CIPM MRA
Comparison reports

SIM.T-K9.4

Realization of the ITS-90 of the triple point of Argon

KEY COMPARISON

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SIM.T-K9.4

A bilateral comparison of the argon triple point

FINAL REPORT

National Institute of Standards and Technology (NIST), USA
National Research Council (NRC), Canada

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October 2026

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1. INTRODUCTION

This document reports the results of a bilateral comparison of the argon triple point (Ar TP) realizations between the National Institute of Standards and Technology (NIST) of the USA and the National Research Council (NRC) of Canada.

This report has been prepared and approved by the two participants indicated in section 2. The contents of this report follow the CIPM MRA-G-11 [1] and the CCT WG-KC/17-03, Comparison protocol template, dated 5-October-2017. The official status of the comparison has been conveyed and approved as an RMO Key Comparison through the Inter-American Metrology System (SIM) Working Group 3, with the identification code **SIM.T-K9.4**.

NIST had a specific requirement to establish a new link to the argon triple point (Ar TP, -189.3442 °C) and the results of the CCT-K9 [2] comparison that is independent of the original NIST submission to the CCT-K9 for that fixed point temperature. The objective of this comparison was to establish the degree of equivalence between the Ar TP as realized at the NRC and that of NIST. This was accomplished through the use of two capsule-type SPRT (CSPRT) transfer standards supplied by NIST. Both participants realized the Ar TP using immersion-type fixed point cells and recorded those temperatures as values of resistance ratios $W=R(\text{Ar TP})/R(\text{WTP})$, where R(Ar TP) and R(WTP) are the electrical resistances of the two transfer standards measured in the argon triple point and in the water triple point (WTP), respectively.

The technical procedures described in the technical protocol (Appendix C) were primarily focused on the measurement and handling of two transfer standards. Procedures specific to the realizations and measurement of the Ar TP were not prescribed in the protocol and these were determined by the staff of the two participating laboratories. The method of realization chosen by NRC was sufficient to convey traceability to the NRC Ar TP realization as submitted to the CCT-K9, and will be detailed in the following sections.

This comparison report contains descriptions of the realization procedures used by the pilot and the participant laboratories, as well as the results of the comparison and the linkage to the CCT-K9 key comparison reference value (KCRV).

2. PARTICIPANTS

The participating institutes are:

- **National Institute of Standards and Technology (NIST)**
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  Contact: Sergey Dedyulin
  Phone: +1 343 990 8646
  E-mail: Sergey.Dedyulin@nrc-cnrc.gc.ca

NIST was the pilot of this bilateral comparison, from the standpoint of providing the traveling artifacts and taking the main responsibility for reporting of the results of the comparison. NRC was the participant of this comparison and will provide the linkage to the Ar TP KCRV of the CCT-K9.

The two laboratories accepted the general and the technical instructions and strictly followed the procedures of the protocol.

3. COMPARISON METHODOLOGY

The comparison was structured as a closed loop, to compare the results of Ar TP realizations at the two laboratories, using two transfer CSPRTs, in a sequence that started and ended at NIST. NIST performed the first set of measurements for the comparison between February/2024 and May/2024. The second set of measurements was performed at NRC using the transfer SPRTs between May 2024 and June/2025. A third and final set of measurements was then performed back at NIST, again using these same two transfer SPRTs between September/2025 and October/2025. A shorthand notation for the sequence of the principal measurement sets would be: NIST-NRC-NIST. Once the final measurements were performed in the third set at NIST, the measurement phase of the comparison was completed.

4. TRAVELING STANDARDS

NIST provided two capsule-type SPRTs (CSPRTs) as transfer standards, as described in Table 1 below:

Table 1. Traveling standards characteristics

SPRT ID	CSPRT #1	CSPRT #2
Manufacturer	Rosemount/Collins	Hart Scientific
Model	162D	5686
Serial number	5341	101
Nominal resistance at 0 °C	25.5 Ω	25.3 Ω
Number of wires	4	4

The transfer standards are CSPRTs that were adapted for use in immersion-type fixed point cells. This adaptation was essential for the purposes of this comparison since the Ar TP realizations were to be performed using immersion-type fixed point cells, as was the case in the CCT-K9 comparison [2]. At NIST, the adaptations were accomplished via specially designed glass adaptor tubes pumped and backfilled with helium gas for improved thermal contact, originally utilized for the NIST SRM 1750, and two sets of tubes are provided by NIST for the purposes of this comparison. Usage of the adapter probes is described in reference [3]. At NRC, a custom stainless steel/Garolite adapter was used instead of the 7.57 mm OD glass adapter tube provided by NIST to fit the 7.37 mm ID thermometer wells of NRC Ar cryostat. For the WTP measurements, the original NIST glass-tube adapter was used to provide a hermetic seal against water present in the thermometer well. The same wire harness provided by NIST was used in both cases. The wire harness was terminated by a plastic Swagelok tee which allowed an exchange gas (helium at a pressure of 0.5 PSIG) to be connected to the adapter tube for all the measurements. Figure 1 shows the custom NRC adapter.



Figure 1: Stainless steel/Garolite G10 adapter for Rosemount 162D s/n 5341 CSPRT to fit in NRC Ar TP cryostat. The connection between steel and Garolite parts was press-fit, not hermetic.

The decision to use CSPRTs for this comparison rather than long-stem SPRTs (LSPRTs) was motivated by two factors. First, the handling and transportation of CSPRTs is much simpler, since the sensors can be easily removed from the adapting tube and placed inside their compact transport cases that can be safely hand-carried from one NMI to another. Second, the results of the original CCT-K9 comparison suggested that the shipping of the LSPRTs could have introduced significant drifts in the measured resistance ratios in the participant NMIs before and after the LSPRTs were sent to NIST (see section 4 of reference [2]), which resulted in increased comparison uncertainties. Therefore, the CSPRTs were chosen as transfer standards to minimize the drifts associated with shipping of the thermometers.

The transfer standards were transported separately from the adapter tubes, inside their original cases, to prevent damage to the sensors, were handled only by authorized persons, and were stored in such a way as to prevent damage. The transfer CSPRTs were not annealed during this comparison.

During the course of the comparison, it was identified that CSPRT #1 drifted more than the specified 0.2 mK in Section 6 of the technical protocol (see Appendix C). Upon return to NIST, it was confirmed that the thermometer was unstable at the Ar TP, therefore the results of the bilateral comparison, as well as the linkage to the key comparison CCT-K9, will be based on the results obtained with CSPRT #2 only. Nevertheless, the measurement results with both thermometers are disclosed and discussed in this report.

