EURAMET Comparison 1462

Supplementary CCQM comparison Euramet.QM-S12

Electrolytic conductivity at pure water level

Final Report

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Summary

Electrolytic conductivity in aqueous solutions is one of the most common electrochemical measurement techniques in industry. Since it is sensitive to the amount content of dissolved ions in a solution, a limiting value for conductivity is a clear and simple quality criterium for the ionic purity of water. The relevant measuring range for pure water applications is roughly between 0.055 µS cm^{-1} (ultrapure water) and 150 µS cm^{-1} at 25 °C. For instance, the European, Japanese and United States (USP) Pharmacopoeia have specified the requirements for purified water, highly purified water and water for injection for pharmaceutical use based on conductivity. Sectors that also use conductivity limits for water purity are electrical power production, food industry, electronic industry and analytical laboratories.

At low conductivity levels it is not feasible to circulate water samples for comparison measurements, since the conductivity value is instable due to inevitable ionic contamination. The main contamination results from carbon dioxide in ambient air that dissolves in water and builds H_3O^+ and hydrogen carbonate ions. The contribution of these ions to conductivity is around 1 µS cm^{-1}. Hence, it is impossible to provide stable samples having usable uncertainties in the conductivity range of interest.

EURAMET 1271, performed in 2013, was the first successful comparison measurement of pure water conductivity. In the meanwhile, more NMIs, the majority of which is situated in Europe, have built measurement capabilities in the pure water range. EURAMRET 1271 covered a measurement range up to 50 µS cm^{-1}, whereas more and more customers request conductivity cell calibration in the range up to 150 µS cm^{-1}. Consequently, this comparison intends to extend the measurement range and to enable more NMIs to get support for potential CMCs. Therefore, this comparison is additionally intended being a supplementary CCQM comparison.

A commercial conductivity measurement meter, including a conductivity measurement cell, was used for the comparison in a Round-Robin scheme. The devices were provided by PTB and were sent from one institute to another. Each institute had to measure the conductivity of a reference solution using the conductivity meter. The reference solution could either be pure water or a measurement standard solution that was reasonably stable in the range of interest. In the first scheme, the cell had to be integrated in a closed pure water flow though system to minimize impurification by CO_2. An adequate fixture for this setup was provided by PTB. In

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the second scheme, the cell was immersed into the measurement standard solution under temperature-controlled conditions. Essentially, the institutes had to report the conductivity values indicated by the conductivity meter and the conductivity reference value assigned to the water in the flow though system or that of the measurement standard solution, respectively. The coordinating institute calculated adjusted cell constants for the cell from the reported values, which were used to calculate linking conductivities, the actual quantities to be finally compared.

The results showed good equivalence in all conductivity ranges, with only a few inconsistent values. Adequate comparison reference values are suggested that can serve to calculate robust degrees of equivalences for the participants usable to support respective CMC claims.

Schedule

May 2018	Declaration of Intent
August 2018	Invitation
September 2018	Registration
Dec 2018 - April 2020	Measurement period
April 2020	End of reporting
September 2020	Draft A
Autumn 2020	Approval of Supplementary Comparison at CCQM meeting (Draft B)
November 2020	Approval by EUAMET-TC-MC & SCEA

It must be noted that the measurement period took an unexpectedly long time due to customs issues. Moreover, LNE and DFM had to repeat the measurements. Therefore, the device had to be sent a second time. Annex 2 lists the actual dates of dispatch and receipt of the devices.

Participating institutes

Table 1 Participants

Institute	Abbr.	Country
Czech Metrology Institute	CMI	Czech Republic
Danish Fundamental Metrology A/S	DFM	Denmark
Główny Urząd Miar / Central Office of Measures	GUM	Poland
Instituto National de Metrologia, Qualidade e Tecnologia	INMETRO	Brasil
Lab. Química del Agua – Centro de Química	INTI	Argentina
Laboratoire National de Métrologie et d’Essais	LNE	France
National Institute of Metrology	NIM	P.R. China
Physikalisch-Technische Bundesanstanstalt	PTB	Germany
Research Institutes of Sweden	RISE	Sweden
D.I. Mendeleyev Institute for Metrology	VNIIM	Russia

Contact persons and addresses are listed in Annex 3.

General process

PTB has integrated the cell in its primary pure water conductivity measurement circuit and has measured the conductivity with the device at 0.055 µS cm^{-1}, 0.5 µS cm^{-1}, 5 µS cm^{-1} and 50 µS cm^{-1} at 25 °C. Afterwards, the devices was sent from one institute to the next for their conductivity measurements. Finally, PTB has measured at all conductivity levels mentioned above again to verify the stability of the device over the run time of the comparison measurements. There has also been an interim check of the devices at PTB after they have been sent around in Europe.

Actions after arrival of the equipment

Each institute had to send an email to the coordinating laboratory to confirm the arrival immediately after receipt of the devices. Likewise, it had to send an email after their dispatch to the next institute.

The package and the equipment had to be inspected for completeness and visible damage. The equipment comprises the following devices:

- Thornton 240-102 conductivity cell (SN 07040173) with lead wires, hereafter referred to as the “comparison cell”, or simply “the cell”,
- fixture (not required by institutes using measurement standard solutions),
- Mettler-Toledo/Thornton 200CR (SN 607040084) conductivity meter.

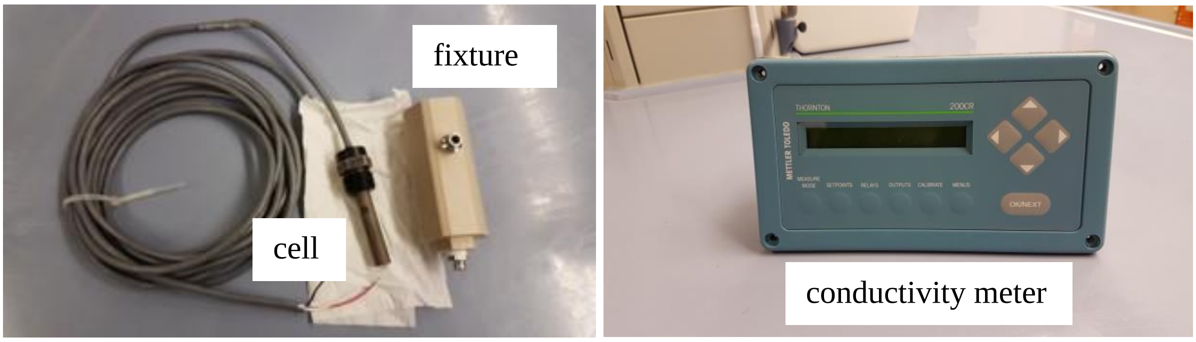

Figure 1 equipment sent from one institute to the next.

Installation requirements

The conductivity meter had to stay in the lab disconnected from power for at least one night after receipt to avoid damage due to condensed water.

The cell had to be cleaned adequately and dried before use, if any impurities were found.

<u>Integration of the cell in flow through systems</u>

The equipment should have arrived with the cell already screwed into the fixture. The participant had to check manually, i.e. without tools and with a little, but still reasonable force, if the cell was still firmly tightened in the fixture. If it was loose, the cell had to be fixed as described in the technical protocol. However, no institute had reported any need to fix the cell.

Afterwards, the fixture was integrated in the flow though system of the participants as shown in figure 2, using 6 mm plastic tubes (preferably some kind of Teflon tube) that had to be pushed into the quick locks of the fixture.

