CCT-K2.3: NRC/NMi-VSL bilateral comparison of capsule-type standard platinum resistance thermometers from 13.8 K to 273.16 K

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Abstract. A bilateral comparison of capsule-type standard platinum resistance thermometers is reported that links the NMi-VSL realization of the International Temperature Scale of 1990 to the results of the Consultative Committee for Thermometry Key Comparison 2 in the temperature range 13.8033 K to 273.16 K.

1. Introduction

The Consultative Committee for Thermometry Key Comparison 2 (CCT-K2) results were published in 2002 [1]. NRC served as the pilot laboratory for CCT-K2 and remains able to perform bilateral comparisons linked to the original key comparison results.

2. Experimental details

2.1 Measurements performed at NMi-VSL

Two capsule-style standard platinum resistance thermometers (CSPRTs L&N 1820627 and Rosemount 1599) were calibrated at NMi-VSL in the ITS-90 temperature range 13.8033 K to 273.16 K. Following the ITS-90 requirements for this temperature range, the resistance of the two CSPRTs was measured at the defining fixed points of hydrogen (13.8033 K), neon (24.5561 K), oxygen (54.3584 K), argon (83.8058 K), mercury (234.3156 K) and water (273.16 K) and at two additional temperatures close to 17.0 K and 20.3 K.

2.1.1 Experimental set up

The facility to realize the ITS-90 at NMi-VSL in the temperature range 13.8033 K to 273.16 K has been described in the literature [2]. For CCT-K2.3, the measurements at the cryogenic fixed points (hydrogen, neon, oxygen, and argon) were realized by adiabatic calorimetry in a homemade cryostat. The thermometers were mounted in a copper block in thermal contact with the sealed triple-point cells. The copper block was suspended inside a temperature-controlled copper shield and a stainless-steel vacuum chamber. After solidifying the gas in the cell, the copper shield was set a few millikelvin higher than the corresponding triple-point temperature and measured heat pulses, alternating with recovery periods, were applied to the cell to progressively melt the substance.

A detailed protocol [3] was followed in performing the measurements at the cryogenic fixed points, allowing investigation of the equilibrium temperature as a function of the fraction of the solid melted, the thermal resistance between the solid-liquid interface and the CSPRT, and the static and dynamic temperature measurement errors.

For the measurements at the two temperatures close to 17.0 K and 20.3 K, the thermal link between the copper block and the copper shield was modified. The original design did not allow accurate measurements because of the unavoidable temperature drift of several mK/h. This excessive temperature drift was due to the weak thermal link between the copper block and the copper shield, which is desirable for the cryogenic triple point measurements (because it promotes adiabatic conditions) described previously, but undesired during the 17.0 K and 20.3 K measurements (because the self-heat, due to the measuring current, in this case is not taken up by the phase transition). For the 17.0 K and 20.3 K measurements, the thermal link was then improved by replacing the manganin leads with copper leads.

The measurements at the mercury and water triple points were performed by immersing the capsule SPRTs in oil within the thermometer well of triple-point cells typically used for long-stem SPRTs.

2.1.2 Resistance measurements

The equipment used to measure the resistance of the thermometers consisted of an AC resistance bridge (modified ASL F18) used in conjunction with 1 Ω, 10 Ω, and 25 Ω Tinsley standard resistors, type 5685A, placed in a temperature-controlled oil bath. The bridge parameters were the same for all the measurements: 25 Hz frequency, 0.1 Hz bandwidth, 10^4 gain, 10^1 quadrature gain.

The measuring current *I* was 5 mA for the hydrogen and neon measurements, 3 mA for the 17.0 K and 20.3 K measurements, 1 and 3 mA for the oxygen measurements, and 1 mA for the argon, mercury, and water measurements. Each measurement point was obtained from a cycle of 90 measurements: 30 measurements at current *I*, 30 measurements at current $I\sqrt{2}$, and again 30 measurements at current *I*. From these measurements, the software calculated the zero current resistance value and, using the information from the database, applied the hydrostatic head correction and isotopic correction.

2.1.3 Traceability

For the measurements at the cryogenic fixed points (hydrogen, neon, oxygen and argon), the following sealed triple point cells were used:
Hydrogen: cell Eb1H2, 0.0655 mol, manufactured by IMGC 2001/03/12
Neon: cell E3Ne, 0.0845 mol, manufactured by IMGC 2000/09/29
Oxygen: cell Eb2/O2, 0.0875 mol, manufactured by IMGC 2001/06/08
Argon: cell E2Ar, 0.1022 mol, manufactured by IMGC 2000/09/08
All these cells were extensively investigated in the framework of the European project "Multicells" [4,5].

For the measurements at the mercury fixed point, cell VSL89T010 was used.

For the measurements at the water triple point, cell VSL03T026, manufactured by NMi-VSL in 2004, was used.

For the two additional temperatures close to 17.0 K and 20.3 K, the CSPRTs were calibrated against a reference temperature that was the average of two 100 Ω rhodium-iron thermometers (226246 and 229080). Thermometer 226246, which was used in CCT-K1, carries the NMi-VSL gas thermometer scale. Thermometer 229080 carries the NPL gas thermometer scale. More details about the history of these two thermometers can be found in [6].

2.1.4 Isotope and impurity effects on the realized triple point temperatures

The resistance values measured at hydrogen and water were corrected for the respective isotopic compositions.

The deuterium concentration in the hydrogen cell (Eb1H2) was (45.8± 0.3) μmolD/molH. Using the depression constant k_D = (5.42 ± 0.31) μK/(μmolD/molH) suggested by [7], a correction of (234 ± 14) μK was applied to the hydrogen triple point temperature.

The neon contained in the measured cell (E3Ne) has the same isotopic composition as the sample 1 investigated by [8]:
$n(^{21}Ne)/\, n(^{20}Ne)=0.0029308 \pm 15$
$n(^{22}Ne)\,)/\, n(^{20}Ne)=0.103275 \pm 51$
Assuming the "Natural Isotopic Composition" given by the IUPAC 2003 tabulation and depression constants 0.07 μK/ppm (^{21}Ne) and 0.147 μK/ppm (^{22}Ne) respectively, a correction of -157 μK would result. However, as there is as yet no international consensus within the thermometry community with respect to the reference composition and sensitivity coefficient, no correction has been applied. Instead, an uncertainty of 157 μK is attributed to the influence of isotopic composition.

The isotopic analysis of the water contained in the triple point of water cell (VSL03T026) gave:
δ^2H = (-51.1 ± 0.8) permil (k = 1)
$\delta^{18}O$ = (-6.93 ± 0.08) permil (k = 1)
Using the Kiyosawa depression constants recommended in CCT/05-33, a correction of +36.7 μK was applied with a standard uncertainty of 1 μK.

The information available regarding impurity content was insufficient to apply corrections. The total impurity concentration was used in combination with the first cryoscopic constant to estimate the uncertainty arising from the presence of impurities.

The calibration temperatures, resistance ratios, and combined standard laboratory uncertainties (u_L, k=1) for the NMi-VSL thermometers are listed in Table 1. The detailed uncertainty budget is included in Appendix A. The final line of Table 1 lists the resistances at the triple point of water.

Table 1. Resistance ratios determined at NMi-VSL. The values in italics at 273.16 K are the resistances of the thermometers (in ohms) at that temperature.

