Final Report of EUROMET.T-S2 (projects EUROMET 391 and 712): Supplementary Comparison of Realizations of the Indium Freezing Point

C. Rauta[1], E. Renaot[2], M.H. Valin[2], M. Elgourdou[2], F. Adunka[3], A. van der Linden[4], A. Steiner[5], J. Bartu[6], M. Smid[7], M. Sindelar[7], E. Tegeler[8], Ute Noatsch[8], J-U. Holtoug[9], V. Chimenti[10], M. Anagnostou[11], T.Weckstrøm[12], G Sutton[13], R. Rusby[13], F. Pavese[14] , P. P.M. Steur[14], P. Marcarino[14], M.J. de Groot[15], E. Filipe[16], I. Lobo[16], J. Ivarsson[17], S. Duris[18], J. Bojkovski[19], Miha Hiti[19], S. Ugur[20], A. K. Dogan[20], E. Grudniewicz[21].

[1]Justervesenet (JV), Norway
(e-mail address for correspondance: cra@akkreditert.no)

[2]Bureau National de Métrologie - Institut National de Métrologie (BNM-INM/CNAM), now Laboratoire National [3]d'Essais - Institut National de Métrologie, France

[4]Bundesamt für Eich und Vermessungswesen (BEV), Austria

[5]Service de la Metrologie (SMD), Belgium

[6]Swiss Federal Office of Metrology (METAS), Switzerland

[7]Czech Metrology Institute (CMI), Czech Republic

[8]Physikalisch-Technische Bundesanstalt (PTB), Germany

[9]Danish Technology Institute (DTI), Denmark

[10]Centro Español de Metrologia (CEM), Spain

[11]Hellenic Institute of Metrology (EIM), Greece

[12]Centre for metrology and accreditation (MIKES), Finland

[13]National Physical Laboratory (NPL), United Kingdom

[14]Istituto di Metrologia "G.Colonnetti" (IMGC), now Istituto Nazionale di Ricerca Metrologica , Italy

[15]Nederlands Meetinstituut - Van Swinden Laboratory (VSL), the Netherlands

[16]Instituto Portugues da Qualidade (IPQ), Portugal

[17]Swedish National Testing and Research Institute (SP), Sweden

[18]Slovak Institute of Metrology (SMU), Slovakia

[19]University of Ljubljana (MIRS/FE-LMK), Slovenia

[20]Ulusal Metrolji Enstitusu (UME), Turkey

[21]Główny Urząd Miar (GUM), Poland

Abstract.

Comparisons of indium freezing point cells have been carried out by the EUROMET TC-THERM group as Projects Nos. 391 and 712. The main objective was to establish the agreement between the realizations of the indium freezing point within different participating laboratories, to identify and eliminate possible discrepancies. The equipment has been made available by BNM-INM. Justervesenet coordinated project no. 391, while project 712 was coordinated by BNM-INM. This paper is the final report of the results obtained, including the uncertainties in the comparisons and the degrees of equivalence between the laboratories.

INTRODUCTION

The freezing point of indium was introduced as a new fixed point in the International Temperature Scale of 1990, ITS-90 [1]. This enabled the realization of the ITS-90 and calibration of platinum resistance thermometers in the temperature range 0 °C to 156 °C at a significantly lower level of uncertainty. For EUROMET Project No. 391, a transfer indium cell (In 114) together with a furnace has been circulated among the nineteen European national laboratories listed in Table 1, for the comparison of their realizations of this fixed point. The stability of the indium cell was verified by the reference laboratory (BNM-INM) in March 1997, January 1998, February 1999, July 2000 and January 2002, and the results demonstrate that, even though the circulation was performed over a long period, the stability of the cell was satisfactory for this type of comparison.

However, during certain periods throughout the circulation, the furnace malfunctioned by not achieving the necessary temperature uniformity along the whole length of the cell. As a consequence, some of the laboratories obtained large temperature differences between the local realization and the circulating one. Therefore, in EUROMET Project No. 712, complementary comparisons were organized using the same instruments, ensuring that the furnace was working optimally. These were carried out as direct comparisons between the laboratory cell and the BNM-INM transfer cell on the premises of BNM-INM. The five participants are listed in Table 2.

Preliminary reports of the results have been published for Project 391 [2] and for Project 712 [3].

Table 1. List of participating laboratories (EUROMET 391) and the indium cells

Laboratory	Country	Indium Cell
Justervesenet (JV)	Norway	Pyrocontrole In 94, sealed
Bureau National de Métrologie-Institut national de Métrologie (BNM-INM/CNAM)	France	Pyrocontrole In 43, sealed
Bundesamt für Eich und Vermessungswesen (BEV)	Austria	Self built, open
Service de la Metrologie (SMD)	Belgium	Pyrocontrole In 135, sealed
Swiss Federal Office of Metrology (METAS)	Switzerland	Pyrocontrole In 88, sealed
Czech Metrology Institute (CMI)	Czech Republic	Isotech In 33, sealed
Physikalisch-Technische Bundesanstalt (PTB)	Germany	Isotech In 22, sealed
Danish Technology Institute (DTI)	Denmark	NPL In 2/96, sealed
Centro Español de Metrologia (CEM)	Spain	Isotech In 97, open
Hellenic Institute of Metrology (EIM)	Greece	Isotech In 49, sealed
Centre for metrology and accreditation (MIKES)	Finland	Isotech In 92, open
National Physical Laboratory (NPL)	UK	NPL In 1, open
Istituto di Metrologia "G.Colonnetti" (IMGC)	Italy	IMGC In CO1, In ICA1, open with valve for pressure control
Nederlands Meetinstituut- Van Swinden Laboratory (VSL)	Netherlands	VSL89T056, open
Instituto Portugues da Qualidade (IPQ)	Portugal	Isotech In 31, sealed
Swedish National Testing and Research Institute (SP)	Sweden	Isotech In 87, open
Slovak Institute of Metrology (SMU)	Slovakia	SMU In-801, sealed
University of Ljubljana (MIRS/FE-LMK)	Slovenia	Isotech In 86, sealed
Ulusal Metrolji Enstitusu (UME).	Turkey	NPL In 7/95, sealed