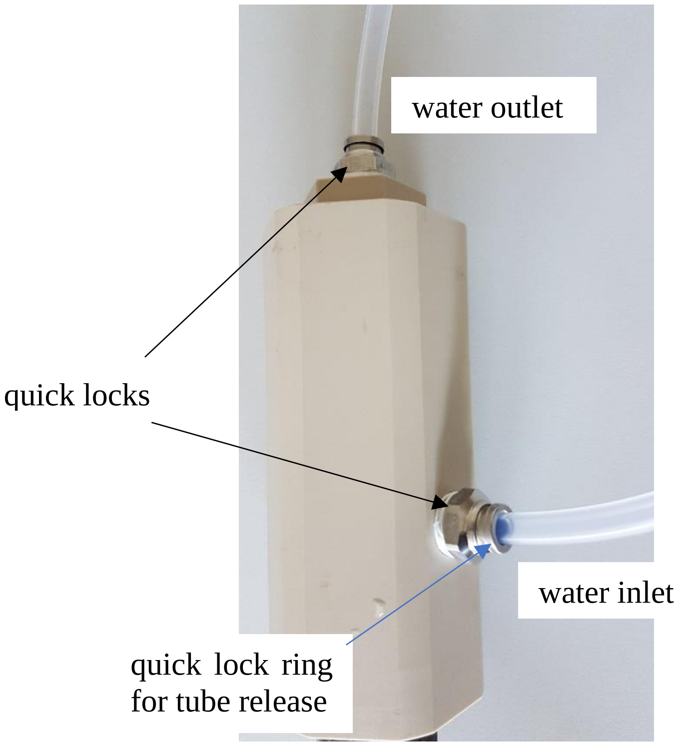

Figure 2 Water flow through the cell

The fixture had to be filled slowly with water. The water was required to flow from the bottom to the top. After filling the fixture had to be shaken a few times while the water was flowing through the cell to remove remaining air bubbles.

b) Installation for measurement of standards

No installation requirements were given for the measurement of conductivity measurement standard. The institutes have been asked to use their typical setup for the calibration of conductivity measurement devices and/or solutions.

c) Other installation issues

The measurement sequence of the Round Robin scheme had been chosen such that the institutes using flow through systems measured first. In this way it was not necessary that they had to mount the cell in the fixture, which would have implied the risk of air leaking into the system, if the assembly has not been performed correctly.

The sensor had an integrated temperature sensor that was not calibrated. Consequently, the temperature reading provided by the measurement unit could not be used as reference temperature. Nevertheless, the indicated temperature value had to be noted, since it could help to understand discrepancies in case the comparison results showed unexpected deviations.

The institutes were not allowed to change the system settings of the conductivity meter. Any change of the system settings, i.e. the kind of temperature compensation, which was turned off by the coordinating institute, and the value of the cell constant, would have invalidated the comparability of the results.

The cell constant had been set to an arbitrary value to obscure the true value of the cell constant, even though it was still within reasonable limits. The participants have been informed that the conductivity value indicated by the Thornton 200CR and their reference value would deviate to some extent for this reason.

Measurement requirements

The conductivity measurements had to be performed according to the standard procedure of the institutes. If possible, the institutes should measure within the range of +/-10 % of the conductivities they had stated in the registration file. However, other conductivities within the range of this comparison are accepted. It was emphasized in the technical protocol that the reference conductivity value and the conductivity measured with the circulated cell must both be referred to the same temperature. This temperature may deviate from 25°C about ± 0.5°C.

Reporting requirements

The participants had to complete a template, provided by the coordinating institute, which included the main information relevant for the comparison, in particular:

- Name and address of the laboratory performing the measurements.
- Date of measurement.
- Source of conductivity reference value (closed flow though system measurement or conductivity standard solution).
- Reference temperatures. These should be the solution temperatures during the conductivity measurements if a flow through cell was used. If a measurement standard solution was used, it should be the reference temperature of the standard. In any case both reported conductivity values (reference value and indicated value) had to be referred to the same temperature.
- Temperature indicated by the Thornton 200CR device, which was just additional information, not used for CRV or DoE calculation.
- Estimate of the potential temperature uncertainty Δt_{me}. of the temperature in the conductivity cell. As mentioned, the temperature sensor of the conductivity cell did not provide a calibrated temperature value. As a consequence, an estimate had to be given for the maximal possible deviation between the temperature in the cell and the temperature at the location of the temperature sensor that was used to measure the solution temperature. This value is needed to calculate the uncertainty of adjusted cell constant (see below).
- Conductivity reference values, their standard uncertainties, coverage factors and the corresponding expanded uncertainty (95.45% coverage interval, which corresponds to a coverage factor 2 at infinite degrees of freedom). It was emphasized that aqueous conductivity standard solutions, i.e. 0.01 mol/kg KCl-aqu solutions, had to consider a standard uncertainty contribution of 0.12 µS/cm that accounts for the effect of CO_2.
- Conductivity values indicated by the conductivity meter and the stability of these values expressed as standard uncertainties. These values could either be determined as a standard deviation of several readings or from the difference between the maximum reading and the minimum reading divided by $2\sqrt{6}$ (assuming a triangular probability distribution function according to GUM).

Furthermore, the participants had to submit a measurement report including the following information:

- Description of the measurement procedure using the conductivity cell and meter
- Description of the measurement method used to determine the reference conductivity values and its uncertainty budget

- The route of traceability for the reference conductivity value

Uncertainties had to be calculated according to the “Guide to the Expression of Uncertainty in Measurement”[1] and its supplements.

Evaluation of the results

The measured conductivity values cannot directly be compared since each institute has used its own flow through system or conductivity reference solutions, respectively, which were differing in conductivity. Instead, adjusted cell constants of the comparison cell were calculated for each institute from the reported results at each nominal conductivity. The adjusted cell constants were used to calculate linking conductivity values. The KCRVs and DoEs were finally calculated from these linking conductivities. The procedure will be described in more detail in the following.

Each participating institute has determined the conductivity κ_{ref} of its reference solution according to its standard operation procedure. This could either be by a primary measurement of pure water conductivity in a closed water flow-through system or by a primary measurement of a stable reference solution or by usage of a conductivity standard provided by another institute. Additionally, the conductivity of the reference solution has been measured with the comparison cell connected to the 200CR conductivity meter. This value is denoted as κ_{dev}. The adjusted cell constant $K_{adj}(\kappa_{nom},i)$ for a participant i at a nominal conductivity κ_{nom} can be calculated from

$$K_{adj}(\kappa_{nom},i)=\frac{\kappa_{ref}(\kappa_{nom},i)}{\kappa_{dev}(\kappa_{nom},i)}K_s \quad , \tag{1}$$

K_s is the cell constant saved in the device setting during the measurement of κ_{dev}.

It should be emphasized, that an institute had to refer the two corresponding values, $\kappa_{dev}(\kappa_{nom},i)$ and $\kappa_{ref}(\kappa_{nom},i)$, to the same temperature $t_{ref}(\kappa_{nom},i)$. However, it was not necessary to compensate all adjusted cell constants $K_{adj}(\kappa_{nom},i)$ to a common reference temperature. Since $\kappa_{dev}(\kappa_{nom},i)$ and $\kappa_{ref}(\kappa_{nom},i)$ have the same dependence on temperature (both refer to the same solution), $K_{adj}(\kappa_{nom},i)$ does not depend on temperature[2]. Thus, all reference temperatures $t_{ref}(\kappa_{nom},i)$ had to be in the range of 25°C, however, they can differ between institutes.

The adjusted cell constants, at a given nominal conductivity, can be used to calculate CRVs and DoEs. However, since the objective of this comparison is to demonstrate the equivalence of conductivity measurements, it is more adequate to compare conductivities rather than cell constants. Moreover, the review process of potential conductivity CMCs in this range will be simplified. Therefore, linking conductivities have been calculated that can be compared with each other. Generally, the conductivity value κ_{dev} indicated by a conductivity meter is determined by the resistance value R_{dev} of the solution in the cell, which is measured by the conductivity meter, and the cell constant K_S, which is stored during the measurement of R_{dev}:

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[1] http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf

[2] Strictly spoken, this is not true. In eq. 1, the temperature dependence of κ_{ref} only depends on the solution properties, while that of κ_{dev} additionally implies the temperature dependence of the comparison cell (i.e. polarization effects and cell dimensions). Consequently, K_{adj} also depends on temperature to some extent. However, the effect is small within the temperature range relevant in this comparison. Moreover, manufacturers of conductivity devices compensate the indicated conductivity for these effects. Thus, the remaining uncertainty due to the temperature dependence of K_{adj} can be neglected.

$$\kappa_{dev} = \frac{K_S}{R_{dev}} \tag{2}$$

Thus, linking conductivities can be calculated for each institute at each nominal conductivity using the adjusted cell constants $K_{adj}(\kappa_{nom},i)$:

$$\kappa_{link}(\kappa_{nom}, i) = \frac{K_{adj}(\kappa_{nom},i)}{R_{dev}(\kappa_{nom})} \quad . \tag{3a}$$

If each institute measures the same solution having exactly κ_{nom}, then $\kappa_{link}(\kappa_{nom},i)$ would be the conductivity value that would be measured by institute i after it had adjusted the cell constant to $K_{adj}(\kappa_{nom},i)$. $R_{dev}(\kappa_{nom})$ is not available, however, it is likewise linked by eq. (2) to the nominal conductivity using the cell constant K_S=0.01 cm^{-1} that has actually been stored during the measurements.

$$\kappa_{nom} = \frac{K_S}{R_{dev}(\kappa_{nom})} \tag{3b}$$

Thus,

$$\kappa_{link}(\kappa_{nom}, i) = \frac{K_{adj}(\kappa_{nom},i)}{K_S}\kappa_{nom} \quad . \tag{3c}$$

In this way linking conductivities $\kappa_{link}(\kappa_{nom},i)$ can be calculated for each institute i that are linked through $K_{adj}(\kappa_{nom},i)$ and that can be compared with each other. Thus, the $\kappa_{link}(\kappa_{nom},i)$ values are finally used to calculate candidate CRVs and preliminary DoEs.