Fixed point	T / K	W(1820627)	W(1599)	u_L / mK
H_2	13.8033	0.001 177 856	0.001 328 760	0.107
IGT	16.98826	0.002 264 738	0.002 422 565	0.224
IGT	20.28222	0.004 236 683	0.004 398 058	0.219
Ne	24.5561	0.008 445 227	0.008 607 741	0.196
O_2	54.3584	0.091 730 333	0.091 869 167	0.160
Ar	83.8058	0.215 874 217	0.215 987 896	0.087
Hg	234.3156	0.844 144 155	0.844 166 266	0.138
H_2O	273.16	*25.543 765*	*25.533 513*	0.090

2.2 Measurements performed at NRC

2.2.1 Comparison measurements

In the original CCT-K2 measurements, CSPRTs calibrated by the participating NMIs were compared at NRC in a nearly isothermal copper block. When the protocol for CCT-K2 was first envisaged, it was assumed that the reporting of the comparison results would include temperatures between the calibration fixed points. However, although such data was collected during the course of the CCT-K2 measurements, the final report focuses nearly exclusively on the results obtained near the defining fixed points of the ITS-90. When planning for CCT-K2.3, it was decided that the NRC measurements would employ the superior thermal environment of the multi-well fixed-point cells that were used very effectively to calibrate the CSPRTs used to determine the temperature of the triple point of xenon [9]. The hydrogen cell used at NRC is filled from the same container of gas that was part of the study to determine the sensitivity coefficient for deuterium contamination [7], the implication being that the triple point temperature of cell SS-M-2 is 13.80338 K.

Table 2. Resistance ratios obtained at NRC. The values in italics are the resistances of the thermometers (in ohms) at 273.16 K.

Fixed point	Cell identification	T / K	W(1820627)	W(1599)	u_L / mK
H_2	SS-M-2	13.80338	0.001 177 949	0.001 328 735	0.20
IGT	Cu block	17.033*	0.002 285 292	0.002 443 054	0.58
IGT	Cu block	20.271*	0.004 228 150	0.004 389 311	0.58
Ne	Cu-M-1	24.5561	0.008 445 748	0.008 607 987	0.20
O_2	Cu-M-3	54.3584	0.091 729 674	0.091 868 491	0.20
Ar	Cu-M-7	83.8058	0.215 873 205	0.215 986 696	0.20
Hg	SS-M-Hg	234.3156	0.844 145 551	0.844 166 839	0.20
H_2O	Cu-M-6	273.16	*25.543 766*	*25.533 508*	0.15

* Temperatures were 17.03323 K and 20.27090 K for S/N 1820627 and 17.03294 K and 20.27063 K for S/N 1599.

2.2.2 *Resistance measurements*

The resistance measurements were made with the same Automatic Systems Laboratories Model F18 resistance bridge used for CCT-K2. A 25 Ω Tinsley Model 5685A reference resistor was used, thermostatted at 25 °C ± 2 mK in a Guildline 9732VT oil bath. From 13.8033 K to 24.5561 K, currents of 5 mA and 5√2 mA were used. At 54.3584 K, currents of 2 mA and 2√2 mA were used. From 83.8058 K to 273.16 K, currents of 1 mA and √2 mA were used.

2.2.3 *Traceability to CCT-K2*

NRC contributed to CCT-K2 a single Leeds and Northrup CSPRT, S/N 1872174, that had been calibrated in specific sealed fixed-point cells produced at NRC (e-H_2 cell 22, Ne cell F15, O_2 cell F10, Ar cell F13), as well as in a hydrogen vapour-pressure cryostat at temperatures near 17.0018 K and 20.2676 K, in a large glass cell suitable for long-stem thermometers (cell Hg-2), and in a large glass triple point of water cell.

The NRC thermometer (L&N 1872174) used in the original CCT-K2 comparison [1] was broken several years ago. In addition, establishing traceability to CCT-K2 via resistance ratios obtained more than 10 years ago for a single CSPRT would offer potentially dubious results without additional checks. The values in Table 2 reflect fixed-point realizations using the multi-well cells currently favoured at NRC. Nonetheless, we have linked the contemporary cells to the single-well sealed cells that were used to calibrate the NRC CSPRT for the CCT-K2 exercise. The resistance ratios of Leeds and Northrup CSPRT S/N 1876687 were measured in the multi-well cells at the same time that the resistance ratios were determined for the NMi-VSL thermometers. Immediately following the comparison exercise, S/N 1876687 was measured in cell 22 (e-H_2), cell F17 (Ne), cell F10 (O_2), and cell F13 (Ar). For e-H_2, O_2, and Ar, the linkage to the cells used for CCT-K2 is direct, assuming that the cells realize the same temperature as they did 10 years earlier.

For Ne, the link to the CCT-K2 cell, F15, was established via measurements carried out with CSPRT S/N 1872174. Cell F17 was measured in September 2002, and 3 months later we determined that cell F15 was 0.053 mK hotter than cell F17.

By this mechanism, we determined that:

1) Hydrogen - SS-M-2 is 0.527 mK hotter than cell 22
2) Neon – Cu-M-1 is 0.112 mK colder than F17, and F17 is 0.053 mK colder than F15
3) Oxygen – Cu-M-3 is 0.098 mK hotter than F10
4) Argon – Cu-M-7 is 0.120 mK colder than F13

The calibration points near 17 K and 20.3 K were obtained differently than was the case for CCT-K2. The RhFe thermometer A140 carrying the NRC interpolating gas thermometer (IGT) scale, and linked to CCT-K1 [10], was used to transfer the NRC IGT-realisation of the ITS-90 to a CSPRT that was installed in the e-H_2 cell SS-M-2 for comparison measurements with the NMi-VSL CSPRTs following the e-H_2 triple point realization.

3. Results

The experimental measurement uncertainty budget remains 0.12 mK at 20.3 K and below and 0.09 mK above 20.3 K, the same as in the CCT-K2 report [1]. This uncertainty component, u_{Exp}, is summed in quadrature with each of the laboratory uncertainties, u_L, from Tables 1 and 2 to form a combined uncertainty, u_C. The pair uncertainty for the comparison, u_P, is obtained by summing in quadrature the combined uncertainties for each laboratory. The justification for treating the experimental uncertainty components as completely uncorrelated when evaluating the pair uncertainty is explained in further detail in the CCT-K2 report. The relevant uncertainty equations are as follows:

$$u_C = \sqrt{u_L^2 + u_{Exp}^2} \quad (1)$$

$$u_p = \sqrt{u_{NRC}^2 + u_{NMi-VSL}^2 + 2u_{Exp}^2} \quad (2)$$

The results of the comparison are summarized in Table 3 and Figure 1 with respect to the current NRC realization of the ITS-90.

Tables 1 and 2 include the triple point of water (TPW) resistances given by NRC and NMi-VSL for their thermometers.

Table 3. Comparison data for the NMi VSL thermometers expressed with respect to the 2006 NRC realization of the ITS-90 based on the new generation of multi-well fixed points. The table includes the expanded pair uncertainties (k = 2) for these temperature differences. The values at 273.16 K express the consistency in the triple point of water realizations at the participating laboratories as carried on the thermometers.

T_{NRC} / K	$T_{NMi-VSL} - T_{NRC}$ / mK		$2u_p$ / mK
	1820627	1599	
13.8033	-0.30	0.18	0.57
17.033*	-0.02	-0.02	1.29
20.271*	0.00	0.00	1.29
24.5561	-0.42	-0.20	0.62
54.3584	0.17	0.17	0.57
83.8058	0.23	0.28	0.51
234.3156	-0.35	-0.14	0.55
273.1600	0.00	0.05	0.43

* Temperatures were 17.03323 K and 20.27090 K for S/N 1820627 and 17.03294 K and 20.27063 K for S/N 1599.