Table 2. List of participating laboratories (EUROMET 712) and the indium cells

Laboratory	Country	Indium Cell
Bureau National de Métrologie-Institut national de Métrologie (BNM-INM/CNAM)	France	Pyrocontrole In 43, sealed
Hellenic Institute of Metrology (EIM)	Greece	Isotech In 49, sealed
Czech Metrology Institute (CMI)	Czech Republic	Isotech In 33, sealed
Główny Urząd Miar (GUM)	Poland	Isotech In 12, sealed
Bundesamt für Eich und Vermessungswesen (BEV)	Austria	Isotech, In 118, sealed

EQUIPMENT

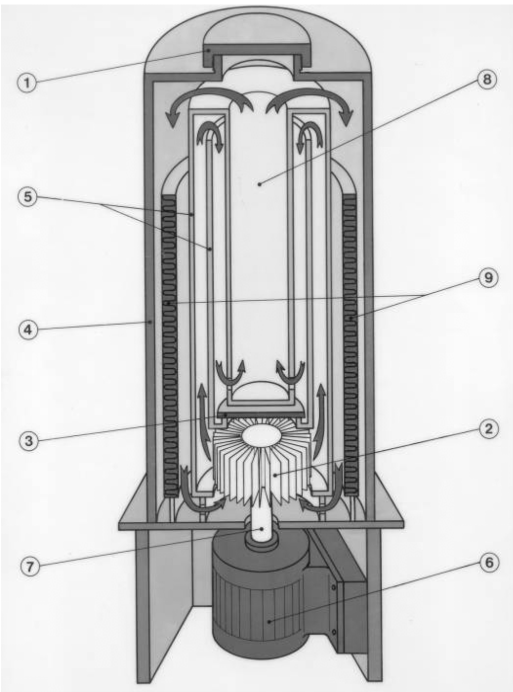
The equipment supplied by BNM-INM and circulated between the 19 laboratories of Project 391 consists of a furnace and an indium fixed-point cell, In114. The furnace was transported by usual freight, while the cell was hand-carried from one laboratory to another. For Project 712 the laboratory cells were taken to BNM-INM and the comparisons were made there.

The Furnace

The circulating furnace works on the forced hot air principle and is constructed according to the BNM-INM design as in Figure 1.

The furnace dimensions were modified to be suitable for freight transportation. As a consequence, it was necessary to shorten the furnace and the height became insufficient to embed the whole length of the transfer cell; thus an uncertainty contribution from the ambient temperature was included in the uncertainty budget.

Figure 1. Operating principle of the air furnace

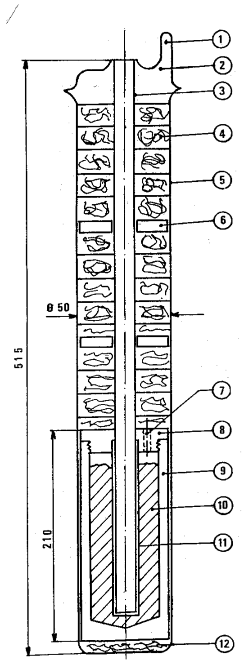


1) Removable cap
2) Fan blade
3) Radiation shield
4) Outer tank
5) Inner tank
6) Motor
7) Main shaft
8) Working space
9) Heaters.

The Transfer Indium Cell

The transfer cell, a sealed model, identification number In 114, was made by PYROCONTROLE under license to BNM-INM. The argon pressure inside the cell is one atmosphere when the cell is at the melting temperature of indium. For transport the cell was accommodated in a specially built carrying case. Figure 2 is a schematic diagram of the cell. The height of indium between the bottom of the well and the surface is 160 ± 5 mm.

Figure 2. The design of the transfer cell



1) Seal
2) Argon gas
3) Quartz thermometer well
4) Carbon felt
5) Quartz sheathing
6) Thermal shunt graphite
7) Graphite screw
8) Graphite crucible cap
9) Graphite crucible
10) Indium
11) Graphite tube
12) Carbon felt.

Local Indium Cells

Tables 1 and 2 summarise the In cells that were used for the local measurements. Of these, 17 cells were sealed and 7 were open. The resistance bridges used for measurements in the laboratories were ASL-F18, Guildline 9975 and MI 6010B. For Project 391, the results were reported as resistance ratios corrected to 0 mA current. The comparisons were performed between 50 % and 80 % liquid phase and the typical duration for the freezing for the transfer cell was 2 to 6 hours, while the typical width of the plateau varied between 0.2 mK to 1.4 mK.

For Project 712 the freezing temperatures of the different cells were compared at a liquid fraction between 50 % and 90 %, and the width of the plateau was between 0.26 mK and 0.44 mK. The comparisons were again made using thermometer resistances corrected to 0 mA.

REALIZATION TECHNIQUE

Each laboratory was free to use its own procedure for the local realization of the In freezing point, consistent with the recommendations of the *Supplementary Information for the ITS-90* [4]:

- 'Indium supercools by 1 K or less, so outside nucleation is usually not necessary. After melting the ingot, the furnace temperature is stabilized a degree Celsius or so below the freezing point. When the temperature indicated by a thermometer has fallen close to the freezing point, the thermometer is withdrawn and allowed to cool for up to one minute before being replaced in the cell. The loss of heat to the thermometer is sufficient to cause rapid nucleation with the formation of a thin mantle of solid indium around the thermometer well; the plateau temperature is then quickly reached'.

It is expected that, using the technique mentioned above, freezing plateaux with durations of several hours can be obtained. The technique applied for the realization of the transfer In freezing point (cell and furnace) was included in the protocol of the comparison.