5. MEASURAND

The measurand of this comparison, as defined in the technical protocol (Appendix C), are the resistance ratios, W(Ar TP):

$$W(Ar\ TP) = \frac{R(Ar\ TP)}{R(WTP)} \tag{1}$$

where R(Ar TP) and R(WTP) are, respectively, the values of electrical resistance of the CSPRT measured at the argon triple point and at the water triple point. For each CSPRT *i*, the difference between the participant laboratories is given as follows:

$$\Delta T_{90,SPRT\ i} = \frac{\bar{W}(Ar\ TP)_{NIST,CSPRT\ i} - W(Ar\ TP)_{NRC,CSPRT\ i}}{dW(Ar\ TP)/dT_{90}} \tag{2}$$

where $\bar{W}(Ar\ TP)_{NIST,SPRT\ i}$ is the average of the W(Ar TP) values with CSPRT *i* at NIST before and after traveling to NRC, $W(Ar\ TP)_{NRC,SPRT\ i}$ is the resistance ratio measured at NRC with CSPRT *i*, and dW(Ar TP)/dT90 is the first derivative of W with relation to the temperature at the

argon triple point, as given by the ITS-90 reference function (i.e., 0.004342 K, as given by Appendix 2 of [4]).

The average temperature difference is then given by:

$$\overline{\Delta T_{90}} = \frac{\Delta T_{90,SPRT\ \#1} + \Delta T_{90,SPRT\ \#2}}{2} \tag{3}$$

The uncertainty of the temperature difference is:

$$u^2(\overline{\Delta T_{90}}) = \frac{u^2\left(\Delta T_{90,CSPRT\ \#1}\right) + u^2\left(\Delta T_{90,CSPRT\ \#2}\right)}{2^2} \tag{4}$$

where:

$$u^2\left(\Delta T_{90,SPRT\ i}\right) = \frac{u^2\left(\overline{W}(Ar\ TP)_{NIST,CSPRT\ i}\right) + u^2\left(W(Ar\ TP)_{NRC,CSPRT\ i}\right)}{(dW(Ar\ TP)/dT_{90})^2} + \left(\frac{c_i \cdot \Delta T_{TPW,CSPRT\ i}}{\sqrt{3}}\right)^2 \tag{5}$$

and

$$u^2\left(\overline{W}(Ar\ TP)_{NIST,CSPRT\ i}\right) = \frac{u^2\left(W(Ar\ TP)_{NIST_PRE,CSPRT\ i}\right) + u^2\left(W(Ar\ TP)_{NIST_POST,CSPRT\ i}\right)}{4} \tag{6}$$

where the subscripts *NIST_PRE* and *NIST_POST* refer to the measurements performed at NIST before and after traveling to NRC, CSPRT *i* refers to each CSPRT (#1 and #2), and $\Delta T_{TPW,SPRT\ i}$ accounts for the observed change in the TPW value of the CSPRT *i* after traveling from NIST to NRC, propagated to the Ar TP using the factor c_i as given by the Appendix 2 of [4].

Since it was identified that during the measurements CSPRT #1 drifted more than 0.2 mK, the temperature difference was taken as the temperature difference measured with CSPRT #2 only, $\Delta T_{90,SPRT\ \#2}$. Therefore:

$$\overline{\Delta T_{90}} = \Delta T_{90,SPRT\ \#2} = \frac{\overline{W}(Ar\ TP)_{NIST,CSPRT\ \#2} - W(Ar\ TP)_{NRC,CSPRT\ \#2}}{dW(Ar\ TP)/dT_{90}} \tag{7}$$

and

$$u^2(\overline{\Delta T_{90}}) = \frac{u^2\left(\overline{W}(Ar\ TP)_{NIST,CSPRT\ \#2}\right) + u^2\left(W(Ar\ TP)_{NRC,C\ SPRT\ \#2}\right)}{(dW(Ar\ TP)/dT_{90})^2} + \left(\frac{c_i \cdot \Delta T_{TPW,CSPRT\ \#2}}{\sqrt{3}}\right)^2 \tag{8}$$

where:

$$u^2\left(\overline{W}(Ar\ TP)_{NIST,CSPRT\ \#2}\right) = \frac{u^2\left(W(Ar\ TP)_{NIST_{PRE},CSPRT\ \#2}\right) + u^2\left(W(Ar\ TP)_{NIST_{POST},CSPRT\ \#2}\right)}{4} \tag{9}$$

The degrees of equivalence of this comparison are the temperature difference $\overline{\Delta T_{90}}$, as given in eq. 7, and its corresponding uncertainty is $u^2(\overline{\Delta T_{90}})$, as given in eq. 8. The uncertainties were estimated following the requirements of Guide for the Expression of Uncertainty [5].

6. MEASUREMENT PROCEDURES

6.1 Preparation of the Transfer standards and Preliminary checks

The two transfer CSPRTs selected by NIST were measured at NIST prior to the beginning of the comparison. Those measurements established reliable values for the SPRT resistances at the WTP and Ar TP temperatures using NIST fixed-point standards, and demonstrated that the thermometers were stable enough to be used as transfer standards. In the sequence, the transfer SPRTs were hand carried from NIST to NRC, being examined for damages when received and checked at the WTP to identify any drifts, before the start of measurements at the Ar TP. Once the measurements were completed at NRC, the transfer SPRTs were hand carried back to NIST, being again examined for damages and checked at the WTP before the start of the measurements. The results of the examinations and verifications at the WTP were exchanged between the participants to help monitor the state and stability of the transfer standards.

6.2 Measurement process and instrumentation

Each participant measured the electrical resistances of the CSPRTs using a resistance bridge, and all measured electrical resistances were corrected to null power (0 mA). Before and after each realization of the Ar TP, the resistance values of the CSPRTs were measured at the WTP. Each participant calibrated the transfer CSPRTs with their fixed-point cell standards and equipment, following their own procedure, and according to the current best practices [4]. The measurement reports in Appendix A detail the equipment and standards used by each laboratory during this comparison.

NIST used a Pond K52 quasi-adiabatic Ar TP system [6], acquired to replace the system used during the CCT-K9 comparison. The CSPRTs were measured using a DC bridge under excitation currents of 0.707 mA and 1 mA, and a 100 W standard resistor thermostatically controlled to within ±10 mK in an air bath. All measured resistance values were extrapolated to 0 mA. The measurements were performed between 30% and 50% of melted fraction. For WTP measurements, a quartz cell Fluke model 5901A-Q was used, which was maintained inside an Isotech model ITL-M-18233 WTP maintenance bath.

The Ar TP cell s/n F13, used by NRC in the CCT-K2 [7] and CCT-K9 [2] comparisons, could not be used in this comparison. It was detected that the amount of heat needed to melt the sample had reduced dramatically and the measured plateaux were broader and colder, even when used in two different cryostats. For that reason, Ar TP cell s/n Cu-M-7 was used instead for the measurements of this comparison. The cell was filled in 2006 and compared to cell F13 as described in CCT-K2.5 report [8]. The reported temperature difference between cells Cu-M-7 and F13 is -0.12 mK with an uncertainty of 0.07 mK (k=1). It was determined that the amount of heat necessary to realize the Ar TP using the cell remained the same since the cell was fabricated, indicating that the cell remains in good condition. The realizations were performed in the cryostat described in [9], and the measurements were performed between 50% and 60% of melted fraction. The CSPRTs were measured using a DC bridge under excitation currents of 1 mA and 1.414 mA, and a 100 W standard resistor thermostatically controlled in an oil bath. For WTP measurements, a borosilicate Jarrett cell B11-2053 was used, which was maintained inside an NRC-made ice-box container.