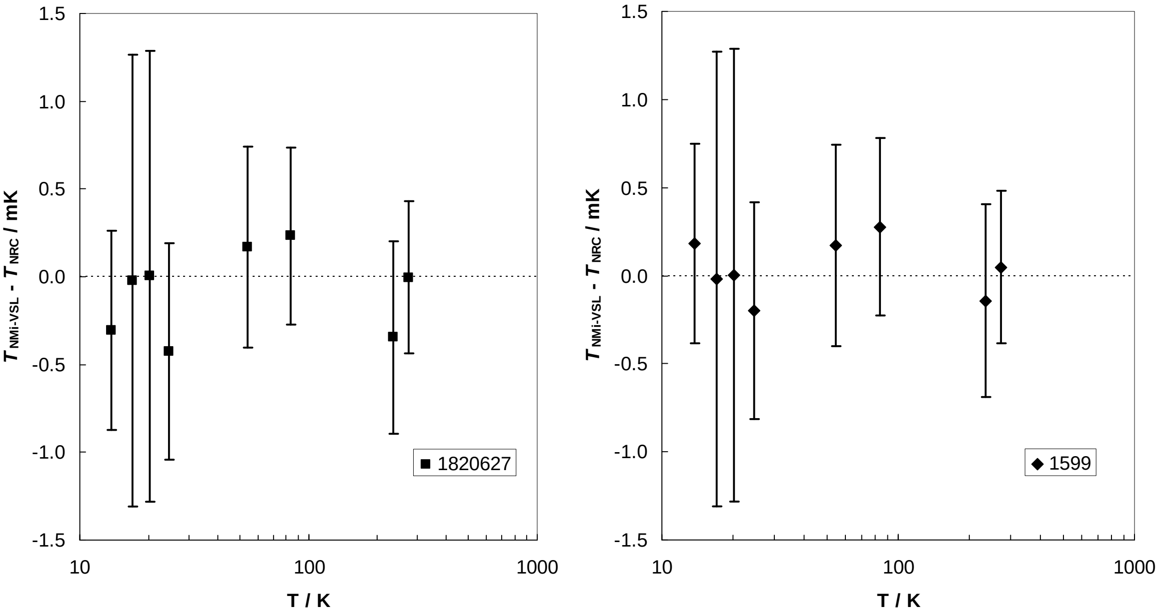

Figure 1. The comparison data for the NMi-VSL CSPRTs plotted with respect to the 2006 NRC realization of the ITS-90 based on the new generation of multi-well fixed points. The error bars represent the expanded uncertainties of the temperature differences, $2u_p$.

The NMi-VSL data may be related to the CCT-K2 results by combining the results from Table 3 with the differences reported for the NRC thermometer with respect to the KCRV as determined by the CCT-K2 exercise. Since the NRC thermometer was used in both Groups A and B of CCT-K2, the degrees of equivalence for NMi-VSL with respect to the CCT-K2 KCRV were calculated for both determinations of ($T_{NRC\text{-}1996} - T_{KCRV}$) according to Equation 3. These values, together with their average, are compiled in Table 4.

$$D_{NMi-VSL} = \left(T_{NMi-VSL} - T_{NRC-2006}\right) + \left(T_{NRC-2006} - T_{NRC-1996}\right) + \left(T_{NRC-1996} - T_{KCRV}\right)_{CCT-K2} \quad (3)$$

The expanded uncertainty, U, of the NMi-VSL degree of equivalence (also listed in Table 4), is obtained by appropriately combining the uncertainties of the bracketed terms in Equation 3. The uncertainty of ($T_{VSL} - T_{NRC}$) is readily identified as u_p from Equation 2, and reported in Table 3. Since the CCT-K2 KCRV has zero uncertainty by definition, the uncertainty of the third term in Equation 3, ($T_{NRC\text{-}1996} - T_{KCRV}$), is determined solely by the uncertainty in $T_{NRC\text{-}1996}$. This is simply the combined standard uncertainty of the NRC calibration in 1996, $u_{NRC\text{-}1996}$, and the experimental comparison uncertainty of CCT-K2, which is equal to u_{Exp}, calculated according to Equation 1. The NRC laboratory uncertainties for CCT-K2 are identical to those in Table 1 with the exception of the points near 17 K and 20.3 K, where the corresponding CCT-K2 uncertainties were 0.2 mK.

In combining the bracketed terms of Equation 3, we must consider the extent to which the two uncertainties for T_{NRC} and $T_{NRC\text{-}1996}$ are correlated. With the exception of the 17 K and 20.3 K calibration temperatures, the 1996 and 2006 calibrations utilized (except for Ne) the same fixed-point cells, resistance bridge, and experimental apparatus. Under the assumption that the temperatures realized by the NRC sealed cells are stable in time, the Type B components of the uncertainty budgets for CCT-K2 and this bilateral key comparison can be considered to be completely correlated, and so only the Type A repeatability component from the full laboratory uncertainty budget should be counted twice – once as the component of u_{NRC} for this measurement comparison, and once to accommodate the uncorrelated component of $u_{NRC-1996}$ reported in CCT-K2. This component is u_{TypeA} = 0.07 mK for all five triple point temperatures. Equation 4 summarizes the calculation of the expanded uncertainties of Table 4 for the NMi-VSL degree of equivalence to the Key Comparison Reference Value of CCT-K2 for all but the 17 K and 20.3 K temperatures.

$$U = 2\sqrt{\left(u_{NRC}^2 + u_{NMi-VSL}^2 + 2u_{Exp}^2\right) + u_{TypeA}^2 + u_{Exp}^2} \qquad (4)$$

The 17 K and 20.3 K calibration temperatures were realized with different techniques and apparatus in 2006 (interpolating gas thermometer) than in 1996 (hydrogen vapour pressure measurements), so no reduction in overall uncertainty due to correlated Type B components can be claimed. The expanded uncertainties at these two temperatures are derived using Equation 5. [We are not able to link these values to CCT-K2.]

$$U = 2\sqrt{\left(u_{NRC}^2 + u_{NMi-VSL}^2 + 2u_{Exp}^2\right) + u_{NRC-1996}^2 + u_{Exp}^2} \qquad (5)$$

Table 4 and Figure 2 show that the differences from the KCRV for thermometer 1820627 agree with the CCT-K2 KCRV within the expanded combined uncertainties, U, at all temperatures *except* 24.5561 K.

Table 5 and Figure 3 show that the differences from the KCRV for thermometer 1599 agree with the CCT-K2 KCRV within the expanded combined uncertainties, U, at all temperatures.

Table 4. The degrees of equivalence, D, for NMi-VSL thermometer 1820627 expressed with respect to the KCRV for Groups A and B from the CCT-K2 report and their average, mediated by the NRC realization of ITS-90. The table includes the expanded uncertainties of the degrees of equivalence, U (k = 2).

T / K	D_A / mK	D_B / mK	D_{Avg} / mK	U / mK
13.8033	-0.12	-0.13	-0.12	0.63
17.035	-0.02	0.09	0.03	1.37
20.271	0.03	0.10	0.07	1.37
24.5561	-0.65	-0.71	-0.68	0.66
54.3584	0.45	0.51	0.48	0.62
83.8058	0.29	0.35	0.32	0.55
234.3156	-0.49	-0.49	-0.49	0.59

Table 5. The degrees of equivalence, *D*, for NMi-VSL thermometer 1599 expressed with respect to the KCRV for Groups A and B from the CCT-K2 report and their average, mediated by the NRC realization of ITS-90. The table includes the expanded uncertainties of the degrees of equivalence, *U* (*k* = 2).