MEASUREMENT UNCERTAINTIES

The uncertainty budgets reported by the laboratories for the EUROMET Project 391 are given in Table 3. The first part includes components of uncertainty in the comparisons, u_1 to u_6, taking account of correlations in the measurements. It includes contributions from the reproducibility of the temperature differences, self-heating, perturbing heat exchanges, electrical effects, temperature variations on the plateau, and the reproducibility of the transfer cell. The reproducibility component u_1 takes into account the combined stability of the thermometer, the bridge and the standard resistor.

The second part gives the components of uncertainty, u_7 to u_{10}, in the local realizations of the indium point, due to chemical impurities, gas pressure, hydrostatic effect, and the long-term reproducibility of the local cell (if assessed separately from components u_7 and u_8 for impurity and gas pressure).

As the height of the circulated furnace was not sufficient to embed the whole of the transfer cell, the internal pressure of argon in the cell depended slightly on the ambient temperatures in the different laboratories. If one assumes that those variations lie inside an interval of 5 °C (20 °C to 25 °C), it is estimated that the temperature of the transfer cell will be different by a maximum of ± 0.02 mK.

The uncertainty contribution from the reproducibility of the transfer cell was calculated by BNM-INM from the minimum and maximum differences found relative to its cell In43, as follows:

$$(T_{In43} - T_{In114})_{Max} - (T_{In43} - T_{In114})_{Min} = (T_{In114})_{Min} - (T_{In114})_{Max} \qquad (1)$$

with the result:

$$u_{reproducibility} = \frac{\left| (T_{In43} - T_{In114})_{\max} - (T_{In43} - T_{In114})_{\min} \right|}{2\sqrt{3}} \qquad (2)$$

$$= 0.46 / 3.46 = 0.13 \text{ mK.}$$

The component u_6 includes $u_{reproducibility}$ and also a small contribution (± 0.02 mK) coming from the ambient conditions.

Table 3. Uncertainties in the comparisons of realizations in EUROMET 391. All components are given in mK

	Component of uncertainty	INM	JV	METAS	PTB	VSL	SP	MIKES	NPL	IMGC	CEM
u_1	Short term reproducibility	0.03	0.09	0.126	0.03	0.22	0.04	0.139	0.023	0.332	0.025
u_2	Self-heating	0.03	0.06	0.06	0.05	0.002	0.058	0.018	0.05	0.008	0.04
u_3	Perturbing heat exchanges	0.1	0.13	0.04	0.04	0.03	0.058	0.004	0.05	0.18	0.173
u_4	Electrical effect	0.01	0.01	0.03	0.02	0.032	0.007	0.002	0.06	0.006	0.015
u_5	Temperature variation on the plateau	0.04	0.1	0.03	0.02	0.058	0.116	0.20	0.20	0.006	0.07
u_6	Reproducibility of the cell In 114 during the time of the project	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
	Standard uncertainty (sub-total)	**0.17**	**0.24**	**0.20**	**0.15**	**0.27**	**0.20**	**0.19**	**0.26**	**0.40**	**0.23**
	Expanded uncertainty (sub-total at *k* = 2)	**0.35**	**0.48**	**0.41**	**0.30**	**0.56**	**0.40**	**0.40**	**0.51**	**0.85**	**0.47**
u_7	Purity	0.24	0.33	0.47	0.26	0.027	0.40	0.289	0.29	0.27	0.23
u_8	Gas pressure	0.02	0.02	0.1	0.1	0.002	0.005	0.005	0.04	0.035	0.037
u_9	Hydrostatic head effects	0.01	0.023	0.01	0.02	0.019	0.013	0.019	0.03	0.006	0.019
u_{10}	Long-term reproducibility of local cell	0.10	*	*	0.05	*	*	0.3	*	*	*
	Standard uncertainty	**0.31**	**0.41**	**0.52**	**0.32**	**0.27**	**0.45**	**0.50**	**0.39**	**0.48**	**0.33**
	Expanded uncertainty (total at *k* = 2)	**0.63**	**0.82**	**1.05**	**0.64**	**0.57**	**0.89**	**1.00**	**0.78**	**1.01**	**0.66**

	Component of uncertainty	IPQ	DTI	SMD	UME	FE-LMK	SMU	EIM	CMI	INM Feb. 2002	IMGC Jan. 2003
u_1	Short term reproducibility	0.026	0.02	0.06	0.11	0.15	0.03	0.02	0.03	0.03	0.332
u_2	Self-heating	0.04	0.15	0.15	0.04	0.04	0.03	0.03	0.03	0.03	0.008
u_3	Perturbing heat exchanges	0.087	0.058	0.2	0.12	0.07	0.07	0.04	0.04	0.1	0.18
u_4	Electrical effect	0.02	0.03	0.2	0.034	0.028	0.05	0.01	0.01	0.01	0.006
u_5	Temperature variation on the plateau	0.058	0.05	0.5	0.03	0.17	0.04	0.05	0.04	0.04	0.006
u_6	Reproducibility of the cell In 114 during the time of the project	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
	Standard uncertainty (sub-total)	**0.17**	**0.20**	**0.61**	**0.22**	**0.27**	**0.17**	**0.15**	**0.15**	**0.17**	**0.40**
	Expanded uncertainty (sub-total at *k* = 2)	**0.35**	**0.40**	**1.22**	**0.44**	**0.57**	**0.33**	**0.30**	**0.30**	**0.35**	**0.85**
u_7	Purity	0.235	0.48	0.8	0.27	0.47	0.4	0.80	0.47	0.24	0.27
u_8	Gas pressure	0.034	0.05	0.12		0.05	0.06	0.10	0.02	0.02	0.035
u_9	Hydrostatic head effects	0.019	0.02	0.02	0.01	0.02	0.016	0.01	0.01	0.01	0.006
u_{10}	Long-term reproducibility of local cell	0.026	0.13	0.10	0.10	*	0.10	0.10	0.05	0.10	*
	Standard uncertainty	**0.30**	**0.54**	**1.02**	**0.36**	**0.55**	**0.45**	**0.83**	**0.50**	**0.31**	**0.48**
	Expanded uncertainty (total at *k* = 2)	**0.59**	**1.09**	**2.04**	**0.73**	**1.10**	**0.90**	**1.65**	**0.99**	**0.63**	**1.01**

* this component is included in the assessment of u_7 and u_8.