7. COMPARISON RESULTS

Table 2 summarizes the measurement results at both laboratories. The results with CSPRT #1 are marked in red because the drift observed with this standard exceeded the maximum acceptable

value at the WTP and therefore they were not used in the calculations. Figure 2 shows the deviations of the measured WTP values with relation to the average of all measurements for both SPRTs. It is possible to see that between measurements 3 and 4, CSPRT #1 drifted about 0.8 mK at the WTP, four times the maximum allowed, while the resistance of CSPRT #2 at the WTP stayed within 0.086 mK over the whole comparison. Despite such large drift of CSPRT #1 at the WTP, the average difference between the Ar TP realizations at NIST and NRC using it was only 0.1 mK. Nevertheless, the measurement results with CSPRT #1 were excluded from the calculations of temperature differences for this comparison. Figure 3 shows graphically the results of the measurements of the Ar TP realized at NIST and NRC. Again, it is possible to see that SPRT #1 progressively drifted as SPRT #2 remained stable during the loop NIST-NRC-NIST. The temperature difference $\overline{\Delta T_{90}}$ is given by eq. 7 and its corresponding uncertainty $u^2(\overline{\Delta T_{90}})$ is given by eq. 8.

Table 2 – Measurement results. Values in red were not used for the degree-of-equivalence calculations

		Initial WTP		Ar TP		Final WTP	
		Resistance	Std. dev.	W	U (k=2)	Resistance	Std. dev.
		ohms	ohms		mK	ohms	ohms
NIST pre-NRC	SPRT #1	25.4553956	0.0000013	0.21609539	0.17	25.4553936	0.0000011
	SPRT #2	25.3768135	0.0000023	0.21597638	0.17	25.3768102	0.0000019
NRC	SPRT #1	25.4553899	0.0000029	0.21609604	0.33	25.4554744	0.0000065
	SPRT #2	25.3768081	0.0000029	0.21597632	0.33	25.3768119	0.0000022
NIST post-NRC	SPRT #1	25.4554864	0.0000012	0.21609743	0.17	25.4554711	0.0000014
	SPRT #2	25.376816	0.0000016	0.21597623	0.17	25.3768167	0.0000018