T / K	D_A / mK	D_B / mK	D_{Avg} / mK	*U* / mK
13.8033	0.37	0.36	0.36	0.63
17.035	-0.02	0.09	0.04	1.37
20.271	0.03	0.10	0.07	1.37
24.5561	-0.43	-0.49	-0.46	0.66
54.3584	0.45	0.51	0.48	0.62
83.8058	0.34	0.40	0.37	0.55
234.3156	-0.28	-0.28	-0.28	0.59

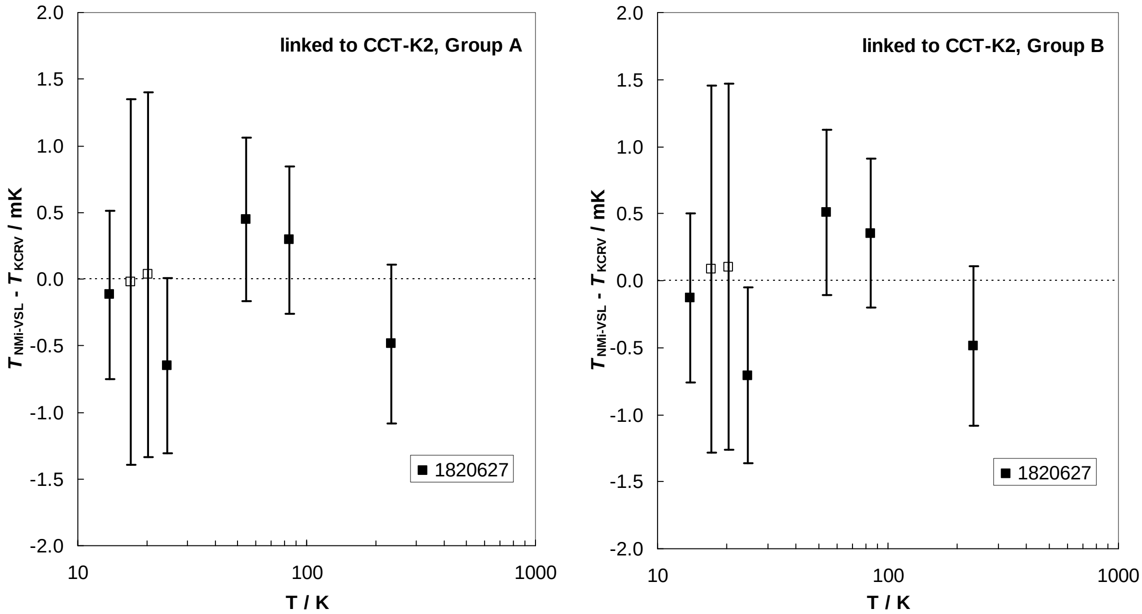

Figure 2. The comparison data for the NMi-VSL CSPRT S/N 1820627 plotted with respect to the KCRV determined from the two Groups of measurements from the CCT-K2 report, mediated by the NRC realization of the ITS-90. The error bars represent the expanded uncertainties, *U*.

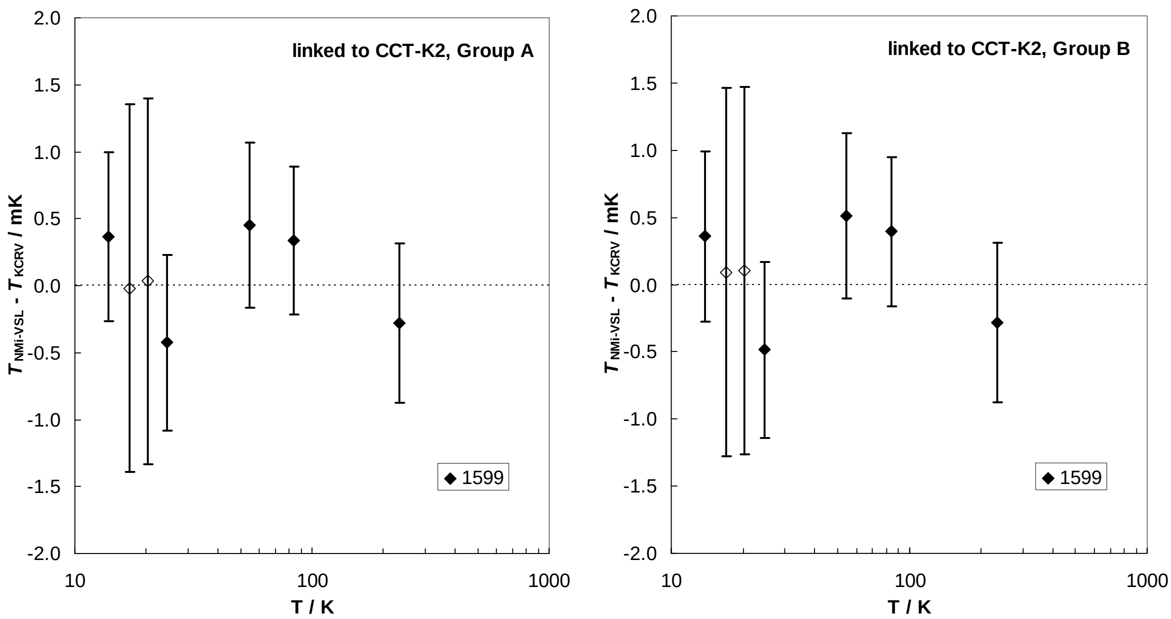

Figure 3. The comparison data for the NMi-VSL CSPRT S/N 1599 plotted with respect to the KCRV determined from the two Groups of measurements from the CCT-K2 report, mediated by the NRC realization of the ITS-90. The error bars represent the expanded uncertainties, *U*.

4. Conclusion

The NRC/NMi-VSL bilateral comparison of capsule-style platinum resistance thermometers over the range 13.8 K to 273.16 K has revealed calibrations at NMi-VSL to be in agreement with the KCRV of CCT-K2 within the expanded uncertainty for all temperatures of the comparison with the possible exception of the triple point of neon at 24.5561 K, where the difference from the KCRV for one of the CSPRTs exceeds the expanded uncertainty. The linkage to the CCT-K2 data supports the evaluation of the NMi-VSL CMCs in Appendix C of the KCDB.

References

1. Steele A.G., Fellmuth B., Head D.I., Hermier Y., Kang K.H., Steur P.P.M., Tew W.L., *Metrologia*, 2002, **39**, 551-571
2. Peruzzi A., Bosma R., van den Ark J., *Int. J. Thermophys.*, 2007, 1882-1892
3. Fellmuth B., Wolber L., Protocol for the investigation of the thermal properties of multicells, Report EU project MULTICELLS (Contract No. GRD1-1999-10423), Physicalisch-Technische Bundesanstalt (PTB), Berlin, Germany
4. Pavese F., "Century-Stable Accurate Cryogrenic-Temperature Fixed Points: Problems Solved and Problems to be solved", in *Temperature: Its Measurement and Control in Science and Industry*, Volume 7, ed. by D.C. Ripple, 2003, pp. 167-172
5. Pavese F., Ferri D., Peroni I., Pugliese A., Steur P. P. M., Fellmuth B., Head D., Lipinski L., Peruzzi A., Szmyrka-Grzebyk A., Wolber L., in *Temperature: Its Measurement and Control in Science and Industry*, Volume 7, ed. by D.C. Ripple, 2003, pp. 173-178
6. de Groot M.J., Mooibroek J., Bloembergen P., Durieux M., Reesink A.L., Yuzhu M., "International comparison of rhodium-iron resistance thermometers between 0.65 K and 27 K and measurement of helium vapour pressure" in *TEMPMEKO '93 : proceedings of the 5th International Symposium on Temperature and Thermal Measurements in Industry and Science* (Prague, Czech Republic, November 10-12, 1993), 1993, pp. 90-
7. Fellmuth B., Wolber L., Hermier Y., Pavese F., Steur P.P.M., Peroni I., Szmyrka-Grzebyk A., Lipinski L., Tew W.L., Nakano T., Sakurai H., Tamura O., Head D.I., Hill K.D., Steele A.G. "Isotopic and other influences on the realization of the triple point of hydrogen", *Metrologia*, 2005, **42** (4), 171-193. doi:10.1088/0026-1394/42/4/001
8. Pavese F., Fellmuth B., Head D.I., Hermier Y., Hill K.D., Valkiers S., "Evidence of a systematic deviation of the isotopic composition of neon from commercial sources compared with its isotopic composition in air", *Analytical Chemistry*, 2005, **77** (15), 5076-5080. doi:10.1021/ac048083f
9. Hill K.D., Steele A.G., "The triple point of xenon", *Metrologia*, 2005, **42** (4), 278-288. doi:10.1088/0026-1394/42/4/013
10. Rusby R., Head D., Meyer C., Tew W., Tamura O., Hill K.D., de Groot M., Storm A., Peruzzi A., Fellmuth BV., Engert J., Astrov D., Dedikov Y., Kytin G., "Final Report on CCT-K1: Realizations of the ITS-90, 0.65 K to 24.5561 K, using rhodium–iron resistance thermometers", *Metrologia*, 2006, **43**, Tech. Suppl., 03002

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Appendix A

The detailed uncertainty budget for the NMi-VSL thermometers.