The uncertainties in EUROMET 712 are given in Table 4. The first part relates to the comparisons at BNM-INM: reproducibility, self-heating, perturbing heat exchanges, electrical effects, temperature variation on the plateau, and the reproducibility of the transfer cell In114. Most were reported in [3].

The second part relates to the realization of the indium fixed point at the five laboratories. They were also reported in [3] but they were not relevant to the cell comparisons at BNM-INM. They comprise components for the purity of the indium, the gas pressure in the cell, the hydrostatic head effect, and the long-term reproducibility of the local cell

The BNM-INM component, u_3, associated with perturbing heat exchanges, is smaller than in Table 3 because the thermal characteristics (stability, uniformity, etc.) of the air-flow furnace used in EUROMET 712 was notably better in than the furnace circulated in EUROMET 391.

Table 4. Uncertainties in EUROMET 712: Part 1 gives the uncertainties in the comparisons at BNM-INM; Part 2 gives the additional uncertainties in the laboratory realizations. All components are in mK.

Part 1: Uncertainties in the comparisons at BNM-INM.

	Component of uncertainty	**INM**	**CMI**	**GUM**	**EIM**	**BEV**
u_1	Short term reproducibility	0.03	0.03	0.06	0.02	0.05
u_2	Self-heating	0.03	0.03	0.03	0.03	0.03
u_3	Perturbing heat exchanges	0.03	0.04	0.06	0.04	0.06
u_4	Electrical effect	0.01	0.01	0.01	0.01	0.01
u_5	Temperature variation on the plateau	0.04	0.04	0.05	0.05	0.07
u_6	Reproducibility of the cell In 114 during the time of the project	0.06	0.06	0.06	0.06	0.06
	Combined uncertainty	**0.09**	**0.10**	**0.12**	**0.10**	**0.12**
	Expanded uncertainty (at *k* = 2)	**0.19**	**0.19**	**0.24**	**0.19**	**0.25**

Part 2: Additional components for the local indium point realizations.

u_7	Purity	0.24	0.47	0.55	0.80	0.30
u_8	Gas pressure	0.02	0.02	0.10	0.10	0.02
u_9	Hydrostatic head effects	0.01	0.01	0.03	0.01	0.01
u_{10}	Long-term reproducibility of local cell	0.10	0.05	0.07	0.10	0.25
	Combined uncertainty (all components)	**0.28**	**0.49**	**0.58**	**0.82**	**0.41**
	Expanded uncertainty (at *k* = 2)	**0.55**	**0.98**	**1.15**	**1.64**	**0.82**

RESULTS

The laboratories reported results for EUROMET 391 as the project progressed, as is shown in Table 5 and plotted in Figure 3. They are presented as the means of the temperature differences between the local cell and the transfer cell, expressed in millikelvins. The uncertainties are the expanded total of the laboratory values in Table 3, including the contribution from the long-term reproducibility of the transfer cell. Uncertainty bars in Figure 3 are shown, both for the comparison uncertainties alone and including the local realization uncertainties.

The BNM-INM results are the reference measurements, and BNM-INM (mean) is the average of the five reference measurements. The temperature differences obtained are given in Figure 3 showing that all the differences except two lie between – 0.61 mK and + 1.09 mK. However, three of the laboratories (IMGC, BEV and EIM) obtained a temperature difference larger than 1 mK.

Table 5. Temperature differences, with uncertainties, between the local realization and the transfer realization of the indium freezing point in EUROMET 391. All values are given in mK.

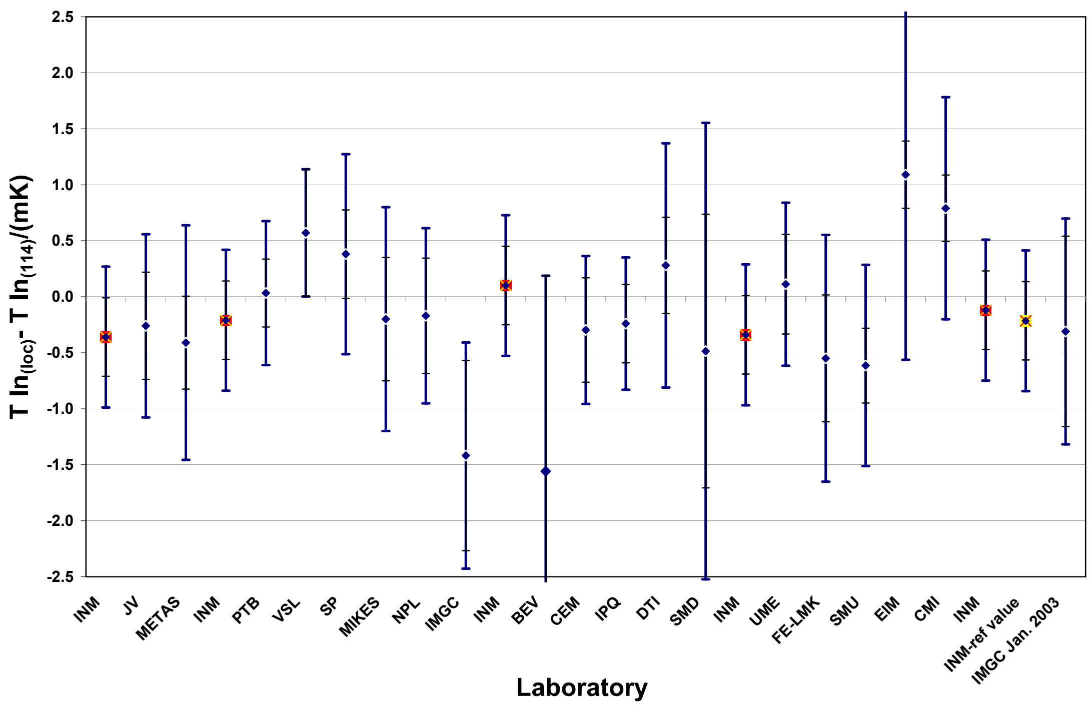
Laboratory	BNM-INM March 1997	JV	METAS	BNM-INM January 1998	PTB	VSL	SP	MIKES	NPL
$T_{\text{(In lab)}} - T_{\text{In 114)}}$	-0.36	-0.26	-0.41	-0.21	0.03	0.57	0.38	-0.20	-0.17
Uncertainty ($k = 2$)	0.63	0.82	1.05	0.63	0.64	0.57	0.89	1.00	0.78