	ΔT_{90}	U (k=2)
	mK	mK
SPRT #1	**0.09**	**0.41**
SPRT #2	**0.00**	**0.35**

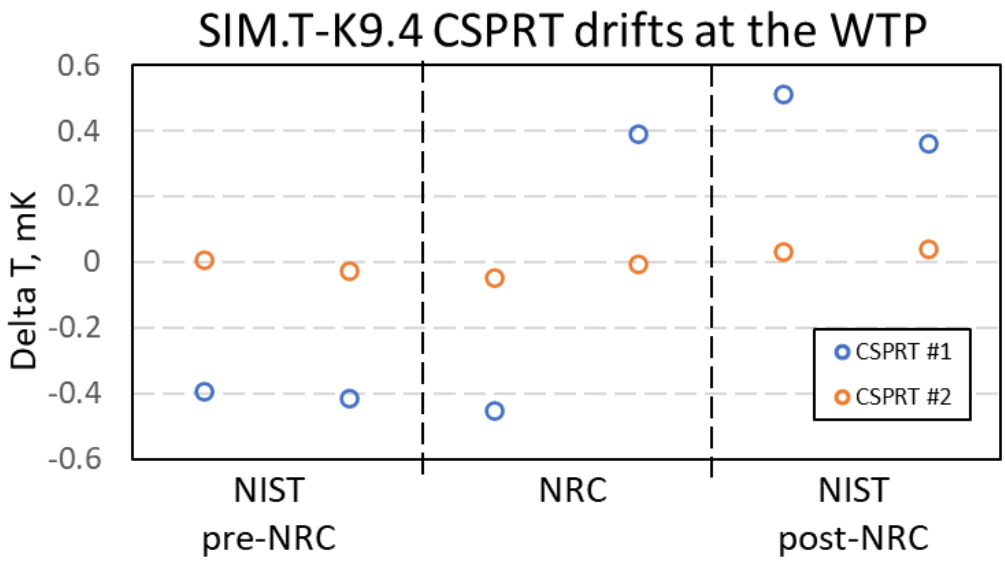


Figure 1 – CSPRT drifts at the WTP

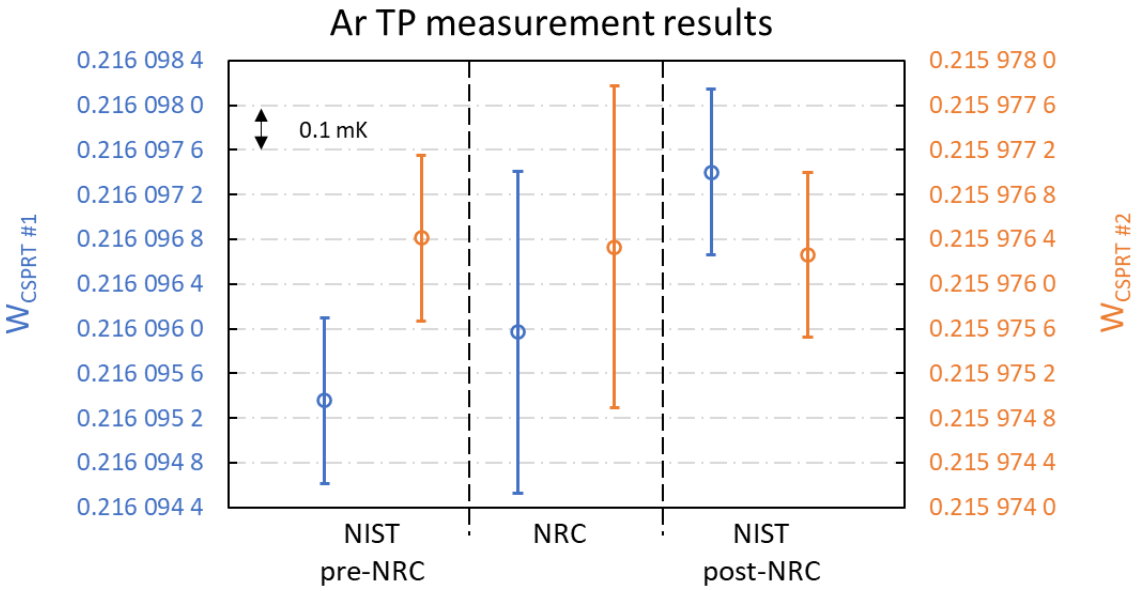


Figure 3 – Ar TP measurement results with both SPRTs at NIST and NRC

8. CCT-K9 KCRV LINKAGE

This comparison was intended to be linked to the key comparison CCT-K9 results [2]. The temperature differences between the contemporary NIST Ar TP realization and that of the NRC should then be linked to the CCT-K9 KCRV for the Ar TP. This required establishing a complete traceability chain to the NRC realizations of the Ar TP, as performed for the submission to the CCT-K9 comparison. However, during the preparations for the measurements at NRC, it was found that the cell used during the CCT-K9 comparison, identified as F13, failed and could no longer be used, as reported in 6.2. Because of this issue, NRC switched to cell Cu-M-7, which was employed in the key comparison CCT-K2.5 [8]. Before this comparison it was compared against the cell F13. As reported in the CCT-K2.5 report, the difference of the cell Cu-M-7 temperature relative to the cell F13 is -0.12 mK, with an uncertainty of 0.07 mK (k=1), assigned as a type A uncertainty.

With this information, the temperature difference between the NIST current realization of the Ar TP and the NRC realization of the Ar TP, as performed at the CCT-K9 comparison can be corrected for the difference between the two NRC cells, and is then estimated as:

$$\Delta T_{90_{NIST,NRC}} = \overline{\Delta T_{90}} + \Delta T_{90_{NRC(Cu-M-7,F13)}} \tag{10}$$

where $\overline{\Delta T_{90}}$ is the temperature difference measured during this comparison, as given by equation 7, and $\Delta T_{90_{NRC(Cu-M-7,F13)}}$ is the temperature difference between the NRC cells Cu-M-7 and F13, as reported in the CCT-K2.5 report [8]. Therefore, the difference $\Delta T_{90_{NIST,NRC}}$ is equal to -0.12 mK with an expanded uncertainty of 0.38 mK (k=2).

The temperature difference between the NIST current realization of the Ar TP and the CCT-K9 KCRV at the Ar TP, $\Delta T_{90_{NIST,\ K9_KCRV}}$, is finally given by

$$\Delta T_{90_{NIST,\ K9_KCRV}} = \Delta T_{90_{NIST,NRC}} + \Delta T_{90_{NRC,\ K9_KCRV}} \tag{11}$$

where $\Delta T_{90_{NRC,\ K9_KCRV}}$ is the temperature difference between the NRC realization of the Ar TP, as performed for the CCT-K9 comparison, and the CCT-K9 KCRV. The uncertainty is then given by:

$$u^2\left(\Delta T_{90_{\mathrm{NIST,\ K9_KCRV}}}\right) = u^2\left(\Delta T_{90_{\mathrm{NIST,NRC}}}\right) + u^2\left(\Delta T_{90_{\mathrm{NRC,\ K9_KCRV}}}\right) \quad (12)$$

Table 3 summarizes the link of NIST's Ar TP realization to the CCT-K9 KCRV, and figure 4 illustrates the results of NIST and NRC at the CCT-K9 compared to the results of this comparison.

Table 3. NIST and NRC temperature differences with relation to the CCT-K9 KCRV. Values in mK.

NMI / Comparison	ΔT_{NMI}-$\Delta T_{CCT\text{-}K9\ KCRV}$	U, k=2
NIST / CCT-K9	-1.41	0.54
NRC / CCT-K9	-0.06	0.65
NIST / SIM.T-K9.4	**-0.18**	**0.75**

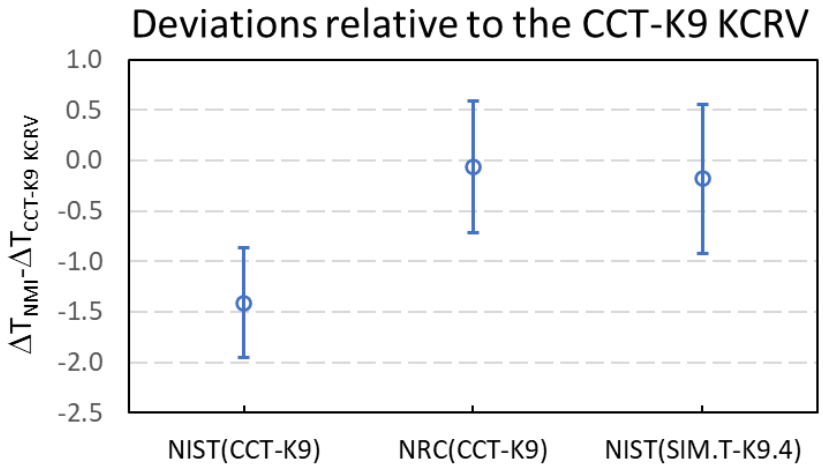


Figure 4 – NIST and NRC results at the CCT-K9 compared to the results of this comparison.

9. CONCLUSIONS

The SIM.T-K9-4 comparison between NIST and NRC revealed that the difference between the current realizations of the Ar TP performed at NIST and NRC is 0.00 ± 0.35 mK. This result allowed determining the difference between the NIST current realization of the Ar TP and the CCT-K9 KCRV at the Ar TP as -0.18 ± 0.75 mK. These results demonstrate the equivalence of realizations of the Ar TP between NIST and its international peer NMIs, supporting the reinstatement of NIST's CMCs in the Appendix C of the KCDB.

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APPENDIX A – MEASUREMENT REPORTS

1. NIST pre-NRC results

MEASUREMENT REPORT TEMPLATE

Identification :

Laboratory :	NIST
Contact :	Klaus Quelhas
e-mail :	klaus.quelhas@nist.gov

Transfer standard information :

SPRT ID :	162D5341		
Manufacturer :	Rosemount		
Model :	162D		
Serial number :	5341		
Date of transfer standard arrival :			
Initial value of *R(TPW)* (Ω) :	25.4553956	±	0.0000013
Final value of *R(TPW)* (Ω) :	25.4553936	±	0.0000011

Calibration results :

Ar TP Cell ID	*W*(Ar TP)	Expanded uncertainty (°C)	Effective Degrees of Freedom
19335	0.21609539	0.00017	648.3

MEASUREMENT SYSTEM INFORMATION

Standards:

Description	Manufacturer	Model	Traceability
Ar TP cell	Pond Engineering	K52 s/n 19335	NIST
WTP cell	Fluke	5901A-Q s/n 5080	NIST
Standard resistor	Tinsley	5685A s/n 261632	NIST

Resistance Measurement Instrument(s):

Description	Manufacturer	Model	Traceability
Resistance bridge	Isotech	microK Gold s/n ITL38503/1	NIST

Ar TP Cell and Maintenance System:

Description	Manufacturer	Model	Publication(s)
Ar TP realization apparatus	Pond Engineering	K52 s/n 19335	-
WTP maintenance bath	Isotech	s/n 39811/1	-