Unfortunately, this comparison scheme has turned out to have a drawback for a few institutes. Looking at eq. (1), it becomes obvious that two further uncertainties affect the linking conductivities which depend on the measurement setup of an institute. Firstly, a deviation between the reference temperature t_{ref} and the actual temperature t_{dev} affects eq. (1) since κ_{ref} and κ_{dev} must be assigned to the same temperature. This deviation can be considered as an uncertainty contribution to κ_{dev}, using

$$\kappa_{dev}(t_{ref}) = \frac{\kappa_{dev}(t_{dev})}{1+\alpha_\kappa(t_{dev}-t_{ref})} \, . \tag{4}$$[3]

With α_κ being the linear temperature coefficient of the conductivity of the reference solution (at 25 °C). Thus,

$$u(\kappa_{dev})_{\Delta tme} = \frac{\kappa_{dev}(t_{ref})\alpha_\kappa \Delta t_{me}}{\sqrt{6}} \, . \tag{5}$$

Note that the actual difference is not known. Thus, t_{dev} is set equal to t_{ref} in eq. (4). Consequently, $\kappa_{dev}(t_{dev})$ is equal to $\kappa_{dev}(t_{ref})$. However, an uncertainty $u(t_{dev})= \Delta t_{me}/\sqrt{6}$ must be assigned to t_{dev} to account for the difference, assuming a triangular probability distribution of the potential deviations within an estimated maximum value Δt_{me} that had to be provided by the participants.

Secondly, the stability of the measurement setup, i.e. of reading of the conductivity meter, $u(\kappa_{dev})_{stab}$, also contributes to the uncertainty of the linking conductivity. The participants therefore had to provide an estimate for the stability expressed as standard uncertainty. The combined standard uncertainty of the linking conductivity, $u_{\mathrm{c}}(\kappa_{link}(\kappa_{nom},i))$, for each institute i at all nominal conductivities κ_{nom}, have been calculated by the coordinating institute straight forward according to GUM, using eqs. (1-5) and the uncertainties of $\kappa_{dev}(\kappa_{nom},i)$ and $\kappa_{ref}(\kappa_{nom},i)$.

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[3] the indicators κ_{nom} and institute i have been omitted here for simplicity reasons.

For a few institutes, the uncertainties of the linking conductivities are significantly larger than the uncertainties of the corresponding reference values because of unexpectedly large Δt_{me} and $u(\kappa_{dev})_{stab}$ values. In these cases, the consistency of κ_{link} values with the KCRV cannot be used as prove for the consistency of the reference values κ_{ref}, since $u(\kappa_{link})$ is a bad representative for $u(\kappa_{ref})$.

It is proposed to calculate the DoEs of the linking conductivities without considering Δt_{me} and $u(\kappa_{dev})_{\mathrm{stab}}$ for the following reason. From the perspective of conductivity CMCs, the conductivity reference values $\kappa_{ref}(\kappa_{nom},i)$ are the actual quantities which need prove for equivalence. For this purpose, the varying reference values of the participants are made comparable within this comparison scheme by measuring $\kappa_{dev}(\kappa_{nom},i)$ and by calculating linking conductivities as described. It is necessary to progress the uncertainty of the reference values through the correction process, however, the uncertainties of the correction process, i.e. Δt_{me} and $u(\kappa_{dev})_{\mathrm{stab}}$, need not to be considered. Under this condition, the uncertainty of the linking conductivity is an adequate representative for the uncertainty of the reference value and DoE statements can be applied to the stated conductivity reference values.

Obviously, institutes having large Δt_{me} and $u(\kappa_{dev})_{\mathrm{stab}}$ values might end up with inconsistent linking conductivities not because of a poor κ_{ref} values but because of a poor setup to measure κ_{dev}. This is a general drawback of the comparison scheme that cannot be avoided and that has to be accepted. Institutes showing poor performance in this regard must therefore improve their setup to measure κ_{dev}.

Given the calibration of a cell constant should be provided by an institute as a metrological service and should be supported by a CMC, Δt_{me} and $\mathrm{u}(\kappa_{dev})_{\mathrm{stab}}$ must obviously be considered, since in this case K_{adj} is the actual measurement result of the calibration. Therefore, the DoEs of the adjusted cell constants $K_{adj}(\kappa_{nom},i)$ have also been calculated to support respective CMC claims of cell constant calibration, including the uncertainty contributions of Δt_{me} and $\mathrm{u}(\kappa_{dev})_{\mathrm{stab}}$. This will be included in the final report as additional information to provide support for CMC claims of cell constant calibration.

In other words, the DoE for a linking conductivity provides support for the capability to issue a reference conductivity value, while the DoE for an adjusted cell constant provides support for the capability to compare the reference conductivity value with the conductivity value indicated by a device under test.

Results

Stability of the device

The equipment had been integrated into the measurement setup at PTB before and after it has been sent around, i.e. 12 December 2018 and 13 March 2020, respectively. The conductivity of the closed water circuit had been adjusted to the nominal conductivity levels and the conductivities had been measured to verify the stability of the cell equipment. The conductivity of ultrapure water has additionally been measured 10.05.2020, when the equipment had been sent to PTB for an interim check.

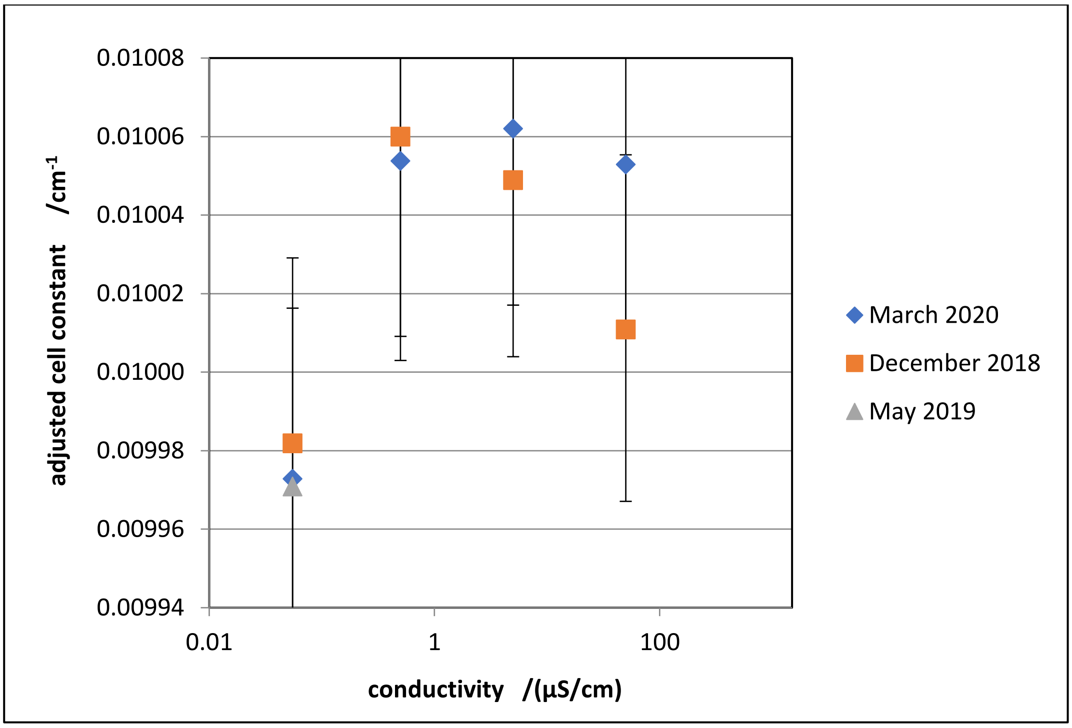

Figure 3 Measurement results of the adjusted cell constant before, during and after the Round Robin comparison. The uncertainty bars refer to expanded (k=2) uncertainties.