Laboratory	IMGC	BNM-INM March 1999	BEV	CEM	IPQ	DTI	SMD	BNM-INM July 2000	UME
$T_{\text{(In lab)}} - T_{\text{(In 114)}}$	*	0.10	**	-0.30	-0.24	-0.59	-0.49	-0.34	0.11
Uncertainty ($k = 2$)	*	0.63	**	0.66	0.59	1.09	2.04	0.73	0.73

Laboratory	FE-LMK	SMU	EIM	CMI	BNM-INM February 2002	BNM-INM (mean)	IMGC January 2003
$T_{\text{(In lab)}} - T_{\text{(In 114)}}$	-0.55	-0.61	1.09	0.79	-0.12	-0.22	-0.31
Uncertainty ($k = 2$)	1.10	0.90	1.65	0.99	0.63	0.63	1.01

*Withdrawn due to malfunctioning of the transfer furnace (see text and Figure 5)
**Withdrawn due to failure of the local standard.

Figure 3. The temperature differences in EUROMET 391, given in chronological order, with uncertainty bars (at $k = 2$) both for the comparison uncertainties alone, and including the local realization uncertainties.



The analysis and investigations made by IMGC (Italy) during its first period of measurements showed that the transfer furnace might not have been functioning properly during that time. The anomaly could have been provoked by disturbances from the transportation of the furnace. Measurements were performed on the temperature distribution along the thermometer well during the freezing of indium for both the local cell and the transfer cell. Figure 5 shows that the temperature distribution followed the Clausius-Clapeyron curve in the local cell, but it did not follow the same pattern in the transfer cell. On the basis of these results, IMGC was allowed to do additional measurements with the repaired furnace within Project 391.

Figure 4. Temperature distribution along the thermometer wells during freezing, IMGC first measurements. The full line represents the calculated hydrostatic effect

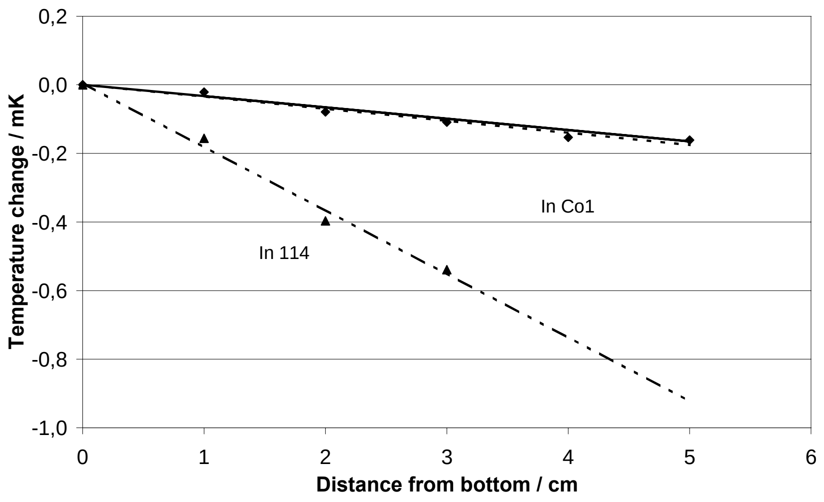
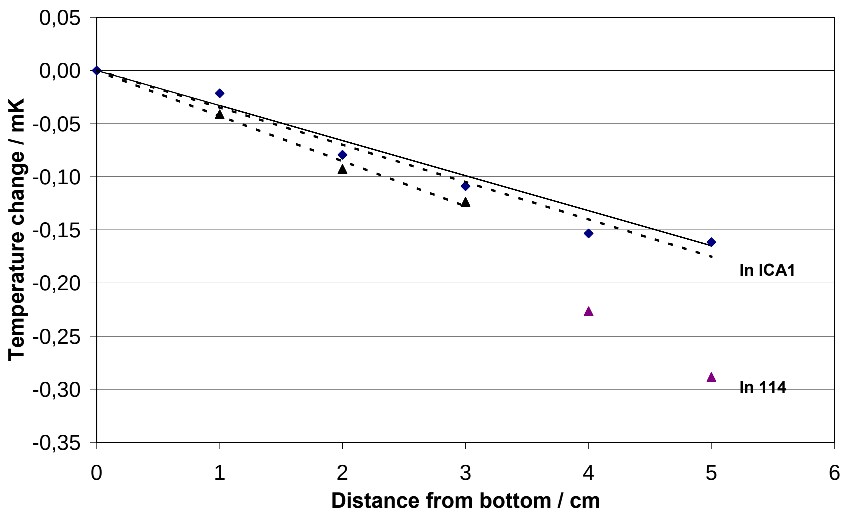


Figure 5. Temperature distribution along the thermometer wells during freezing (IMGC 2003). The full line represents the calculated hydrostatic effect.