MEASUREMENT REPORT TEMPLATE

Identification :

Laboratory :	NIST
Contact :	Klaus Quelhas
e-mail :	klaus.quelhas@nist.gov

Transfer standard information :

SPRT ID :	56860101		
Manufacturer :	Hart		
Model :	5686		
Serial number :	0101		
Date of transfer standard arrival :			
Initial value of *R(TPW)* (Ω) :	25.3768135	±	0.0000023
Final value of *R(TPW)* (Ω) :	25.3768102	±	0.0000019

Calibration results:

Ar TP Cell ID	*W*(Ar TP)	Expanded uncertainty (°C)	Effective Degrees of Freedom
19335	0.21597638	0.00017	648.3

MEASUREMENT SYSTEM INFORMATION

Standards:

Description	Manufacturer	Model & s/n	Traceability
Ar TP cell	Pond Engineering	K52 s/n 19335	NIST
WTP cell	Fluke	5901A-Q s/n 5080	NIST
Standard resistor	Tinsley	5685A s/n 261632	NIST

Resistance Measurement Instrument(s):

Description	Manufacturer	Model	Traceability
Resistance bridge	Isotech	microK Gold s/n ITL38503/1	NIST

Ar TP Cell and Maintenance System:

Description	Manufacturer	Model & s/n	Publication(s)
Ar TP realization apparatus	Pond Engineering	K52 s/n 19335	-
WTP maintenance bath	Isotech	ITL-M-18233 s/n 39811/1	-

2. NRC results

MEASUREMENT REPORT TEMPLATE

Identification :

Laboratory :	NRC
Contact :	Sergey Dedyulin
e-mail :	Sergey.Dedyulin@nrc-cnrc.gc.ca

Transfer standard information :

SPRT ID :	162D5341		
Manufacturer :	Rosemount		
Model :	162D		
Serial number :	5341		
Date of transfer standard arrival :	May 7, 2024		
Initial value of *R(TPW)* (Ω) :	25.455 389 9	±	0.000 002 9
Final value of *R(TPW)* (Ω) :	25.455 474 4	±	0.000 006 5

Calibration results :

Ar TP Cell ID	*W*(Ar TP)	Expanded uncertainty (°C)	Effective Degrees of Freedom
Cu-M-7	0.216 096 04	3.3E-04	

MEASUREMENT SYSTEM INFORMATION

Standards :

Description	Manufacturer	Model & s/n	Traceability
Ar reference cell	NRC	Cu-M-7	NRC
Triple-point-of-water cell	Jarrett	B11-2053	NRC
100 Ω Standard Resistor	Tinsley	5685A s/n 262464	NRC

Resistance Measurement Instrument(s) :

Description	Manufacturer	Model & s/n	Traceability
DC Resistance bridge	MI	6020T-P s/n 1104565	NRC

Ar TP Cell and Maintenance System :

Description	Manufacturer	Model	Publication(s)
1-stage LSPRT cryostat with separately-controlled quasi-adiabatic shield	NRC	n/a	*Rev. Sci. Instrum.* **55**, 1321–1324 (1984)

MEASUREMENT REPORT TEMPLATE

Identification :

Laboratory :	NRC
Contact :	Sergey Dedyulin
e-mail :	Sergey.Dedyulin@nrc-cnrc.gc.ca

Transfer standard information :

SPRT ID :	56860101		
Manufacturer :	Hart		
Model :	5686		
Serial number :	0101		
Date of transfer standard arrival :	May 7, 2024		
Initial value of *R(TPW)* (Ω) :	25.376 808 1	±	0.000 002 9
Final value of *R(TPW)* (Ω) :	25.376 811 9	±	0.000 002 2

Calibration results :

Ar TP Cell ID	*W*(Ar TP)	Expanded uncertainty (°C)	Effective Degrees of Freedom
Cu-M-7	0.215 976 32	3.3E-04	

MEASUREMENT SYSTEM INFORMATION

Standards :

Description	Manufacturer	Model & s/n	Traceability
Ar reference cell	NRC	Cu-M-7	NRC
Triple-point-of-water cell	Jarrett	B11-2053	NRC
100 Ω Standard Resistor	Tinsley	5685A s/n 262464	NRC

Resistance Measurement Instrument(s) :

Description	Manufacturer	Model & s/n	Traceability
DC Resistance bridge	MI	6020T-P s/n 1104565	NRC

Ar TP Cell and Maintenance System :

Description	Manufacturer	Model	Publication(s)
1-stage LSPRT cryostat with separately-controlled quasi-adiabatic shield	NRC	n/a	*Rev. Sci. Instrum.* **55**, 1321–1324 (1984)

3. NIST post-NRC results

MEASUREMENT REPORT TEMPLATE

Identification :

Laboratory :	NIST
Contact :	Klaus Quelhas
e-mail :	klaus.quelhas@nist.gov

Transfer standard information :

SPRT ID :	162D5341		
Manufacturer :	Rosemount		
Model :	162D		
Serial number :	5341		
Date of transfer standard arrival :	09/2025		
Initial value of *R(TPW)* (Ω) :	25.4554864	±	0.0000012
Final value of *R(TPW)* (Ω) :	25.4554 11	±	0.0000014

Calibration results :

Ar TP Cell ID	*W*(Ar TP)	Expanded uncertainty (°C)	Effective Degrees of Freedom
19335	0.21609743	0.00017	648.3

MEASUREMENT SYSTEM INFORMATION

Standards:

Description	Manufacturer	Model & s/n	Traceability
Ar TP cell	Pond Engineering	K52 s/n 19335	NIST
WTP cell	Fluke	5901A-Q s/n 5080	NIST
Standard resistor	Tinsley	5685A s/n 261632	NIST

Resistance Measurement Instrument(s):

Description	Manufacturer	Model	Traceability
Resistance bridge	Isotech	microK Gold s/n ITL38503/1	NIST

Ar TP Cell and Maintenance System:

Description	Manufacturer	Model & s/n	Publication(s)
Ar TP realization apparatus	Pond Engineering	K52 s/n 19335	-
WTP maintenance bath	Isotech	ITL-M-18233 s/n 39811/1	-

MEASUREMENT REPORT TEMPLATE

Identification :

Laboratory :	NIST
Contact :	Klaus Quelhas
e-mail :	klaus.quelhas@nist.gov

Transfer standard information :

SPRT ID :	56860101		
Manufacturer :	Hart		
Model :	5686		
Serial number :	0101		
Date of transfer standard arrival :	09/2025		
Initial value of *R(TPW)* (Ω) :	25.3768160	±	0.0000016
Final value of *R(TPW)* (Ω) :	25.3768167	±	0.0000018

Calibration results:

Ar TP Cell ID	*W*(Ar TP)	Expanded uncertainty (°C)	Effective Degrees of Freedom
19335	0.21597623	0.00017	648.3