The deviation at 50 µS/cm is a little larger compared to the values at other nominal conductivities. However, it is still smaller than the uncertainty of the difference (DoE/U(DoE)=0.67<1). Thus, the deviation is not significant. Moreover, the adjusted cell constants are stable at the other conductivities. Therefore, the deviation at 50 µS/cm must result from an instability of the measurement rather than the devices. Overall, the devices can be considered stable over the runtime of the comparison.

Reported results

Table 2 lists the dates of measurement, the kind of measurement setup and the nominal conductivities the participants were measuring at. Most institutes have used a flow-throw system to measure the conductivity of pure water in a closed system. In these cases, small amounts of an electrolyte, usually KCl, have been added to adjust conductivity. Three institutes have measured reference solutions. The kind of reference solution is mentioned in the third column. It should be mentioned that INTI has measured a conductivity standard around 150 µS cm^{-1}. This measurement is compared with the measurements of other institutes at 50 µS cm^{-1}.

Table 2 Measurements methods and measurement dates

Institute	nominal conductivities µS/cm µS cm^{-1}	kind of measurement/reference solution (*)	date measured
PTB	0.055	flow through cell	21.12.2018
	0.5	flow through cell	21.12.2018
	5	flow through cell	21.12.2018
	50	flow through cell	21.12.2018
LNE	5	flow through cell	10.04.2019
	50	flow through cell	05.04.2019
RISE	0.055	flow through cell	05.02.2019
	0.5	flow through cell	05.02.2019
	5	flow through cell	05.02.2019
	50	flow through cell	05.02.2019
DFM	0.055	flow through cell	27.03.2020
	0.5	flow through cell	27.03.2020
	5	flow through cell	27.03.2020
	50	flow through cell	27.03.2020
CMI	0.055	flow through cell	23.03.2019
	0.5	flow through cell	20.03.2019
	5	flow through cell	15.03.2019
	50	flow through cell	12.03.2019
GUM	5	5µS/cm standard 30%n-propanol / 70%KCl_{aqu}	25/26.042019
	50	50µS/cm standard 30%n-propanol / 70%KCl_{aqu}	19/23.04.2019
NIM	0.055	flow through cell	20.06.2019
	0.5	flow through cell	16.06.2019
	5	flow through cell	13.06.2019
	50	flow through cell	13.06.2019
VNIIM	0.5	flow through cell	06-08.08.2019
	5	flow through cell	13-15.18.2019
	50	flow through cell	20-22.08.2019
INTI	50 (150)	0.001M KCl_{aqu} standard	02/03.12.2019

Institute	nominal conductivities µS/cm $\mu S\ cm^{-1}$	kind of measurement/reference solution (*)	date measured
INMETRO	0.5	gravimetrically diluted 5µS/cm standard of 30%n-propanol / 70%KClaqu	15/16.01.2020
	5	5µS/cm standard 30%n-propanol / 70%KCl_{aqu}	13/14.01.2020
	50	50µS/cm standard 30%n-propanol / 70%KCl_{aqu}	13/14.01.2020

(*) here, a flow thorough cell implies pure water as the corresponding reference solution, that is water plus small amounts of electrolytes (i.e. dissolved KCl)

Table 3 lists the reported measurement results. Figure 4 illustrates linking conductivities with standard uncertainties. Figure 5 lists the corresponding adjusted cell constants. Please note that the relative uncertainties of the adjusted cell constants can be larger than those of the linking conductivities. K_{adj} includes contributions from Δt_{me} and $u(\kappa_{dev})_{\mathrm{stab}}$ while κ_{link} doesn't for the reason mentioned above.

Table 3 Reported results

institute	nominal µS/cm	value t_{ref}	max. possible deviation (*) Δt_{me}	reference conductivity κ_{ref}	standard uncertainty u(κ_{ref})	coverage factor	U(κ_{ref})	conductivity indictade by 200CR κ_{dev}	stability (expressed as standard uncertainty) u(κ_{dev})
	µS cm^{-1}	°C	°C	µS cm^{-1}	µS cm^{-1}		µS cm^{-1}	µS cm^{-1}	µS cm^{-1}
PTB	0.055	25.035	0.01	0.05490	0.00013	2	0.00026	0.0550	0.0000
	0.5	25.053	0.01	0.5202	0.0011	2	0.0021	0.5171	0.0003
	5	25.040	0.01	4.955	0.0110	2	0.022	4.9309	0.0003
	50	25.038	0.01	49.87	0.11	2	0.22	49.820	0.003
LNE	5	25.364	0.12	5.655	0.014	2	0.028	5.438	0.024
	50	24.959	0.5	48.961	0.157	2	0.315	45.97	0.39
RISE	0.055	25.001	0.005	0.0556	0.0017	2	0.0034	0.0563	0.000014
	0.5	25.006	0.005	0.5070	0.00287	2	0.00574	0.504	0.0015
	5	25.004	0.005	5.067	0.0266	2	0.0532	5.075	0.0004
	50	25.061	0.005	49.86	0.278	2	0.556	49.38	0.018
DFM	0.055	25.0009	0.01	0.054588	0.000080	2	0.00016	0.0549015	0.0000091
	0.5	24.999	0.01	0.49934	0.00070	2	0.0014	0.49947	0.00016
	5	24.9987	0.01	5.0088	0.0058	2	0.012	5.00233	0.00069
	50	24.99903	0.01	49.999	0.058	2	0.12	50.055	0.010
CMI	0.055	25.01	0.04	0.05472	0.0002	2	0.00041	0.05538	0.0001
	0.5	24.99	0.04	0.5127	0.001	2	0.0021	0.5157	0.0002
	5	24.98	0.04	4.887	0.01	2	0.019	4.918	0.001
	50	25	0.04	49.73	0.1	2	0.2	50.6	0.02
GUM	5	24.9904	0	5.08	0.09	2	0.19	4.999	0.01
	50	24.9919	0	49.13	0.09	2	0.18	49.14	0.01

institute	nominal µS/cm µS cm^{-1}	value t_{ref} °C	max. possible deviation (*) Δt_{me} °C	reference conductivity κ_{ref} µS cm^{-1}	standard uncertainty u(κ_{ref}) µS cm^{-1}	coverage factor	U(κ_{ref}) µS cm^{-1}	conductivity indictade by 200CR κ_{dev} µS cm^{-1}	stability (expressed as standard uncertainty) u(κ_{dev}) µS cm^{-1}
NIM	0.055	25.063	0.010	0.05753	0.00032	2	0.00064	0.058	0.000
	0.5	25.035	0.010	0.4493	0.0010	2	0.0020	0.450	0.001
	5	25.069	0.010	5.035	0.004	2	0.008	5.032	0.002
	50	24.982	0.010	50.02	0.13	2	0.26	49.99	0.03
VNIIM	0.5	25.12	0.07	0.5028	0.00123	2	0.00246	0.5	0.003
	5	25.005	-0.01	5.0184	0.00681	2	0.01362	5.013	0.021
	50	24.97	-0.03	50.36	0.06615	2	0.1323	50.42	0.183
INTI	50 (150)	24.7	0.1	146.8	2.3	2	4.6	146.2	0.6
INMETRO	0.5	25.000	0.00	0.466	0.012	2	0.025	0.521	0.044
	5	25.000	0.00	4.991	0.014	2	0.029	4.971	0.011
	50	25.000	0.00	49.85	0.025	2	0.05	49.762	0.031

(*) between actual temperature in the cell and the location of the temperature sensor

