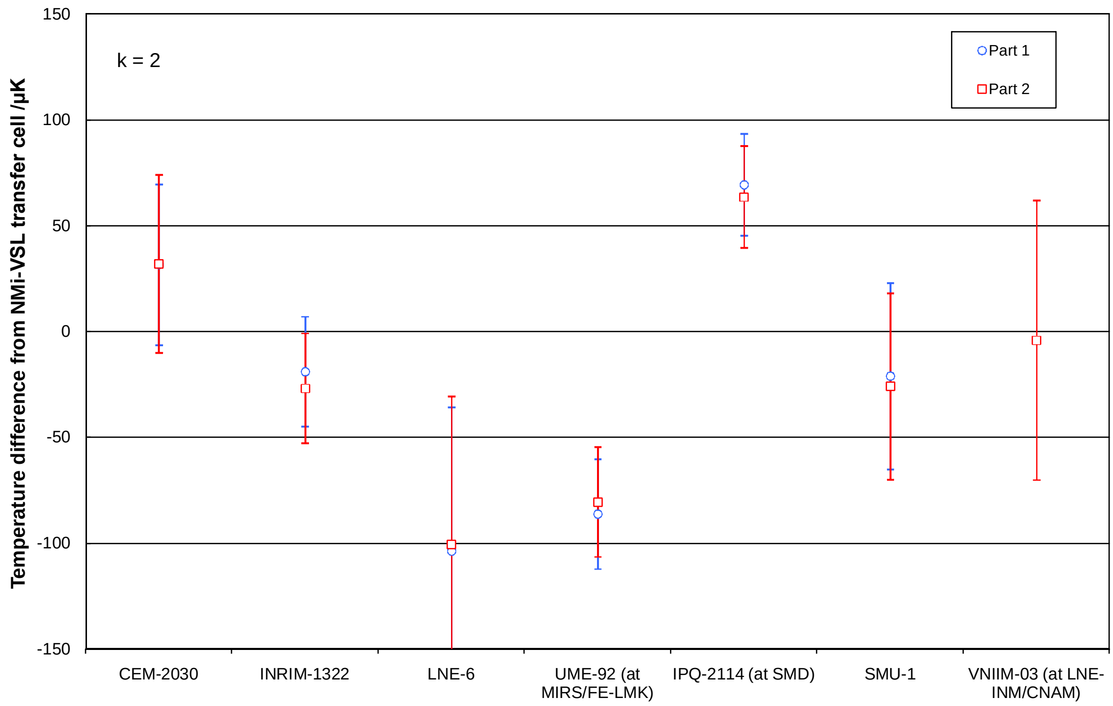


Figure 2: Temperature difference, measured during part 1 and part 2 of the comparison, between the CCT-K7 transfer cell available at each co-pilot laboratory and the NMi-VSL transfer cell (uncertainty bars at k = 2).

3.5 TEMPERATURE DIFFERENCES BETWEEN THE CCT-K7 TRANSFER CELLS, AS OBSERVED IN THIS COMPARISON

The temperature differences between the CCT-K7 transfer cells available in this comparison can be calculated by combining the results of the pilot's and co-pilots' measurements of section 3.3 and 3.4:

$$(T_i{}^{CCT\text{-}K7} - T_{VSL}{}^{CCT\text{-}K7})^{EU\text{-}K7} = (T_{VSLi}{}^{EU\text{-}K7} - T_{VSL}{}^{CCT\text{-}K7})_{pilot} - (T_{VSLi}{}^{EU\text{-}K7} - T_i{}^{CCT\text{-}K7})_{co\text{-}pilot}$$

$$u^2(T_i{}^{CCT\text{-}K7} - T_i{}^{CCT\text{-}K7})^{EU\text{-}K7} = u^2(T_{VSLi}{}^{EU\text{-}K7} - T_{VSL}{}^{CCT\text{-}K7})_{pilot} + u^2(T_{VSLi}{}^{EU\text{-}K7} - T_i{}^{CCT\text{-}K7})_{co\text{-}pilot}$$

The results of the calculations are shown in Table VII and figure 3.

CCT-K7 transfer cell i	**Part 1**		**Part 2**	
	$(T_i^{CCT\text{-}K7} - T_{VSL}^{CCT\text{-}K7})^{EU\text{-}K7}$ /µK	$u(T_i^{CCT\text{-}K7} - T_i^{CCT\text{-}K7})^{EU\text{-}K7}$ /µK (k = 1)	$(T_i^{CCT\text{-}K7} - T_{VSL}^{CCT\text{-}K7})^{EU\text{-}K7}$ /µK	$u(T_i^{CCT\text{-}K7} - T_i^{CCT\text{-}K7})^{EU\text{-}K7}$ /µK (k = 1)
CEM-2030	-5.5	26	-5.1	27
INRIM-1322	-17.9	22	-25.8	22
LNE-6	-122.6	39	-119.4	39
UME-92	-90.2	22	-84.4	22
IPQ-2214	36.1	22	30.4	22
SMU-1	-64.0	29	-68.9	29
VNIIM-03	-	-	-23.0	38

Table VII: Temperature differences between the CCT-K7 transfer cells available in this comparison and associated combined standard uncertainty.

3.6 TEMPERATURE DIFFERENCES BETWEEN THE CCT-K7 TRANSFER CELLS AVAILABLE IN THIS COMPARISON, AS OBSERVED AT BIPM DURING CCT-K7 COMPARISON

The temperature differences between the CCT-K7 transfer cells available in this comparison, as observed at BIPM during CCT-K7, can be obtained directly from Table 16 of the CCT-K7 report (pag. 40/98). These temperature differences are reported in Table VIII and Figure 3, adopting NMi-VSL CCT-K7 transfer cell as reference.

CCT-K7 transfer cell i	$(T_i^{CCT\text{-}K7} - T_{VSL}^{CCT\text{-}K7})^{CCT\text{-}K7}$ /µK	$u(T_i^{CCT\text{-}K7} - T_{VSL}^{CCT\text{-}K7})^{CCT\text{-}K7}$ /µK (k = 1)
CEM-2030	3.5	13
INRIM-1322	-62.7	12
LNE-6	-127.3	12
UME-92	-51.3	12
IPQ-2214	30.5	12
SMU-1	-62.8	12
VNIIM-03	-49.5	12

Table VIII: Temperature differences, measured at BIPM during CCT-K7, between the CCT-K7 transfer cells also available in this comparison and associated combined standard uncertainty.

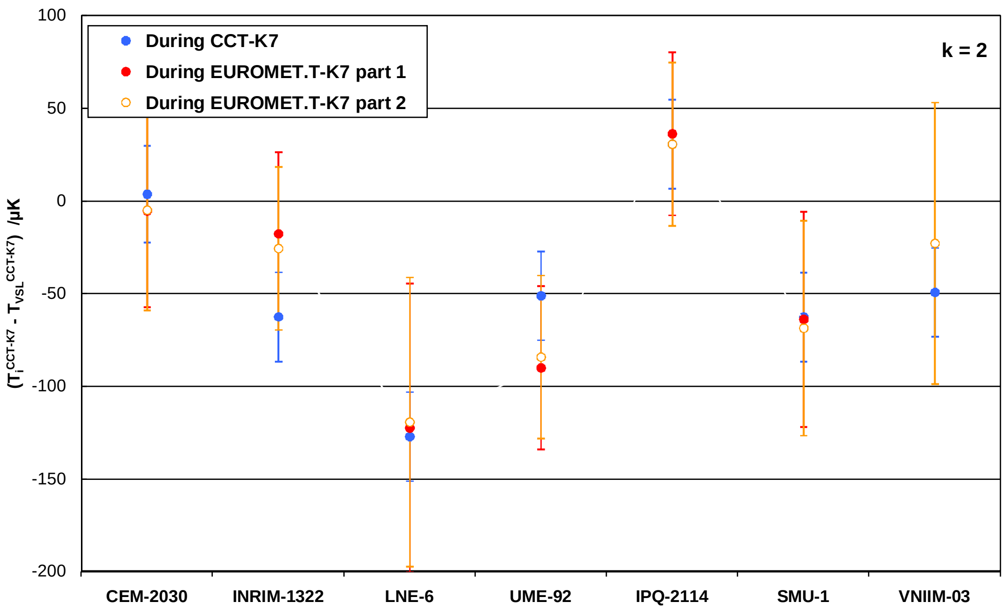


Figure 3: Temperature differences between the CCT-K7 transfer cells available in this comparison, with NMi-VSL CCT-K7 cell as reference: (1) as measured at BIPM during CCT-K7 (blue dots), (2) as measured during part 1 of this comparison (red dots) and (3) as measured during part 2 of this comparison (orange open circles). The temperature of NMi-VSL CCT-K7 transfer cell was arbitrarily assumed as reference. Uncertainty bars at k = 2.

3.7 CONSISTENCY CHECK

The assumption that the cells used in CCT-K7 as transfer cell are still realizing the same temperature can be checked quantitatively with statistical tools.
Here we simply calculate the discrepancy ΔT_i between the CCT-K7 result and EUROMET.T-K7 result as follows (see Table IX and Figure 4):

$$\Delta T_i = (T_i^{CCT\text{-}K7} - T_{VSL}{}^{CCT\text{-}K7})^{EU\text{-}K7} - (T_i^{CCT\text{-}K7} - T_{VSL}{}^{CCT\text{-}K7})^{CCT\text{-}K7}$$

$$u^2(\Delta T_i) = u^2(T_i^{CCT\text{-}K7} - T_{VSL}{}^{CCT\text{-}K7})^{EU\text{-}K7} + u^2(T_i^{CCT\text{-}K7} - T_{VSL}{}^{CCT\text{-}K7})^{CCT\text{-}K7}$$

CCT-K7 transfer cell i	**Part 1**		**Part 2**	
	$(T_i^{CCT\text{-}K7} - T_{VSL}{}^{CCT\text{-}K7})^{EU\text{-}K7}$ - $(T_i^{CCT\text{-}K7} - T_{VSL}{}^{CCT\text{-}K7})^{CCT\text{-}K7}$ **/µK**	***uncertainty* /µK (*k* = 1)**	$(T_i^{CCT\text{-}K7} - T_{VSL}{}^{CCT\text{-}K7})^{EU\text{-}K7}$ - $(T_i^{CCT\text{-}K7} - T_{VSL}{}^{CCT\text{-}K7})^{CCT\text{-}K7}$ **/µK**	***uncertainty* /µK (*k* = 1)**
CEM-2030	-9.0	29	-8.6	31
INRIM-1322	44.8	25	36.9	25
LNE-6	4.7	40	7.9	41
UME-92	-38.9	25	-33.1	25
IPQ-2214	5.6	25	-0.1	25
SMU-1	-1.2	31	-6.0	31
VNIIM-03	-	-	26.5	39

Table IX: Temperature differences, measured at BIPM during CCT-K7, between the CCT-K7 transfer cell also available in this comparison and associated combined standard uncertainty.

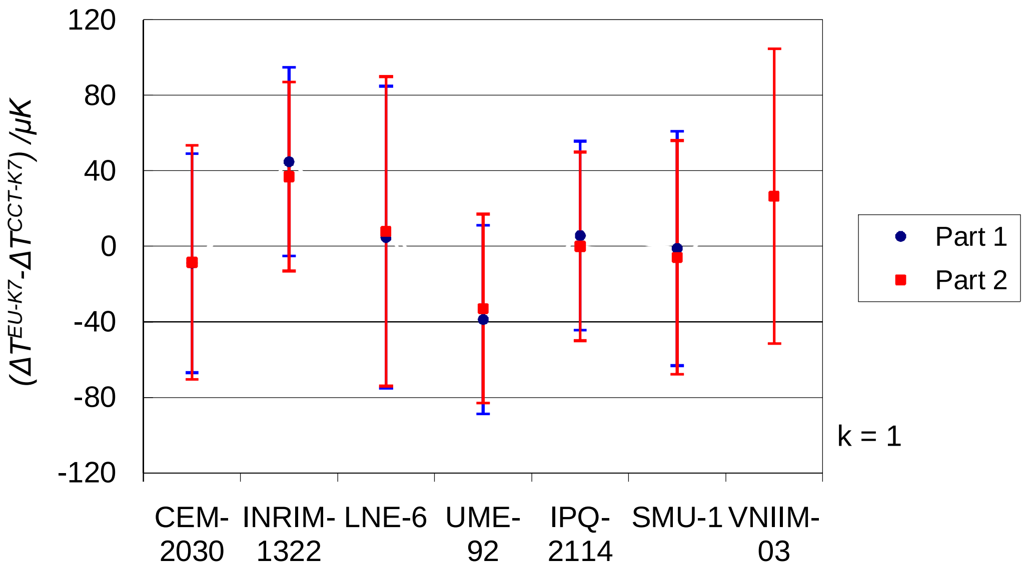


Figure 4: Discrepancy between CCT-K7 and this comparison of the relative position of the cells (uncertainties with $k = 1$).

3.8 CONCLUSIONS

The measurements performed in part 1 and part 2 show that it is reasonable to assume that the CCT-K7 transfer cells used in this comparison are still reproducing the equivalence established in CCT-K7 between CEM, IPQ, LNE, NMi-VSL and SMU.
Some doubts remain about 3 cells: INRIM-1322, UME-92 and VNIIM-03. INRIM confirmed that the chance that cell INRIM-1322 has drifted with respect to CCT-K7 is high, as the cell was observed to be shifted with respect to INRIM national reference.
The doubts about UME-92 and INRIM-1322 cells pose the problem of deciding which is the best way to link the transfer cells of non-co-pilots laboratories assigned to MIRS/FE-LMK (DZM-LPM, ZMDM, UME) and to INRIM (EIM, MIKES and PTB) to CCT-K7.
Probably, for MIRS/FE-LMK and INRIM linkage to CCT-K7, the best way is to use the NMi VSL transfer cell instead.

4. MEASUREMENTS OF TRANSFER CELLS AT CO-PILOTS' LABORATORIES DURING PART 2

4.1 INTRODUCTION

In this chapter we summarize the results of the measurements performed at the co-pilots' laboratories on all transfer cells during part 2 of the comparison.
By combining the measurements at the co-pilots and pilot laboratories, the temperature differences between all transfer cells are calculated, using as reference cell the NMi-VSL CCT-K7 transfer cell (Cell VSL-094).

4.2 MEASUREMENTS AT CEM

During part 2 of the comparison, CEM measured the following cells:

- CEM-2030 (the same transfer cell used by CEM during CCT-K7)
- VSL-030 (NMi-VSL transfer cell assigned to CEM)
- BRML-5016 (BRML transfer cell)
- MKHE-092 (MKHE transfer cell)

The results are expressed in terms of the temperature difference of each cell with respect to CEM CCT-K7 cell in Table X and Figure 5.

Transfer cell	First mantle		Second mantle	
	T(cell i) – T(CEM-2030) /µK	Standard uncertainty (*k* = 1) /µK	T(cell i) – T(CEM-2030) /µK	Standard uncertainty (*k* = 1) /µK
VSL-030	-32.3	21	-31.6	21
BRML-5016	46.9	21	48.3	21
MKEH-092	-66.2	21	-74.8	21

Table X: Measurements at CEM: temperature difference of each cell from CEM CCT-K7 transfer cell and associated standard uncertainty.

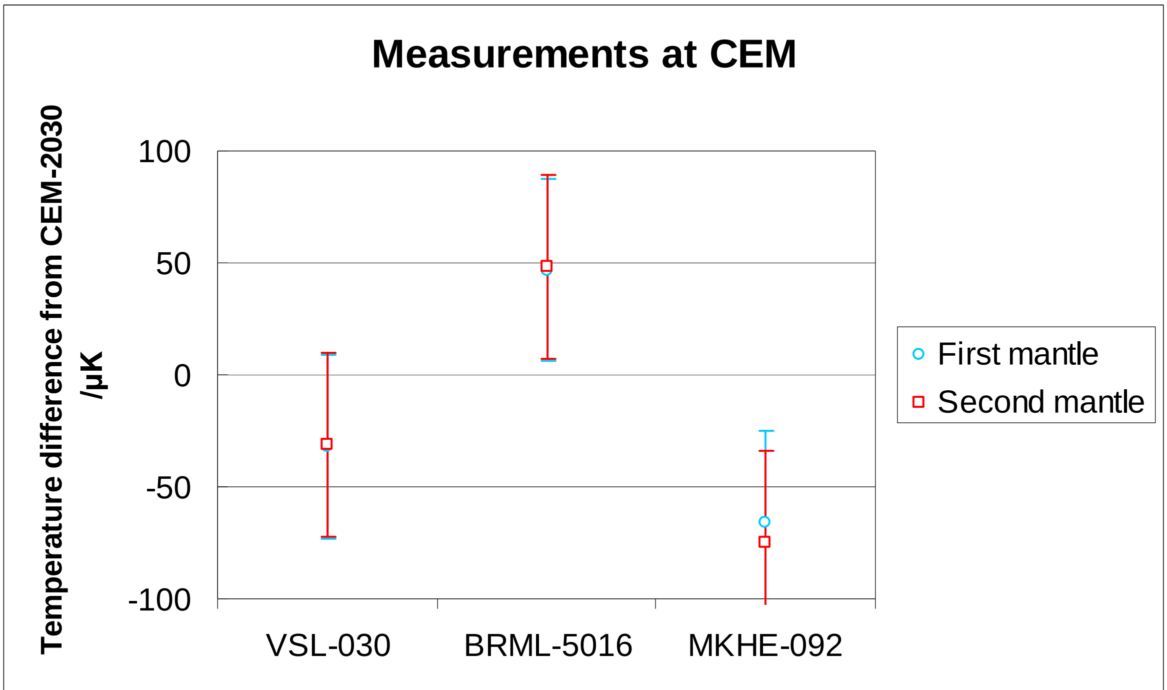


Figure 5: Measurements at CEM: temperature difference of each cell from CEM CCT-K7 transfer cell. The uncertainty bars show the expanded uncertainty for *k* = 2.

4.2 MEASUREMENTS AT INRIM

During part 2 of the comparison, INRIM measured the following cells:

- INRIM-1322 (the same transfer cell used by INRIM during CCT-K7)
- VSL-003 (NMi-VSL transfer cell assigned to INRIM)
- EIM-997 (EIM transfer cell)
- PTB-627 (PTB transfer cell)
- MIKES-1449 (MIKES transfer cell)

The results are expressed in terms of temperature difference of each cell with respect to INRIM CCT-K7 cell in Table XI and Figure 6.

Transfer cell	First mantle		Second mantle	
	T(cell i) – T(INRIM-1322) /µK	**Standard uncertainty (*k* = 1) /µK**	**T(cell i) – T(CEM-2030) /µK**	**Standard uncertainty (*k* = 1) /µK**
VSL-003	43.9	13	10.2	13
EIM-997	-6.5	13	-47.3	13
PTB-627	21.8	13	-17.3	13
MIKES-1449	29.4	13	-5.3	13

Table XI: Measurements at INRIM: temperature difference of each cell from INRIM CCT-K7 transfer cell and associated standard uncertainty.

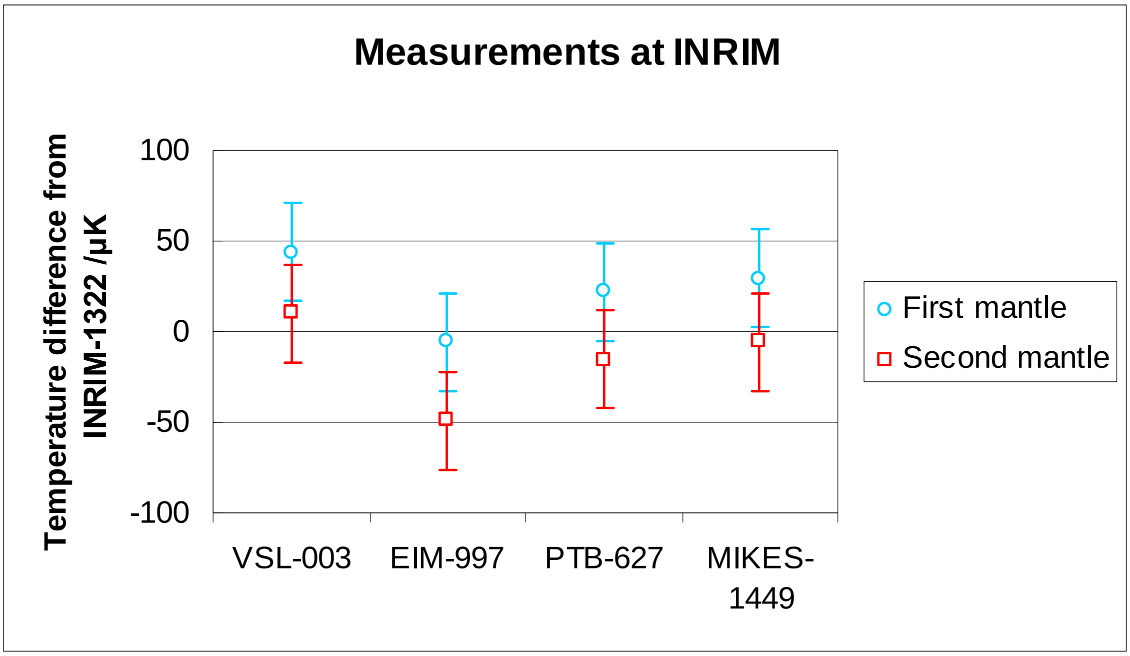


Figure 6: Measurements at INRIM: temperature difference of each cell from INRIM CCT-K7 transfer cell. The uncertainty bars show the expanded uncertainty.

4.3 MEASUREMENTS AT LNE-INM/CNAM

During part 2 of the comparison, LNE-INM/CNAM measured the following cells:

- LNE-6 (the same transfer cell used by LNE-INM/CNAM during CCT-K7)
- VSL-001 (NMi-VSL transfer cell assigned to LNE-INM/CNAM)
- VNIIM-03 (VNIIM transfer cell, which is also the cell that VNIIM used as transfer in CCT-K7)
- JV-1026 (JV transfer cell)
- DTI-199 (DTI transfer cell)

The results are expressed in terms of temperature difference of each cell with respect to LNE-INM/CNAM CCT-K7 cell in Table XII and Figure 7.

Transfer cell	**First mantle**		**Second mantle**	
	T(cell i) – T(LNE-6) /µK	**Standard uncertainty (*k* = 1) /µK**	**T(cell i) – T(CEM-2030) /µK**	**Standard uncertainty (*k* = 1) /µK**
VSL-001	106.8	35	94.6	35
VNIIM-03	102.5	33	-	-
JV-1026	159.6	33	166.5	33
DTI-199	84.9	39	73.2	39

Table XII: Measurements at LNE-INM/CNAM: temperature difference of each cell from LNE-INM/CNAM CCT-K7 transfer cell and associated standard uncertainty.