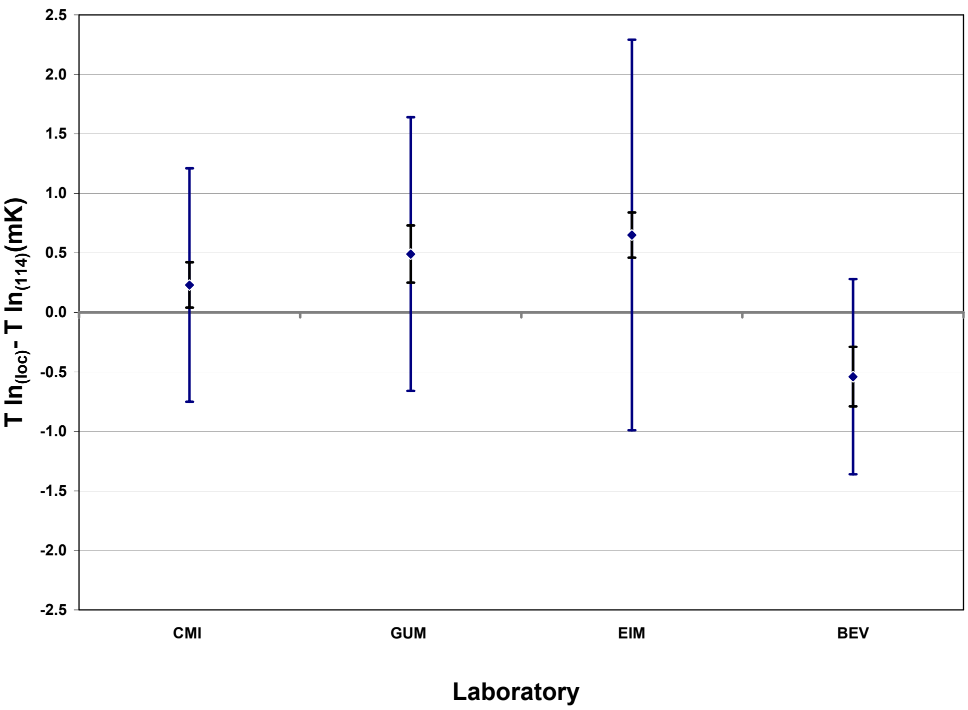
The later (January 2003) measurements at IMGC were performed with the same equipment, but a different cell (0.3 mK ± 0.2 mK higher), and the results are given in Table 5, last entry. The laboratory measured once more the temperature distribution along the thermometer well during freezing (Figure 5) and the results show good agreement with the calculated (Clausius-Clapeyron) dependence over the first three centimetres from the bottom of the transfer Indium cell. These data confirm that the transfer apparatus was working well the second time

The results for Project 712 are given in Table 6 and plotted in Figure 6. The inner uncertainty bars refer to the comparisons at BNM-INM, while the larger uncertainties include the additional uncertainties relating to the realizations of the indium point at the participating laboratories.

Table 6. Temperature differences, with uncertainties, between the local realization and the transfer realization of the indium freezing point in EUROMET 712. All values are given in mK.

Laboratory	CMI	GUM	EIM	BEV
$T_{(\text{In lab})} - T_{(\text{In 114})}$	0.23	0.49	0.65	-0.54
Uncertainty ($k = 2$)	0.98	1.15	1.64	0.82

Figure 6. The temperature differences in EUROMET 712, with uncertainty bars (at $k = 2$) both for the comparison uncertainties alone, and including the local realization uncertainties



DEGREES OF EQUIVALENCE

The results of the two projects have been combined and the inter-laboratory degrees of equivalence have been calculated. The differences are shown in Figure 7, and the degrees of equivalence are tabulated in Table 7 in the format of Appendix B of the BIPM KCDB. They are given as differences between pairs of laboratories, *i* and *j*, with the combined uncertainties at $k = 2$, thus $(Ti - Tj) \pm Uij$ / mK. No KCRV has been derived in this project.

CONCLUSIONS

EUROMET Project No.391, the comparison of realizations of the indium freezing point, was based on the circulation of an indium cell and an airflow furnace. Nineteen European laboratories were involved in this comparison. During the comparison period the reproducibility of the transfer cell was periodically checked by comparison with another BNM-INM cell.

The results of this project give the agreement within EUROMET member countries between the different realizations of the freezing point of indium. The temperature differences (T_{local} - T_{In114}) obtained are mostly situated within the interval of about ± 1 mK. However, three of the laboratories appeared to obtain a value for the temperature difference larger than 1 mK. One of these could do additional measurements showing that its first results are to be discarded. Three others joined a new EUROMET Project, No. 712, together with BNM-INM and a new participant. This complementary project was carried out as a direct comparison, between the laboratory cell ant the BNM-INM transfer cell on the premises of BNM-INM with the assistance of a laboratory delegate. The initial discrepancies were thus resolved.

REFERENCES

1. Preston-Thomas, H., Metrologia **27**, 3-10 and 107, 1990
2. Rauta, C., Renaot, E. and Bonnier, G., *Temperature, its Measurement and Control in Science and Industry*, Vol 7, edited by D. C. Ripple, American Institute of Physics Conference Proceedings 684, 2003, pp 897-902.
3. Renaot E., Valin M. H., Bonnier G., Smid M., Sindelar M., Anagnostou M., Grudniewicz E., *Complementary comparison of Indium Fixed Point cells (EUROMET Project No 712)*, Proceedings of TEMPMEKO 2004, edited by D. Zvizdic, LPM Zagreb, pp 1099-1106, 2005.
4. *Supplementary Information for the ITS-90*, BIPM, Sèvres, France, 1990, p 44

Table 7. Degrees of equivalence for EUROMET Projects 391 and 712.
Differences between pairs of laboratories, *i* and *j*, with the combined uncertainties at $k = 2$: $(Ti - Tj) \pm Uij$ / mK.