Uncertainty components (*k*=1)	**e-H_2**	**17 K**	**20 K**	**Ne**	**O_2**	**Ar**	**Hg**	**H_2O**
Isotopic composition	14	-	-	157	0	0	0	1
Chemical impurities	20	-	-	30	50	10	12	69
Liquidus point identification	30	-	-	50	40	50	58	10
Reference scale (ICGT)	-	200	200	-	-	-	-	-
Hydrostatic head correction	5	-	-	19	15	33	74	8
Self-heat correction	23	30	30	30	34	20	30	23
Residual Gas pressure	0	-	-	0	0	0	0	3
Static temperature measurement error	20	-	-	20	20	20	-	-
Dynamic temperature measurement error	20	-	-	20	20	20	-	-
Temperature drift correction	-	53	25	-	-	-	-	-
Standard resistor	1	1	1	1	4	7	35	41
Resistance ratio bridge	80	80	80	80	4	4	14	15
TPW propagation	2	2	2	2	8	17	73	-
Reproducibility	46	-	-	46	139	52	50	26
Standard combined uncertainty (*k*=1)	107	224	219	196	160	87	138	90

Appendix B

Tables of bilateral equivalence, including links to the original CCT-K2 data. The elements above the diagonal are the pair differences (in mK) and their expanded (*k*=2) uncertainty. The $QDE_{0.95}$ confidence intervals for pairwise agreement are given below the diagonal. Further information is found in the CCT-K2 report. The linked results for NMi-VSL are shown in dark blue. 'NMi-VSL A' is CSPRT 1820627 and 'NMi-VSL B' is CSPRT 1599.

Table B.1: Linked bilateral equivalence matrix for comparison measurements near the hydrogen triple point.

H_2 Group A	BNM	IMGC	NIST	NPL	NRC	KCRV	VNIIFTRI	NMI-VSL A	NMI-VSL B
BNM	-	-2.39 ± 4.17	-3.13 ± 4.17	-2.78 ± 4.18	-2.45 ± 4.19	-2.71 ± 4.16	-1.29 ± 4.39	-2.59 ± 4.21	-3.08 ± 4.21
IMGC	*5.83*	-	-0.74 ± 0.47	-0.39 ± 0.53	-0.06 ± 0.56	-0.32 ± 0.32	1.10 ± 1.44	-0.20 ± 0.72	-0.69 ± 0.72
NIST	*6.56*	*1.12*	-	0.35 ± 0.54	0.68 ± 0.57	0.42 ± 0.34	1.84 ± 1.44	0.54 ± 0.72	0.05 ± 0.72
NPL	*6.22*	*0.82*	*0.79*	-	0.33 ± 0.62	0.07 ± 0.42	1.49 ± 1.46	0.19 ± 0.77	-0.30 ± 0.77
NRC	*5.90*	*0.56*	*1.15*	*0.84*	-	-0.26 ± 0.46	1.16 ± 1.47	-0.14 ± 0.79	-0.63 ± 0.79
KCRV	*6.14*	*0.58*	*0.70*	*0.43*	*0.64*	-	1.42 ± 1.40	0.12 ± 0.64	-0.37 ± 0.64
VNIIFTRI	*4.97*	*2.28*	*3.02*	*2.69*	*2.37*	*2.57*	-	-1.30 ± 1.54	-1.79 ± 1.54
NMI-VSL A	*6.06*	*0.80*	*1.14*	*0.84*	*0.82*	*0.67*	*2.57*	-	-0.49 ± 0.91
NMI-VSL B	*6.54*	*1.28*	*0.71*	*0.93*	*1.28*	*0.90*	*3.06*	*1.24*	-

H_2 Group B	BNM	IMGC	NIST	NPL	NRC	PTB	KCRV	VNIIFTRI	NMI-VSL A	NMI-VSL B
BNM	-	-2.43 ± 4.17	-3.02 ± 4.17	-2.55 ± 4.18	-2.33 ± 4.19	-2.58 ± 4.18	-2.60 ± 4.16	-1.17 ± 4.39	-2.47 ± 4.21	-2.96 ± 4.21
IMGC	*5.87*	-	-0.59 ± 0.47	-0.12 ± 0.48	0.10 ± 0.56	-0.15 ± 0.54	-0.17 ± 0.32	1.26 ± 1.44	-0.04 ± 0.72	-0.53 ± 0.72
NIST	*6.45*	*0.97*	-	0.47 ± 0.50	0.69 ± 0.57	0.44 ± 0.56	0.42 ± 0.34	1.85 ± 1.44	0.55 ± 0.72	0.06 ± 0.72
NPL	*5.99*	*0.53*	*0.88*	-	0.22 ± 0.58	-0.03 ± 0.57	-0.05 ± 0.36	1.38 ± 1.45	0.08 ± 0.73	-0.41 ± 0.73
NRC	*5.78*	*0.58*	*1.16*	*0.70*	-	-0.25 ± 0.64	-0.27 ± 0.46	1.16 ± 1.47	-0.14 ± 0.79	-0.63 ± 0.79
PTB	*6.03*	*0.61*	*0.90*	*0.56*	*0.78*	-	-0.02 ± 0.44	1.41 ± 1.47	0.11 ± 0.78	-0.38 ± 0.78
KCRV	*6.03*	*0.43*	*0.70*	*0.37*	*0.65*	*0.43*	-	1.43 ± 1.40	0.13 ± 0.64	-0.36 ± 0.64
VNIIFTRI	*4.86*	*2.44*	*3.03*	*2.57*	*2.37*	*2.62*	*2.58*	-	-1.30 ± 1.54	-1.79 ± 1.54
NMI-VSL A	*5.94*	*0.70*	*1.15*	*0.73*	*0.82*	*0.79*	*0.68*	*2.57*	-	-0.49 ± 0.91
NMI-VSL B	*6.42*	*1.12*	*0.72*	*1.02*	*1.28*	*1.02*	*0.89*	*3.06*	*1.24*	-

Table B.2: Linked bilateral equivalence matrix for comparison measurements near 17 K.