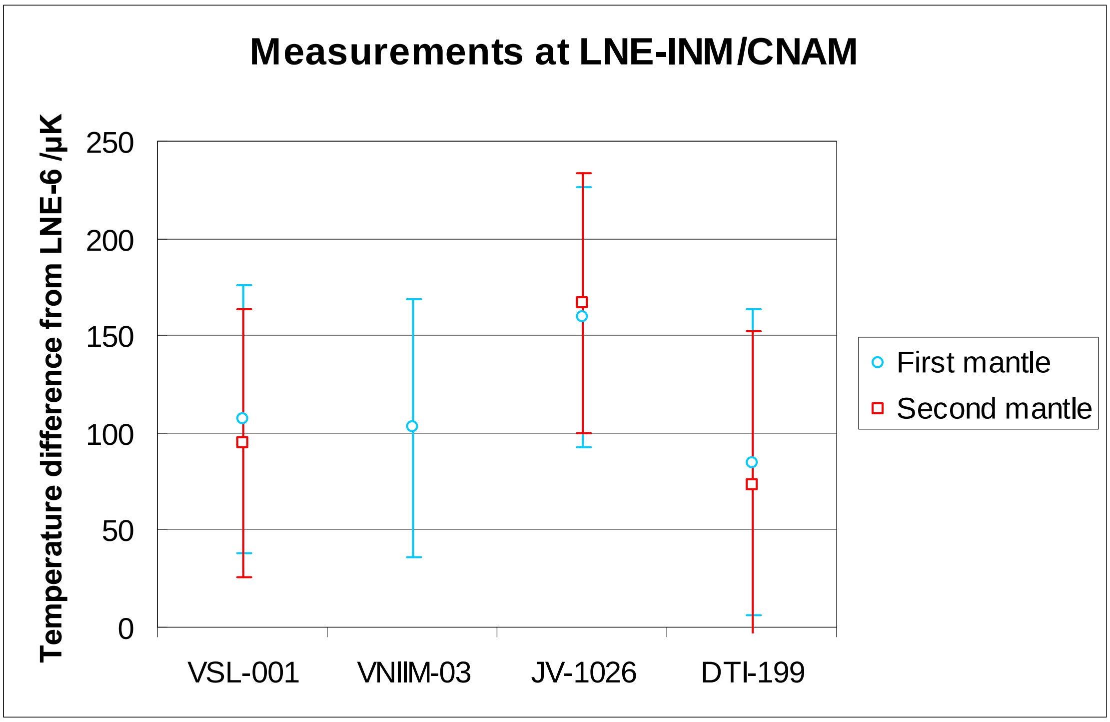


Figure 7: Measurements at LNE-INM/CNAM: temperature difference of each cell from LNE-INM/CNAM CCT-K7 transfer cell. The uncertainty bars show the expanded uncertainty.

4.4 MEASUREMENTS AT MIRS/FE-LMK

During part 2 of the comparison, MIRS/FE-LMK measured the following cells:

- UME-92 (the same transfer cell used by UME during CCT-K7)
- VSL-004 (NMi-VSL transfer cell assigned to MIRS/FE-LMK)
- MIRS-002 (MIRS/FE-LMK transfer cell)
- DZM-04 (DZM-LPM transfer cell)
- ZMDM-182 (ZMDM transfer cell)

The results are expressed in terms of temperature difference of each cell with respect to UME-92 CCT-K7 cell in Table XIII and Figure 8.

Transfer cell	First mantle		Second mantle	
	T(cell i) – T(UME-92) /µK	**Standard uncertainty (*k* = 1) /µK**	**T(cell i) – T(UME-92) /µK**	**Standard uncertainty (*k* = 1) /µK**
VSL-004	80.3	13	80.8	13
MIRS-002	74.1	13	72.6	13
DZM-04	99.8	13	97.9	13
ZMDM-182	-223.2	13	-242.9	13

Table XIII: Measurements at MIRS/FE-LMK: temperature difference of each cell from UME CCT-K7 transfer cell and associated standard uncertainty..

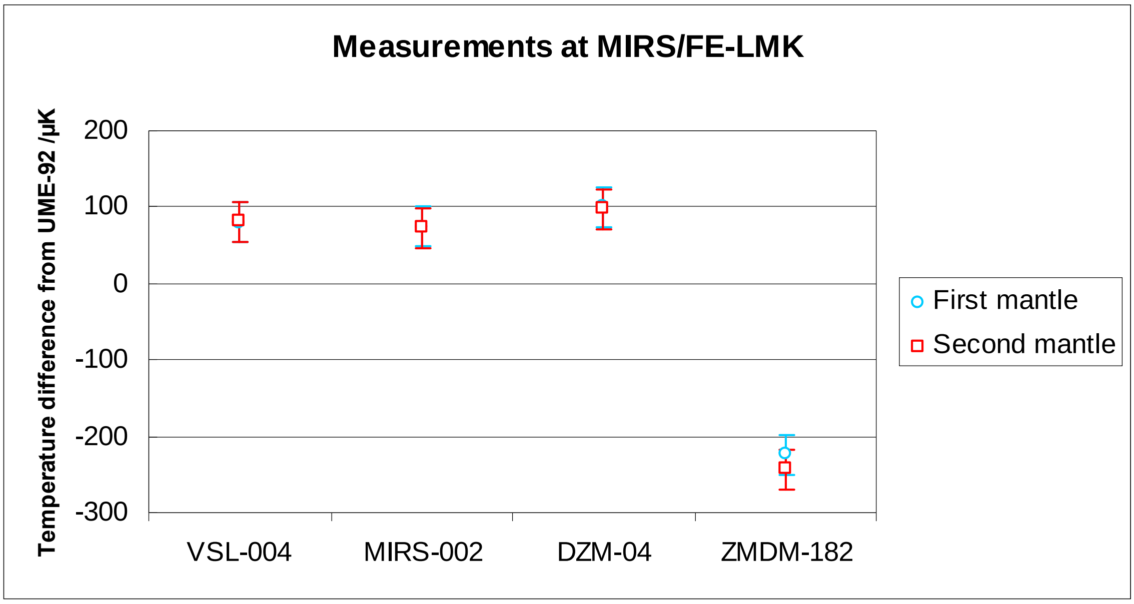


Figure 8: Measurements at MIRS/FE-LMK: temperature difference of each cell from UME CCT-K7 transfer cell. The uncertainty bars show the expanded uncertainty.

4.5 MEASUREMENTS AT SMD

During part 2 of the comparison, SMD measured the following cells:

- IPQ-2114 (the same transfer cell used by IPQ during CCT-K7)
- VSL-029 (NMi-VSL transfer cell assigned to SMD)
- SMD-5017 (SMD transfer cell)
- BEV-332 (BEV transfer cell)
- NML-1011 (NML transfer cell)

The results are expressed in terms of temperature difference of each cell with respect to IPQ CCT-K7 cell in Table XIV and Figure 9.

Transfer cell	First mantle		Second mantle	
	T(cell i) – T(IPQ-2114) /µK	Standard uncertainty (*k* = 1) /µK	T(cell i) – T(IPQ-2114) /µK	Standard uncertainty (*k* = 1) /µK
VSL-029	-69.5	12	-57.4	12
SMD-5017	9.8	12	7.6	12
BEV-332	-48.7	12	-41.0	12
NML-1011	8.8	12	5.7	12

Table XIV: Measurements at SMD: temperature difference of each cell from IPQ CCT-K7 transfer cell and associated standard uncertainty.

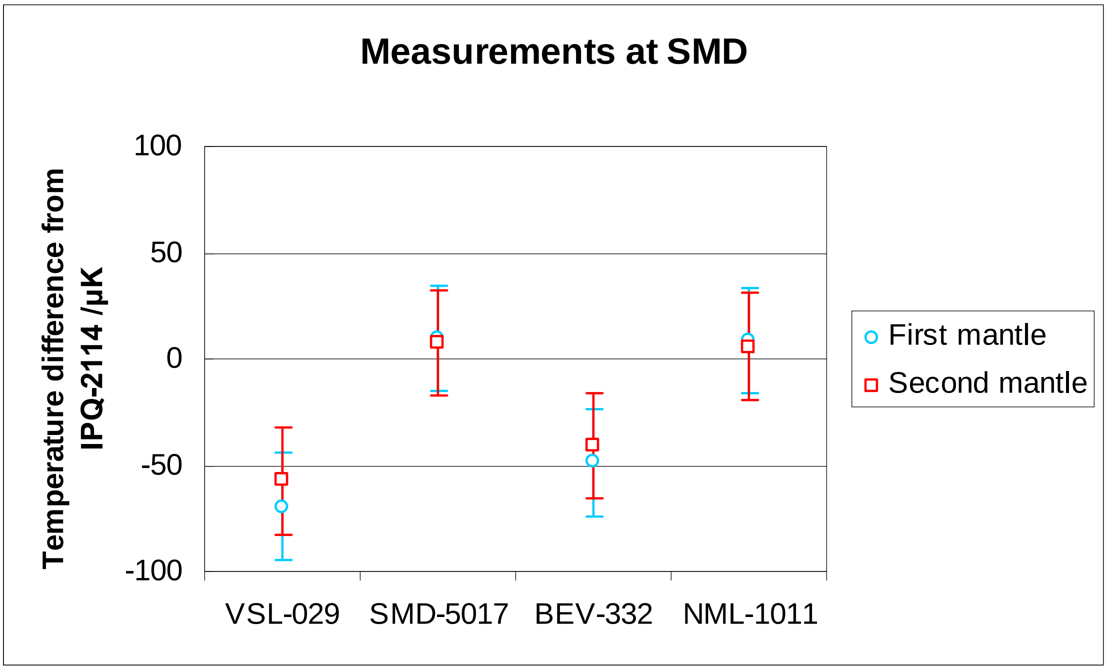


Figure 9: Measurements at SMD: temperature difference of each cell from IPQ CCT-K7 transfer cell. The uncertainty bars show the expanded uncertainty.

4.6 MEASUREMENTS AT SMU

During part 2 of the comparison, SMU measured the following cells:

- SMU-1 (the same transfer cell used by SMU during CCT-K7)
- VSL-032 (NMi-VSL transfer cell assigned to SMU)
- VMT-2005 (VMT/PFI transfer cell)
- CMI-1038 (CMI transfer cell)
- GUM-957 (GUM transfer cell)

The results are expressed in terms of temperature difference of each cell with respect to SMU CCT-K7 cell in Table XV and Figure 10.

Transfer cell	**First mantle**		**Second mantle**	
	T(cell i) – T(SMU-1) /µK	**Standard uncertainty (*k* = 1) /µK**	**T(cell i) – T(SMU-1) /µK**	**Standard uncertainty (*k* = 1) /µK**
VSL-032	21.3	22	30.8	22
VMT-2005	110.9	22	104.2	22
CMI-1038	-119.6	22	-156.5	22
GUM-957	-190.1	22	-230.9	22

Table XV: Measurements at SMU: temperature difference of each cell from SMU CCT-K7 transfer cell and associated standard uncertainty.

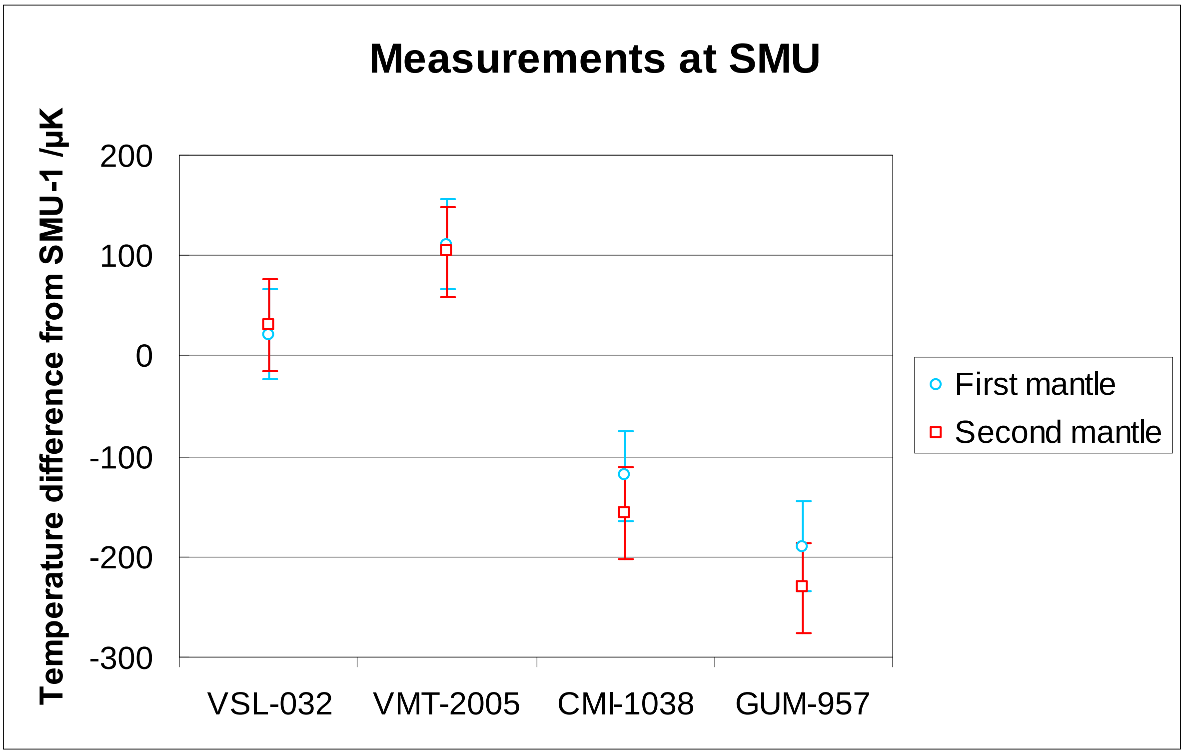


Figure 10: Measurements at SMU: temperature difference of each cell from SMU CCT-K7 transfer cell. The uncertainty bars show the expanded uncertainty.

4.7 TEMPERATURE DIFFERENCES BETWEEN THE TRANSFER CELLS

The temperature differences between the transfer cells can be obtained by combining the pilot and copilots measurements. In the following, the NMi-VSL CCT-K7 cell (cell VSL-094) is arbitrarily chosen as reference for calculating these temperature differences:

$$(T_{cell\ i}^{\ Group\ j} - T_{VSL}^{\ CCT\text{-}K7})^{EU\text{-}K7} = (T_{cell\ i}^{\ Group\ j} - T_{VSLj}^{\ EU\text{-}K7})_{co\text{-}pilot\ j} + (T_{VSLj}^{\ EU\text{-}K7} - T_{VSL}^{\ CCT\text{-}K7})_{pilot}$$

$$u^2(T_{cell\ i}^{\ Group\ j} - T_{VSL}^{\ CCT\text{-}K7})^{EU\text{-}K7} = (T_{cell\ i}^{\ Group\ j} - T_{VSLj}^{\ EU\text{-}K7})_{co\text{-}pilot\ j} + (T_{VSLj}^{\ EU\text{-}K7} - T_{VSL}^{\ CCT\text{-}K7})_{pilot}$$

Note that cell i from group j (with j = 1 to 6) in this case can be either a non-co-pilot transfer cell from group j or the transfer cell of co-pilot j.
The results of these calculations are reported in table XVI and Figure 11. The results obtained in different ice mantles were averaged. Moreover, as at each copilot laboratory the NMi-VSL transfer cell and CCT-K7 available cell were measured both in Part 1 and Part 2 of the comparison, for these cells the results were also averaged over Part 1 and Part 2.

Transfer Cell	**Temperature difference from VSL-094 /µK**	**Standard uncertainty (*k* = 1) /µK**
CEM-2030	-5.3	27
VSL-030	-37.0	18
BRML-5016	42.5	27
MKEH-092	-75.6	27
INRIM-1322	-21.9	22
VSL-003	1.2	18
EIM-997	-52.8	22
PTB-627	-23.6	22
MIKES-1449	-13.8	22
LNE-INM/CNAM	-121.0	39
VSL-001	-18.7	18
VNIIM-03	-23.0	38
JV-1026	43.7	38
DTI-199	-40.4	43
UME-92	-87.3	22
VSL-004	-3.8	18
MIRS-002	-12.5	22
DZM-04	14.5	22
ZMDM-182	-317.4	22
IPQ-2114	33.2	22
VSL-029	-33.1	18
SMD-5017	46.5	22
BEV-332	-14.5	22
NML-1011	37.6	22
SMU-1	-66.4	29
VSL-032	-42.8	18
VMT-2005	38.7	29
CMI-1038	-206.9	29
GUM-957	-279.4	29

Table XVI: Temperature difference between the transfer cells and NMi-VSL CCT-K7 cell. Cells in bold character were used as transfer cells also in CCT-K7. The results obtained in different ice mantles were averaged.

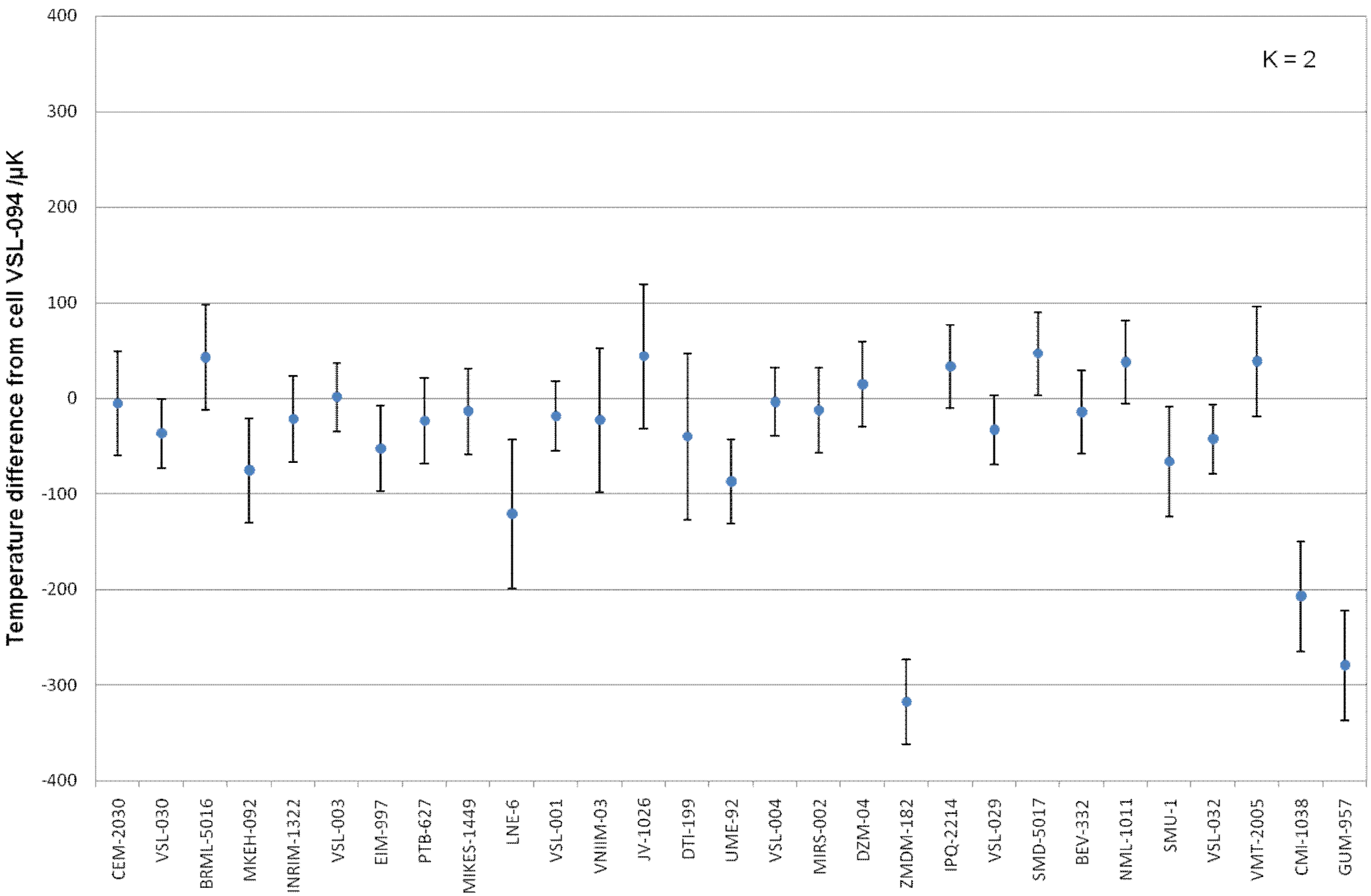


Figure 11: Temperature difference between the transfer cells and NMi-VSL CCT-K7 cell (VSL-094). The uncertainty bars show the expanded uncertainty (k = 2).

5. TEMPERATURE DIFFERENCE BETWEEN THE TRANSFER CELLS AND THE NATIONAL REFERENCE

Each participant *i* determined the temperature difference between its transfer cell and its national reference, and the corresponding combined standard uncertainty, respectively:

T_i *(transfer cell) –* T_i *(national reference)*
u(T_i *(transfer cell) –* T_i *(national reference))*

The national reference is assumed to represent the ideal water triple point temperature, within a related realization uncertainty which includes the effects of impurities and isotopes.
In this chapter, for national reference we mean the national reference as resulting from the measurements performed in this comparison. Apart from the intrinsic variability of the national reference when measured from time to time, the national references defined in this chapter may differ from the corresponding CCT-K7 national references also because the laboratories may have decided to change the definition of their national reference, in the time frame between the end of CCT-K7 and the beginning of this comparison, as considered in CCT WG8 report to the 23rd CCT Meeting.
When confusion may arise from the “old” and the “new” national references, the wording CCT-K7 national reference and EUROMET.T-K7 national reference will be used.
The measurements performed by each one of the 24 participant laboratories, together with a short description of the way each laboratory defined its national reference, are reported in Appendix 4 and summarized in Tables XVII and XVIII.