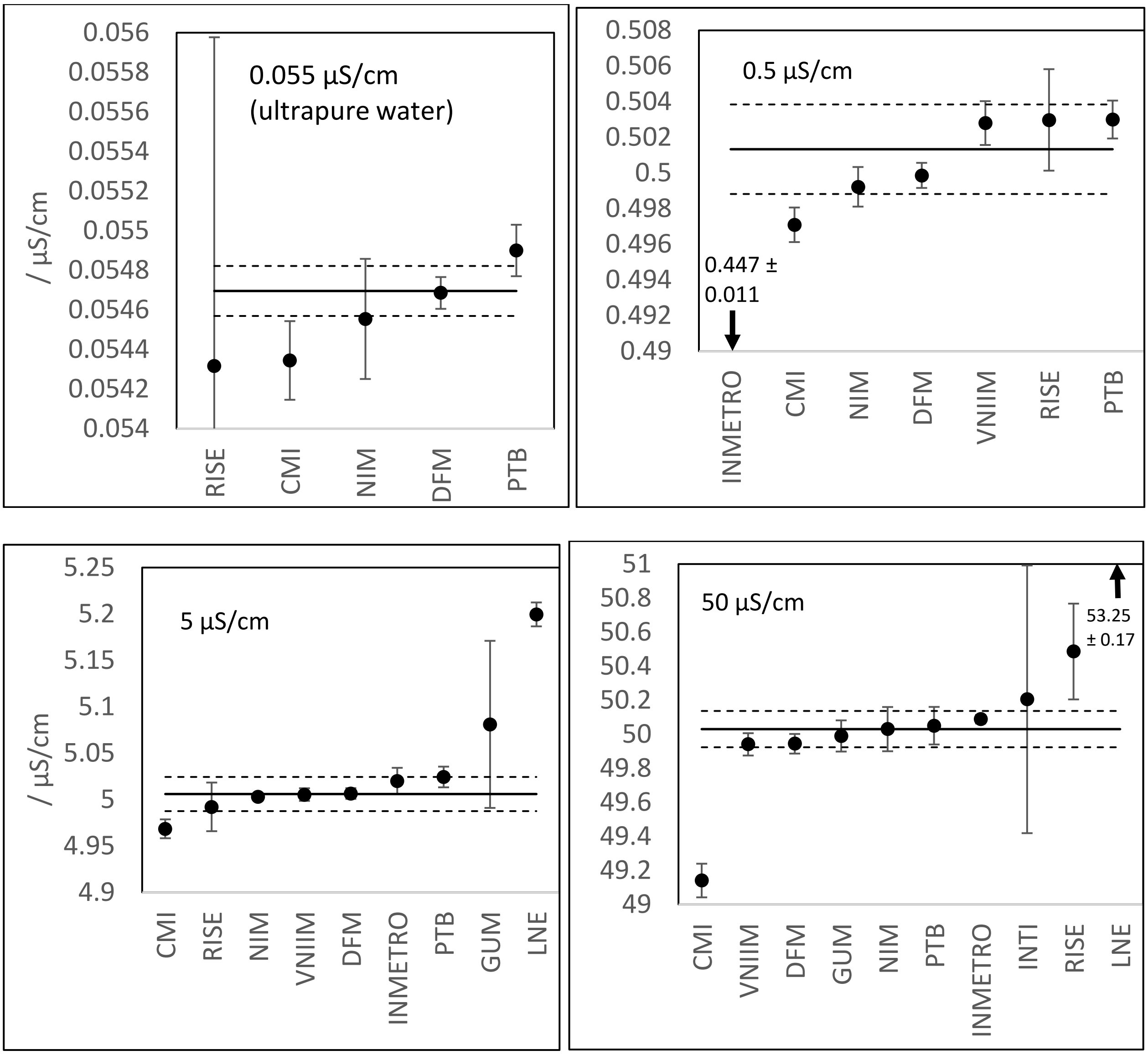

Figure 4 Linking conductivities, calculated from the reported results. The bars indicate standard uncertainties. The solid line represents the proposed CRV (see next section), the dashed line indicates its expanded uncertainty (k=2). The conductivity values noted inside the figures are the nominal condctivities.

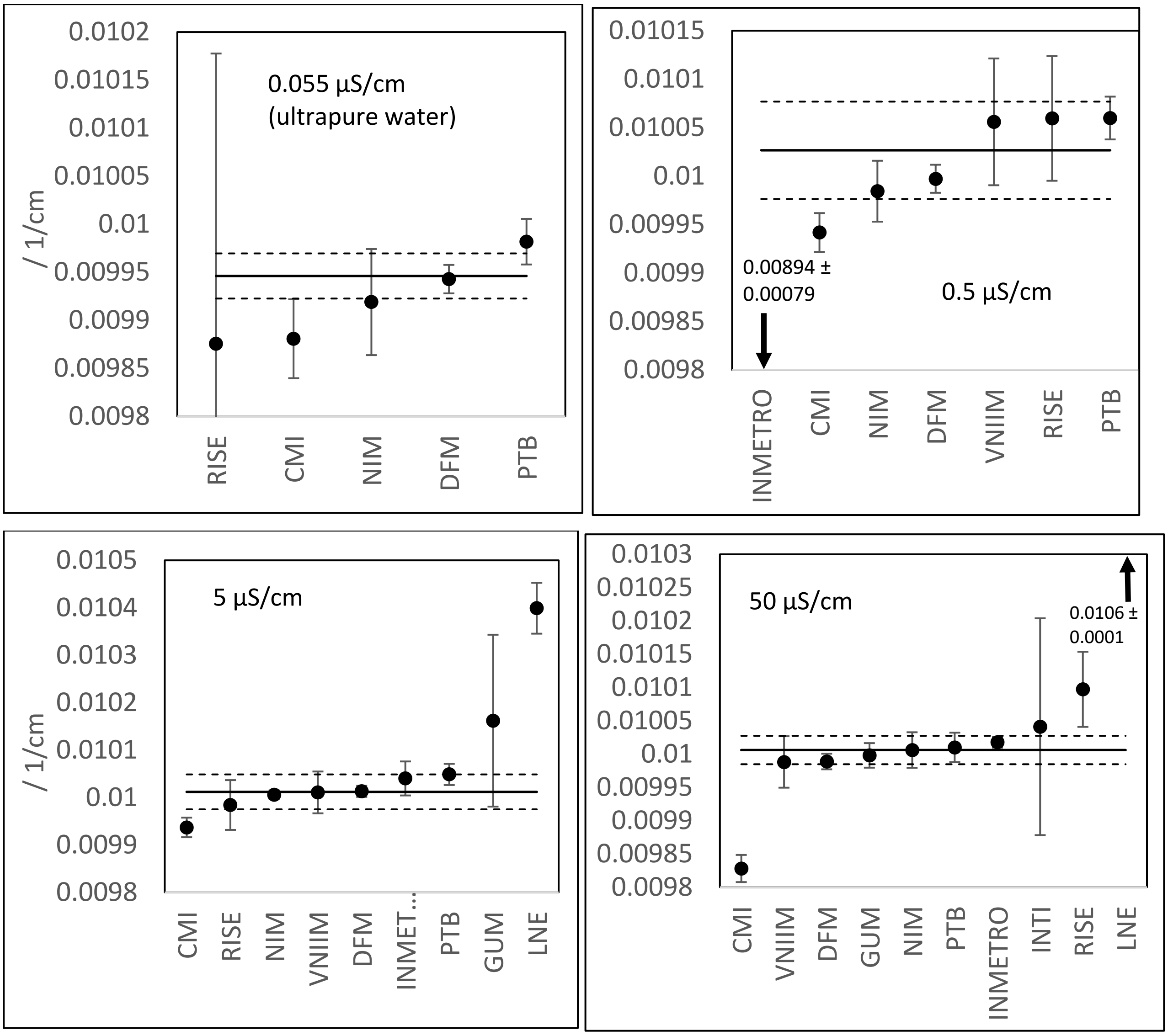

Figure 5 Adjusted cell constants, calculated from the reported results. The bars indicate standard uncertainties. The solid line represents the proposed CRV (see next section), the dashed line indicates its expanded uncertainty (k=2). The conductivity values noted inside the figures are the nominal condctivities.