17 K Group A	NIST	NPL	NRC	KCRV	VNIIFTRI	NMI-VSL A	NMI-VSL B
NIST	-	-0.07 ± 0.58	-0.06 ± 0.55	-0.01 ± 0.30	0.29 ± 1.86	0.01 ± 1.41	0.01 ± 1.41
NPL	*0.59*	-	0.01 ± 0.68	0.06 ± 0.50	0.36 ± 1.91	0.08 ± 1.47	0.08 ± 1.47
NRC	*0.55*	*0.67*	-	0.05 ± 0.46	0.35 ± 1.90	0.07 ± 1.45	0.07 ± 1.45
KCRV	*0.29*	*0.50*	*0.46*	-	0.30 ± 1.84	0.02 ± 1.38	0.02 ± 1.38
VNIIFTRI	*1.91*	*2.00*	*1.98*	*1.89*	-	-0.28 ± 2.30	-0.28 ± 2.30
NMI-VSL A	*1.39*	*1.44*	*1.43*	*1.36*	*2.31*	-	0.00 ± 1.95
NMI-VSL B	*1.39*	*1.44*	*1.43*	*1.36*	*2.31*	*1.93*	-

17 K Group B	NIST	NPL	NRC	PTB	KCRV	VNIIFTRI	NMI-VSL A	NMI-VSL B
NIST	-	0.10 ± 0.55	-0.17 ± 0.55	-0.20 ± 0.67	0.01 ± 0.30	0.20 ± 1.86	-0.08 ± 1.41	-0.08 ± 1.41
NPL	*0.57*	-	-0.27 ± 0.65	-0.30 ± 0.76	-0.09 ± 0.46	0.10 ± 1.90	-0.18 ± 1.45	-0.18 ± 1.45
NRC	*0.63*	*0.81*	-	-0.03 ± 0.76	0.18 ± 0.46	0.37 ± 1.90	0.09 ± 1.45	0.09 ± 1.45
PTB	*0.76*	*0.93*	*0.74*	-	0.21 ± 0.60	0.40 ± 1.94	0.12 ± 1.50	0.12 ± 1.50
KCRV	*0.29*	*0.48*	*0.56*	*0.71*	-	0.19 ± 1.84	-0.09 ± 1.38	-0.09 ± 1.38
VNIIFTRI	*1.86*	*1.86*	*1.99*	*2.05*	*1.83*	-	-0.28 ± 2.30	-0.28 ± 2.30
NMI-VSL A	*1.39*	*1.46*	*1.43*	*1.49*	*1.36*	*2.31*	-	0.00 ± 1.95
NMI-VSL B	*1.39*	*1.46*	*1.43*	*1.49*	*1.36*	*2.31*	*1.93*	-

Table B.3: Linked bilateral equivalence matrix for comparison measurements near 20.3 K.

20.3 K Group A	NIST	NPL	NRC	KCRV	VNIIFTRI	NMI-VSL A	NMI-VSL B
NIST	-	0.06 ± 0.57	-0.06 ± 0.54	0.00 ± 0.28	0.33 ± 1.74	-0.03 ± 1.39	-0.03 ± 1.39
NPL	0.57	-	-0.12 ± 0.68	-0.06 ± 0.50	0.27 ± 1.79	-0.09 ± 1.45	-0.09 ± 1.45
NRC	0.54	0.71	-	0.06 ± 0.46	0.39 ± 1.78	0.03 ± 1.44	0.03 ± 1.44
KCRV	0.28	0.50	0.46	-	0.33 ± 1.72	-0.03 ± 1.36	-0.03 ± 1.36
VNIIFTRI	1.83	1.83	1.90	1.80	-	-0.36 ± 2.19	-0.36 ± 2.19
NMI-VSL A	1.36	1.43	1.41	1.34	2.26	-	0.00 ± 1.92
NMI-VSL B	1.36	1.43	1.41	1.34	2.26	1.90	-

20.3 K Group B	NIST	NPL	NRC	PTB	KCRV	VNIIFTRI	NMI-VSL A	NMI-VSL B
NIST	-	-0.06 ± 0.54	-0.19 ± 0.54	-0.48 ± 0.66	-0.06 ± 0.28	0.20 ± 1.74	-0.16 ± 1.39	-0.16 ± 1.39
NPL	0.54	-	-0.13 ± 0.65	-0.42 ± 0.76	0.00 ± 0.46	0.26 ± 1.78	-0.10 ± 1.44	-0.10 ± 1.44
NRC	0.64	0.69	-	-0.29 ± 0.76	0.13 ± 0.46	0.39 ± 1.78	0.03 ± 1.44	0.03 ± 1.44
PTB	1.02	1.04	0.92	-	0.42 ± 0.60	0.68 ± 1.82	0.32 ± 1.49	0.32 ± 1.49
KCRV	0.30	0.45	0.52	0.91	-	0.26 ± 1.72	-0.10 ± 1.36	-0.10 ± 1.36
VNIIFTRI	1.75	1.81	1.90	2.19	1.76	-	-0.36 ± 2.19	-0.36 ± 2.19
NMI-VSL A	1.39	1.42	1.41	1.59	1.34	2.26	-	0.00 ± 1.92
NMI-VSL B	1.39	1.42	1.41	1.59	1.34	2.26	1.90	-

Table B.4: Linked bilateral equivalence matrix for comparison measurements near the neon triple point.

Ne Group A	BNM	IMGC	KRISS	NIST	NPL	NRC	KCRV	VNIIFTRI	NMI-VSL A	NMI-VSL B
BNM	-	-0.13 ± 1.12	-0.03 ± 1.15	0.11 ± 1.13	0.08 ± 1.17	0.04 ± 1.17	-0.02 ± 1.08	-0.30 ± 1.28	0.63 ± 1.27	0.41 ± 1.27
IMGC	1.12	-	0.10 ± 0.49	0.24 ± 0.43	0.21 ± 0.52	0.17 ± 0.52	0.11 ± 0.28	-0.17 ± 0.74	0.76 ± 0.72	0.54 ± 0.72
KRISS	1.13	0.52	-	0.14 ± 0.51	0.11 ± 0.59	0.07 ± 0.59	0.01 ± 0.40	-0.27 ± 0.79	0.66 ± 0.77	0.44 ± 0.77
NIST	1.12	0.59	0.57	-	-0.03 ± 0.54	-0.07 ± 0.54	-0.13 ± 0.32	-0.41 ± 0.75	0.52 ± 0.73	0.30 ± 0.73
NPL	1.15	0.64	0.62	0.53	-	-0.04 ± 0.62	-0.10 ± 0.44	-0.38 ± 0.81	0.55 ± 0.79	0.33 ± 0.79
NRC	1.14	0.61	0.60	0.55	0.61	-	-0.06 ± 0.44	-0.34 ± 0.81	0.59 ± 0.79	0.37 ± 0.79
KCRV	1.06	0.34	0.39	0.40	0.47	0.45	-	-0.28 ± 0.68	0.65 ± 0.66	0.43 ± 0.66
VNIIFTRI	1.38	0.79	0.93	1.03	1.05	1.01	0.84	-	0.93 ± 0.95	0.71 ± 0.95
NMI-VSL A	1.67	1.35	1.29	1.12	1.20	1.24	1.19	1.71	-	-0.22 ± 0.93
NMI-VSL B	1.47	1.13	1.08	0.91	0.99	1.03	0.97	1.49	1.01	-