Laboratory	Definition of national reference	Reference cells	δ^2H (‰)	$\delta^{18}O$ (‰)	Impurity content	Correction applied?
BEV	One cell	Isotech B II 340 (year 2004)	unknown	unknown	unknown	no
CEM	Two cells with known isotopic composition, transferrred and maintained by the mean value of the corrections of a group of 6 cells	Hart A-Q5021 Isotech 556 Jarret 1179 , Isotech 2030, Isotech 2036, NPL645	-2 46.2	-0.3 4.2	unknown unknown	yes
CMI	One cell	NPL 32 1025	unknown	unknown	unknown	no
DZM-LPM	One cell	Isotech E11 (year 2003)	yes	yes	unknown	no
DTI	Any reference cell	-	unknown	unknown	unknown	yes
EIM	One cell	VNIIM 0/14 (year 2004)	unknown	unknown	unknown	no
GUM	One cell	NPL 32 782 (1998)	unknown	unknown	unknown	no
INM	4 cells	NPL 1032 (year 2001) Isotech B11 65 270 (year 2005) 2 cells made in house (year 2002 and 2003)	unknown +1 unknown	unknown +6 unknown	unknown unknown unknown	no
INRIM	Group of 3 cells	IMGC 31 and IMGC 34 (both before year 1993) Hart 1322 (2002)	unknown yes	unknown yes	unknown unknown	yes
IPQ	One cell	Jarrett A 11 50 542	35.07	3.57	unknown	no
JV	Group of 3 cells	815 (year 1995) DG1040 (Hart Scientific, year 2006) DG1053 (Hart Scientific, year 2006)	unknown 5 5	unknown 0.2 0.2	unknown unknown unknown	no
LNE-INM/CNAM	Group of 2 cells	Hart Scientific 1422 Hart Scientific 1020	yes yes	yes yes	unknown	yes
MIKES	One cell	Hart Scientific 5901A G (year 2006)	-2	-0.2	unknown	no
MIRS/FE-LMK	Group of 3 cells	VSL06T002 VSL06T006 VSL06T007	yes	yes yes yes	<100 nmol/mol (ICPMS)	yes
MKEH	One cell	VSL00T058	unknown	unknown	unknown	no

NMi VSL	Mean of a group of 12 cells, maintaned by the known difference of each cell of the group from the mean of the group itself	VSL-026, VSL-028, VSL-029, VSL-030, VSL-032, VSL-039, VSL-001, VSL-002, VSL-003, VSL-004, VSL-006, VSL-007	-20 to -75	-4 to -10	<100 nmol/mol (ICPMS)	yes
NML	Three cells	Hart Scientific 5901D-Q1011 (year 2006) Hart Scientific 5901D-Q1012 (year 2006) Hart Scientific 5901A-Q5006 (year 2005)	-3 1.8 -3	-0.2 -0.3 -0.5	unknown unknown unknown	no
PTB	One cell (VSL98T090)	VSL98T090 PTB 551 PTB 552	unknown +0.1 +1.1	unknown +6 +12	unknown <100 nmol/mol <100 nmol/mol	yes
SMD	Mean of 2 cells	Hart A-Q5017 Isotech A11/50/545	-2 33.5	-0.7 3.6	unknown unknown	yes
SMU	One cell	Isotech C-12 100	unknown	unknown	unknown	no
UME	One cell	UME 1994	unknown	unknown	unknown	no
VMT/PFI	One cell	Hart Scientific 5901 (year 2000)	unknown	unknown	unknown	no
VNIIM	Mean of 4 cells	VNIIM0/22, VNIIM0/23 (same water as VNIIM0/22)	-87.7 -87.7	-12.2 -12.2	unknown	yes
ZMDM	One cell	Hart Scientific 5901A-G	6	-0.3	unknown	yes

Table XVII: Overview information available from the participants on the definition of the national reference

Transfer cell	T(transfer cell) – T (national ref.) /µK	Standard uncertainty (k = 1) /µK
BEV-332	5.9	173
CEM-2030	-56.7	40
CMI-1038	103.3	54
DZM-4	4.9	45
DTI-199	10.8	53
EIM-997	-98.2	111
GUM-957	29.5	70
INM-5016	45.5	58
INRIM-1322	-19.7	23
IPQ-2114	3.6	77
JV-1026	189.8	190
LNE-6	-138.5	53
MIKES-1449	2.8	61
MIRS-002	-47.0	18
MKEH-092	1.8	63
NML-1011	-2.3	104
PTB-627	-62.9	29
SMD-5017	9.6	29
SMU-1	-60.1	55
UME-92	-1.5	74
VMT-2005	101.1	116
VNIIM-03	-86.2	36
VSL-094	-13.9	28
ZMDM-182	-166.7	117

Table XVIII: Temperature differences between the transfer cell and the national reference at each participant laboratory, and associated combined standard uncertainty.

6. TEMPERATURE DIFFERENCES BETWEEN THE NATIONAL REFERENCES AND NMi-VSL REFERENCE CELL

We can now combine the results of the measurements at the pilot's laboratory, the co-pilots laboratories and non-co-pilots laboratories to find the temperature difference of each national reference from the NMi-VSL reference cell (VSL-094) and its corresponding uncertainty.

For the measurements at the pilot's laboratory we have:

$T_{VSLj} - T_{VSL}^{\ CCT\text{-}K7}$ $\quad j = 1,2...6$

$u(T_{VSLj} - T_{VSL}^{\ CCT\text{-}K7})$ $\quad j = 1,2...6 \quad (k = 1)$

For the measurements at the co-pilots laboratories we have:

$T_{Cell\ i}^{\ Group\ j} - T_{VSLj}$ $\quad j = 1,2...6 \quad i = 1, 2, 3, 4$

$u(T_{Cell\ i}^{\ Group\ j} - T_{VSLj})$ $\quad j = 1,2...6 \quad i = 1, 2, 3, 4 \quad (k = 1)$

For the measurements at the non-co-pilots laboratories we have:

$T_{Cell\ i}^{\ Group\ j} - T_{i,j}^{Nat\ Ref}$ $\quad j = 1,2...6 \quad i = 1, 2, 3, 4$

$u(T_{Cell\ i}^{\ Group\ j} - T_{i,j}^{Nat\ Ref})$ $\quad j = 1,2...6 \quad i = 1, 2, 3, 4 \quad (k = 1)$

By combining the measurements at the pilot's laboratory, the measurements at the co-pilots laboratory and the measurements at the non-co-pilots laboratories we have:

$$T_{i,j}^{Nat\ Ref} - T_{VSL}^{\ CCT\text{-}K7} = (T_{VSLj} - T_{VSL}^{\ CCT\text{-}K7}) + (T_{Cell\ i}^{\ Group\ j} - T_{VSLj}) - (T_{Cell\ i}^{\ Group\ j} - T_{i,j}^{Nat\ Ref})$$

$$u^2(T_{i,j}^{Nat\ Ref} - T_{VSL}^{\ CCT\text{-}K7}) = u^2(T_{VSLj} - T_{VSL}^{\ CCT\text{-}K7}) + u^2(T_{Cell\ i}^{\ Group\ j} - T_{VSLj}) + u^2(T_{Cell\ i}^{\ Group\ j} - T_{i,j}^{Nat\ Ref})$$

The results are reported in Table XIX and Figure 12.

Laboratory	*T*(nat. ref.) - *T*(VSL-094) /µK	Standard uncertainty (k = 1) /µK
INM	**-2.9**	**64**
MKEH	**-77.4**	**69**
EIM	**45.4**	**113**
MIKES	**-16.6**	**65**
PTB	**39.3**	**37**
DTI	**-51.2**	**68**
JV	**-146.1**	**194**
VNIIM	**63.1**	**52**
DZM-LPM	**9.6**	**50**
UME	**-85.8**	**77**
ZMDM	**-150.7**	**119**
BEV	**-20.4**	**174**
IPQ	**29.6**	**80**
NML	**39.9**	**106**
CMI	**-310.2**	**61**
GUM	**-308.9**	**75**
VMT	**-62.4**	**119**

Laboratory	*T*(nat. ref.) - *T*(VSL-094) /µK	Standard uncertainty /µK (k = 1)
CEM	**51.2**	**44**
INRIM	**1.8**	**29**
LNE-INM/CNAM	**15.9**	**56**
MIRS/FE-LMK	**33.0**	**25**
SMD	**44.4**	**34**
SMU	**-3.9**	**58**
NMi-VSL	**13.9**	**28**

Table XIX: Temperature difference between the national reference of each participant laboratory and NMi-VSL reference cell (VSL-094).

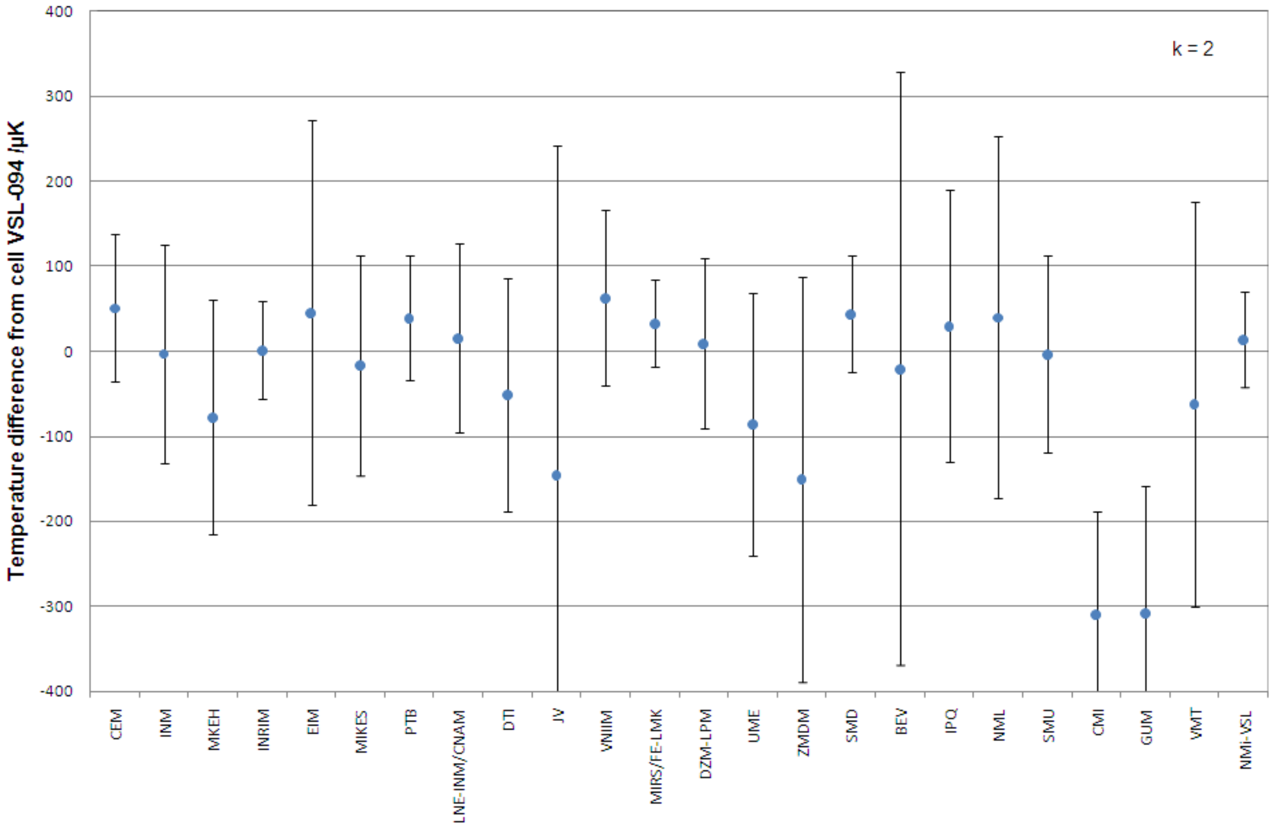


Figure 12: Temperature difference between the national reference of each participant laboratory and NMi-VSL reference cell (VSL-094). The uncertainty bars shows the expanded uncertainty (k = 2).

7. DEGREES OF EQUIVALENCE, PAIR EQUIVALENCE AND LINKAGE MECHANISM

7.1 EURAMET.T-K7 REFERENCE VALUE

The EURAMET.T-K7 Reference Value (ERV in the following) was defined as the weighted mean of the individual results for the national reference, with the exclusion of the CMI and GUM results (24 – 2 = 22 laboratories):

$$\left(T_{ERV} - T_{VSL094}\right) = \frac{\sum_{i=1}^{22} \left(T_i - T_{VSL094}\right) \Big/ u^2\left(T_i - T_{VSL094}\right)}{\sum_{i=1}^{22} 1 \Big/ u^2\left(T_i - T_{VSL094}\right)}$$

Note that both the individual results and the ERV are expressed in terms of temperature differences from the NMi-VSL CCT-K7 cell (VSL094).
The uncertainty of the ERV is calculated as the variance of the weighted mean:

$$u^2\left(T_{ERV} - T_{VSL094}\right) = \frac{1}{\sum_{i=1}^{22} 1 \Big/ u^2\left(T_i - T_{VSL094}\right)}$$

The result is:
$(T_{ERV} - T_{VSL094})$ = 15.6 μK
$u(T_{ERV} - T_{VSL094})$ = 10.5 μK
Now the end results of EURAMET.T-K7 can be expressed in terms of temperature difference of each participant with respect to the ERV (see Table XX).

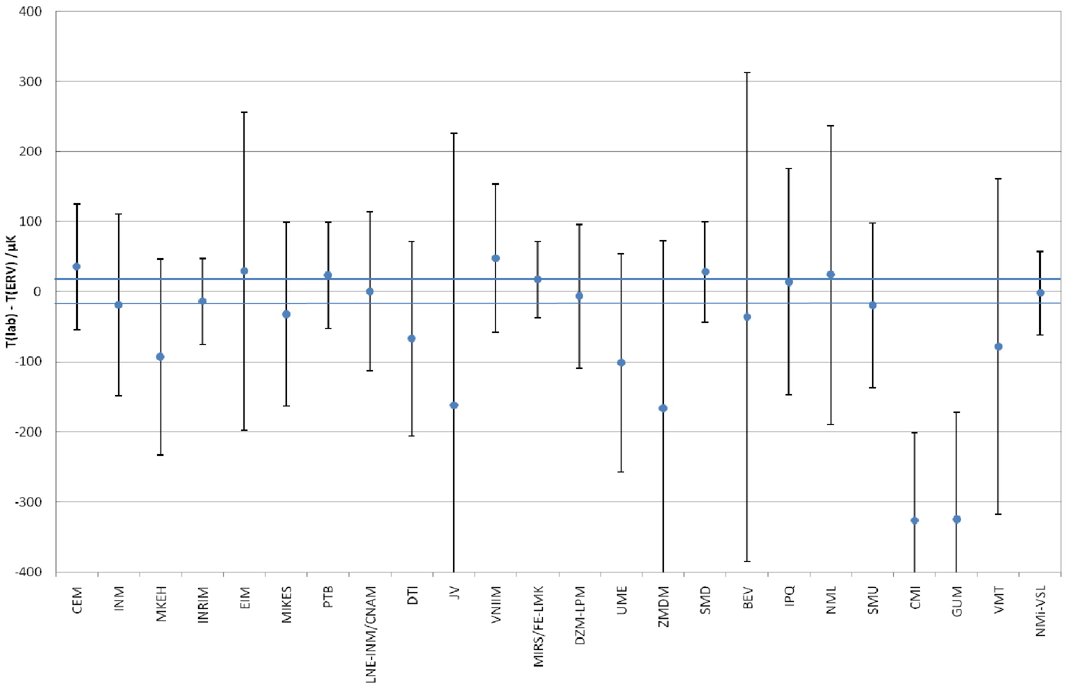


Figure 12: Degrees of equivalence and associated uncertainty (k=2). The blue lines shows the uncertainty (k=2) of the ERV.

Laboratory	*T(Lab i) - T(ERV)* /µK	*U(k = 2)* /µK
INM	-19	130
MKEH	-93	139
EIM	30	227
MIKES	-32	131
PTB	24	76
DTI	-67	139
JV	-162	388
VNIIM	48	106
DZM-LPM	-6	102
UME	-101	156
ZMDM	-166	239
BEV	-36	349
IPQ	14	161
NML	24	214
CMI	-326	124
GUM	-324	152
VMT	-78	240
CEM	36	90
INRIM	-14	62
LNE-INM/CNAM	0	114
MIRS/FE-LMK	17	55
SMD	29	72
SMU	-19	118
NMi-VSL	-2	60

Table XX: Degrees of equivalence and associated uncertainty (k = 2).

7.2 PAIR EQUIVALENCE

The bilateral equivalence between any pair of EURAMET.T-K7 participants (say participant *i* from group *j* and participant *k* from group *l*) is expressed by:

1. The temperature difference $T_{ij} - T_{kl}$ between the national references of the two participants
2. The uncertainty $u(T_{ij} - T_{kl})$ of the same temperature difference

The temperature difference $T_{ij} - T_{kl}$ can be easily calculated from the individual differences from T_{ERV} as:

$$(T_{ij} - T_{kl}) = (T_{ij} - T_{ERV}) - (T_{kl} - T_{ERV})$$

For the uncertainty $u(T_{ij} - T_{kl})$ we make a distinction between intra-group pairs (pairs of participants belonging to the same group) and inter-group pairs (pairs of participants belonging to different groups).

For any pair of participants from intra-group *j*:

$$u^2(T_{ij} - T_{kj}) = u^2(T_{ij}^{\text{Transfer Cell}} - T_{kj}^{\text{Transfer Cell}}) + u^2(T_{ij}^{\text{Transfer Cell}} - T_{ij}^{\text{Nat Ref}}) + u^2(T_{kj}^{\text{Transfer Cell}} - T_{kj}^{\text{Nat Ref}})$$

where:

- $u^2(T_{ij}^{Transfer\ Cell} - T_{kj}^{Transfer\ Cell})$ is the uncertainty of the co-pilot *j* when measuring the temperature differences between the transfer cells during part 2 of the comparison
- $u^2(T_{ij}^{Transfer\ Cell} - T_{ij}^{Nat\ Ref})$ is the uncertainty of participant *i* from group *j* when measuring the temperature difference between its transfer cell and its national reference
- $u^2(T_{kj}^{Transfer\ Cell} - T_{kj}^{Nat\ Ref})$ is the uncertainty of participant *k* from group *j* when measuring the temperature difference between its transfer cell and its national reference.

For inter-group pair of participants (participant *i* from group *j* and participant *k* from group *l*):

$$u^2(T_{ij} - T_{kl}) = u^2(T_{ij}^{Transfer\ Cell} - T_{ij}^{Nat\ Ref}) + u^2(T_{ij}^{Transfer\ Cell} - T_j^{VSL}) + u^2(T_j^{VSL} - T_l^{VSL}) + u^2(T_{kl}^{Transfer\ Cell} - T_l^{VSL}) + u^2(T_{kl}^{Transfer\ Cell} - T_{kl}^{Nat\ Ref})$$

where:

- $u^2(T_{ij}^{Transfer\ Cell} - T_{ij}^{Nat\ Ref})$ is the uncertainty of the participant *i* from group *j* when measuring the temperature differences between its transfer cell and its national reference
- $u^2(T_{ij}^{Transfer\ Cell} - T_j^{VSL})$ is the uncertainty of the co-pilot *j* when measuring the temperature differences between the transfer cell of participant *i* from group *j* and the NMi-VSL transfer cell assigned to group *j*
- $u^2(T_j^{VSL} - T_l^{VSL})$) is the uncertainty of NMi-VSL when measuring the transfer cells to be sent to the co-pilots
- $u^2(T_{kl}^{Transfer\ Cell} - T_l^{VSL})$ is the uncertainty of the co-pilot *l* when measuring the temperature differences between the transfer cell of participant *k* from group *l* and the NMi-VSL transfer cell assigned to group *l*
- $u^2(T_{kl}^{Transfer\ Cell} - T_{kl}^{Nat\ Ref})$ is the uncertainty of the participant *k* from group *l* when measuring the temperature differences between its transfer cell and its national reference

Lab *j* ⇒

Lab *i* ⇓	D_i / µK	U_i / µK	CEM D_{ij} / µK	CEM U_{ij} / µK	INM D_{ij} / µK	INM U_{ij} / µK	MKEH D_{ij} / µK	MKEH U_{ij} / µK	INRIM D_{ij} / µK	INRIM U_{ij} / µK	EIM D_{ij} / µK	EIM U_{ij} / µK	MIKES D_{ij} / µK	MIKES U_{ij} / µK
CEM	**36**	90			**54**	146	**129**	155	**49**	98	**6**	240	**68**	152
INM	**-19**	130	**-54**	146			**74**	176	**-5**	136	**-48**	257	**14**	178
MKEH	**-93**	139	**-129**	155	**-74**	176			**-79**	145	**-123**	262	**-61**	186
INRIM	**-14**	62	**-49**	98	**5**	136	**79**	145			**-44**	228	**18**	132
EIM	**30**	227	**-6**	240	**48**	257	**123**	262	**44**	228			**62**	254
MIKES	**-32**	131	**-68**	152	**-14**	178	**61**	186	**-18**	132	**-62**	254		
PTB	**24**	76	**-12**	108	**42**	143	**117**	152	**37**	78	**-6**	231	**56**	137
LNE-INM/CNAM	**0**	114	**-35**	137	**19**	166	**93**	174	**14**	120	**-30**	250	**33**	167
DTI	**-67**	139	**-102**	159	**-48**	184	**26**	191	**-53**	145	**-97**	239	**-35**	185
JV	**-162**	388	**-197**	405	**-143**	416	**-69**	419	**-148**	400	**-192**	456	**-129**	416
VNIIM	**48**	106	**12**	130	**66**	161	**141**	169	**61**	113	**18**	246	**80**	148
MIRS/FE-LMK	**17**	55	**-18**	94	**36**	133	**110**	142	**31**	68	**-12**	229	**50**	134
DZM-LPM	**-6**	102	**-42**	128	**13**	159	**87**	167	**8**	110	**-36**	245	**26**	160
UME	**-101**	156	**-137**	173	**-83**	197	**-8**	204	**-88**	161	**-131**	271	**-69**	198
ZMDM	**-166**	239	**-202**	251	**-148**	268	**-73**	273	**-152**	242	**-196**	326	**-134**	269
SMD	**29**	72	**-7**	105	**47**	141	**122**	150	**43**	82	**-1**	233	**61**	142
BEV	**-36**	349	**-72**	357	**-17**	369	**57**	372	**-22**	351	**-66**	413	**-4**	369
IPQ	**14**	161	**-22**	178	**33**	202	**107**	208	**28**	166	**-16**	275	**46**	202
NML	**24**	214	**-11**	226	**43**	248	**117**	250	**38**	217	**-6**	308	**57**	246
SMU	**-19**	118	**-55**	140	**-1**	169	**74**	176	**-6**	124	**-49**	251	**13**	170
CMI	**-326**	124	**-361**	146	**-307**	173	**-233**	181	**-312**	130	**-356**	255	**-294**	174
GUM	**-324**	152	**-360**	170	**-306**	194	**-231**	201	**-311**	157	**-354**	269	**-292**	195
VMT/PFI	**-78**	240	**-114**	251	**-59**	268	**15**	273	**-64**	243	**-108**	327	**-46**	269
NMi-VSL	**-2**	60	**-37**	96	**17**	135	**91**	144	**12**	71	**-32**	230	**31**	136