Communication with the participating institutes

A first assessment of the adjusted cell constants by the coordinating institute has revealed a few unusual values, which showed either a significant deviation from the bulk of the results or an unusually large uncertainty. The institutes have been informed by the coordinating institute about the kind of observation, however, no quantitative information was disclosed by that time. The institutes were asked to check their values for numerical errors, i.e. transcription and calculation errors. Table 4 lists the institutes that have been informed, the kind of observation and the reply of the institute.

Table 4 Communication with institutes

Institute	Observation	Reply/corrective action
RISE	Large uncertainties at 0.055 and 0.5 µS cm^{-1}	Revised report, correcting transcription errors from the GUM-workbench for uncertainty calculation.
CMI	Deviation of adjusted cell constant at 50 µS cm^{-1}.	Results checked, no errors found
LNE	Deviation of adjusted cell constant at 5 and 50 µS cm^{-1}.	Results checked, no errors found. It was noticed that the temperature control (air bath) deviated from usual one (water bath), which has caused instability.
INMETRO	Deviation of adjusted cell constant at 0.5 µS cm^{-1}.	Results checked, no error found, stability issues with 0.5µS/cm conductivity standard were assumed.
NIM	Deviation of adjusted cell constant at 0.055 and 5 µS cm^{-1}. Further, the number of decimal places of reported conductivity values at these levels was smaller as those indicated by the device (by the time of the interim measurement at PTB).	Revised report, with minor improvements of data evaluation; no reason could be found for the small number of decimal places.

Comparison Reverence Values

CCQM document CCQM/13-22 [1] was used to calculate estimates for the comparison reference values (CRV). Table 5 shows the candidate CRVs for linking conductivities.

Table 5 Candidate CRVs for linking conductivities (upper values) and their expanded (k=2) uncertainties (lower value). The bold numbers indicate the CRVs, finally approved by EURAMET TC-MC/SCEA and CCQM-EAWG.

κ_{nom} µS/cm	weighted mean w/o (*) µS/cm	weighted mean w (*) µS/cm	median µS/cm	DerSimonian Laird µS/cm	mean µS/cm
0.055	**0.05470**	0.05470	0.05455	0.05468	0.05456
	0.00013	0.00015	0.00035	0.00020	0.00024
0.5	0.50016	0.5002	**0.5013**	0.5005	0.5008
	0.00085	0.0018	**0.0025**	0.0021	0.0022
5	5.0035	5.0035	**5.006**	5.004	5.013
	0.0054	0.0086	**0.018**	0.012	0.025
50	50.013	50.01	**50.03**	49.93	49.99
	0.040	0.14	**0.11**	0.24	0.25

(*) w/o without dispersion, w with dispersion

Figure 6 illustrates the candidate CRVs together with their expanded uncertainties and the approved CRVs (bold). Basically, all estimates belonging to the same conductivity level have rather similar values. The procedure for choosing the (finally approved) CRVs will is described in the following.

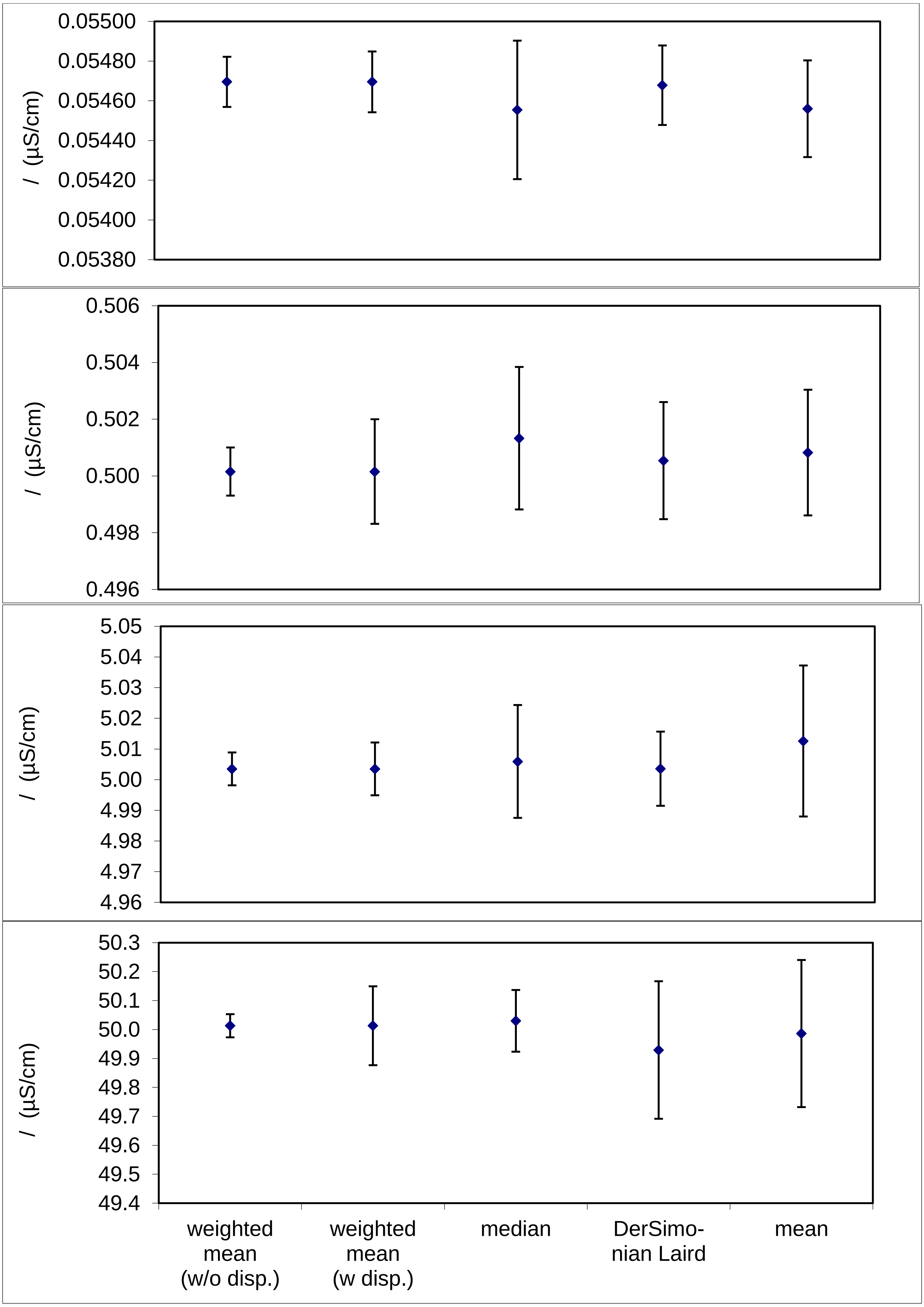

Figure 6 Candidate CRVs and their exp. uncertainties for the different conductivity levels.

The procedure follows reference [1] for the most part. In can roughly be summarized by the following steps:

1. Selection of a preliminary CRV that fits visually to the reported results and plot of a figure that includes the results, their uncertainties and the preliminary CRV (here, figure 5 can serve for the purpose of illustration).
2. If there is sufficient evidence in a report or other information available that cast doubts on the validity or the independence of a result, such values may be excluded.
3. Selection of a consistent subset, by applying one or more of the following criteria:
    - χ^2-test passed → chosen subset is considered consistent.
    - If the various estimators in figure 6 are consistent (mean may be excluded), i.e. uncertainties overlap significantly, the subset is considered robust for CRV calculation, since it provides equivalent CRV estimators.
    - If one of the consistency categories A - C of table 6 can be reasonably applied to figure 5, the subset is considered acceptable for CRV calculation
4. If no subset can be identified, exclusion of outliers (i.e. anomalous DoEs or uncertainties) should be discussed in EAWG and item 3 should be reviewed.
5. Selection of the most appropriate consistency category and the corresponding CRV estimator from table 6 and figure 7.