MEASUREMENT SYSTEM INFORMATION

Standards:

Description	Manufacturer	Model & s/n	Traceability
Ar TP cell	Pond Engineering	K52 s/n 19335	NIST
WTP cell	Fluke	5901A-Q s/n 5080	NIST
Standard resistor	Tinsley	5685A s/n 261632	NIST

Resistance Measurement Instrument(s):

Description	Manufacturer	Model	Traceability
Resistance bridge	Isotech	microK Gold s/n ITL38503/1	NIST

Ar TP Cell and Maintenance System:

Description	Manufacturer	Model & s/n	Publication(s)
Ar TP realization apparatus	Pond Engineering	K52 s/n 19335	-
WTP maintenance bath	Isotech	ITL-M-18233 s/n 39811/1	-

APPENDIX B – UNCERTAINTY BUDGETS

1. NIST

UNCERTAINTY ANALYSIS TEMPLATE

Fixed Point cell ID:	19335

Description	**Type (A or B)**	**Systematic or Random**	**Contribution to uncertainty mK**	**Degrees of freedom**
Phase transition repeatability	A	Random	0.038	27
Chemical impurities	B	Systematic	0.049	Inf
Slope of plateau	B	Systematic	0.028	Inf
Bridge repeatability	A	Random	0.009	500
Bridge non-linearity	B	Systematic	0.018	37
Reference resistor stability	B	Systematic	0.005	Inf
Self-heating correction	B	Systematic	0.016	Inf
Hydrostatic head correction	B	Systematic	0.030	Inf
Heat flux	B	Systematic	0.030	Inf
Propagated TPW measurement	B	Random	0.008	Inf

Combined uncertainty, mK	0.085
Effective degrees of freedom	648.3
Coverage factor *k*	2.00
Expanded uncertainty, mK	0.17

2. NRC

UNCERTAINTY ANALYSIS TEMPLATE

Fixed Point cell ID:	**Ar Cu-M-7**

Description	**Type (A or B)**	**Systematic or Random**	**Contribution to uncertainty mK**	**Degrees of freedom**
Phase transition repeatability	A	R	0.056	
Chemical impurities	B	S	0.142	
Bridge non-linearity	B	S	0.012	
Reference resistor stability	B	S	0.008	
Self-heating correction	B	S	0.017	
Hydrostatic head correction	B	S	0.006	
Perturbing heat exchanges	B	S	0.057	
Propagated TPW measurement	B	S	0.014	

Combined uncertainty, mK	0.165
Effective degrees of freedom	
Coverage factor *k*	2
Expanded uncertainty, mK	0.330

APPENDIX C – TECHNICAL PROTOCOL

SIM.T-K9.X[1]

A Bilateral comparison of the Argon triple point

National Institute of Standards and Technology (NIST), USA
National Research Council (NRC), Canada

TECHNICAL PROTOCOL

Klaus Quelhas (NIST), Weston Tew (NIST), Richmond Wang (NIST), Sergey Dedyulin (NRC), Patrick Rourke (NRC), Andrea Peruzzi (NRC),

July 16, 2024, Version 1.6

[1] To be determined

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APPENDICES

APPENDIX 1. DETAILS OF PARTICIPATING INSTITUTES
APPENDIX 2. MEASUREMENT REPORT TEMPLATE
APPENDIX 3. UNCERTAINTY ANALYSIS TEMPLATE

10. INTRODUCTION

10.1. This document describes the technical protocol of a bilateral comparison of the argon triple point temperature between the National Institute of Standards and Technology (NIST) of the USA and the National Research Council (NRC) of Canada.

10.2. This technical protocol has been prepared and approved by the two participants indicated above. The content of this protocol follows the CCT WG-KC/17-03, Comparison protocol template, dated 5-October-2017. The official status of the comparison has been conveyed and approved as a RMO key comparison through the Inter-American Metrology System (SIM), Working Group 3.

10.3. NIST has a specific requirement to establish a new link to the Ar TP and the results of the CCT-K9 [1] comparison that is independent of the original NIST submission to the CCT-K9 for that fixed point temperature. The objective of this comparison is to establish the degree of equivalence between the argon triple point (Ar TP) as realized at the NRC and that of the NIST. This is to be accomplished through the use of two SPRT transfer standards supplied by NIST. Both participants will realize the Ar TP using immersion-type fixed point cells and record those temperatures as values for resistance ratio $W=R(\text{Ar TP})/R(\text{WTP})$ on the two traveling standards.

10.4. The technical procedures described in this protocol are primarily focused on the measurement and handling of two transfer standards. Procedures specific to the realizations and measurement of the Ar TP are not prescribed in this protocol and these are determined by the staff of the two participating laboratories. The method of realization chosen by NRC will be sufficient to convey traceability to the NRC Ar TP realizations as submitted to the CCT-K9. The final report for this comparison will contain descriptions of the realization procedures used by the pilot and the participant.

11. PARTICIPANTS

11.1. Details of mailing and electronic addresses are given in Appendix 1. The participating institutes are:

- NIST, Sensor Science Division, Temperature and Humidity Group – USA
- NRC, Metrology Research Center, Thermometry and Radiometry Group – Ottawa, Canada

11.2. NIST is the pilot of this bilateral comparison, from the standpoint of providing the traveling artifacts and taking the main responsibility for reporting of the results of the comparison. NRC is the participant of this comparison and will provide the linkage to the Ar TP KCRV for the CCT-K9 [1].

11.3. The two laboratories accept the general instructions and the technical protocol written down in this document and commit themselves to follow strictly the procedures of this protocol as well as the version of the "Guidelines for Key Comparisons" [2] in effect at the time of the initiation of the Bilateral Comparison.

11.4. Once the protocol and list of participants have been approved, no change to the protocol or list of participants may be made without agreement by both laboratories.

11.5. The participants must be able to submit an uncertainty budget of their temperature measurements according to section 7.4 and Appendix 3.

12. COMPARISON METHODOLOGY

3.1 Structure

The comparison will be structured as a closed loop, to compare the results of Ar TP realizations at the two laboratories, using two transfer SPRTs, in a sequence that starts and ends at NIST. NIST will perform the first set of measurements for the comparison. The second set of measurements will be performed at the NRC using the transfer SPRTs. A third and final set of measurements will then be performed back at NIST, again using these same two transfer SPRTs. A shorthand notation for the sequence of the principal measurement sets would be: NIST-NRC-NIST. Once the final measurements are performed in the third set at NIST, the measurement phase of the comparison will be completed.