Lab *j*

Lab *i*	D_i / μK	U_i / μK	PTB D_{ij} / μK	PTB U_{ij} / μK	LNE-INM/CNAM D_{ij} / μK	LNE-INM/CNAM U_{ij} / μK	DTI D_{ij} / μK	DTI U_{ij} / μK	JV D_{ij} / μK	JV U_{ij} / μK	VNIIM D_{ij} / μK	VNIIM U_{ij} / μK	MIRS/FE-LMK D_{ij} / μK	MIRS/FE-LMK U_{ij} / μK
CEM	**36**	90	**12**	108	**35**	137	**102**	159	**197**	405	**-12**	130	**18**	94
INM	**-19**	130	**-42**	143	**-19**	166	**48**	184	**143**	416	**-66**	161	**-36**	133
MKEH	**-93**	139	**-117**	152	**-93**	174	**-26**	191	**69**	419	**-141**	169	**-110**	142
INRIM	**-14**	62	**-37**	78	**-14**	120	**53**	145	**148**	400	**-61**	113	**-31**	68
EIM	**30**	227	**6**	231	**30**	250	**97**	239	**192**	456	**-18**	246	**12**	229
MIKES	**-32**	131	**-56**	137	**-33**	167	**35**	185	**129**	416	**-80**	148	**-50**	134
PTB	**24**	76			**23**	128	**90**	151	**185**	402	**-24**	116	**6**	81
LNE-INM/CNAM	**0**	114	**-23**	128			**67**	170	**162**	409	**-47**	144	**-17**	117
DTI	**-67**	139	**-90**	151	**-67**	170			**-228**	412	**-19**	151	**-49**	142
JV	**-162**	388	**-185**	402	**-162**	409	**228**	412			**-209**	402	**-179**	399
VNIIM	**48**	106	**24**	116	**47**	144	**19**	151	**209**	402			**30**	110
MIRS/FE-LMK	**17**	55	**-6**	81	**17**	117	**49**	142	**179**	399	**-30**	110		
DZM-LPM	**-6**	102	**-30**	119	**-6**	146	**73**	166	**156**	406	**-54**	140	**-23**	100
UME	**-101**	156	**-125**	167	**-102**	187	**168**	203	**60**	424	**-149**	182	**-119**	154
ZMDM	**-166**	239	**-190**	247	**-167**	261	**233**	273	**-5**	462	**-214**	257	**-184**	238
SMD	**29**	72	**5**	93	**29**	126	**38**	149	**191**	401	**-19**	119	**11**	77
BEV	**-36**	349	**-60**	353	**-36**	116	**103**	372	**126**	527	**-84**	361	**-53**	350
IPQ	**14**	161	**-10**	172	**14**	192	**53**	208	**176**	427	**-34**	187	**-3**	164
NML	**24**	214	**1**	221	**24**	237	**42**	250	**186**	449	**-23**	233	**7**	215
SMU	**-19**	118	**-43**	132	**-20**	157	**86**	176	**142**	412	**-67**	151	**-37**	121
CMI	**-326**	124	**-349**	138	**-326**	162	**393**	181	**-164**	414	**-373**	156	**-343**	128
GUM	**-324**	152	**-348**	163	**-325**	184	**391**	201	**-163**	423	**-372**	179	**-342**	155
VMT/PFI	**-78**	240	**-102**	247	**-78**	261	**145**	273	**84**	462	**-126**	258	**-95**	241
NMi-VSL	**-2**	60	**-25**	84	**-2**	119	**68**	144	**160**	397	**-49**	112	**-19**	66

Lab *j* ⇨

Lab *i* ⇩	D_i / µK	U_i / µK	DZM-LPM D_{ij} / µK	DZM-LPM U_{ij} / µK	UME D_{ij} / µK	UME U_{ij} / µK	ZMDM D_{ij} / µK	ZMDM U_{ij} / µK	SMD D_{ij} / µK	SMD U_{ij} / µK	BEV D_{ij} / µK	BEV U_{ij} / µK	IPQ D_{ij} / µK	IPQ U_{ij} / µK
CEM	**36**	90	**42**	128	**137**	173	**202**	251	**7**	105	**72**	357	**22**	178
INM	**-19**	130	**-13**	159	**83**	197	**148**	268	**-47**	141	**17**	369	**-33**	202
MKEH	**-93**	139	**-87**	167	**8**	204	**73**	273	**-122**	150	**-57**	372	**-107**	208
INRIM	**-14**	62	**-8**	110	**88**	161	**152**	242	**-43**	82	**22**	351	**-28**	166
EIM	**30**	227	**36**	245	**131**	271	**196**	326	**1**	233	**66**	413	**16**	275
MIKES	**-32**	131	**-26**	160	**69**	198	**134**	269	**-61**	142	**4**	369	**-46**	202
PTB	**24**	76	**30**	119	**125**	167	**190**	247	**-5**	93	**60**	353	**10**	172
LNE-INM/CNAM	**0**	114	**6**	146	**102**	187	**167**	261	**-29**	126	**36**	116	**-14**	192
DTI	**-67**	139	**-73**	166	**-168**	203	**-233**	273	**-38**	149	**-103**	372	**-53**	208
JV	**-162**	388	**-156**	406	**-60**	424	**5**	462	**-191**	401	**-126**	527	**-176**	427
VNIIM	**48**	106	**54**	140	**149**	182	**214**	257	**19**	119	**84**	361	**34**	187
MIRS/FE-LMK	**17**	55	**23**	100	**119**	154	**184**	238	**-11**	77	**53**	350	**3**	164
DZM-LPM	**-6**	102			**95**	175	**160**	252	**-35**	116	**30**	360	**-20**	185
UME	**-101**	156	**-95**	175			**65**	278	**-130**	165	**-65**	379	**-115**	219
ZMDM	**-166**	239	**-160**	252	**-65**	278			**-195**	245	**-130**	420	**-180**	285
SMD	**29**	72	**35**	116	**130**	165	**195**	245			**65**	351	**15**	166
BEV	**-36**	349	**-30**	360	**65**	379	**130**	420	**-65**	351			**-50**	379
IPQ	**14**	161	**20**	185	**115**	219	**180**	285	**-15**	166	**50**	379		
NML	**24**	214	**30**	232	**126**	260	**191**	317	**-4**	217	**60**	403	**10**	260
SMU	**-19**	118	**-13**	149	**82**	189	**147**	262	**-48**	130	**17**	365	**-33**	194
CMI	**-326**	124	**-320**	154	**-224**	194	**-160**	265	**-355**	136	**-290**	365	**-340**	198
GUM	**-324**	152	**-318**	177	**-223**	212	**-158**	279	**-353**	161	**-288**	377	**-338**	217
VMT/PFI	**-78**	240	**-72**	256	**23**	282	**88**	335	**-107**	246	**-42**	420	**-92**	285
NMi-VSL	**-2**	60	**4**	109	**100**	150	**165**	242	**-31**	80	**34**	350	**-16**	165

Lab *j*

Lab *i*	D_i / µK	U_i / µK	NML D_{ij} / µK	NML U_{ij} / µK	SMU D_{ij} / µK	SMU U_{ij} / µK	CMI D_{ij} / µK	CMI U_{ij} / µK	GUM D_{ij} / µK	GUM U_{ij} / µK	VMT/PFI D_{ij} / µK	VMT/PFI U_{ij} / µK	NMi-VSL D_{ij} / µK	NMi-VSL U_{ij} / µK
CEM	**36**	90	**11**	226	**55**	140	**361**	146	**360**	170	**114**	251	**37**	96
INM	**-19**	130	**-43**	248	**1**	169	**307**	173	**306**	194	**59**	268	**-17**	135
MKEH	**-93**	139	**-117**	250	**-74**	176	**233**	181	**231**	201	**-15**	273	**-91**	144
INRIM	**-14**	62	**-38**	217	**6**	124	**312**	130	**311**	157	**64**	243	**-12**	71
EIM	**30**	227	**6**	308	**49**	251	**356**	255	**354**	269	**108**	327	**32**	230
MIKES	**-32**	131	**-57**	246	**-13**	170	**294**	174	**292**	195	**46**	269	**-31**	136
PTB	**24**	76	**-1**	221	**43**	132	**349**	138	**348**	163	**102**	247	**25**	84
LNE-INM/CNAM	**0**	114	**-24**	237	**20**	157	**326**	162	**325**	184	**78**	261	**2**	119
DTI	**-67**	139	**-42**	250	**-86**	176	**-393**	181	**-391**	201	**-145**	273	**-68**	144
JV	**-162**	388	**-186**	449	**-142**	412	**164**	414	**163**	423	**-84**	462	**-160**	397
VNIIM	**48**	106	**23**	233	**67**	151	**373**	156	**372**	179	**126**	258	**49**	112
MIRS/FE-LMK	**17**	55	**-7**	215	**37**	121	**343**	128	**342**	155	**95**	241	**19**	66
DZM-LPM	**-6**	102	**-30**	232	**13**	149	**320**	154	**318**	177	**72**	256	**-4**	109
UME	**-101**	156	**-126**	260	**-82**	189	**224**	194	**223**	212	**-23**	282	**-100**	150
ZMDM	**-166**	239	**-191**	317	**-147**	262	**160**	265	**158**	279	**-88**	335	**-165**	242
SMD	**29**	72	**4**	217	**48**	130	**355**	136	**353**	161	**107**	246	**31**	80
BEV	**-36**	349	**-60**	403	**-17**	365	**290**	365	**288**	377	**42**	420	**-34**	350
IPQ	**14**	161	**-10**	260	**33**	194	**340**	198	**338**	217	**92**	285	**16**	165
NML	**24**	214			**44**	239	**350**	242	**349**	**258**	**102**	317	**26**	216
SMU	**-19**	118	**-44**	239			**306**	161	**305**	183	**59**	**260**	**-18**	123
CMI	**-326**	124	**-350**	242	**-306**	161			**-1**	182	**-248**	260	**-324**	**129**
GUM	**-324**	152	**-349**	258	**-305**	183	**1**	182			**-246**	274	**-323**	156
VMT/PFI	**-78**	240	**-102**	317	**-59**	260	**248**	260	**246**	274			**-76**	242
NMi-VSL	**-2**	60	**-26**	216	**18**	123	**324**	129	**323**	156	**76**	242		

7.3 LINKING EURAMET.T-K7 TO CCT-K7

For the link between EURAMET.T-K7 comparison and CCT-K7 comparison, we have to make use of the results obtained by the laboratories that participated in both CCT-K7 and EURAMET.T-K7.
Potential linking laboratories are CEM, INRIM, IPQ, LNE-INM/CNAM, NMi-VSL, SMU, UME and VNIIM.
The linkage mechanism is usually established by using the linking laboratories results to define a quantity that remained unchanged across both CCT-K7 and EURAMET.T-K7 comparison.
In this specific case, we considered three different possibilities:

1. The mean temperature of the national references of the linking laboratories remained unchanged.
2. After correcting the CCT results of the linking laboratories on the basis of the redefinition of the national reference, the mean temperature of the national references of the linking laboratories remained unchanged.
3. The mean of the temperatures realized by the transfer cells of the linking laboratories remained unchanged.

Option 1 was discarded because in the time window between the end of CCT-K7 and the beginning of EURAMET.T-K7, most of the linking laboratories shifted their national reference for the triple point temperature on the basis of an improved knowledge of the isotopic composition of the reference cells' water.
Option 2 was discarded too, because some of the linking laboratories (e.g. IPQ), in spite of realizing a systematically higher triple point temperature, did not formally changed the national definition for the temperature of the triple point of water.
Supported by the results showed in Chapter 3, we choose option 3.
In Chapter 3 and 4 we showed that there exist well-grounded reasons to question the stability of INRIM, UME and VNIIM transfer cells. For this reason we decided to exclude the transfer cells of INRIM, UME and VNIIM from the stationary mean temperature of the linking laboratories.
The linkage between CCT-K7 and EURAMET.T-K7 can be established as follows:

The position of the linking cells with respect to the KCRV during CCT-K7 was (from final report of CCT-K7):

$$(T_{CEM-2030} - T_{KCRV})\big|_{CCT-K7} = 52.0\mu K$$
$$(T_{IPQ-2114} - T_{KCRV})\big|_{CCT-K7} = 79.0\mu K$$
$$(T_{LNE-6} - T_{KCRV})\big|_{CCT-K7} = -78.8\mu K$$
$$(T_{VSL-094} - T_{KCRV})\big|_{CCT-K7} = 48.5\mu K$$
$$(T_{SMU-1} - T_{KCRV})\big|_{CCT-K7} = -14.3\mu K$$

The position of the mean of the linking cells with respect to the KCRV during CCT-K7 is then calculated as (from final report of CCT-K7):

$$\frac{1}{5}\sum_{i=1}^{5}(T_i^{Linking} - T_{KCRV})\big|_{CCT-K7} = 17.3\mu K$$

The position of CCT-K7 KCRV in EURAMET.T-K7 comparison can be localized by requiring the previous equation as a constraint, where the position of the KCRV (for example with respect to ERV) is the quantity to be determined:

$$(T_{KCRV} - T_{ERV})\big|_{EURAMET.T-K7}$$

Then the constraint to be imposed to the linking cells in EURAMET.T-K7 comparison is: $\frac{1}{5}\sum_{i=1}^{5}(T_i^{Linking} - T_{KCRV})\big|_{EURAMET.T-K7} = 17.3\mu K$ which can be rewritten as:

$$\frac{1}{5}\sum_{i=1}^{5}\left[(T_i^{Linking} - T_{ERV}) - (T_{KCRV} - T_{ERV})\right]_{EURAMET.T-K7} = 17.3\mu K$$

And with some algebra:

$$(T_{KCRV} - T_{ERV})\big|_{EURAMET.T-K7} = \frac{1}{5}\left[\sum_{i=1}^{5}(T_i^{Linking} - T_{ERV})\big|_{EURAMET.T-K7} - 86.5\mu K\right] = -64.7\,\mu K$$

The uncertainty of the difference $(T_{KCRV} - T_{ERV})\big|_{EURAMET.T-K7}$ was calculated as:

$$u(T_{KCRV} - T_{ERV})\big|_{EURAMET.T-K7} = \sqrt{u^2(T_{KCRV} - T_{VSL094}) + u^2(T_{ERV} - T_{VSL094})} =$$
$$\sqrt{u^2(1/5\sum_{i=1}^{5}(T_i^{linking} - T_{VSLo94})) + u^2(T_{ERV} - T_{VSL094})} = 19.7\,\mu K$$

APPENDIX 1: TECHNICAL PROTOCOL FOR THE EUROMET COMPARISON OF WATER TRIPLE POINT CELLS (EUROMET.T-K7)

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Version 2.2 (09/05/06)

1. Introduction

During the last meeting held in Vienna in April 2005, the EUROMET Thermometry Technical Committee decided to initiate a key comparison of water triple point cells (WTPCs) as regional extension of CIPM key comparison CCT-K7.
The NMi VSL was charged with organizing this comparison, with support from co-pilot institutes CEM, IMGC, LNE-INM/CNAM, MIRS/FE-LMK, SMD and SMU. Following the usual acronym generation, this comparison is designated as EUROMET.T-K7.

This technical protocol describes the objectives of the comparison, its organization and procedures to be followed by the participants. It has been drawn up according to the following documents:

- The technical supplement to the CIPM document "*Mutual Recognition Arrangement of national measurement standards and of calibration and measurement certificates issued by national metrology institutes (MRA)* " [1].
- The BIPM document "*Guidelines for CIPM key comparison*" [2].
- The EUROMET guide n. 3 "*Euromet Guidelines on Conducting Comparisons*" [3].

To ensure proper link to its corresponding CIPM key comparison, this technical protocol is in most of its parts very similar to that already used for CCT-K7.

All participants to this comparison accept the general instructions and commit themselves to follow the procedures described in this technical report.

Once the protocol and the list of participants have been agreed, no change to the protocol or to the list of participants may be accepted without prior agreement of all the participants.

2. Objectives of the comparison

In light of:

- the results of CCT-K7,
- the CCT document CCT/05-07 "*Summary of Facts Relating to Isotopic Effects and the Triple Point of Water: report of the ad hoc Task Group on the triple point of water*" [4],
- the CCT document CCT/05-08 "*Methodologies for the estimation of the uncertainties and the correction of fixed point temperatures attributable to the influence of chemical impurities*" [5],
- the CCT WG8 report to the 23rd CCT Meeting [6],

it is expected that in the near future many institutes will change their national definition realization of the water triple point temperature. This comparison will collect the information on the change made on the national definitions (for the institutes that participated to CCT-K7) and will lead the EUROMET members that did not take part to CCT-K7 to face the isotopic and chemical impurities issues addressed in the above-mentioned documents.

The specific objectives of this comparison are:

1) A direct comparison of water triple point cells to quantify the differences between the cells, providing a link to CCT-K7 to the EUROMET members that did not take part to CCT-K7.

2) A comparison of the national realizations of the WTP temperature. As all the participants will adopt the methodologies described in the above-mentioned documents (mostly concerning isotopic and impurity effects), it will be interesting to compare the new distribution of the national references to the one generated by CCT-K7.

3. Organization of the comparison

The participants with corresponding contact person are listed in the following table:

Acronym	Contact person	Country
BRML-INM	Sonia Gaita	Romania
CEM	M. Dolores del Campo Maldonado	Spain
CMI	Marek Smid	Czech Republic
DZM-LPM	Davor Zvizdic	Croatia
DTI	Annette Bronnum	Denmark
EIM	Miltiadis Anagnostou	Greece
GUM	Elzbieta Grudnewicz	Poland
IMGC[1]	Peter Steur	Italy
IPQ	Eduarda Felipe	Portugal
JV	Ingvild Antonsen	Norway
LNE-INM/CNAM	Eliane Renaot	France
Mikes	Thua Weckstrom	Finland
MIRS/FE-LMK	Jovan Bojkovski	Slovenia
NMi VSL	Andrea Peruzzi	The Netherlands
NML	Mary White	Ireland
OMH	Emese Andras	Hungary
PTB	Erich Tegeler	Germany
SMD	Miruna Dobre	Belgium
SMU	Stanislav Duris	Slovakia
UME	Aliye Kartal Dogan	Turkey
VMT/PFI	Vladas Augevicius and Antanas Pauzha	Lithuania
VNIIM	Anatoly Pokhodun	Russia
ZMDM	Slavica Simic	Serbia and Montenegro

Table 1: List of participants with corresponding contact persons.
[1]INRIM in the next future.

The resources and time required to perform the comparison with the same collapsed star organization scheme of CCT-K7 were such that no EUROMET member would have accepted to undertake the work. For this reason a different organization scheme was adopted.

The measurement pattern can be essentially divided into two parts:

- **Part 1** (see following points1.1 to 1.7) in which the link to CCT-K7 is re-established for the co-pilot participants by using the CCT-K7 transfer cells in combination with the NMi VSL transfer cells.
- **Part 2** (see following points 2.1 to 2.6) in which the link to CCT-K7 is established for all the non-co-pilot participants.

Part 1

1.2 NMi VSL prepares a set of 6 cells of known isotopic composition (which in the following will be designated as *NMi VSL transfer cells*).
1.2 NMi VSL compares the set of 6 NMi VSL transfer cells with its *national standard* and its *reference cell for the comparison* (cell VSL98T094, which was used as transfer cell during CCT-K7).
1.3One *NMi VSL transfer cell* is transferred to each one of the 6 co-pilots laboratories.
1.5 Each participant laboratory selects one *transfer cell* for the comparison. The laboratories that participated to CCT-K7 (except for PTB) adopt as *transfer cell* for this comparison the same cell that they used as transfer cell in CCT-K7.
1.5 The non-copilot laboratories that participated to CCT-K7 compare the selected *transfer cell* to their own national reference (cell or group of cells).
1.6 The non-copilot laboratories that participated to CCT-K7 deliver the selected *transfer cell* to the assigned co-pilot.
1.8 The copilot laboratories that participated to CCT-K7 compare the received *NMi VSL transfer cell* with the cell they used as transfer cell in CCT-K7 and with their national reference. The copilot laboratories that did not participate to CCT-K7 compare the following cells: the received *NMi VSL transfer cell*, the transfer cell of the non-copilot laboratory that participated to CCT-K7, the local transfer cell and the local national reference.

Part 2

2.7 Each non-copilot laboratory that did not participate to CCT-K7 compares its selected *transfer cell* to its own national reference (single cell or group of cells).
2.8 Each non-co-pilot laboratory that did not participate to CCT-K7 delivers the selected transfer cell to the assigned co-pilot.
2.9 The co-pilot measures the group of cells formed by its own *transfer cell*, the *NMi VSL transfer cell* and the assigned non-co-pilot's *transfer cells* and a maximum of three cells.
2.10 The co-pilots deliver the NMi VSL transfer cell back to NMi VSL and the non-copilot labs retrieve their respective transfer cells.
2.11 Each non-co-pilot participant laboratory re-compares the received cells to its national reference.
2.12 NMi VSL re-compares the *NMi VSL transfer cells* to its national reference.

The transport of the cells to and from the assigned co-pilot laboratory is within the responsibility of the non-co-pilot laboratories. The transport of the *NMi VSL transfer cells* from and to NMi VSL is under the responsibility of the co-pilots laboratories.
The cells should be hand-carried. The cells must be accompanied by an ATA carnet or a temporary export document (where appropriate). Also an eventual insurance of

the cells for the transport is within the responsibility of the non-co-pilot laboratories. Before dispatching the cell, the sending laboratory shall inform the receiving laboratory and the pilot institute. After arrival of the cell, the receiving laboratory shall inform the pilot institute and, immediately after receipt, shall check for any damage of the cell and report it to the pilot institute. If a laboratory uses special parts with its cell, like a bushing or a foam pad, these should also be sent to the co-pilot laboratory, together with the description of its use (if necessary).

The timetable of the comparison is the following:

- 01/07/06 Starting date: NMi VSL prepares and compare with its national standard a set of 6 cells (*NMi VSL transfer cells*). Non-co-pilot laboratories that participated to CCT-K7 compare their transfer cell to their national reference.
- 30/09/06 Deadline transport of *NMi VSL transfer cells* to the co-pilot laboratories and CCT-K7 cells to co-pilot laboratories.
- 31/12/06 Deadline delivery (to the pilot institute) of co-pilot laboratories' results of the measurements specified at point 1.7.
- 31/12/06 Deadline delivery of non-copilot cells (from the laboratories that did not take part to CCT-K7) to co-pilot laboratories and delivery of the results (to the pilot institute) of the comparison of the selected transfer cell with the national standard.
- 31/03/07 Deadline delivery of non-copilots' transfer cells back to their original lab.
- 31/04/07 Deadline delivery (to the pilot institute) of the results of the co-pilot measurements specified at point 2.3.
- 30/06/07 Deadline delivery of the results of the measurements after returning the cells to the original laboratories (if no significant change is observed, this is not needed).

4. Co-pilots and pilots assignment

The following participants volunteered to be co-pilots:

- CEM (Spain)
- IMGC (Italy)
- LNE-INM/CNAM (France)
- MIRS/FE-LMK (Slovenia)
- SMD (Belgium)
- SMU (Slovakia)

All the participants were sub-divided in 6 groups, each one of them including one co-pilot as follows (bold characters for co-pilots):

- **CEM**, OMH, BRML-INM
- CMI, GUM, **SMU**, VMT/PFI
- EIM, **IMGC,** Mikes, PTB,
- DTI, JV, **LNE-INM/CNAM,** VNIIM
- DZM-LPM, **MIRS/FE-LMK**, UME, ZMDM
- IPQ**,** NML, **SMD**

Only one technically based constraint was imposed on the group composition: to have at least one CCT-K7 participant within each group.

The co-pilots combined standard uncertainty for the temperature difference of two water triple point cells should be less than 25 μK.

5. Selection of the transfer cells

One mandatory constrain is imposed on the selection of the transfer cells for this comparison: **the laboratories that participated to CCT-K7 must use (with the exception of PTB) as transfer cell the same cell that they used as transfer cell in CCT-K7.**

In all the other cases, the cells chosen as transfer cells for this comparison should be carefully selected. The quality of the transfer cells should not significantly differ from the reference cell or cells used at each NMI. No cells must be used whose quality is suspect on simple inspection procedures or which are known for any kind of abnormal behavior.