Ne Group B	BNM	IMGC	KRISS	NIST	NPL	NRC	PTB	KCRV	VNIIFTRI	NMI-VSL A	NMI-VSL B
BNM	-	-1.99 ± 2.81	-1.73 ± 2.83	-1.92 ± 2.82	-1.69 ± 2.83	-1.76 ± 2.83	-2.14 ± 2.83	-1.88 ± 2.80	-2.10 ± 2.88	-1.17 ± 2.88	-1.39 ± 2.88
IMGC	4.31	-	0.26 ± 0.49	0.07 ± 0.43	0.30 ± 0.47	0.23 ± 0.52	-0.15 ± 0.49	0.11 ± 0.28	-0.11 ± 0.74	0.82 ± 0.72	0.60 ± 0.72
KRISS	4.06	0.66	-	-0.19 ± 0.51	0.04 ± 0.55	-0.03 ± 0.59	-0.41 ± 0.57	-0.15 ± 0.40	-0.37 ± 0.79	0.56 ± 0.77	0.34 ± 0.77
NIST	4.24	0.44	0.62	-	0.23 ± 0.50	0.16 ± 0.54	-0.22 ± 0.51	0.04 ± 0.32	-0.18 ± 0.75	0.75 ± 0.73	0.53 ± 0.73
NPL	4.02	0.69	0.54	0.64	-	-0.07 ± 0.58	-0.45 ± 0.55	-0.19 ± 0.38	-0.41 ± 0.78	0.52 ± 0.76	0.30 ± 0.76
NRC	4.09	0.66	0.58	0.62	0.58	-	-0.38 ± 0.59	-0.12 ± 0.44	-0.34 ± 0.81	0.59 ± 0.79	0.37 ± 0.79
PTB	4.47	0.56	0.88	0.64	0.90	0.87	-	0.26 ± 0.40	0.04 ± 0.79	0.97 ± 0.77	0.75 ± 0.77
KCRV	4.19	0.34	0.48	0.32	0.50	0.49	0.59	-	-0.22 ± 0.68	0.71 ± 0.66	0.49 ± 0.66
VNIIFTRI	4.47	0.75	1.02	0.82	1.05	1.01	0.78	0.79	-	0.93 ± 0.95	0.71 ± 0.95
NMI-VSL A	3.55	1.41	1.20	1.35	1.15	1.24	1.60	1.25	1.71	-	-0.22 ± 0.93
NMI-VSL B	3.77	1.19	0.98	1.13	0.93	1.03	1.38	1.03	1.49	1.01	-

Table B.5: Linked bilateral equivalence matrix for comparison measurements near the oxygen triple point.

O_2 Group A	BNM	IMGC	KRISS	NIST	NPL	NRC	KCRV	VNIIFTRI	NMI-VSL A	NMI-VSL B
BNM	-	0.13 ± 0.57	-0.16 ± 0.62	-0.14 ± 0.56	-0.09 ± 0.63	-0.25 ± 0.68	-0.07 ± 0.52	0.09 ± 0.86	-0.52 ± 0.81	-0.52 ± 0.81
IMGC	0.62	-	-0.29 ± 0.42	-0.27 ± 0.31	-0.22 ± 0.43	-0.38 ± 0.50	-0.20 ± 0.24	-0.04 ± 0.72	-0.65 ± 0.66	-0.65 ± 0.66
KRISS	0.68	0.63	-	0.02 ± 0.39	0.07 ± 0.50	-0.09 ± 0.56	0.09 ± 0.34	0.25 ± 0.76	-0.36 ± 0.71	-0.36 ± 0.71
NIST	0.61	0.53	0.39	-	0.05 ± 0.41	-0.11 ± 0.48	0.07 ± 0.20	0.23 ± 0.71	-0.38 ± 0.65	-0.38 ± 0.65
NPL	0.64	0.58	0.50	0.41	-	-0.16 ± 0.57	0.02 ± 0.36	0.18 ± 0.77	-0.43 ± 0.72	-0.43 ± 0.72
NRC	0.82	0.79	0.57	0.52	0.64	-	0.18 ± 0.44	0.34 ± 0.81	-0.27 ± 0.76	-0.27 ± 0.76
KCRV	0.53	0.40	0.38	0.24	0.35	0.54	-	0.16 ± 0.68	-0.45 ± 0.62	-0.45 ± 0.62
VNIIFTRI	0.85	0.71	0.88	0.82	0.83	1.01	0.74	-	-0.61 ± 0.92	-0.61 ± 0.92
NMI-VSL A	1.19	1.20	0.94	0.92	1.02	0.90	0.96	1.37	-	0.00 ± 0.88
NMI-VSL B	1.19	1.20	0.94	0.92	1.02	0.90	0.96	1.37	0.87	-

O_2 Group B	BNM	IMGC	KRISS	NIST	NPL	NRC	PTB	KCRV	VNIIFTRI	NMI-VSL A	NMI-VSL B
BNM	-	0.17 ± 0.55	-0.09 ± 0.60	0.06 ± 0.55	-0.05 ± 0.58	-0.23 ± 0.67	-0.17 ± 0.68	0.01 ± 0.50	0.11 ± 0.84	-0.50 ± 0.80	-0.50 ± 0.80
IMGC	0.63	-	-0.26 ± 0.42	-0.11 ± 0.34	-0.22 ± 0.38	-0.40 ± 0.50	-0.34 ± 0.52	-0.16 ± 0.24	-0.06 ± 0.72	-0.67 ± 0.66	-0.67 ± 0.66
KRISS	0.62	0.60	-	0.15 ± 0.42	0.04 ± 0.45	-0.14 ± 0.56	-0.08 ± 0.57	0.10 ± 0.34	0.20 ± 0.76	-0.41 ± 0.71	-0.41 ± 0.71
NIST	0.55	0.39	0.50	-	-0.11 ± 0.38	-0.29 ± 0.50	-0.23 ± 0.52	-0.05 ± 0.24	0.05 ± 0.72	-0.56 ± 0.66	-0.56 ± 0.66
NPL	0.58	0.54	0.45	0.43	-	-0.18 ± 0.53	-0.12 ± 0.55	0.06 ± 0.30	0.16 ± 0.74	-0.45 ± 0.69	-0.45 ± 0.69
NRC	0.78	0.81	0.61	0.70	0.62	-	0.06 ± 0.64	0.24 ± 0.44	0.34 ± 0.81	-0.27 ± 0.76	-0.27 ± 0.76
PTB	0.74	0.77	0.58	0.66	0.59	0.63	-	0.18 ± 0.46	0.28 ± 0.82	-0.33 ± 0.77	-0.33 ± 0.77
KCRV	0.49	0.36	0.38	0.25	0.32	0.60	0.56	-	0.10 ± 0.68	-0.51 ± 0.62	-0.51 ± 0.62
VNIIFTRI	0.85	0.71	0.84	0.71	0.79	1.01	0.96	0.69	-	-0.61 ± 0.92	-0.61 ± 0.92
NMI-VSL A	1.16	1.22	0.99	1.11	1.02	0.90	0.97	1.02	1.37	-	0.00 ± 0.88
NMI-VSL B	1.16	1.22	0.99	1.11	1.02	0.90	0.97	1.02	1.37	0.87	-

Table B.6: Linked bilateral equivalence matrix for comparison measurements near the argon triple point.

Ar Group A	BNM	IMGC	KRISS	NIST	NPL	NRC	KCRV	VNIIFTRI	NMi-VSL A	NMi-VSL B
BNM	-	0.27 ± 0.45	-0.48 ± 0.52	0.07 ± 0.45	0.10 ± 0.52	-0.11 ± 0.59	0.07 ± 0.40	-0.20 ± 0.75	-0.22 ± 0.69	-0.27 ± 0.69
IMGC	0.64	-	-0.75 ± 0.39	-0.20 ± 0.28	-0.17 ± 0.39	-0.38 ± 0.48	-0.20 ± 0.20	-0.47 ± 0.67	-0.49 ± 0.59	-0.54 ± 0.59
KRISS	0.91	1.07	-	0.55 ± 0.39	0.58 ± 0.48	0.37 ± 0.56	0.55 ± 0.34	0.28 ± 0.72	0.26 ± 0.66	0.21 ± 0.66
NIST	0.46	0.43	0.87	-	0.03 ± 0.39	-0.18 ± 0.48	0.00 ± 0.20	-0.27 ± 0.67	-0.29 ± 0.59	-0.34 ± 0.59
NPL	0.55	0.50	0.98	0.39	-	-0.21 ± 0.56	-0.03 ± 0.34	-0.30 ± 0.72	-0.32 ± 0.66	-0.37 ± 0.66
NRC	0.62	0.78	0.83	0.58	0.67	-	0.18 ± 0.44	-0.09 ± 0.78	-0.11 ± 0.71	-0.16 ± 0.71
KCRV	0.41	0.36	0.83	0.20	0.34	0.54	-	-0.27 ± 0.64	-0.29 ± 0.56	-0.34 ± 0.56
VNIIFTRI	0.84	1.02	0.88	0.83	0.90	0.78	0.80	-	-0.02 ± 0.85	-0.07 ± 0.85
NMi-VSL A	0.79	0.98	0.80	0.78	0.86	0.73	0.75	0.84	-	-0.05 ± 0.79
NMi-VSL B	0.84	1.03	0.76	0.83	0.91	0.76	0.80	0.84	0.78	-