	Laboratory j →													
Laboratory i↓	**BNM-INM**		**JV**		**METAS**		**PTB**		**VSL**		**SP**		**MIKES**	
BNM-INM			**0.04**	1.03	**0.19**	1.22	**-0.25**	0.90	**-0.79**	0.85	**-0.60**	1.09	**-0.02**	1.18
JV	**-0.04**	1.03			**0.15**	1.33	**-0.29**	1.04	**-0.83**	1.00	**-0.64**	1.21	**-0.06**	1.29
METAS	**-0.19**	1.22	**-0.15**	1.33			**-0.44**	1.23	**-0.98**	1.19	**-0.79**	1.38	**-0.21**	1.45
PTB	**0.25**	0.90	**0.29**	1.04	**0.44**	1.23			**-0.54**	0.86	**-0.35**	1.10	**0.23**	1.19
VSL	**0.79**	0.85	**0.83**	1.00	**0.98**	1.19	**0.54**	0.86			**0.19**	1.06	**0.77**	1.15
SP	**0.60**	1.09	**0.64**	1.21	**0.79**	1.38	**0.35**	1.10	**-0.19**	1.06			**0.58**	1.34
MIKES	**0.02**	1.18	**0.06**	1.29	**0.21**	1.45	**-0.23**	1.19	**-0.77**	1.15	**-0.58**	1.34		
NPL	**0.05**	1.00	**0.09**	1.13	**0.24**	1.31	**-0.20**	1.01	**-0.74**	0.97	**-0.55**	1.18	**0.03**	1.27
CEM	**-0.08**	0.91	**-0.04**	1.05	**0.11**	1.24	**-0.33**	0.92	**-0.87**	0.87	**-0.68**	1.11	**-0.10**	1.20
IPQ	**-0.02**	0.86	**0.02**	1.01	**0.17**	1.20	**-0.27**	0.87	**-0.81**	0.82	**-0.62**	1.07	**-0.04**	1.16
DTI	**-0.37**	1.26	**-0.33**	1.36	**-0.18**	1.51	**-0.62**	1.26	**-1.16**	1.23	**-0.97**	1.41	**-0.39**	1.48
SMD	**-0.27**	2.14	**-0.23**	2.20	**-0.08**	2.29	**-0.52**	2.14	**-1.06**	2.12	**-0.87**	2.23	**-0.29**	2.27
UME	**0.33**	0.96	**0.37**	1.10	**0.52**	1.28	**0.08**	0.97	**-0.46**	0.93	**-0.27**	1.15	**0.31**	1.24
FE-LMK	**-0.33**	1.27	**-0.29**	1.37	**-0.14**	1.52	**-0.58**	1.27	**-1.12**	1.24	**-0.93**	1.41	**-0.35**	1.49
SMU	**-0.39**	1.10	**-0.35**	1.22	**-0.20**	1.38	**-0.64**	1.10	**-1.18**	1.07	**-0.99**	1.27	**-0.41**	1.35
IMGC	**-0.09**	1.19	**-0.05**	1.30	**0.10**	1.46	**-0.34**	1.20	**-0.88**	1.16	**-0.69**	1.35	**-0.11**	1.42
CMI	**0.45**	1.17	**0.49**	1.28	**0.64**	1.44	**0.20**	1.17	**-0.34**	1.13	**-0.15**	1.32	**0.43**	1.40
GUM	**0.71**	1.31	**0.75**	1.41	**0.90**	1.56	**0.46**	1.32	**-0.08**	1.28	**0.11**	1.45	**0.69**	1.52
EIM	**0.87**	1.76	**0.91**	1.83	**1.06**	1.95	**0.62**	1.76	**0.08**	1.74	**0.27**	1.87	**0.85**	1.92
BEV	**-0.32**	1.03	**-0.28**	1.16	**-0.13**	1.33	**-0.57**	1.04	**-1.11**	1.00	**-0.92**	1.21	**-0.34**	1.29

Table 7. Degrees of equivalence for EUROMET Projects 391 and 712, continued.
Differences between pairs of laboratories, *i* and *j*, with the combined uncertainties at $k = 2$: $(Ti - Tj) \pm Uij$ / mK.