The following tests should be made on the cells and will be repeated at reception of the cells at the co-pilot NMI:

- No floating material should be visible in the water.
- There should be a sharp “click” audible if the cell is gently inverted, indicating very low amount of residual air (“water hammer test”).
- For the cells where it is possible, a McLeod type test should be made by inverting the cell and entrapping air in the side arm or in the filling extension. The allowable bubble size for an acceptable cell depends on the cell type. For example, for a Jarrett Type A cell, the bubble diameter should not be larger than about 5 mm, corresponding to a temperature depression of 5 μK. Prior to testing for air, the cells should be held vertically at room temperature overnight.

Each co-pilot NMI reserves the right to reject transfer cells that do not meet the minimum selection criteria when tested on receipt. Laboratories normally using other tests are invited to apply them in addition and to describe them.

Laboratories are asked to provide as soon as possible information about the dimensions (in cm) of the chosen cells. This particularly applies to cells with unusual dimensions (for examples, very large or very small cells).

6.1. Measurements instructions and reporting

Each laboratory must carefully select its transfer cell according to the criteria given in paragraph 5 and compare it against its national reference (single cell or set of cells).

The measurements should be performed on two separately prepared ice mantles of the transfer cell and, for each prepared ice mantle, the direct comparison to the national reference should be finalized within two weeks with typically one measurement per day. The measurements should not start earlier than 7 days after the preparation of the ice mantle. Depending on the local preparation technique, the minimum waiting time required might be longer than 7 days. A minimum of 10 measurements per mantle should be reported in the appropriate Measurement Report Form A (see appendix 1). Before each measurement an inner melt shall be induced. The recommended method for inducing the inner melt is the insertion of a room temperature metal or glass rod in the thermometer well for a few seconds. The ice mantle should then be freely rotating around the well when a small rotational impulse is given to it. The well should be filled with pre-cooled pure water up to the level of the water in the cell, when the

thermometer is in place. To reduce the transfer uncertainty, the participants might consider preparing the ice mantle of the transfer cell by using the same technique adopted by the assigned co-pilot. In this case, the two parts will have to arrange themselves the needed exchange of information. Apart from this, the measurement procedure should be the one normally applied by the laboratory.
For each transfer cell, an immersion profile should be provided, to ensure that the measurement really senses the temperature of the ice/water interface. For each position, the self-heating correction should be determined and applied. The step width should be 1 or 2 cm, and the measurements should be taken up to about 10 cm below the water surface. The position of the sensor at which the comparison with the reference cell(s) was made should be indicated.
After its return from the co-pilot laboratory, the stability of the cell must be checked with an additional comparison against the national reference. The full set of measurements described above should be repeated.
If the cell is found to be stable, this information should be given to the coordinator; in this case only the measurements made before sending the cell to the co-pilot will be used. If a small, but significant drift is discovered, the laboratory should send the new results (within 3 months after receiving back the transfer cell) to the coordinator, in the same form as before and a new final value for the temperature of the cell can be determined, based on all measurements. If a cell is found unstable ($\Delta T > 100\ \mu$K, or criteria identified by the participant before the comparison begins), the laboratory should inform NMi VSL as early as possible, and within 6 months. In case the feedback measurement is not provided within the time foreseen, only the first result will be used for the data analysis.

6.2. Reporting the measurement results

Each laboratory must report the performed measurements by filling the appropriate Measurement Report Forms. The Measurement Report Forms shown in the Appendixes will be made available in the form of Excel sheets to be filled by the participants. The reporting of the measurement results will include at least the following:

- The daily results obtained during the two measurement phases on the two separately prepared mantles. The self-heating (0 mA) and hydrostatic head correction (immersion depth) should be applied to the results, and the corrections for the transfer cell also communicated separately. Based on these data sets a resulting temperature difference of the transfer cell from the national reference has to be stated.

- The immersion profile of the transfer cell, indicating the position of the sensor at which the calibration was made.

- A detailed budget for the uncertainty of the temperature realized by the transfer cell has to be provided, which follows the general guidance of the 'GUM' [7]. This budget shall include the uncertainty of the national standard (realization uncertainty) and of the direct comparison of the transfer cell to the standard. A model uncertainty budget is given in the Appendix 1.

- The equipment used for the calibration: description of the national reference, technique to prepare the ice mantel, type of storage container, type of thermometer, type of resistance bridge (AC or DC), type of reference resistor and whether or not it is temperature controlled, purchase or manufacturing date of reference cell(s) and transfer cell, measurement currents, and age of mantles of the reference cell(s). If available, the results of an isotope and/or impurity analysis.

The Measurement Report Forms shown in the Appendixes will be made available in the form of Excel sheets to be filled by the participants.

7. General rules of the comparison

To resolve problems concerning eventual incomplete or anomalous data, the general rules of the guidelines for CIPM key comparison [2] will be applied. The full text can be found on the BIPM web page (www.bipm.fr/pdf/guidelines.pdf), and in the following we give an extract of some rules that are the most important according to our experience:

• During the comparison, as the results are received by the pilot institute, they are kept confidential by the pilot institute until all the participants have completed their measurements and all the results have been received, or until the date limit for receipt of results has passed.

• A result from a participant is not considered complete without an associated uncertainty, and is not included in the draft report unless it is accompanied by an uncertainty supported by a complete uncertainty budget. Uncertainties are drawn up following the guidance given in the technical protocol.

• If, on examination of the complete set of results, the pilot institute finds results that appear to be anomalous, the corresponding institutes are invited to check their results for numerical errors but without being informed as to the magnitude or sign of the apparent anomaly. If no numerical error is found the result stands and the complete set of results is sent to all participants. Note that once all participants have been informed of the results, individual values and uncertainties may be changed or removed, or the complete comparison abandoned, only with the agreement of all participants and on the basis of a clear failure of the travelling standard or some other phenomenon that renders the comparison or part of it invalid.

• An institute that considers its result unrepresentative of its standards may request a subsequent separate bilateral comparison with the pilot institute or one of the participants. This should take place as soon as possible after the completion of the comparison in progress. The subsequent bilateral comparison is considered as a new and distinct comparison (see paragraph 10).

It is difficult to give in advance an unambiguous criterion for what constitutes anomalous data. The pilot will consider this depending on the real data. Data, which according to common sense would be called an outlier, will be considered as anomalous and the corresponding laboratory will be asked to verify its calculation. In case of any doubt we will contact the corresponding laboratory.

8. References

[1] "*Mutual Recognition Arrangement of national measurement standards and of calibration and measurement certificates issued by national metrology institutes (MRA)* ", BIPM, 1999.

[2] T. J. Quinn, "*Guidelines for CIPM key comparison*", 1 March 1999, BIPM, Paris.

[3] EUROMET Guide n. 3, "*Euromet Guidelines on Conducting Comparisons*", version 02.7.

[4] "*Summary of Facts Relating to Isotopic Effects and the Triple Point of Water: report of the ad hoc Task Group on the triple point of water*", CCT document CCT/05-07.

[5] "*Methodologies for the estimation of the uncertainties and the correction of fixed point temperatures attributable to the influence of chemical impurities*", the CCT document CCT/05-08.

[6] CCT WG8 report to the 23rd CCT Meeting (2005).

[7] "*Guide to the expression of uncertainty in measurement*", ISO, 1993, ISBN 92-67-10188-9.

Appendix 1: Measurement Report Form A (for non-co-pilot laboratories)

Laboratory:

Contact person:

Contact address and e-mail:

Transfer cell (n° and type):

Purchase or manufacture date:

Measurement results on first ice mantle

Date of preparation of first ice mantle of transfer cell:

Technique for preparation:

Date of preparation of the mantle of the reference cell(s):

Date of measurement	**Temperature difference from national reference**	**Experimental standard deviation of temperature difference from national reference**	**Distance from sensor midpoint to surface level of water in 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 preparation of second ice mantle:

Technique for preparation:

Date of preparation of the mantle of the reference cell(s):

Date of measurement	**Temperature difference from national reference**	**Experimental standard deviation of temperature difference from national reference**	**Distance from sensor midpoint to surface level of water in 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 the measurements

Description of national reference (1 or several cells, purchase or manufacture date):

Type of resistance bridge, AC or DC:

Measurement current:

Number and sampling frequency of repeated measurements:

Type of reference resistor:

Is reference resistor temperature-controlled? (If yes, state stability):

Type of thermometer, length of sensor:

Storage container for WTP cells:

Immersion profile (only for transfer cell)

Distance from sensor midpoint to free surface level of the liquid water	**Temperature variation**

The above table is for reporting measurement of the hydrostatic head effect. Measurements should be taken at a step width of 1 to 2 cm. Thermometer readings should be corrected for self-heating, measured at each position.

Uncertainty Budget

The uncertainty budget should include the components listed on the table, to which others can be added if necessary. The uncertainty budget shown here can only be considered as a model. Additional uncertainty components can be added reflecting the peculiarities of each participant laboratory. Please explain, how the contributions of chemical impurities and isotope variation were evaluated.

The repeatability for a single ice mantle is understood as the experimental standard deviation of the daily obtained temperature differences between the transfer cell and the national reference, divided by the square root of the number of daily results (here typically 10). The reproducibility for different ice mantles represents the additionally variability introduced by measuring on several different ice mantles.

All contributions should be stated at the level of one standard uncertainty.

Origin	**Contribution (k=1)**
National reference (Uncertainties related only to properties of the reference cell)	
Chemical impurities (please explain how estimated)	
Isotopic variation (please explain how estimated)	
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 transfer cell	
Hydrostatic head of reference cell	
SPRT self-heating in the transfer cell and reference cell [5]	
Perturbing heat exchanges [6]	
others	
Total uncertainty	

[1] Estimate of the reproducibility of the temperature reference due to changes in the following quantities: crystal size, the age of the mantles, different mantles, the handling of the cells before preparation of the mantle.

[2] The repeatability for a single ice mantle is understood as the experimental standard deviation of the daily obtained temperature differences between the transfer cell and the national reference, divided by the square root of the number of daily results (here typically 10). This component takes also in account the stability of reference resistor (temperature effect).

[3] The reproducibility for different ice mantles represents the additional variability introduced by measuring on several different ice mantles on transfer cell (probably the laboratory uses the same ice mantle of the reference cell during the time of measurements).

[4] The observed temperature differences between the transfer and the reference cells could depend on the type of SPRT's. This component takes into account possible SPRT internal insulation leakage.

[5] These uncertainties could be strongly positively correlated. All the measurements are corrected for self-heating effect. If the thermal resistances have approximately the same magnitude in transfer and reference cells the difference between the self-heating corrections is very small. In addition the uncertainties on self-heating corrections in transfer and reference cells are strongly correlated. In this case the uncertainty in self-heating corrections only contributes to the Type A uncertainty of the comparison of the cells.

[6] This component could be estimated:

- by comparing the deviations from expected hydrostatic pressure correction obtained in transfer and reference cells (by changing immersion depth over the length of the sensor $\approx$ 5 cm).
- by modifying the thermal exchange between thermometer and its environment during the measurements on transfer and reference cells.

Appendix 2: Measurement Report Form B1 (for co-pilot laboratories when establishing the link to CCT-K7)

Laboratory:

Contact person:

Contact address and e-mail:

Transfer cell (identification number, type, purchase or manufacture date):

Did your laboratory participate to CCT-K7?

CCT-K7 cell[1] (property, identification number, type, purchase or manufacture date):

NMi VSL transfer cell (identification number):

Measurement results on first ice mantle

Date of preparation of first ice mantle of transfer cell, CCT-K7 cell, NMi VSL transfer cell and cell (or group of cells) defining the national reference:

Technique for preparation of the ice mantle:

Date of measurement	**Temperature difference of transfer cell from CCT-K7 cell (and corresponding experimental standard deviation)**	**Temperature difference of NMi VSL cell from CCT-K7 cell cell (and corresponding experimental standard deviation)**	**Temperature difference of national reference cell from CCT-K7 cell cell (and corresponding experimental standard deviation)**
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. The corrections should also be provided separately for each measured cell.

[1] In case the laboratory took part to CCT-K7, this must be the same as transfer cell.

Measurement results on second ice mantle

Date of preparation of second ice mantle of transfer cell, CCT-K7 cell, NMi VSL transfer cell and cell (or group of cells) defining the national reference:

Technique for preparation of the ice mantle:

Date of measurement	**Temperature difference of transfer cell from CCT-K7 cell cell (and corresponding experimental standard deviation)**	**Temperature difference of NMi VSL cell from CCT-K7 cell cell (and corresponding experimental standard deviation)**	**Temperature difference of national reference cell from CCT-K7 cell cell (and corresponding experimental standard deviation)**
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. The corrections should also be provided separately for each measured cell.

Equipment used for the measurements

Description of national reference (1 or several cells, purchase or manufacture date):

Type of resistance bridge, AC or DC:

Measurement current:

Number and sampling frequency of repeated measurements:

Type of reference resistor:

Is reference resistor temperature-controlled? (If yes, state stability):

Type of thermometer, length of sensor:

Storage container for WTP cells:

Immersion profile (one for each measured cell)

Distance from sensor midpoint to free surface level of the liquid water	**Temperature variation**

The above table is for reporting measurement of the hydrostatic head effect. Measurements should be taken at a step width of 1 to 2 cm. Thermometer readings should be corrected for self-heating, measured at each position.

Uncertainty Budget

The uncertainty budget should include the components listed on the table, to which others can be added if necessary. Since the "CCT guidance document on the uncertainties of SPRT calibrations" of WG 3 does not yet exist and the pilot cannot replace the working group, the budget shown here can only be a model. Some additional guidance can however be obtained from the draft documents [6]. Please explain, how the contributions of chemical impurities and isotope variation were evaluated.

The repeatability for a single ice mantle is understood as the experimental standard deviation of the daily obtained temperature differences between the transfer cell and the national reference, divided by the square root of the number of daily results (here typically 10). The reproducibility for different ice mantles represents the additionally variability introduced by measuring on several different ice mantles.

All contributions should be stated at the level of one standard uncertainty.

Origin	Contribution (k=1)
National reference (Uncertainties related only to properties of the reference cell)	
Chemical impurities (please explain how estimated)	
Isotopic variation (please explain how estimated)	
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 transfer cell	
Hydrostatic head of reference cell	
SPRT self-heating in the transfer cell and reference cell [5]	
Perturbing heat exchanges [6]	
others	
Total uncertainty	

[1] Estimate of the reproducibility of the temperature reference due to changes in the following quantities: crystal size, the age of the mantles, different mantles, the handling of the cells before preparation of the mantle.

[2] The repeatability for a single ice mantle is understood as the experimental standard deviation of the daily obtained temperature differences between the transfer cell and the national reference, divided by the square root of the number of daily results (here typically 10). This component takes also in account the stability of reference resistor (temperature effect).

[3] The reproducibility for different ice mantles represents the additional variability introduced by measuring on several different ice mantles on transfer cell (probably the laboratory uses the same ice mantle of the reference cell during the time of measurements).

[4] The observed temperature differences between the transfer and the reference cells could depend on the type of SPRT's. This component takes into account possible SPRT internal insulation leakage.

[5] These uncertainties could be strongly positively correlated. All the measurements are corrected for self-heating effect. If the thermal resistances have approximately the same magnitude in transfer and reference cells the difference between the self-heating corrections is very small. In addition the uncertainties on self-heating corrections in transfer and reference cells are strongly correlated. In this case the uncertainty in self-heating corrections only contributes to the Type A uncertainty of the comparison of the cells.

[6] This component could be estimated:

- by comparing the deviations from expected hydrostatic pressure correction obtained in transfer and reference cells (by changing immersion depth over the length of the sensor ≈ 5 cm).
- by modifying the thermal exchange between thermometer and its environment during the measurements on transfer and reference cells.

Appendix 3: Measurement Report Form B2 (for co-pilot laboratories when establishing bilateral equivalence between non-copilot participants)

Laboratory:

Contact person:

Contact address and e-mail:

Did your laboratory participate to CCT-K7?

CCT-K7 cell (property, identification number, type, purchase or manufacture date):

NMi VSL transfer cell (identification number):

Non-copilot cell 1 (property, identification number, type, purchase or manufacture date):

Non-copilot cell 2 (property, identification number, type, purchase or manufacture date):

Non-copilot cell 3 (property, identification number, type, purchase or manufacture date):

Measurement results on first ice mantle

Date of preparation of first ice mantle of CCT-K7 cell, NMi VSL transfer cell and non-copilot cells:

Technique for preparation of the ice mantle:

Date of measurement	**Temperature difference of NMi VSL cell from CCT-K7 cell cell (and corresponding experimental standard deviation)**	**Temperature difference of non-copilot cell 1 from CCT-K7 cell cell (and corresponding experimental standard deviation)**	**Temperature difference of non-copilot cell 2 from CCT-K7 cell cell (and corresponding experimental standard deviation)**	**Temperature difference of non-copilot cell 3 from CCT-K7 cell cell (and corresponding experimental standard deviation)**
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. The corrections should also be provided separately for each measured cell.

Measurement results on second ice mantle

Date of preparation of second ice mantle of CCT-K7 cell, NMi VSL transfer cell and non-copilot cells:

Technique for preparation of the ice mantle:

Date of measurement	**Temperature difference of NMi VSL cell from CCT-K7 cell cell (and corresponding experimental standard deviation)**	**Temperature difference of non-copilot cell 1 from CCT-K7 cell cell (and corresponding experimental standard deviation)**	**Temperature difference of non-copilot cell 2 from CCT-K7 cell cell (and corresponding experimental standard deviation)**	**Temperature difference of non-copilot cell 3 from CCT-K7 cell cell (and corresponding experimental standard deviation)**
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. The corrections should also be provided separately for each measured cell.

Equipment used for the measurements

Type of resistance bridge, AC or DC:

Measurement current:

Number and sampling frequency of repeated measurements:

Type of reference resistor:

Is reference resistor temperature-controlled? (If yes, state stability):

Type of thermometer, length of sensor:

Storage container for WTP cells:

Immersion profile (one for each measured cell)

Distance from sensor midpoint to free surface level of the liquid water	**Temperature variation**

The above table is for reporting measurement of the hydrostatic head effect. Measurements should be taken at a step width of 1 to 2 cm. Thermometer readings should be corrected for self-heating, measured at each position.

Uncertainty Budget

The uncertainty budget should include the components listed on the table, to which others can be added if necessary. Some additional guidance can however be obtained from the draft documents [6]. Please explain, how the contributions of chemical impurities and isotope variation were evaluated.

The repeatability for a single ice mantle is understood as the experimental standard deviation of the daily obtained temperature differences between the transfer cell and the national reference, divided by the square root of the number of daily results (here typically 10). The reproducibility for different ice mantles represents the additionally variability introduced by measuring on several different ice mantles.

All contributions should be stated at the level of one standard uncertainty.

Origin	**Contribution (k=1)**
National reference (Uncertainties related only to properties of the reference cell)	
Chemical impurities (please explain how estimated)	
Isotopic variation (please explain how estimated)	
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 transfer cell	
Hydrostatic head of reference cell	
SPRT self-heating in the transfer cell and reference cell [5]	
Perturbing heat exchanges [6]	
others	
Total uncertainty	

[1] Estimate of the reproducibility of the temperature reference due to changes in the following quantities: crystal size, the age of the mantles, different mantles, the handling of the cells before preparation of the mantle.

[2] The repeatability for a single ice mantle is understood as the experimental standard deviation of the daily obtained temperature differences between the transfer cell and the national reference, divided by the square root of the number of daily results (here typically 10). This component takes also in account the stability of reference resistor (temperature effect).

[3] The reproducibility for different ice mantles represents the additional variability introduced by measuring on several different ice mantles on transfer cell (probably the laboratory uses the same ice mantle of the reference cell during the time of measurements).

[4] The observed temperature differences between the transfer and the reference cells could depend on the type of SPRT's. This component takes into account possible SPRT internal insulation leakage.

[5] These uncertainties could be strongly positively correlated. All the measurements are corrected for self-heating effect. If the thermal resistances have approximately the same magnitude in transfer and reference cells the difference between the self-heating corrections is very small. In addition the uncertainties on self-heating corrections in transfer and reference cells are strongly correlated. In this case the uncertainty in self-heating corrections only contributes to the Type A uncertainty of the comparison of the cells.

[6] This component could be estimated:

- by comparing the deviations from expected hydrostatic pressure correction obtained in transfer and reference cells (by changing immersion depth over the length of the sensor ≈ 5 cm).
- by modifying the thermal exchange between thermometer and its environment during the measurements on transfer and reference cells.