3.2 Timetable

Activity	Start Month
Comparison planning	Feb 2024
Initial/Qualifying measurements at NIST	Feb 2024
Delivery of transfer SPRTs to NRC	May 2024
Final Draft of the Protocol	Jul 2024
Submit protocol to SIM/WG3 for approval.	Jul 2024
Completion of the measurements at NRC	Sept 2024
Return of the transfer SPRTs to NIST	Oct 2024
Completion of the measurements at NIST	Nov 2024
Draft A ready to both participants for comments	Dec 2024
Draft B ready and submitted to CCT-WG-KC	Jan 2025
Submit Final Report for publication	May 2025

13. TRAVELING STANDARDS

4.1 Transfer Standards

NIST will provide two capsule-type SPRTs as transfer standards, as described below:

SPRT ID	SPRT #1	SPRT #2
Manufacturer	Rosemount/Collins	Hart Scientific
Model	162D	5686
Serial number	5341	101

Nominal resistance at 0 °C	25.5 Ω	25.3 Ω
Number of wires	4	4

The transfer SPRTs are capsule types that are adapted for use in immersion-type fixed point cells. This adaptation is essential for the purposes of this comparison since the Ar TP realizations are to be preformed using immersion-type fixed point cells, as was the case in the CCT-K9 comparison [1]. The adaptations are accomplished via specially designed glass adaptor tubes, originally utilized for the NIST SRM 1750 and two sets of tubes are provided by NIST for the purposes of this comparison. Usage of the adapter probes is described in reference [3].

The decision of using capsule-type SPRTs (CSPRTs) for this comparison rather than long-stem SPRTs (LSPRTs) was motivated by two factors. First, the handling and transportation of the CSPRTs is much simpler, since the sensor can be easily removed from the adapting tube and placed inside compact transport cases that can be safely hand-carried from one NMI to another. Second, the results of the original CCT-K9 comparison suggested that the shipping of the SPRTs could have introduced significant drifts in the measured resistance ratios in the participant NMIs before and after the LSPRTs were sent to NIST (see section 4 of [1]), which resulted in increased uncertainties. Therefore, the CSPRTs were chosen as transfer standards to minimize the drifts associated with shipping of the thermometers.

4.2 Handling of the Transfer SPRTs

The transfer standards will be transported separately of the adaptor tubes, inside their original cases, to prevent damage to the sensors. The transfer SPRTs should always be transported in their original cases, be handled only by authorized persons and stored in such a way as to prevent damage. The transfer standards should not be removed from their case while in transit. The transfer SPRTs should not be annealed under any circumstance. The transfer SPRTs used in this comparison must not be modified, adjusted or used for any purpose other than described in this document, nor given to any party other than the participants of this comparison.

14. ORGANIZATION

5.1 Transport of Artefacts

NIST will be responsible for transporting the transfer SPRTs between the two laboratories.

5.2 Unexpected Delays

If there is any unusual occurrence that could potentially delay, interrupt or compromise the execution of this comparison, during transport or during measurements, both participating laboratories should be notified immediately before proceeding. The contact information of both participating laboratories is detailed in Appendix 1.

15. COMMUNICATIONS

S

Routine communications between the participant and pilot lab team members can be initiated by any team member identified here as a protocol author. Communications pertaining to the protocol and or measurements should be courtesy copied to all of the team members from both labs.

After receiving the transfer standards, the participant laboratory should report their first measured resistance values at the water triple point to the pilot laboratory before proceeding with the calibrations. A stability criterion is ABS[$(R(TPW)_{NIST} - R(TPW)_{NRC}$]/(dR/dT) <=0.2 mK will be used to evaluate the suitability of the transfer standards. If a drift bigger than the criteria is observed, then both participants should be notified immediately before proceeding.

Upon shipping or otherwise transferring custody of the transfer standards back to the pilot laboratory, the participant laboratory should report the last measured resistance values at the water triple point (WTP) to the pilot laboratory within one week after the custody transfer of the transfer standards.

Once the NIST-NRC-NIST measurement loop is completed and the measurement results of both laboratories are ready, the laboratories will exchange their measurement results per the terms of section 7.4 below. Since NIST is the laboratory in need to reestablish the link with the CCT-K9 KCRV, it will be the first to share the results, immediately followed by NRC.

16. MEASUREMENT PROCEDURES

7.1 Measurand

The measurand of this comparison are the *W(*Ar TP*)* measured values:

$$W(Ar\ TP) = \frac{R(Ar\ TP)}{R(WTP)} \tag{1}$$

where *R(Ar TP)* and *R(WTP)* are, respectively, the values of electrical resistance of the SPRT measured at the argon triple point and at the water triple point. With the measured values of *W(Ar TP)*, the difference between both laboratories, for each SPRT *i*, is given as follows:

$$\Delta T_{90,SPRT\ i} = \frac{W(Ar\ TP)_{NIST,SPRT\ i} - W(Ar\ TP)_{NRC,SPRT\ i}}{dW(Ar\ TP)/dT_{90}} \tag{2}$$

where $dW(Ar\ TP)/dT_{90}$ is the first derivative of W with relation to the temperature at the argon triple point.

The average temperature difference is then given by:

$$\overline{\Delta T_{90}} = \frac{\Delta T_{90,SPRT\ \#1} + \Delta T_{90,SPRT\ \#2}}{2} \tag{3}$$

7.2 Preparation of the Transfer standards and Preliminary checks

The two transfer SPRTs are selected by NIST and preliminary measurements are made at NIST prior to the start of the comparison. Those measurements will establish reliable values for the SPRT resistances at the WTP and Ar TP temperatures using NIST fixed point standards and systems. The transfer SPRTs will then be hand carried from NIST to NRC according to the timetable detailed in 3.2. These SPRTs should be examined when received by NRC, before the start of measurements, and verified that they are undamaged. NRC will perform preliminary checks of the two SPRTs at the WTP and the two laboratories will share these results to compare the R(WTP) values obtained at NIST just prior to transport with those obtained at NRC just after receipt. This information exchange will occur within 1 week of the initial WTP checks at NRC.

7.3 Measurement process

Each participant will measure the electrical resistances of the SPRTs using a resistance bridge or an instrument of suitable quality and uncertainty to resolve changes in resistance of 0.5 ppm or less of 5.5 Ω and 0.1 ppm or less at 25 Ω.

All the measured electrical resistances must be corrected to zero power (0 mA).

Each participant will follow its own procedure while calibrating the transfer SPRTs with their fixed point standards, according to the current best practices [4]. Since the transfer standards are both capsule-type SPRTs, no annealing or other heat treatment processes are required and should not be applied.

The transfer SPRTs will be used in conjunction with the NRC Ar TP cell that was used as the basis for the NRC submissions to the CCT-K9 comparison. The NRC staff will decide the exact procedures to be used, understanding that traceability to the results of the CCT-K9 is the objective.

Before and after each realization of the Ar TP, the R(WTP) values of the SPRTs must be measured.

If unacceptable performance or failure of the transfer standard is detected, the participants will discuss the situation and agree a course of action.

7.4 Reporting measurement results

Both participating laboratories will report their measurement results according to the template in Appendix 2. A separate measurement report page will be prepared for each of the two transfer SPRTs.