Ar Group B	BNM	IMGC	KRISS	NIST	NPL	NRC	PTB	KCRV	VNIIFTRI	NMi-VSL A	NMi-VSL B
BNM	-	0.20 ± 0.48	0.10 ± 0.56	0.07 ± 0.49	0.15 ± 0.51	-0.13 ± 0.62	-0.11 ± 0.61	0.11 ± 0.44	-0.22 ± 0.78	-0.24 ± 0.71	-0.29 ± 0.71
IMGC	0.60	-	-0.10 ± 0.39	-0.13 ± 0.30	-0.05 ± 0.33	-0.33 ± 0.48	-0.31 ± 0.47	-0.09 ± 0.20	-0.42 ± 0.67	-0.44 ± 0.59	-0.49 ± 0.59
KRISS	0.58	0.43	-	-0.03 ± 0.40	0.05 ± 0.43	-0.23 ± 0.56	-0.21 ± 0.54	0.01 ± 0.34	-0.32 ± 0.72	-0.34 ± 0.66	-0.39 ± 0.66
NIST	0.50	0.38	0.40	-	0.08 ± 0.34	-0.20 ± 0.49	-0.18 ± 0.47	0.04 ± 0.22	-0.29 ± 0.68	-0.31 ± 0.60	-0.36 ± 0.60
NPL	0.58	0.34	0.43	0.37	-	-0.28 ± 0.51	-0.26 ± 0.49	-0.04 ± 0.26	-0.37 ± 0.69	-0.39 ± 0.62	-0.44 ± 0.62
NRC	0.66	0.73	0.69	0.61	0.70	-	0.02 ± 0.61	0.24 ± 0.44	-0.09 ± 0.78	-0.11 ± 0.71	-0.16 ± 0.71
PTB	0.63	0.69	0.66	0.57	0.67	0.60	-	0.22 ± 0.42	-0.11 ± 0.77	-0.13 ± 0.70	-0.18 ± 0.70
KCRV	0.48	0.26	0.33	0.23	0.27	0.60	0.57	-	-0.33 ± 0.64	-0.35 ± 0.56	-0.40 ± 0.56
VNIIFTRI	0.87	0.97	0.92	0.85	0.94	0.78	0.78	0.86	-	-0.02 ± 0.85	-0.07 ± 0.85
NMi-VSL A	0.83	0.93	0.88	0.81	0.90	0.73	0.73	0.81	0.84	-	-0.05 ± 0.79
NMi-VSL B	0.88	0.98	0.93	0.86	0.95	0.76	0.77	0.86	0.84	0.78	-

Table B.7: Linked bilateral equivalence matrix for comparison measurements near the mercury triple point.

Hg Group A	BNM	IMGC	KRISS	NIST	NPL	NRC	KCRV	VNIIFTRI	NMi-VSL A	NMi-VSL B
BNM	-	-0.17 ± 0.59	-0.11 ± 0.76	-0.35 ± 0.63	-0.34 ± 0.68	-0.09 ± 0.71	-0.23 ± 0.56	0.03 ± 1.04	0.26 ± 0.82	0.05 ± 0.82
IMGC	0.67	-	0.06 ± 0.56	-0.18 ± 0.34	-0.17 ± 0.43	0.08 ± 0.48	-0.06 ± 0.20	0.20 ± 0.90	0.43 ± 0.63	0.22 ± 0.63
KRISS	0.78	0.56	-	-0.24 ± 0.59	-0.23 ± 0.64	0.02 ± 0.68	-0.12 ± 0.52	0.14 ± 1.02	0.37 ± 0.79	0.16 ± 0.79
NIST	0.87	0.46	0.73	-	0.01 ± 0.47	0.26 ± 0.52	0.12 ± 0.28	0.38 ± 0.92	0.61 ± 0.66	0.40 ± 0.66
NPL	0.90	0.53	0.77	0.46	-	0.25 ± 0.58	0.11 ± 0.38	0.37 ± 0.96	0.60 ± 0.71	0.39 ± 0.71
NRC	0.72	0.50	0.67	0.69	0.73	-	-0.14 ± 0.44	0.12 ± 0.98	0.35 ± 0.74	0.14 ± 0.74
KCRV	0.69	0.23	0.56	0.35	0.43	0.51	-	0.26 ± 0.88	0.49 ± 0.60	0.28 ± 0.60
VNIIFTRI	1.02	0.97	1.04	1.14	1.17	0.99	1.00	-	0.23 ± 1.07	0.02 ± 1.07
NMi-VSL A	0.95	0.95	1.03	1.15	1.18	0.96	0.98	1.14	-	-0.21 ± 0.85
NMi-VSL B	0.81	0.75	0.84	0.95	0.98	0.78	0.78	1.05	0.93	-

Hg Group B	BNM	IMGC	KRISS	NIST	NPL	NRC	PTB	KCRV	VNIIFTRI	NMi-VSL A	NMi-VSL B
BNM	-	-0.80 ± 0.59	-1.10 ± 0.76	-0.96 ± 0.61	-0.85 ± 0.66	-0.73 ± 0.71	-0.93 ± 0.68	-0.87 ± 0.56	-0.61 ± 1.04	-0.38 ± 0.82	-0.59 ± 0.82
IMGC	1.29	-	-0.30 ± 0.56	-0.16 ± 0.31	-0.05 ± 0.39	0.07 ± 0.48	-0.13 ± 0.43	-0.07 ± 0.20	0.19 ± 0.90	0.42 ± 0.63	0.21 ± 0.63
KRISS	1.73	0.76	-	0.14 ± 0.57	0.25 ± 0.62	0.37 ± 0.68	0.17 ± 0.64	0.23 ± 0.52	0.49 ± 1.02	0.72 ± 0.79	0.51 ± 0.79
NIST	1.46	0.42	0.62	-	0.11 ± 0.42	0.23 ± 0.50	0.03 ± 0.45	0.09 ± 0.24	0.35 ± 0.91	0.58 ± 0.65	0.37 ± 0.65
NPL	1.39	0.40	0.76	0.46	-	0.12 ± 0.56	-0.08 ± 0.51	-0.02 ± 0.34	0.24 ± 0.94	0.47 ± 0.69	0.26 ± 0.69
NRC	1.32	0.49	0.93	0.64	0.59	-	-0.20 ± 0.58	-0.14 ± 0.44	0.12 ± 0.98	0.35 ± 0.74	0.14 ± 0.74
PTB	1.49	0.49	0.71	0.44	0.52	0.68	-	0.06 ± 0.38	0.32 ± 0.96	0.55 ± 0.71	0.34 ± 0.71
KCRV	1.33	0.24	0.66	0.29	0.33	0.51	0.39	-	0.26 ± 0.88	0.49 ± 0.60	0.28 ± 0.60
VNIIFTRI	1.47	0.96	1.33	1.11	1.04	0.99	1.12	1.00	-	0.23 ± 1.07	0.02 ± 1.07
NMi-VSL A	1.06	0.94	1.37	1.11	1.04	0.96	1.13	0.98	1.14	-	-0.21 ± 0.85
NMi-VSL B	1.27	0.74	1.16	0.90	0.83	0.78	0.93	0.78	1.05	0.93	-