Appendix 4: Information about the definition of national reference and the link to CCT K7

4.1 For all laboratories

Description of national reference (Is the national reference defined by a single cell or a group of cells):

Available information about the isotopic composition of the national reference cell(s):

Available information about the impurity content of the national reference cell(s):

4.2 Only for laboratories that participated to CCT-K7

Describe in details how the national reference was defined for CCT-K7:

Describe in details how the national reference is defined for this comparison:

Provide details about the magnitude and the technical basis for the eventual change in the definition of the national reference for this comparison with respect to its definition in CCT-K7:

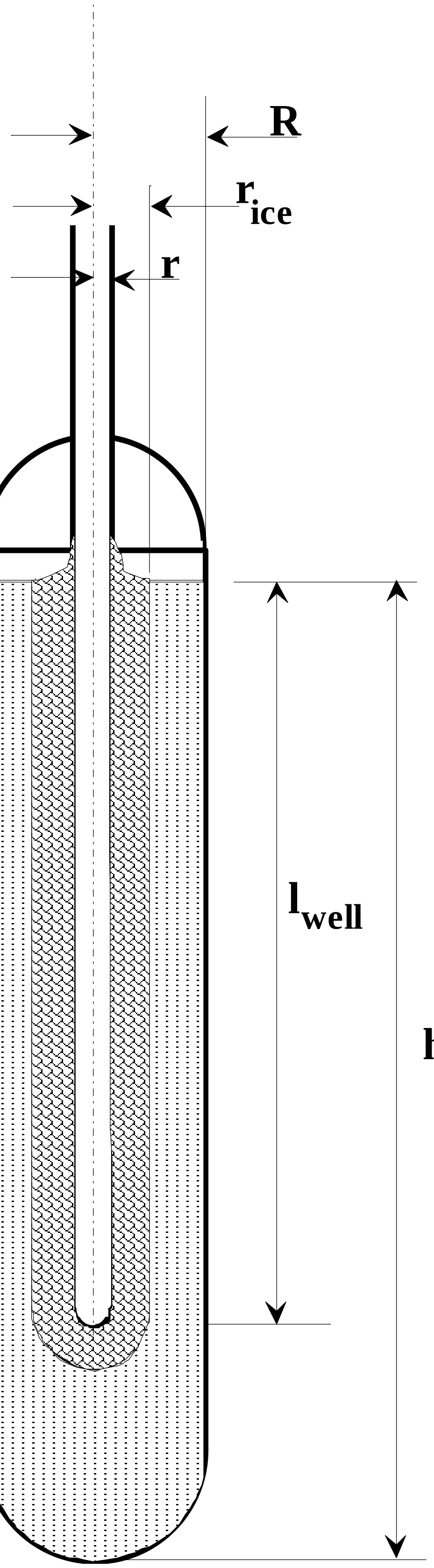
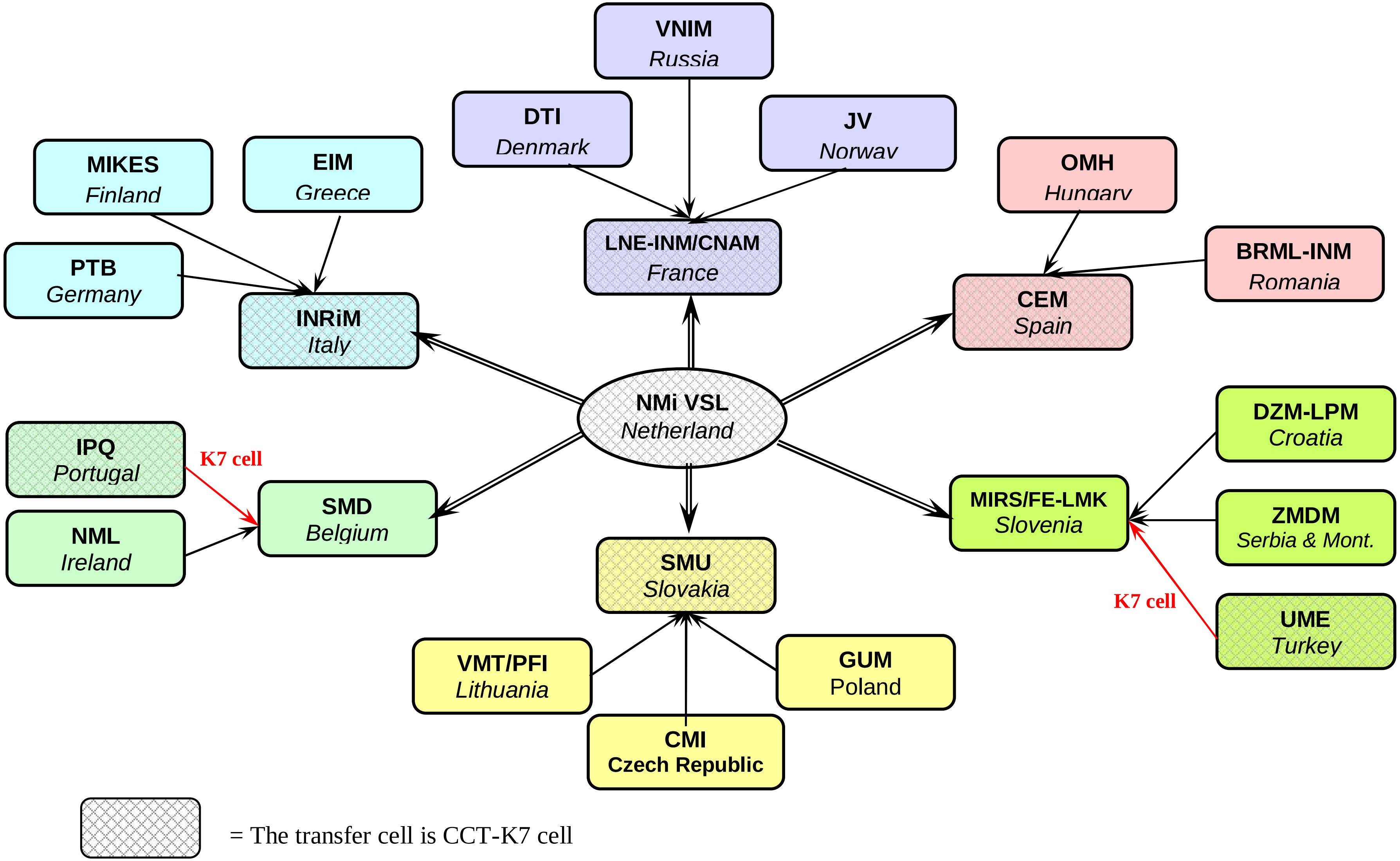


Figure 1: Water triple point cell with ice mantle. R is the radius of the cell, r is the radius of the thermometer well, h_w is the water level when no ice is present, l_{well} is the length of the thermometer well within the water and r_{ice} is the radius of the ice mantle.

Scheme of the organization of the comparison

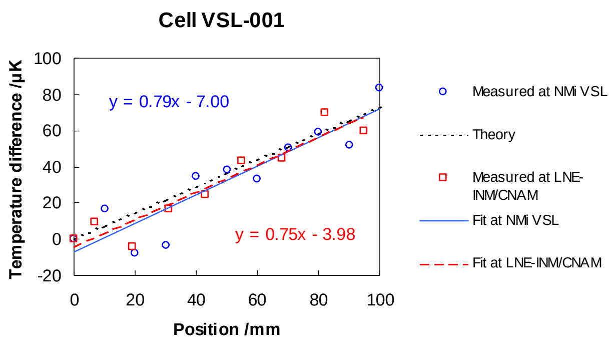


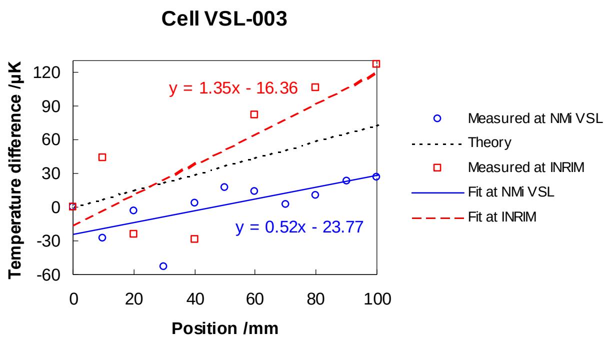
APPENDIX 2: LIST OF PARTICIPANTS AND CONTACT PERSONS DETAILS

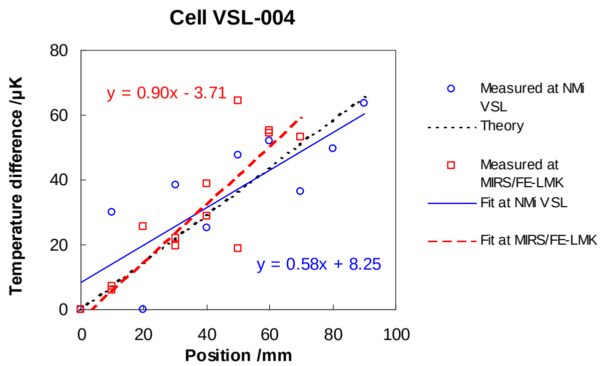
Institute	Country	Contact person	e-mail
BEV (Bundesamt für Eich und Vermessungswesen)	Austria	Rosenkranz Peter	Peter.Rosenkranz@bev.gv.at
CEM (Centro Español de Metrologia)	Spain	M. Dolores del Campo Maldonado	ddelcampo@cem.es
CMI (Czech Metrology Institute)	Czech Republic	Marek Smid	msmid@cmi.cz
DZM-LPM	Croatia	Davor Zvizdić	davor.zvizdic@fsb.hr
DTI (Teknologisk Institut)	Denmark	Mikkel Bo Nielsen	Mikkel.Bo.Nielsen@teknologisk.dk
EIM (Hellenic Institute of Metrology)	Greece	Miltiadis Anagnostou	miltiadis.anagnostou@eim.gr
GUM (Central Office of Measures)	Poland	Elzbieta Grudnewicz	psyschem@gum.gov.pl
INM (National Institute of Metrology)	Romania	Mihaela Nedea	mihaela.nedea@inm.ro
INRIM (Istituto Nazionale di Ricerca Metrologica)	Italy	Peter Steur	p.steur@imgc.cnr.it
IPQ (Instituto Português da Qualidade)	Portugal	Eduarda Filipe	EFilipe@mail.ipq.pt
JV (Norwegian Metrology Service)	Norway	Ingvild Antonsen	ingvild.antonsen@justervesenet.no
LNE-INM/CNAM (Institut National de Métrologie/Conservatoire National des Arts et Métiers)	France	Eliane Renaot	renaot@cnam.fr
MIKES (Centre for Metrology and Accreditation)	Finland	Thua Weckstrom	thua.weckstrom@mikes.fi
MIRS/FE-LMK (University of Ljubljana)	Slovenia	Jovan Bojkovski	jovan.bojkovski@fe.uni-lj.si
MKEH (Hungarian Trade Licensing Office)	Hungary	Emese Turzó-András	thurzo-a@mkeh.hu
NMi-VSL (NMi Van Swinden Laboratorium)	The Netherlands	Andrea Peruzzi	aperuzzi@nmi.nl
NML (National Metrology Laboratory)	Ireland	Mary White	Mary.White@enterprise-ireland.com
PTB (Physikalisch-Technische Bundesanstalt)	Germany	Erich Tegeler	Erich.Tegeler@ptb.de
SMD (FPS Economy, DG Quality and Safety, Metrology Division)	Belgium	Miruna Dobre	Miruna.Dobre@mineco.fgov.be
SMU (Slovak Institute of Metrology)	Slovakia	Juraj Ranostaj	ranostaj@smu.gov.sk
UME (Ulusal Metroloji Enstitüsü)	Turkey	Aliye Kartal Dogan	aliye.kartal@ume.tubitak.gov.tr
VMT/PFI (State Metrology Service)	Lithuania	Vladas Augevicius	augevicius@pfi.lt
VNIIM	Russia	Anatoly Pokhodun	a.i.pokhodun@vniim.ru
ZMDM	Serbia & Mont.	Slavica Simic	temperatura@szmdm.sv.gov.yu

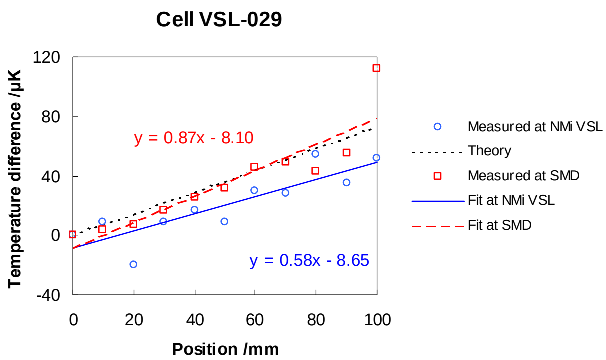
APPENDIX 3: IMMERSION PROFILES

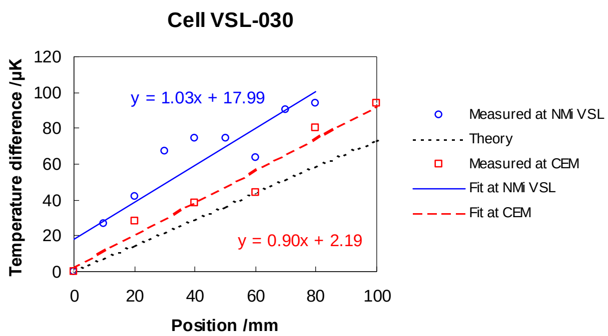
A3.1 IMMERSION PROFILES OF NMi-VSL TRANSFER CELLS

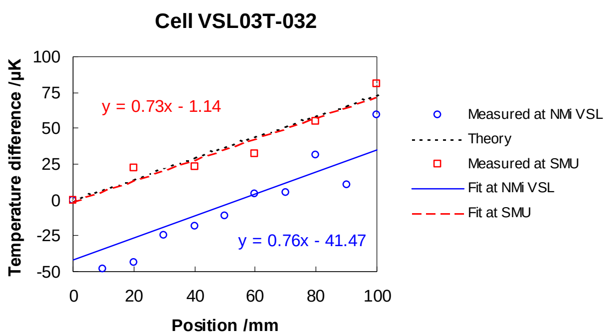






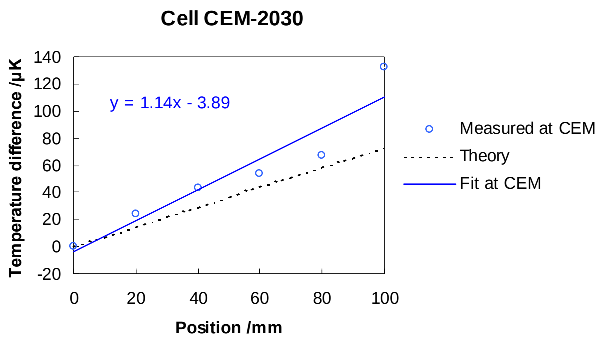


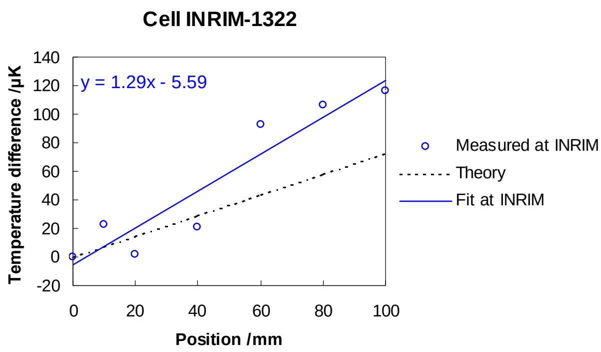


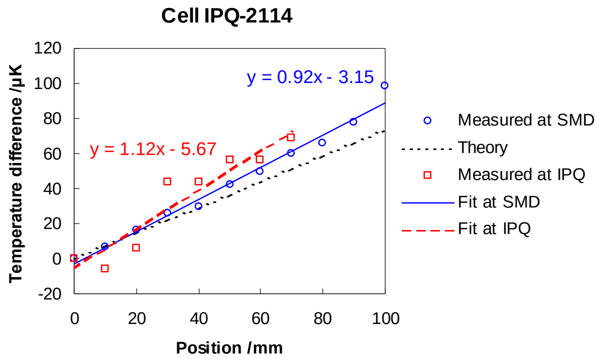


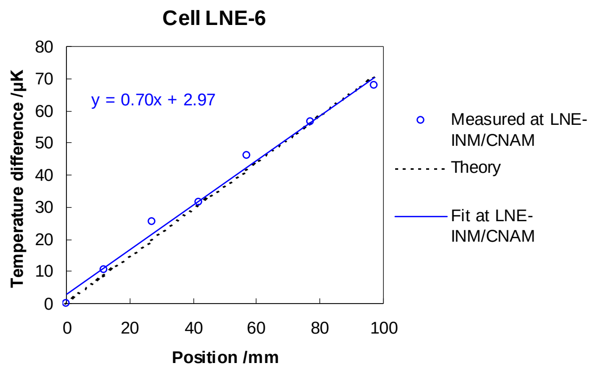
Note: For the profile measured at INRIM (cell VSL-003), when the linear fit is extended to the experimental points above 100 mm the fit line is $y = 0.98x - 6.02$.

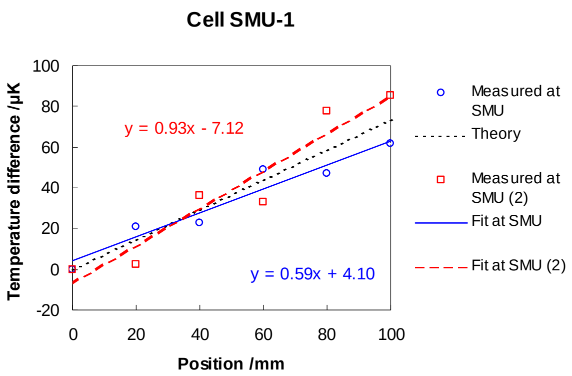
A3.2 IMMERSION PROFILES OF CCT-K7 TRANSFER CELLS

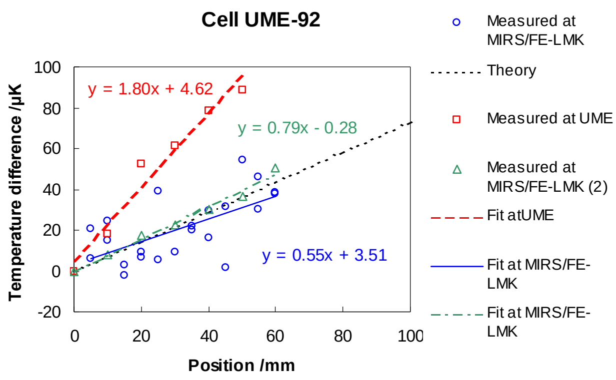


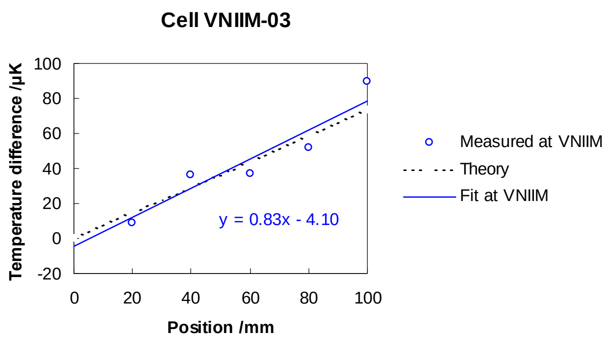


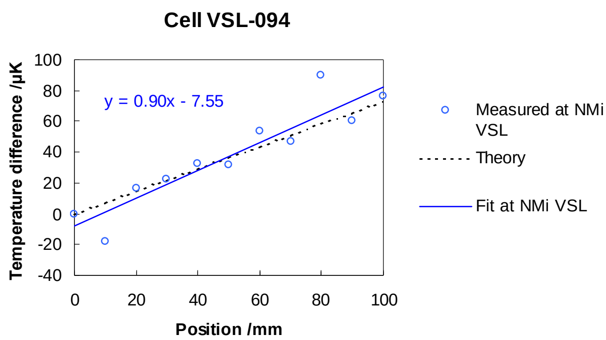




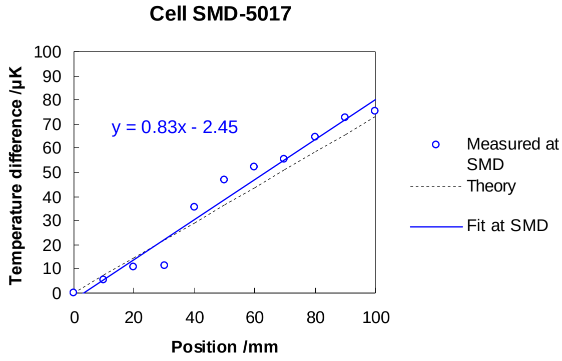




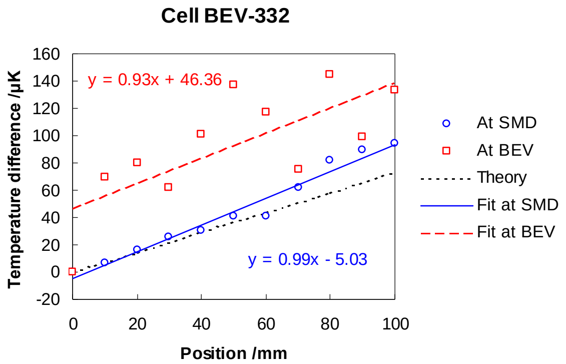


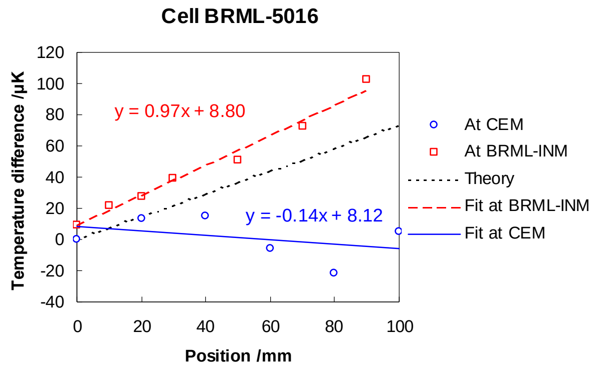


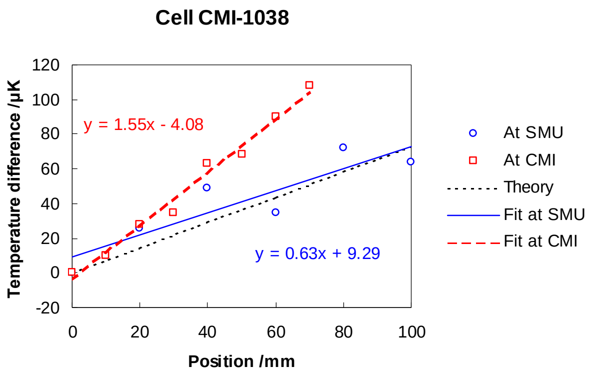
A3.3 IMMERSION PROFILES OF CO-PILOTS' NON-CCT-K7 TRANSFER CELLS

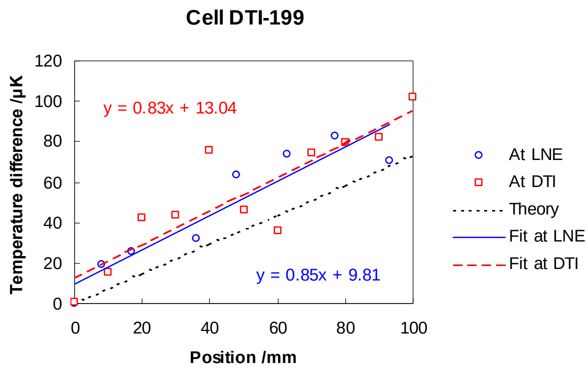


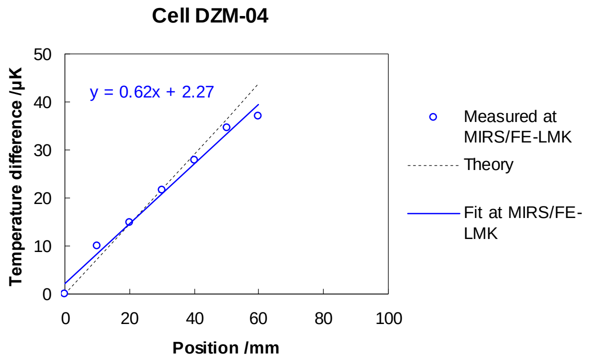
A3.4 IMMERSION PROFILES OF NON-CO-PILOTS' TRANSFER CELLS

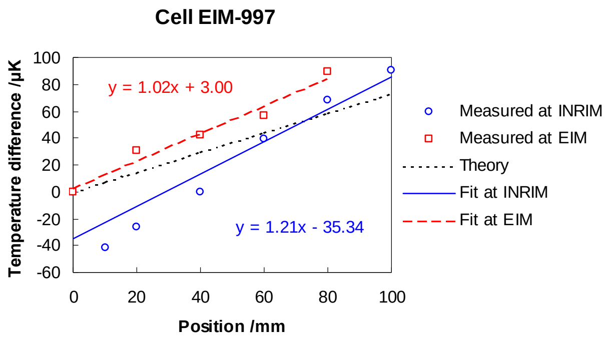


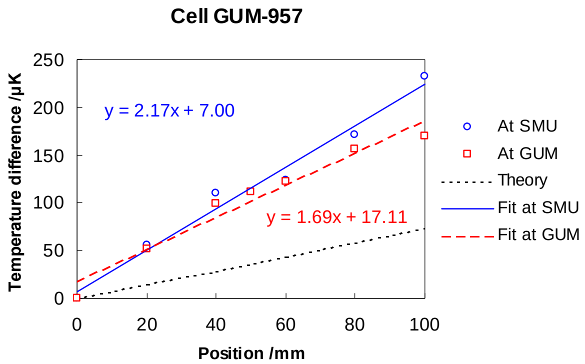


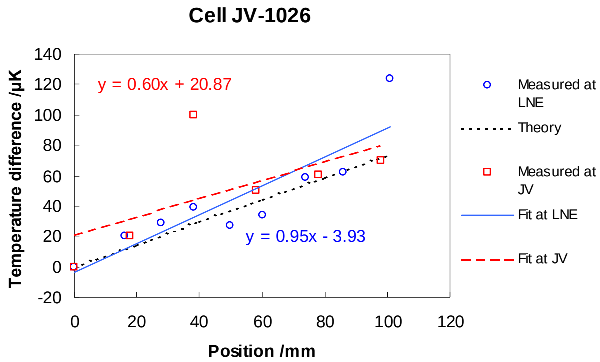


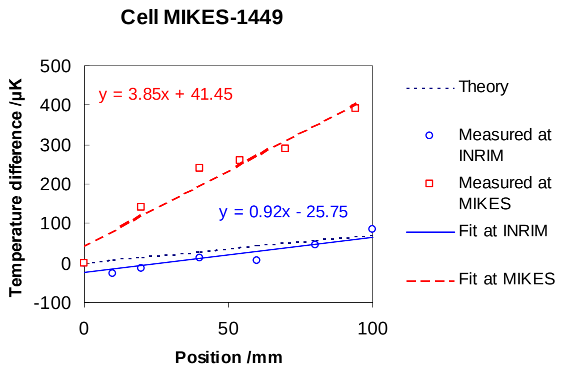


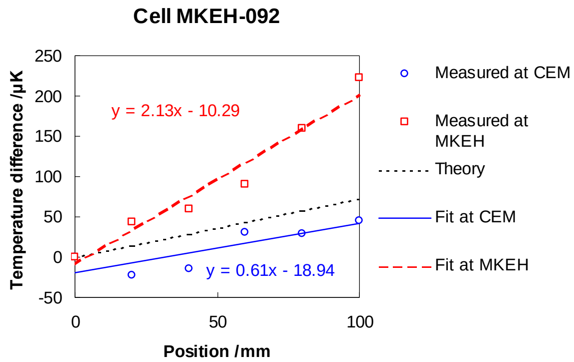

Cell DZM-04
Temperature difference /µK
Position /mm
y = 0.62x + 2.27
Measured at MIRS/FE-LMK
Theory
Fit at MIRS/FE-LMK