	Laboratory j →													
Laboratory i↓	**NPL**		**CEM**		**IPQ**		**DTI**		**SMD**		**UME**		**FE-LMK**	
BNM-INM	**-0.05**	1.00	**0.08**	0.91	**0.02**	0.86	**0.37**	1.26	**0.27**	2.14	**-0.33**	0.96	**0.33**	1.27
JV	**-0.09**	1.13	**0.04**	1.05	**-0.02**	1.01	**0.33**	1.36	**0.23**	2.20	**-0.37**	1.10	**0.29**	1.37
METAS	**-0.24**	1.31	**-0.11**	1.24	**-0.17**	1.20	**0.18**	1.51	**0.08**	2.29	**-0.52**	1.28	**0.14**	1.52
PTB	**0.20**	1.01	**0.33**	0.92	**0.27**	0.87	**0.62**	1.26	**0.52**	2.14	**-0.08**	0.97	**0.58**	1.27
VSL	**0.74**	0.97	**0.87**	0.87	**0.81**	0.82	**1.16**	1.23	**1.06**	2.12	**0.46**	0.93	**1.12**	1.24
SP	**0.55**	1.18	**0.68**	1.11	**0.62**	1.07	**0.97**	1.41	**0.87**	2.23	**0.27**	1.15	**0.93**	1.41
MIKES	**-0.03**	1.27	**0.10**	1.20	**0.04**	1.16	**0.39**	1.48	**0.29**	2.27	**-0.31**	1.24	**0.35**	1.49
NPL			**0.13**	1.02	**0.07**	0.98	**0.42**	1.34	**0.32**	2.18	**-0.28**	1.07	**0.38**	1.35
CEM	**-0.13**	1.02			**-0.06**	0.89	**0.29**	1.27	**0.19**	2.14	**-0.41**	0.98	**0.25**	1.28
IPQ	**-0.07**	0.98	**0.06**	0.89			**0.35**	1.24	**0.25**	2.12	**-0.35**	0.94	**0.31**	1.25
DTI	**-0.42**	1.34	**-0.29**	1.27	**-0.35**	1.24			**-0.10**	2.31	**-0.70**	1.31	**-0.04**	1.55
SMD	**-0.32**	2.18	**-0.19**	2.14	**-0.25**	2.12	**0.10**	2.31			**-0.60**	2.17	**0.06**	2.32
UME	**0.28**	1.07	**0.41**	0.98	**0.35**	0.94	**0.70**	1.31	**0.60**	2.17			**0.66**	1.32
FE-LMK	**-0.38**	1.35	**-0.25**	1.28	**-0.31**	1.25	**0.04**	1.55	**-0.06**	2.32	**-0.66**	1.32		
SMU	**-0.44**	1.19	**-0.31**	1.12	**-0.37**	1.08	**-0.02**	1.41	**-0.12**	2.23	**-0.72**	1.16	**-0.06**	1.42
IMGC	**-0.14**	1.28	**-0.01**	1.21	**-0.07**	1.17	**0.28**	1.49	**0.18**	2.28	**-0.42**	1.25	**0.24**	1.49
CMI	**0.40**	1.25	**0.53**	1.18	**0.47**	1.14	**0.82**	1.47	**0.72**	2.26	**0.12**	1.22	**0.78**	1.47
GUM	**0.66**	1.39	**0.79**	1.33	**0.73**	1.29	**1.08**	1.58	**0.98**	2.34	**0.38**	1.36	**1.04**	1.59
EIM	**0.82**	1.82	**0.95**	1.77	**0.89**	1.74	**1.24**	1.97	**1.14**	2.62	**0.54**	1.80	**1.20**	1.97
BEV	**-0.37**	1.13	**-0.24**	1.05	**-0.30**	1.01	**0.05**	1.36	**-0.05**	2.20	**-0.65**	1.10	**0.01**	1.37

Table 7. Degrees of equivalence for EUROMET Projects 391 and 712, continued.
Differences between pairs of laboratories, *i* and *j*, with the combined uncertainties at $k = 2$: $(Ti - Tj) \pm Uij$ / mK.

	Laboratory j →											
Laboratory i↓	**SMU**		**IMGC**		**CMI**		**GUM**		**EIM**		**BEV**	
BNM-INM	**0.39**	1.10	**0.09**	1.19	**-0.45**	1.17	**-0.71**	1.31	**-0.87**	1.76	**0.32**	1.03
JV	**0.35**	1.22	**0.05**	1.30	**-0.49**	1.28	**-0.75**	1.41	**-0.91**	1.83	**0.28**	1.16
METAS	**0.20**	1.38	**-0.10**	1.46	**-0.64**	1.44	**-0.90**	1.56	**-1.06**	1.95	**0.13**	1.33
PTB	**0.64**	1.10	**0.34**	1.20	**-0.20**	1.17	**-0.46**	1.32	**-0.62**	1.76	**0.57**	1.04
VSL	**1.18**	1.07	**0.88**	1.16	**0.34**	1.13	**0.08**	1.28	**-0.08**	1.74	**1.11**	1.00
SP	**0.99**	1.27	**0.69**	1.35	**0.15**	1.32	**-0.11**	1.45	**-0.27**	1.87	**0.92**	1.21
MIKES	**0.41**	1.35	**0.11**	1.42	**-0.43**	1.40	**-0.69**	1.52	**-0.85**	1.92	**0.34**	1.29
NPL	**0.44**	1.19	**0.14**	1.28	**-0.40**	1.25	**-0.66**	1.39	**-0.82**	1.82	**0.37**	1.13
CEM	**0.31**	1.12	**0.01**	1.21	**-0.53**	1.18	**-0.79**	1.33	**-0.95**	1.77	**0.24**	1.05
IPQ	**0.37**	1.08	**0.07**	1.17	**-0.47**	1.14	**-0.73**	1.29	**-0.89**	1.74	**0.30**	1.01
DTI	**0.02**	1.41	**-0.28**	1.49	**-0.82**	1.47	**-1.08**	1.58	**-1.24**	1.97	**-0.05**	1.36
SMD	**0.12**	2.23	**-0.18**	2.28	**-0.72**	2.26	**-0.98**	2.34	**-1.14**	2.62	**0.05**	2.20
UME	**0.72**	1.16	**0.42**	1.25	**-0.12**	1.22	**-0.38**	1.36	**-0.54**	1.80	**0.65**	1.10
FE-LMK	**0.06**	1.42	**-0.24**	1.49	**-0.78**	1.47	**-1.04**	1.59	**-1.20**	1.97	**-0.01**	1.37
SMU			**-0.30**	1.35	**-0.84**	1.33	**-1.10**	1.46	**-1.26**	1.87	**-0.07**	1.22
IMGC	**0.30**	1.35			**-0.54**	1.41	**-0.80**	1.53	**-0.96**	1.93	**0.23**	1.30
CMI	**0.84**	1.33	**0.54**	1.41			**-0.26**	1.51	**-0.42**	1.91	**0.77**	1.28
GUM	**1.10**	1.46	**0.80**	1.53	**0.26**	1.51			**-0.16**	2.00	**1.03**	1.41
EIM	**1.26**	1.87	**0.96**	1.93	**0.42**	1.91	**0.16**	2.00			**1.19**	1.83
BEV	**0.07**	1.22	**-0.23**	1.30	**-0.77**	1.28	**-1.03**	1.41	**-1.19**	1.83		