In addition to the measurement results, both laboratories will provide a detailed evaluation of their measurement uncertainties according to the example shown in Appendix 3. The measurement uncertainties will be reported in terms of temperature, for a 95% confidence level [5].

17. COMPARISON RESULTS

The pilot laboratory will analyze the results of comparison. The results of the comparison are:

a) The bilateral differences, as described in section 7.1, eq. 3, and

b) The uncertainties of the bilateral differences, given by:

$$u^2(\overline{\Delta T_{90}}) = \frac{u^2\left(\Delta T_{90,SPRT\ \#1}\right) + u^2\left(\Delta T_{90,SPRT\ \#2}\right)}{2^2} \quad (4)$$

where:

$$u^2\left(\Delta T_{90,SPRT\ i}\right) = \frac{u^2\left(W(Ar\ TP)_{NIST,SPRT\ i}\right) + u^2\left(W(Ar\ TP)_{NRC,SPRT\ i}\right) + \left(\frac{\Delta W_{TPW,SPRT\ i}}{\sqrt{3}}\right)^2}{(dW(Ar\ TP)/dT_{90})^2} \quad (5)$$

where *SPRT i* refers to each SPRT (#1 and #2), and $\Delta W_{TPW,SPRT\ i}$ accounts for the observed change in the TPW value of the *SPRT i* after traveling from NIST to NRC.

The degrees of equivalence of the comparison are the temperature difference $\overline{\Delta T_{90}}$ as given in eq. 3, and its corresponding uncertainty $u^2(\overline{\Delta T_{90}})$, as given in eq. 4.

The pilot laboratory will prepare the Draft A according to the timetable provided in 3.2, which will be available for review for a period of time no longer than two weeks.

Once the Draft A is approved by both participants, the pilot laboratory will then prepare the Draft B, which will be submitted to CCT-WG-KC for approval.

18. CCT K9 AR TP LINKAGE MECHANISM

This comparison is intended to be linked to the key comparison CCT-K9 results [1]. The temperature differences between the contemporary (2024) NIST Ar TP realization and that of the NRC is then linked to the CCT-K9 KCRV for the Ar TP. This is accomplished through traceability to the NRC realizations of the Ar TP performed for submission to the CCT-K9. from the key comparison reference value (KCRV), for each fixed point, shall be given by:

$$\mathrm{T_{90}(NIST)} - \mathrm{T_{90}(K9_{KCRV})} = \overline{\Delta \mathrm{T_{90}}} + \left(\mathrm{T_{90}(NRC)} - \mathrm{T_{90}(K9_{KCRV})}\right) \quad (7)$$

where $\mathrm{T_{90}(K9_{KCRV})}$ refers to the CCT-K9 KCRV and $\overline{\Delta T_{90}}$ is the temperature difference of this comparison, as given by eq. 3. The uncertainty is then given by:

$$u^2\left(\mathrm{T_{90}(NIST)} - \mathrm{T_{90}(K9_{KCRV})}\right) = u^2(\overline{\Delta T_{90}}) + \mathrm{u^2}\left(\mathrm{T_{90}(NRC)} - \mathrm{T_{90}(K9_{KCRV})}\right) \quad (8)$$

10. DOCUMENT REVISION HISTORY

Version	Date	Description of Change(s)
1.0	7-May-2024	First Draft
1.1	8-May-2024	Working Draft
1.2	11-May-2024	Working Draft
1.3	17-June 2024	Working Draft
1.4	21-June-2024	Working Draft
1.5	5-July-2024	Working Draft
1.6	16-July-2024	Edits Sections 3.2, 6 & 7.4

1.6 Submitted	16-July-2024	As Submitted for Approval

REFERENCES

1 T Herman et al, *ITS-90 SPRT calibration from the Ar TP to the Zn FP*, Metrologia 60 03001, 2023

2 Measurement comparisons in the CIPM MRA, CIPM MRA-D-05 version 1.6, BIPM, Paris.

3 W L Tew and G F Strouse (2001) Standard Reference Material 1750: Standard Platinum Resistance Thermometers, 13.8033 K to 429.7485 K, NIST Special Publication 260-139, doi:10.6028/NIST.SP.260-139

4 CCT/BIPM - *Guide to the Realization of the ITS-90*, www.bipm.org

5 JCGM 100:2008 - *Evaluation of measurement data – Guide to the expression of uncertainty in measurement*, www.bipm.org

6 K D Hill, T Nakano, P. Steur, (2015) Final report on CCT-K2.5: NRC/NMIJ/INRIM comparison of capsule-type standard platinum resistance thermometers from 13.8 K to 273.16 K, *Metrologia* 52 03003, DOI 10.1088/0026-1394/52/1A/03003

APPENDIX 1

DETAILS OF PARTICIPATING INSTITUTES

National Institute of Standards and Technology (NIST),

Address: Sensor Science Division, 100 Bureau Drive, MS 8363, Gaithersburg, MD 20899 USA
Contact: Richmond Wang
Phone: +1 301 975 6152
E-mail: Richmond.Wang@nist.gov

National Research Council – (NRC)

Address: Metrology Research Center, National Research Council of Canada, 1200 Montreal Road, Building M-36, Ottawa, ON, K1A 0R6, Canada
Contact: Sergey Dedyulin
Phone: +1 613 998 6077
E-mail: Sergey.Dedyulin@nrc-cnrc.gc.ca

APPENDIX 2

MEASUREMENT REPORT TEMPLATE

Identification :

Laboratory :	
Contact :	
e-mail :	

Transfer standard information :

SPRT ID :			
Manufacturer :			
Model :			
Serial number :			
Date of transfer standard arrival :			
Initial value of *R(TPW)* (Ω) :		±	
Final value of *R(TPW)* (Ω) :		±	

Calibration results :

Ar TP Cell ID	*W*(Ar TP)	Expanded uncertainty (°C)	Effective Degrees of Freedom

MEASUREMENT SYSTEM INFORMATION

Standards :

Description	Manufacturer	Model	Traceability

Resistance Measurement Instrument(s) :

Description	Manufacturer	Model	Traceability

Ar TP Cell and Maintenance System :

Description	Manufacturer	Model	Publication(s)

APPENDIX 3

UNCERTAINTY ANALYSIS TEMPLATE

Fixed Point cell ID:				
Description	**Type (A or B)**	**Systematic or Random**	**Contribution to uncertainty mK**	**Degrees of freedom**
Phase transition repeatability				
Chemical impurities				
Slope of plateau				
Bridge repeatability				
Bridge non-linearity				
Bridge Quad. Effects				
Reference resistor stability				
Self-heating correction				
Hydrostatic head correction				
Heat flux				
Propagated TPW measurement				

Combined uncertainty, mK	
Effective degrees of freedom	
Coverage factor *k*	
Expanded uncertainty, mK	