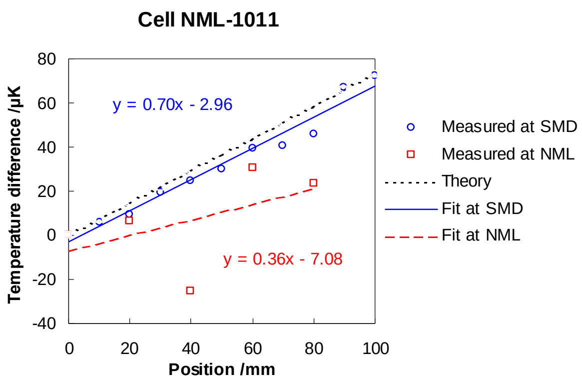

Cell EIM-997
Temperature difference /µK
Position /mm
y = 1.02x + 3.00
y = 1.21x - 35.34
Measured at INRIM
Measured at EIM
Theory
Fit at INRIM
Fit at EIM

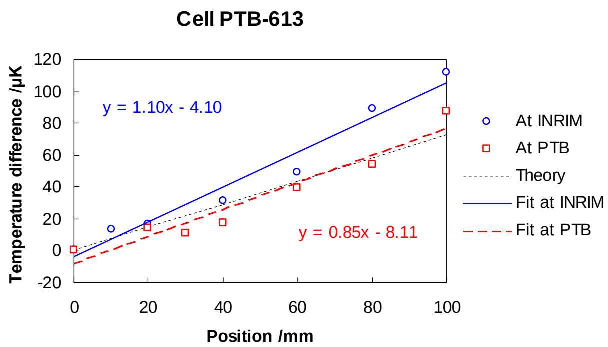

Cell GUM-957
Temperature difference /µK
Position /mm
y = 2.17x + 7.00
y = 1.69x + 17.11
At SMU
At GUM
Theory
Fit at SMU
Fit at GUM

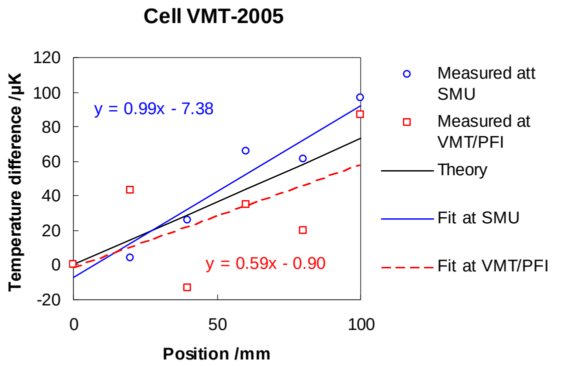

Cell JV-1026
Temperature difference /µK
Position /mm
y = 0.60x + 20.87
y = 0.95x - 3.93
Measured at LNE
Theory
Measured at JV
Fit at LNE
Fit at JV

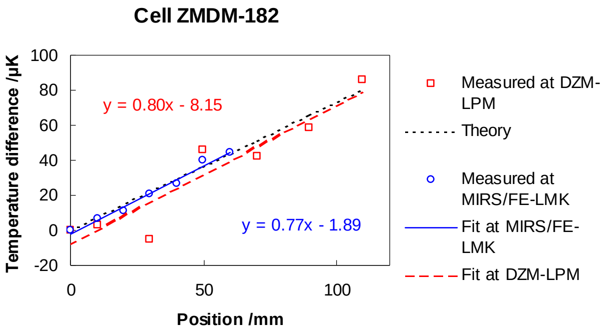

Cell MIKES-1449
Temperature difference /µK
Position /mm
y = 3.85x + 41.45
y = 0.92x - 25.75
Theory
Measured at INRIM
Measured at MIKES
Fit at INRIM
Fit at MIKES


Cell MKEH-092
Temperature difference /µK
Position /mm
y = 2.13x - 10.29
y = 0.61x - 18.94
Measured at CEM
Measured at MKEH
Theory
Fit at CEM
Fit at MKEH


Cell NML-1011
Temperature difference /µK
Position /mm
y = 0.70x - 2.96
y = 0.36x - 7.08
Measured at SMD
Measured at NML
Theory
Fit at SMD
Fit at NML


Cell PTB-613
Temperature difference /µK
Position /mm
y = 1.10x - 4.10
y = 0.85x - 8.11
At INRIM
At PTB
Theory
Fit at INRIM
Fit at PTB





Note: For the profiles measured at INRIM (cell INRIM-1322, EIM-997, MIKES-1449 and PTB-613), when the linear fit is extended to the experimental points above 100 mm the fit lines are respectively $y = 0.88x + 7.32$, $y = 1.37x - 40.33$, $y = 1.26x - 36.67$ and $y = 1.13x - 5.04$.

APPENDIX 4. CALIBRATION OF THE TRANSFER CELLS BY THE PARTICIPANTS

A4.1 INTRODUCTION

Each participant *i* determined the temperature difference between its transfer cell and its national reference and the corresponding combined standard uncertainty:

T_i *(transfer cell) –* T_i *(national reference)*
u(T_i *(transfer cell) –* T_i *(national reference))*

The national reference is assumed to represent the ideal water triple point temperature, within a related realization uncertainty which includes the effects of impurities and isotopes.
In this chapter for national reference we mean the national reference as resulting from the measurements performed in this comparison. Apart from the intrinsic variability of the national reference when measured from time to time, the national references defined in this chapter may differ from the corresponding CCT-K7 national references also because the laboratories may have decided to change the definition of their national reference in the time frame between the end of CCT-K7 and the beginning of this comparison, as considered in CCT WG8 report to the 23rd CCT Meeting.
When confusion may arise from the “old” and the “new” national references, the wording CCT-K7 national reference and EUROMET.T-K7 national reference will be used.

A4.2 NATIONAL REFERENCE OF BEV

First mantle				Second mantle			
Date	**T(BEV-332) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(BEV-332) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(BEV-332) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(BEV-332) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
13/12/06	4	9	8	31/05/07	19	9	6
14/12/06	3	7	7	01/06/07	-15	7	7
15/12/06	-12	7	9	04/06/07	9	8	7
18/12/06	1	9	7	05/06/07	4	6	7
19/12/06	7	7	7	06/06/07	6	7	7
27/12/06	-3	8	8	11/06/07	18	7	8
02/01/07	11	7	6	12/06/07	-11	7	6
08/01/07	51	7	7	13/06/07	27	7	7
15/01/07	-45	9	9	15/06/07	14	9	8
17/01/07	6	6	7	18/06/07	14	7	7
				19/06/07	19	8	5
Mean	**2.2**	**7.6**	**7.5**		**9.5**	**7.5**	**6.8**
St.D.Mean	**7.4**				**3.9**		

At BEV the national reference is represented by one cell (Isotech B II 340). No information is available on isotopic composition and impurity content of the cell water.

T (BEV-332) – T (nat. ref.) = 5.9 µK
$u(T$ (BEV-332) – T (nat. ref.)) = 173 µK (k=1)

A4.3 NATIONAL REFERENCE OF CEM

First mantle				Second mantle			
Date	**T(CEM-2030) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(CEM-2030) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(CEM-2030) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(CEM-2030) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
02/11/06	-28.2	6.3	6.3	22/11/06	-55.5	3.6	3.6
03/11/06	-70.8	5.2	5.2	23/11/06	-62.6	6.8	6.8
06/11/06	-56.5	4.7	4.7	24/11/06	-56.8	4.0	4.0
07/11/06	-59.0	9.4	9.4	27/11/06	-44.1	7.4	7.4
08/11/06	-37.5	2.3	2.3	28/11/06	-72.1	4.2	4.2
09/11/06	-53.8	4.3	4.3	29/11/06	-51.8	6.9	6.9
10/11/06	-43.8	3.6	3.6	30/11/06	-63.6	6.2	6.2
13/11/06	-73.8	6.4	6.4	01/12/06	-59.6	3.0	3.0
14/11/06	-68.5	5.2	5.2	04/12/06	-44.7	4.2	4.2
16/11/06	-63.0	3.6	3.6	05/12/06	-68.3	3.2	3.2
Mean **St.D.Mean**	**-55.5** **4.7**	**5.1**	**5.1**		**-57.9** **2.9**	**5.0**	**5.0**

The national reference of CEM is based on two cells with known isotopic composition (Hart A-Q5021 and Isotech 556). Its value is transferred and maintained by the mean value of the corrections of a group of 6 cells.

T (CEM-2030) – T (nat. ref.) = -56.7 µK
$u(T$ (CEM-2030) – T (nat. ref.)) = 40 µK (k=1)

A4.4 NATIONAL REFERENCE OF CMI

First mantle				Second mantle			
Date	**T(CMI-1038) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(CMI-1038) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(CMI-1038) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(CMI-1038) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
20/12/06	75	12.4	13.9	09/01/07	97	11.8	11.6
21/12/06	130	23.1	9.7	10/01/07	110	7.2	9.9
22/12/06	95	9.0	9.6	11/01/07	93	11.0	10.6
23/12/06	114	11.4	12.5	12/01/07	72	14.3	12.2
25/12/06	120	10.7	13.1	13/01/07	65	11.3	11.2
26/12/06	105	10.7	11.4	14/01/07	106	9.5	9.0
27/12/06	110	9.1	9.0	15/01/07	71	20.0	15.4
28/12/06	108	7.6	12.4	16/01/07	139	11.6	11.4
29/12/06	96	8.9	16.2	17/01/07	113	10.2	9.3
30/12/06	107	13.4	10.5	18/01/07	104	11.5	7.0
				19/01/07	106	7.0	13.5
				20/01/07	132	9.1	12.0
Mean **St.D.Mean**	**106.0** **4.8**	**11.6**	**11.8**		**100.7** **6.6**	**11.2**	**11.1**

At CMI the national reference is represented by one cell (NPL, glass cell type 32, s/n 1025). No information is available on isotopic composition and impurity content of the cell water.

T (CMI-1038) – T (nat. ref.) = 103.4 µK
$u(T$ (CMI-1038) – T (nat. ref.)) = 54 µK (k=1)

A4.5 NATIONAL REFERENCE OF DZM-LPM

First mantle				Second mantle			
Date	**T(DZM-4) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(DZM-4) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(DZM-4) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(DZM-4) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
23/01/07	-36.4	34	48	05/02/07	-19.4	21	13
24/01/07	2.2	40	32	06/02/07	5.7	14	12
25/01/07	-16.6	44	43	07/02/07	19.1	16	16
26/01/07	-44.4	37	32	07/02/07	21.6	21	14
27/01/07	-78.3	41	36	08/02/07	66.6	17	15
29/01/07	15.6	38	40	09/02/07	98.1	19	17
30/01/07	32.7	36	40	10/02/07	-21.3	22	19
31/01/07	68.9	36	55	12/02/07	-38.3	20	19
01/02/07	32.4	28	15	13/02/07	-16.5	14	15
				13/02/07	15.3	17	23
				14/02/07	11.2	17	15
				14/02/07	7.9	17	12
Mean **St.D.Mean**	**-2.7** **15.7**	**37.1**	**37.9**		**12.5** **11.0**	**17.9**	**15.8**

At DZM-LPM the national reference is represented by one cell (Isotech, s/n 4, 2003). In a private communication, the manufacturer of the cell stated that a correction of +9 µK should be applied for the isotopic composition, and +23 µK for both isotopic and impurity composition.

T (DZM-4) – T (nat. ref.) = 4.9 µK
u(T (DZM-4) – T (nat. ref.)) = 45 µK (k=1)

A4.6 NATIONAL REFERENCE OF DTI

First mantle				Second mantle			
Date	**T(DTI-199) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(DTI-199) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(DTI-199) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(DTI-199) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
29/11/06	50.5	5.4	4.4	11/12/06	85.8	6.7	4.8
29/11/06	36.4	5.8	3.6	12/12/06	119.0	6.6	5.7
30/11/06	25.8	4.7	11.6	12/12/06	61.4	7.3	6.9
30/11/06	27.5	4.6	4.0	13/12/06	58.1	6.2	4.5
04/12/06	50.5	8.3	6.6	14/12/06	85.9	6.0	4.3
04/12/06	71.8	6.6	5.0	14/12/06	81.8	7.0	4.4
05/12/06	68.7	4.8	3.9	15/12/06	109.2	5.8	3.9
				15/12/06	112.4	5.8	5.1
				18/12/06	92.3	7.2	5.6
				18/12/06	122.6	8.2	6.6
				21/12/06	87.9	6.1	5.2
Mean **St.D.Mean**	**47.3** **7.0**	**5.8**	**3.9**		**92.8** **6.2**	**6.7**	**5.2**
Third mantle							
Date	**T(DTI-199) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(DTI-199) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**				
03/01/07	40.5	5.4	4.0				
04/01/07	55.6	7.9	7.0				
04/01/07	42.9	9.8	9.0				
05/01/07	-8.5	11.0	9.7				
05/01/07	75.4	12.8	8.7				
07/01/07	37.3	8.8	6.3				
08/01/07	25.2	6.3	4.9				
08/01/07	33.1	7.1	5.5				
09/01/07	65.3	8.4	6.2				
09/01/07	21.7	7.5	6.8				
10/01/07	50.5	5.8	6.6				
10/01/07	70.8	7.7	6.0				
11/01/07	53.4	6.5	4.7				
11/01/07	28.3	8.7	6.2				
Mean **St.D.Mean**	**42.2** **5.9**	**8.1**	**6.6**				

At DTI every cell is defined as national reference. In this comparison, the national reference is the average of two cells, the transfer cell and an additional check cell of the same type (Jarret A11).
No information is available on isotopic composition and impurity content of the cell water, but a correction of +50 µK is applied to the national reference (note that the results reported on the table do not incorporate this correction).

T (DTI-199) – T (nat. ref.) = 10.8 µK
u(T (DTI-199) – T (nat. ref.)) = 53 µK (k=1)

A4.7 NATIONAL REFERENCE OF EIM

First mantle				Second mantle			
Date	**T(EIM-997) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(EIM-997) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(EIM-997) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(EIM-997) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
14/11/06	-95.2	4.6	3.9	11/12/06	-84.6	3.7	3.6
14/11/06	18.9	11.2	3.0	11/12/06	-79.2	3.2	2.8
15/11/06	-85.3	3.7	3.4	12/12/06	-107.4	3.8	3.2
15/11/06	-30.0	5.2	4.2	12/12/06	-85.0	3.3	3.0
16/11/06	-96.9	3.3	3.5	13/12/06	-109.4	4.1	4.0
16/11/06	-72.6	3.4	2.5	13/12/06	-87.6	3.4	2.8
17/11/06	-98.3	3.3	3.5	18/12/06	-109.4	3.8	3.8
17/11/06	109.6	3.0	2.4	18/12/06	-130.6	3.0	4.4
20/11/06	-120.9	3.6	3.6	19/12/06	-144.5	4.2	4.5
20/11/06	-148.3	3.4	3.3	19/12/06	-118.8	3.1	3.1
21/11/06	-166.4	3.2	3.2	20/12/06	-122.9	4.3	3.8
21/11/06	-135.8	2.8	3.3	20/12/06	-92.7	2.8	3.0
22/11/06	-111.1	5.5	3.2	21/12/06	-137.9	3.6	4.1
22/11/06	-8.4	3.8	3.0	21/12/06	-135.5	3.3	3.2
27/11/06	-108.7	3.8	3.1	22/12/06	-149.4	4.4	3.8
27/11/06	-112.7	3.1	3.5	22/12/06	-142.9	3.0	3.2
28/11/06	-113.6	3.9	3.5				
28/11/06	-91.0	3.4	3.7				
Mean **St.D.Mean**	**-81.5** **15.7**	**4.1**	**3.3**		**-114.9** **6.0**	**3.6**	**3.5**

At EIM the national reference is represented by one cell (VNIIM, s/n 0/14, 2004). No information is available on isotopic composition and impurity content of the cell water.

T (EIM-997) – T (nat. ref.) = -98.2 µK
u(T (EIM-997) – T (nat. ref.)) = 111 µK (k=1)

A4.8 NATIONAL REFERENCE OF GUM

First mantle				Second mantle			
Date	**T(GUM-957) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(GUM-957) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(GUM-957) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(GUM-957) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
21/11/06	15.3	14.0	11.2	07/12/06	45.3	22.0	13.5
22/11/06	51.8	13.5	13.5	08/12/06	76.6	13.8	13.8
23/11/06	-120.3	13.8	14.0	09/12/06	66.2	22.0	11.2
24/11/06	51.8	11.2	22.0	10/12/06	-1.6	13.8	22.0
25/11/06	4.9	22.0	11.2	11/12/06	53.1	11.2	22.0
26/11/06	30.9	13.8	13.8	12/12/06	92.3	14.0	13.8
27/11/06	15.3	13.5	13.5	13/12/06	3.6	13.5	22.0
28/11/06	15.3	14.0	13.8	14/12/06	79.2	13.8	13.8
29/11/06	20.5	11.2	11.2	15/12/06	-7.4	13.0	13.5
30/11/06	25.7	22.0	22.0	16/12/06	71.4	11.2	13.8
Mean **St.D.Mean**	**11.1** **15.4**	**14.9**	**14.6**		**47.9** **11.6**	**14.8**	**15.9**

At GUM the national reference is represented by one cell (NPL, type 32, s/n 782, 1998). No information is available on isotopic composition and impurity content of the cell water.

T (GUM-957) – T (nat. ref.) = 29.5 µK
u(T (GUM-957) – T (nat. ref.)) = 70 µK (k=1)

A4.9 NATIONAL REFERENCE OF INM

First mantle				Second mantle			
Date	**T(INM-5016) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(INM-5016) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(INM-5016) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(INM-5016) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
12/01/07	25	3.4	3.9	31/01/07	24	1.8	3.1
13/01/07	45	3.2	2.8	01/02/07	38	2.2	2.9
14/01/07	51	1.8	4.3	02/02/07	46	2.4	3.8
15/01/07	42	2.9	4.2	03/02/07	55	2.8	4.4
16/01/07	38	2.0	2.4	04/02/07	41	1.7	2.6
17/01/07	44	2.8	3.0	05/02/07	52	3.1	3.5
18/01/07	58	3.5	3.7	06/02/07	63	2.9	4.0
18/01/07	52	3.7	4.4	07/02/07	58	3.5	4.2
20/01/07	68	3.2	4.2	08/02/07	45	2.9	3.9
21/01/07	46	2.8	3.6	09/02/07	37	3.2	4.1
Mean **St.D.Mean**	**46.3** **3.8**	**2.9**	**3.7**		**44.6** **3.6**	**2.7**	**3.7**

At INM the national reference is represented by one NPL cell (2001), one Isotech cell (2005) and 2 cells made in house (2002 and 2003). No information is available on isotopic composition and impurity content of the cell water.

T (INM-5016) – T (nat. ref.) = 45.5 µK
u(T (INM-5016) – T (nat. ref.)) = 58 µK (k=1)

A4.10 NATIONAL REFERENCE OF INRIM

First mantle				Second mantle			
Date	**T(INRIM-1322) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(INRIM-1322) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(INRIM-1322) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(INRIM-1322) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
16/01/07	-75	3	13	05/02/07	-58	3	16
18/01/07	-53	3	25	05/02/07	-35	3	39
18/01/07	-27	3	42	06/02/07	-34	3	31
19/01/07	-22	4	35	07/02/07	-35	3	29
22/01/07	-16	3	38	07/02/07	-2	4	53
22/01/07	-23	3	38	08/02/07	-36	2	33
23/01/07	6	3	53	09/02/07	-30	3	29
23/01/07	3	2	54	12/02/07	-42	3	24
24/01/07	17	3	60	13/02/07	-20	3	39
24/01/07	-7	4	49	13/02/07	-10	3	47
25/01/07	4	3	53	14/02/07	-32	3	35
26/01/07	4	3	54	14/02/07	-21	3	62
				15/02/07	-6	3	54
Mean **St.D.Mean**	**-15.8** **7.7**	**3.1**	**42.8**		**-23.6** **6.0**	**3.0**	**37.8**

At INRIM the national reference is represented by a group of 3 cells: IMGC-31, IMGC-34 (both manufactured before 1993) and Hart-1322 (2002). The isotopic composition of Hart-1322 is known (analysis provided by IAEA, Vienna and ISO4, Torino).