Note: If no consistent subset can be identified, the comparison should be aborted

Table 6 consistency categories to identify consistent subsets according to ref [1]

	category criteria	**recommended KCRV estimator**	**remark**
category A (sec. 6.3.1)	all results are consistent	mean, weighted mean w/o correction for dispersion	mean is acceptable, if uncertainties are similar
category B (sec. 6.3.3)	over-dispersion (generally underestimated uncertainties), no extreme outliers	weighted mean with correction for dispersion or DSL	decide visually which CRV uncertainty represents the spread and the uncertainty of the results better
category C (sec 6.3.2)	generally consistent with a few outlying values	median	number of institutes in subset must be >4
category D (sec. 6.3.4)	general over-dispersion with one or more outlying values	consider to abort comparison	

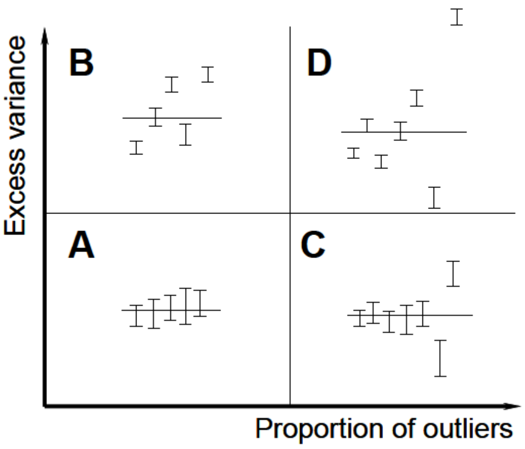

Figure 7 illustration of consistency criteria for the subset

The following subsets and CRV estimates have been finally used.

a) 0.055 µS cm^{-1}

Subset: All institutes that have provided results in this range. No result excluded.

Subset criteria: χ^2-test has been passed. Spread of results fits to consistency category A.

CRV estimate: Weighted mean without dispersion, since uncertainties are different.

b) 0.5 µS cm^{-1}

Subset: All institutes that have provided results in this range, except for the result of INMETRO, who has reported stability issues with the conductivity standard.

Subset criteria: All candidate CRVs provide similar values and the spread of the results fits to consistency category C.

CRV estimate: Median.

c) 5 µS cm^{-1}

Subset: All institutes that have provided results in this range, except for the result of LNE, who has reported stability issues with temperature controll. Furthermore, the reference value of LNE is traceable to PTB, thus, the result of LNE is not independent.

Subset criteria: All candidate CRVs provide similar values and the spread of the results fits to consistency category C.

CRV estimate: Median.

d) 50 µS cm^{-1}

Subset: All institutes that have provided results in this range, except for the result of LNE, who has reported stability issues with temperature controll. Furthermore, the reference value of LNE is traceable to PTB, thus, the result of LNE is not independent.[4]

Subset criteria: All candidate CRVs provide similar values and the spread of the results fits to consistency category C.

CRV estimate: Median.

Since the adjusted cell constants are correlated with the linking conductivities by a constant factor, the proposed CRVs for adjusted cell constants are calculated in the same way as the corresponding linking conductivities. However, it must be noted that the CRV of the adjusted cell constants can not simply be calculated with eq. (3c), since additional uncertainty contributions have been to be considered (see previous section). The proposed CRVs are listed in table 7.

Table 7 summarized the CRVs approved by EAWG durings its online meeting, held 12 October 2020. EURAMET TC-MC & SCEA have approved the CRVs by email.

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[4] NOTE: INTI has used a reference solution which conductivity value is traceable to PTB. Nevertheless, the result can be considered as independent since the primary measurement setup used at PTB to calibrate the reference solution is different from the one used in this comparsion. Therefore, the result of INTI is not excluded from CRV calculation.

Table 7 Approved CRVs (upper values) for linking conductivities and adjusted cell constants and their expanded (k=2) uncertainties (lower values).

κ_{nom} µS cm^{-1}	Linking conductivity µS cm^{-1}	Adjusted cell constant cm^{-1}	kind of CRV cm^{-1}
0.055	0.05470 ±0.00013	0.009946 ±0.000012	weighted mean w/o
0.5	0.5013 ±0.0025	0.0100266 ±0.000025	median
5	5.006 ±0.018	0.010012 ±0.000018	median
50	50.03 ±0.11	0.010006 ±0.000011	median

Degrees of Equivalence

The degrees of equivalence (DoE) and their uncertainties are calculated according to ref [1] with respect to to the proposed CRVs. The results are listed in the subsequent tables 8 and 9.

The tables also state the minimal expanded uncertainties U_{minCMC} that are consistent with the respective CRV, which makes the submission and review of claims of calibration and measurement capabilities (CMC) easier. If a result is consistent, U_{minCMC} is equivalent with the expanded uncertainty reported by the institute. Regarding inconsistened results, it is assumed that they are the result of underestimated or unknown uncertainty contributions, provided that failure of the measurement setup or the sample can be excluded. This comparison may therefore support CMCs claims even if a respective result is inconsistent with the CRV. However, the expanded (95%) level uncertainty of the CMC claim must be equal or larger than U_{minCMC}.

Unfortunately, Ref [1] gives no advice, how to calculate estimates for U_{minCMC} if the reported result is inconsistent. In this case, the calculation is based on the fundamental consistency criterion, that the difference between the reported result and the CRV should be smaller than the expanded (95% level) uncertainty of the difference, i.e.

$$\mathrm{DoE}^2 \leq (k \cdot u(\mathrm{DoE}))^2 \qquad (6)$$

with k being the coverage factor. U_{minCMC} (= $k \cdot u_{\mathrm{minCMC}}$) can be calculated from eq. (6), provided $u(DoE)$ depends on the standard uncertainty $u(x_i)$ of the concerned institute. In this case, $u(x_i)$ has been replaced by u_{minCMC}) in eq. (6) and the equation has been solved for u_{minCMC}. The formula for $u(\mathrm{DoE})$ are different for the various CRV estimates (see ref [1]). Furthermore, it must be distinguished between results that have contributed to the CRV calculation and those that have not contributed. Moreover, in some cases $u(\mathrm{DoE})$ does not depend on the uncertainties of the participants at all. This holds for the mean and the median. Thus, if eq. (6) does not depend on the uncertainty of the concerned institute, the simple relation $u^2(\mathrm{DoE})=u^2(\mathrm{CVR})+u_{minCMC}^2$ is used to calculate u_{minCMC}, or U_{minCMC}, respectively. It must be emphasized that it is possible under this condition that a calculated u_{minCMC} value is smaller than the originally reported uncertainty $u(x_i)$. In this case, the larger value has been assigned to u_{minCMC}.

Finally, note that the minmal uncertainties are expressed as relative uncertainties, since the uncertainties of the linking conductivities can slightly differ from the reported uncertainties.

Table 8a Degrees of Equivalence of conductivities and their exp. uncertainties corresponding to 0.055 µS cm^{-1} nominal conductivity. The column on the right hand side indicates the minimal uncertainty consistent with the CRV.

Laboratory name	quantity value x_i µS/cm	standard uncertainty $u(x_i)$ µS/cm	expanded (95%) uncertainty µS/cm	DoE_i µS/cm	U(DoE) µS/cm	minimal exp. uncertainty consistent with CRV (relative)
RISE	0.0543	1.7E-03	3.3E-03	-3.8E-04	3.3E-03	6.1%
CMI	0.05434	2.0E-04	4.0E-04	-3.5E-04	3.8E-04	0.73%
NIM	0.05455	3.0E-04	6.1E-04	-1.4E-04	5.9E-04	1.1%
DFM	0.054686	8.0E-05	1.6E-04	-9.9E-06	9.9E-05	0.29%
PTB	0.05490	1.3E-04	2.6E-04	2.0E-04	2.3E-04	0.47%

Figure 8a corresponding to table 8a

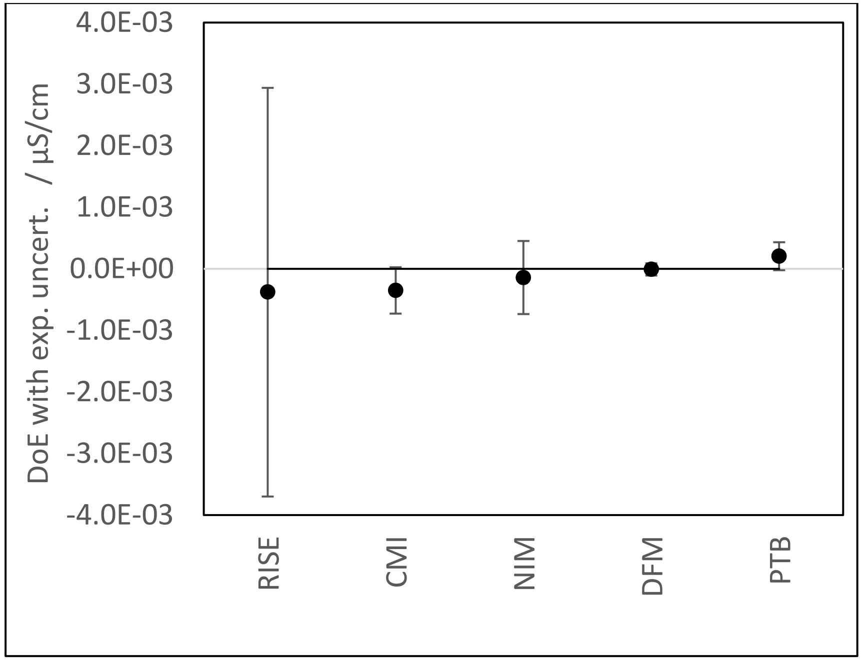


Table 8b Degrees of Equivalence of conductivities and their exp. uncertainties corresponding to 0.5 µS cm^{-1} nominal conductivity. The column on the right hand side indicates the minimal uncertainty consistent with the CRV.