T (INRIM-1322) – T (nat. ref.) = -19.7 µK
u(T (INRIM-1322) – T (nat. ref.)) = 23 µK (k=1)

A4.11 NATIONAL REFERENCE OF IPQ

First mantle				Second mantle			
Date	**T(IPQ-2114) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(IPQ-2114) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(IPQ-2114) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(IPQ-2114) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
09/10/06	40	2	2	23/10/06	20	3	2
10/10/06	0	2	2	24/10/06	50	2	3
12/10/06	-10	3	3	25/10/06	-30	4	2
13/10/06	20	3	2	26/10/06	20	2	2
16/10/06	10	3	3	27/10/06	50	3	2
17/10/06	-50	4	3	30/10/06	-20	3	3
18/10/06	-90	2	2	31/10/06	40	3	3
Mean **St.D.Mean**	**-11.4** **16.8**	**2,7**	**2,4**		**18.6** **12.2**	**2,8**	**2,4**

At IPQ the national reference is represented by one cell with known isotopic composition: Jarrett cell, type A-11-50, s/n 542 (2005).

T (IPQ-2114) – T (nat. ref.) = 3.6 µK
u(T (IPQ-2114) – T (nat. ref.)) = 77 µK (k=1)

A4.12 NATIONAL REFERENCE OF JV

First mantle				Second mantle			
Date	**T(JV-1026) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(JV-1026) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(JV-1026) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(JV-1026) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
02/11/06	37	9.1	8.2	01/12/06	267	6.4	5.5
03/11/06	117	7.3	5.5	02/12/06	217	7.3	7.3
04/11/06	127	9.1	8.2	03/12/06	197	7.3	8.2
05/11/06	87	11	7.3	04/12/06	217	6.4	8.2
06/11/06	97	7.3	8.2	05/12/06	217	8.2	11
07/11/06	147	9.1	8.2	06/12/06	297	9.1	8.2
08/11/06	177	8.2	10	07/12/06	237	6.4	7.3
09/11/06	217	6.4	8.2	08/12/06	237	9.1	10
10/11/06	177	9.1	8.2	11/12/06	277	8.2	8.2
13/11/06	147	9.1	8.2	12/12/06	297	7.3	7.3
Mean	**133.3**	**8.6**	**8.0**		**246.3**	**7.6**	**8.1**
St.D.Mean	**16.4**				**11.4**		

At JV the national reference is represented by the mean of 3 cells (815, DG1040 and DG1053). No information is available on isotopic composition and impurity content.

T (JV-1026) – T (nat. ref.) = 189.8 µK
u(T (JV-1026) – T (nat. ref.)) = 190 µK (k=1)

A4.13 NATIONAL REFERENCE OF LNE-INM/CNAM

First mantle				Second mantle			
Date	**T(LNE-6) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(LNE-6) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(LNE-6) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(LNE-6) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
28/11/06	-79.2	2.4	1.9	08/02/07	-155.0	1.1	1.2
29/11/06	-81.3	1.3	1.3	09/02/07	-173.6	0.9	1.6
30/11/06	-107.1	0.9	1.3	12/02/07	-190.3	1.7	0.8
01/12/06	-110.3	1.1	1.5	13/02/07	-132.7	1.5	3.0
04/12/06	-194.5	1.0	2.1	14/02/07	-140.1	1.7	1.6
11/12/06	-130.9	1.5	1.9	15/02/07	-122.9	2.2	2.1
12/12/06	-149.2	1.3	2.1	16/02/07	-165.3	1.3	1.3
13/12/06	-102.6	1.1	2.2	19/02/07	-122.1	2.6	2.0
14/12/06	-176.7	1.8	1.1	20/02/07	-152.3	1.4	2.3
18/12/06	-135.9	1.3	1.2	22/02/07	-148.8	0.8	0.9
				23/02/07	-149.1	1.4	1.7
Mean	**-126.8**	**1.4**	**1.7**		**-150.2**	**1.5**	**1.7**
St.D.Mean	**12.1**				**6.3**		

At LNE-INM/CNAM the national reference is represented by the average of 2 cells (Hart Scientific 1422 and Hart Scientific 1020) of known isotopic composition.

T (LNE-6) – T (nat. ref.) = -138.5 µK
u(T (LNE-6) – T (nat. ref.)) = 53 µK (k=1)

A4.14 NATIONAL REFERENCE OF MIKES

First mantle				Second mantle			
Date	**T(MIKES-1449) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(MIKES-1449) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(MIKES-1449) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(MIKES-1449) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
05/09/07	-21.4	5.8	6.9	17/09/07	12.7	11.1	10.4
05/09/07	-11.1	6.8	5.2	17/09/07	27.7	10.0	4.2
05/09/07	20.6	5.8	5.9	18/09/07	21.4	7.8	9.5
06/09/07	-48.3	5.8	7.3	18/09/07	10.3	9.2	12.9
06/09/07	-22.2	4.9	6.6	18/09/07	19.8	7.8	8.3
06/09/07	5.6	4.3	6.0	19/09/07	29.3	10.7	9.5
07/09/07	-21.4	5.8	6.9	19/09/07	27.7	7.3	8.0
07/09/07	-45.2	6.0	5.2	19/09/07	50.7	10.0	9.1
07/09/07	-15.1	5.0	5.0	20/09/07	65.0	8.7	8.0
07/09/07	-87.9	5.0	7.5	20/09/07	38.0	7.1	8.5
Mean	**-24.6**	**5.4**	**6.2**		**30.3**	**9.0**	**8.8**
St.D.Mean	**9.6**				**5.4**		

At MIKES the national reference is represented by one cell (Hart Scientific, 5901A-G, 2006) of known isotopic composition.

T (MIKES-1449) – T (nat. ref.) = 2.8 µK
u(T (MIKES-1449) – T (nat. ref.)) = 61 µK (k=1)

A4.15 NATIONAL REFERENCE OF MIRS/FE-LMK

First mantle				Second mantle			
Date	**T(MIRS-002) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(VSL-002) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(MIRS-002) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(VSL-002) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
08/01/07	-47.0	5.0	5.0	12/02/07	-47.0	3.9	3.9
09/01/07	-47.0	6.1	6.1	13/02/07	-47.0	4.0	4.0
10/01/07	-47.0	5.7	5.7	14/02/07	-47.0	2.5	2.5
11/01/07	-47.0	4.7	4.7	15/02/07	-47.0	2.8	2.8
12/01/07	-47.0	5.6	5.6	16/02/07	-47.0	2.7	2.7
15/01/07	-47.0	6.8	6.8	19/02/07	-47.0	5.1	5.1
16/01/07	-47.0	6.4	6.4	20/02/07	-47.0	4.5	4.5
17/01/07	-47.0	6.0	6.0	21/02/07	-47.0	5.7	5.7
18/01/07	-47.0	5.5	5.5	22/02/07	-47.0	4.7	4.7
19/01/07	-47.0	5.8	5.8	26/02/07	-47.0	6.4	6.4
Mean	**-47.0**	**5.7**	**5.7**		**-47.0**	**4.2**	**4.2**
St.D.Mean	**0.0**				**0.0**		

At MIRS/FE-LMK the national reference is represented by the average of 3 cells (VSL06T002, VSL06T006 and VSL06T007). Based on the isotopic analysis, the correction for the 3 cells is respectively +50.3 µK, +45.3 µK and 45.2 µK. For each of the reference cells which form the national reference, the correction from the national reference is determined. In this comparison cell VSL06T002 (named MIRS-002) was used as transfer cell. Its correction from the national reference is +47.0 µK.

T (MIRS -002) – T (nat. ref.) = -47.0 µK
u(T (MIRS -002) – T (nat. ref.)) = 18 µK (k=1)

A4.16 NATIONAL REFERENCE OF MKEH

First mantle				Second mantle			
Date	**T(MKEH-092) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(MKEH-092) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(MKEH-092) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(MKEH-092) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
07/11/06	10	9	9	30/11/06	10	7	8
08/11/06	11	9	9	01/12/06	10	8	9
09/11/06	11	7	8	04/12/06	-10	8	8
10/11/06	3	4	4	05/12/06	3	5	5
13/11/06	-6	6	5	06/12/06	4	6	7
14/11/06	-8	8	8	07/12/06	3	5	4
15/11/06	-8	6	7	08/12/06	11	9	9
16/11/06	-7	8	9	11/12/06	0	5	4
17/11/06	-7	8	6	12/12/06	10	8	9
20/11/06	-7	5	8	13/12/06	3	6	5
Mean	**-0.8**	**7.0**	**7.3**		**4.40**	**6.7**	**6.8**
St.D.Mean	**2.7**						

At MKEH the national reference is represented by one cell.

T (MKEH-092) – T (nat. ref.) = 1.8 µK
u(T (MKEH-092) – T (nat. ref.)) = 63 µK (k=1)

A4.17 NATIONAL REFERENCE OF NMi-VSL

First mantle				Second mantle			
Date	**T(VSL-094) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(VSL-094) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(VSL-094) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(VSL-094) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
24/07/06	13.6	2.9	2.8	25/08/06	-13.1	5.7	2.3
25/07/06	12.3	0.9	0.5	28/08/06	-18.4	2.3	1.0
26/07/06	18.4	1.6	2.3	29/08/06	-16.2	2.0	1.0
27/07/06	15.4	2.9	1.5	30/08/06	-18.7	2.6	1.2
28/07/06	26.0	4.0	3.0	31/08/06	-16.3	2.9	1.1
31/07/06	17.0	3.4	2.8	05/09/06	-15.0	2.6	1.2
02/08/06	26.3	2.8	4.0	06/09/06	-11.6	2.9	1.1
03/08/06	-13.6	1.4	3.1	07/09/06	-4.6	2.9	1.1
04/08/06	4.4	2.9	1.8	08/09/06	-16.3	2.4	1.0
Mean	**-13.3**	**2.5**	**2.4**		**-14.5**	**2.9**	**1.2**
St.D.Mean	**4.0**				**0.5**		

At NMi-VSL the national reference is represented by the mean of a group of 12 cells, maintained by the known difference of each cell of the group from the mean of the group itself. Isotopic composition is known for each cell of the group. Chemical analysis was performed on some of the cells of the group.

T (VSL-94) – T (nat. ref.) = -13.9 µK
u(T (VSL-94) – T (nat. ref.)) = 28 µK (k=1)

A4.18 NATIONAL REFERENCE OF NML

First mantle				Second mantle			
Date	**T(NML-1011) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(NML-1011) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(NML-1011) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(NML-1011) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
22/01/07	-40	7	6	09/01/07	-21	10	7
23/01/07	12	7	6	10/01/07	-19	8	1
24/01/07	0	8	6	11/01/07	2	7	5
25/01/07	-4	7	6	12/01/07	-9	8	6
26/01/07	-17	7	6	13/01/07	23	8	8
27/01/07	-16	7	8	14/01/07	-10	8	7
28/01/07	9	7	7	15/01/07	12	9	9
29/01/07	5	7	7	16/01/07	-23	9	8
30/01/07	3	7	6	17/01/07	6	7	9
31/01/07	14	8	8	18/01/07	27	8	7
Mean	**-3.4**	**7.2**	**6.5**		**-1.2**	**8.0**	**6.6**
St.D.Mean	**5.3**				**5.7**		

At NML the national reference is represented by one cell.

T (NML-1011) – T (nat. ref.) = -2.3
u(T (NML-1011) – T (nat. ref.)) = 104 µK (k=1)

A4.19 NATIONAL REFERENCE OF PTB

First mantle				Second mantle			
Date	**T(PTB-627) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(PTB-627) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(PTB-627) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(PTB-627) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
05/10/06	-70	3.8	3.5	09/11/06	-51	4.3	3.2
06/10/06	-79	2.8	4.9	10/11/06	-84	4.0	2.9
09/10/06	-80	4.7	2.9	13/11/06	-59	3.0	2.4
10/10/06	-38	2.6	2.6	14/11/06	-56	2.8	2.2
11/10/06	-26	3.0	4.1	15/11/06	-63	2.0	2.0
12/10/06	-98	3.7	3.4	16/11/06	-65	1.9	2.0
13/10/06	-22	4.4	3.9	17/11/06	-55	2.7	1.6
16/10/06	-34	3.3	3.2	20/11/06	-54	2.2	3.2
17/10/06	-27	2.6	2.3	21/11/06	-60	2.1	1.5
18/10/06	-65	3.9	2.5	23/11/06	-80	2.3	2.1
19/10/06	-99	3.3	2.9	27/11/06	-77	1.7	1.9
20/10/06	-95	4.7	6.0	29/11/06	-63	2.8	2.2
23/10/06	-51	4.8	6.1	30/11/06	-76	1.9	1.5
24/10/06	-58	2.6	2.8	01/12/06	-60	4.2	3.4
26/10/06	-67	5.0	3.9	04/12/06	-73	2.0	2.8
Mean	**-60.6**	**3.7**	**3.7**		**-65.1**	**2.3**	**2.3**
St.D.Mean	**6.9**				**2.7**		

At PTB the national reference is represented by a group of 3 cells, with age between 1 to 6 years. Isotopic analysis is available for one of the cells, and a correction for the isotopic composition is applied.

T (PTB-627) – T (nat. ref.) = -62.9
u(T (PTB-627) – T (nat. ref.)) = 29 µK (k=1)

A4.20 NATIONAL REFERENCE OF SMD

First mantle				Second mantle			
Date	T(SMD-5017) - T(nat. ref.) /µK	Stand. dev. of mean of T(SMD-5017) /µK	Stand. dev. of mean of T(nat. ref.) /µK	Date	T(SMD-5017) - T(nat. ref.) /µK	Stand. dev. of mean of T(SMD-5017) /µK	Stand. dev. of mean of T(nat. ref.) /µK
20/11/06	0.9	1.4	1.6	11/12/06	9.5	2.1	2.4
21/11/06	-0.5	1.5	1.9	12/12/06	30.7	1.6	1.9
22/11/06	19.3	0.9	2.2	13/12/06	-1.6	1.3	1.7
23/11/06	10.1	1.2	1.5	14/12/06	13.6	1.2	1.5
24/11/06	13.2	1.7	1.9	15/12/06	27.9	1.5	2.0
27/11/06	19.6	1.2	1.4	18/12/06	12.8	1.6	2.6
28/11/06	25.8	1.5	2.1	19/12/06	4.9	1.3	2.1
29/11/06	13.6	1.8	2.0	20/12/06	-5.5	2.0	2.3
30/11/06	4.5	1.3	2.3	21/12/06	-11.8	1.4	2.2
01/12/06	4.5	1.7	2.2	22/12/06	0.4	1.3	2.0
Mean	**11.1**	**1.4**	**1.9**		**8.1**	**1.5**	**2.1**
St.D.Mean	**2.8**				**4.4**		

At SMD the national reference is represented by the mean of two cells (Hart Scientific A-Q5017, 2006 and Isotech A11/50/545, 2006) of known isotopic composition.

T (SMD-5017) – T (nat. ref.) = 9.6
u(T (SMD-5017) – T (nat. ref.)) = 29 µK (k=1)

A4.21 NATIONAL REFERENCE OF SMU

First mantle				Second mantle			
Date	T(SMU-1) - T(nat. ref.) /µK	Stand. dev. of mean of T(SMU-1) /µK	Stand. dev. of mean of T(nat. ref.) /µK	Date	T(SMU-1) - T(nat. ref.) /µK	Stand. dev. of mean of T(SMU-1) /µK	Stand. dev. of mean of T(nat. ref.) /µK
05/10/06	-55	1.9	1.6	30/10/06	-50	4.7	2.4
06/10/06	-95	1.9	1.8	31/10/06	-87	3.5	2.1
09/10/06	-34	1.8	1.7	02/11/06	-41	1.5	1.7
10/10/06	-15	2.9	1.4	04/11/06	-114	1.9	1.5
11/10/06	-49	1.8	1.7	05/11/06	-80	2.3	2.3
12/10/06	-61	1.6	2.3	06/11/06	+27	1.8	2.0
13/10/06	-69	1.3	1.8	07/11/06	-49	2.7	1.4
16/10/06	-87	1.6	1.9	08/11/06	-34	1.9	2.1
17/10/06	-91	1.6	1.3	09/11/06	-61	1.6	1.6
18/10/06	-54	2.1	2.5	10/11/06	-103	2.6	2.7
Mean	**-61**	**1.9**	**1.8**		**-59.2**	**2.5**	**2.0**
St.D.Mean	**8.1**				**12.8**		

At SMU the national reference is represented by one cell (Isotech C12, 2001) of unknown isotopic and chemical composition.

T (SMU-1) – T (nat. ref.) = -60.1
u(T (SMU-1) – T (nat. ref.)) = 55 µK (k=1)

A4.22 NATIONAL REFERENCE OF UME

First mantle				Second mantle			
Date	**T(UME-92) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(UME-92) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(UME-92) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(UME-92) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
10/08/06	-96.8	7.3	10.2	24/08/06	38.8	9.6	11.6
11/08/06	-28.5	10.8	12.0	28/08/06	-102.6	10.8	9.2
14/08/06	-9.3	6.9	13.6	29/08/06	12.0	8.0	10.1
15/08/06	-0.8	7.0	8.7	31/08/06	26.0	9.6	9.7
16/08/06	-45.5	7.8	9.0	04/09/06	31.0	13.5	29.0
18/08/06	18.3	6.0	9.8	05/09/06	109.8	5.0	16.7
21/08/06	37.0	6.4	9.2	07/09/06	-14.3	6.4	14.0
22/08/06	56.8	9.1	8.4	08/09/06	-72.5	9.7	20.3
				09/09/06	-99.3	10.1	11.7
				11/09/06	78.5	13.7	12.0
				12/09/06	49.8	10.1	11.2
				13/09/06	-33.9	16.0	15.3
				14/09/06	30.8	13.7	12.3
				15/09/06	22.9	5.7	11.2
Mean	**-8.6**	**7.6**	**10.1**		**5.5**	**10.1**	**13.9**
St.D.Mean	**17.3**				**16.9**		

At UME the national reference is represented by one cell (UME-4, 1994) of unknown isotopic and chemical composition.

T (UME-92) – T (nat. ref.) = -1.5
$u(T$ (UME-92) – T (nat. ref.)) = 74 µK (k=1)

A4.23 NATIONAL REFERENCE OF VMT/PFI

First mantle				Second mantle			
Date	**T(VMT-2005) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(VMT-2005) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(VMT-2005) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(VMT-2005) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
22/05/06	124.6	5.8	8.5	12/06/06	90.3	5.8	6.4
23/05/06	79.2	5.9	7.5	13/06/06	41.9	4.8	7.8
24/05/06	155.3	10.8	5.9	14/06/06	132.6	9.4	8.8
25/05/06	109.8	10.0	6.5	15/06/06	169.9	8.0	10.2
26/05/06	105.5	10.3	7.8	16/06/06	6.8	6.1	7.3
29/05/06	50.5	13.4	7.4	19/06/06	80.0	8.5	7.7
30/05/06	63.3	11.4	9.5	20/06/06	94.0	8.5	6.8
31/05/06	130.8	8.5	10.7	21/06/06	117.7	9.4	8.0
01/06/06	99.9	7.8	7.5	22/06/06	94.2	11.0	10.0
02/06/06	141.0	7.0	5.4	23/06/06	133.7	7.4	10.5
Mean	**106.0**	**9.1**	**7.7**		**96.1**	**7.9**	**8.4**
St.D.Mean	**10.7**				**14.9**		

At VMT/PFI the national reference is represented by one cell (Hart Scientific 5901, 2000) of unknown isotopic and chemical composition.

T (VMT-2005) – T (nat. ref.) = 101.1µK
$u(T$ (VMT-2005) – T (nat. ref.)) = 116 µK (k=1)

A4.24 NATIONAL REFERENCE OF VNIIM

First mantle				Second mantle			
Date	**T(VNIIM-03) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(VNIIM-03) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(VNIIM-03) - T(nat. ref.) /µK**	**Stand. dev. of mean of T(VNIIM-03) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
09/09/06	-78	4.0	4.1	06/11/06	-82	3.8	4.0
10/09/06	-92	3.9	4.0	07/11/06	-79	4.0	3.9
11/09/06	-91	3.9	4.0	08/11/06	-80	3.8	3.9
12/09/06	-80	3.8	4.1	09/11/06	-94	3.8	4.0
13/09/06	-84	3.9	3.9	10/11/06	-95	4.0	4.1
16/09/06	-79	3.8	3.9	13/11/06	-89	3.9	4.1
17/09/06	-82	4.0	4.1	14/11/06	-88	3.9	3.9
18/09/06	-89	3.9	4.0	15/11/06	-77	4.0	4.0
19/09/06	-92	4.0	4.1	16/11/06	-90	3.8	4.1
20/09/06	-91	3.8	3.9	17/11/06	-95	3.8	4.1
23/09/06	-78	4.0	3.9	20/11/06	-89	4.0	3.9
24/09/06	-90	4.0	3.9	21/11/06	-76	3.9	4.0
25/09/06	-91	3.8	3.9	22/11/06	-95	4.0	3.9
26/09/06	-88	4.0	4.0	23/11/06	-94	3.8	4.0
27/09/06	-76	3.9	4.1	24/11/06	-81	4.0	3.9
Mean	**-85.4**	**3.9**	**4.0**		**-86.9**	**3.9**	**4.0**
St.D.Mean	**1.5**				**1.8**		

At VNIIM the national reference is represented by a group of 4 cells. For this comparison, only two cells of the group were used. Information about the isotopic composition is available for two cells of the group.

T (VNIIM-03) – *T* (nat. ref.) = -86.2 µK
u(*T* (VNIIM-03) – *T* (nat. ref.)) = 36 µK (k=1)

A4.25 NATIONAL REFERENCE OF ZMDM

First mantle				Second mantle			
Date	**T(ZMDM-182) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(ZMDM-182) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**	**Date**	**T(ZMDM-182) -T(nat. ref.) /µK**	**Stand. dev. of mean of T(ZMDM-182) /µK**	**Stand. dev. of mean of T(nat. ref.) /µK**
10/01/07	-169	7.5	7.2	01/02/07	-122	7.1	6.9
11/01/07	-176	6.6	6.7	02/02/07	-137	7	7.3
12/01/07	-165	6.7	7.4	03/02/07	-160	6.7	7
13/01/07	-182	6.6	6.4	05/02/07	-182	6.6	7.7
15/01/07	-209	6.8	6.6	06/02/07	-136	7.2	6.6
16/01/07	-212	6.3	6.5	07/02/07	-173	7.2	6.7
17/01/07	-157	6.6	6.7	08/02/07	-172	6.9	6.4
18/01/07	-148	6.6	7.7	09/02/07	-151	6.6	6.7
19/01/07	-176	6.2	6.9	10/02/07	-141	6.5	7.4
20/01/07	-198	7.2	6.5	12/02/07	-168	6.3	7.3
Mean	**-179.2**	**6.7**	**6.9**		**-154.2**	**6.8**	**7.0**
St.D.Mean	**6.8**				**6.4**		

At ZMDM the national reference is represented by one cell (Hart Scientific 5901, s/n G5018, 2006) of unknown isotopic and chemical composition.
T (ZMDM-182) – *T* (nat. ref.) = -166.7 µK
u(*T* (ZMDM-182) – *T* (nat. ref.)) = 118 µK (k=1)