Laboratory name	quantity value x_i µS/cm	standard uncertainty $u(x_i)$ µS/cm	expanded (95%) uncertainty µS/cm	DoE_i µS/cm	U(DoE) µS/cm	minimal exp. uncertainty consistent with CRV (relative)
INMETRO	0.447	1.2E-02	2.3E-02	-5.4E-02	2.3E-02	12.1%
CMI	0.49709	9.7E-04	1.9E-03	-4.2E-03	4.7E-03	0.39%
NIM	0.4992	1.1E-03	2.2E-03	-2.1E-03	4.7E-03	0.45%
DFM	0.49986	7.0E-04	1.4E-03	-1.5E-03	4.7E-03	0.28%
VNIIM	0.5028	1.2E-03	2.5E-03	1.5E-03	4.7E-03	0.49%
RISE	0.5030	2.8E-03	5.7E-03	1.6E-03	4.7E-03	1.1%
PTB	0.5030	1.1E-03	2.1E-03	1.7E-03	4.7E-03	0.42%

Figure 8b corresponding to table 8b

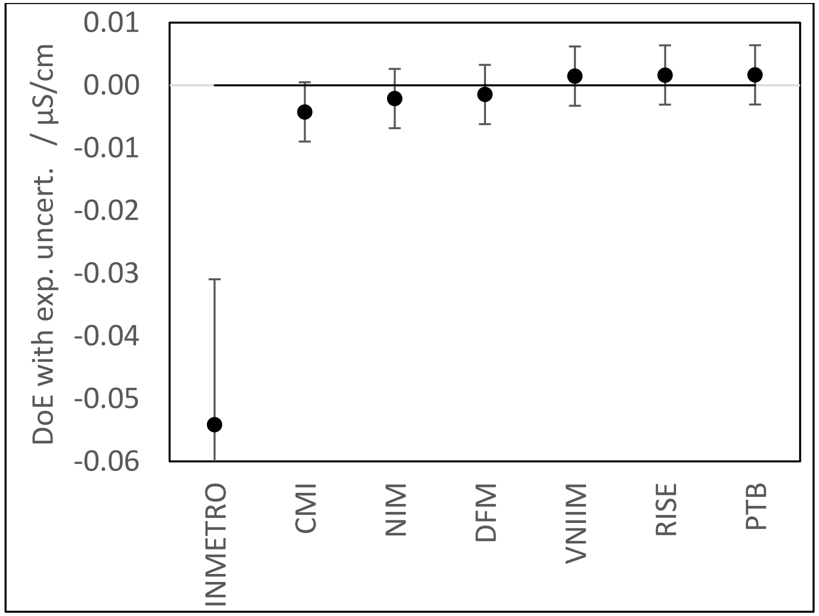


Table 8c Degrees of Equivalence of conductivities and their exp. uncertainties corresponding to 5 µS cm^{-1} nominal conductivity. The column on the right hand side indicates the minimal uncertainty consistent with the CRV.

Laboratory name	quantity value x_i µS/cm	standard uncertainty $u(x_i)$ µS/cm	expanded (95%) uncertainty µS/cm	DoE$_i$ µS/cm	U(DoE) µS/cm	minimal exp. uncertainty consistent with CRV (relative)
CMI	4.968	1.0E-02	2.0E-02	-3.7E-02	4.0E-02	0.4%
RISE	4.992	2.6E-02	5.2E-02	-1.4E-02	4.0E-02	1.05%
NIM	5.0030	4.0E-03	7.9E-03	-3.0E-03	4.0E-02	0.16%
VNIIM	5.0054	6.8E-03	1.4E-02	-5.6E-04	4.0E-02	0.27%
DFM	5.0065	5.8E-03	1.2E-02	5.6E-04	4.0E-02	0.23%
INMETRO	5.020	1.4E-02	2.8E-02	1.4E-02	4.0E-02	0.6%
PTB	5.024	1.1E-02	2.2E-02	1.8E-02	4.0E-02	0.44%
GUM	5.081	9.0E-02	1.8E-01	7.5E-02	4.0E-02	3.5%
LNE	5.200	1.3E-02	2.6E-02	1.9E-01	3.2E-02	3.7%

Figure 8c corresponding to table 8c

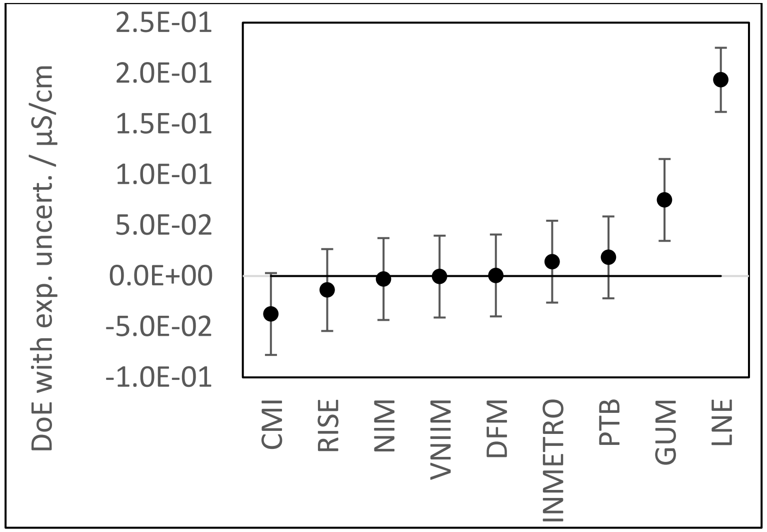


Table 8d Degrees of Equivalence of conductivities and their exp. uncertainties corresponding to 50 µS cm^{-1} nominal conductivity. The column on the right hand side indicates the minimal uncertainty consistent with the CRV.

Laboratory name	quantity value x_i µS/cm	standard uncertainty $u(x_i)$ µS/cm	expanded (95%) uncertainty µS/cm	DoE_i µS/cm	U(DoE) µS/cm	minimal exp. uncertainty consistent with CRV (relative)
CMI	49.140	9.9E-02	2.0E-01	-8.9E-01	2.5E-01	1.8%
VNIIM	49.940	6.6E-02	1.3E-01	-9.0E-02	2.5E-01	0.26%
DFM	49.944	5.8E-02	1.2E-01	-8.6E-02	2.5E-01	0.23%
GUM	49.990	9.2E-02	1.8E-01	-4.0E-02	2.5E-01	0.37%
NIM	50.03	1.3E-01	2.6E-01	0.0E+00	2.5E-01	0.52%
PTB	50.05	1.1E-01	2.2E-01	2.0E-02	2.5E-01	0.44%
INMETRO	50.088	2.5E-02	5.0E-02	5.8E-02	2.5E-01	0.10%
INTI	50.21	7.9E-01	1.6E+00	1.8E-01	2.5E-01	3.1%
RISE	50.49	2.8E-01	5.6E-01	4.6E-01	2.5E-01	1.1%
LNE	53.25	1.7E-01	3.4E-01	3.2E+00	3.6E-01	6.0%

Figure 8d corresponding to table 8d

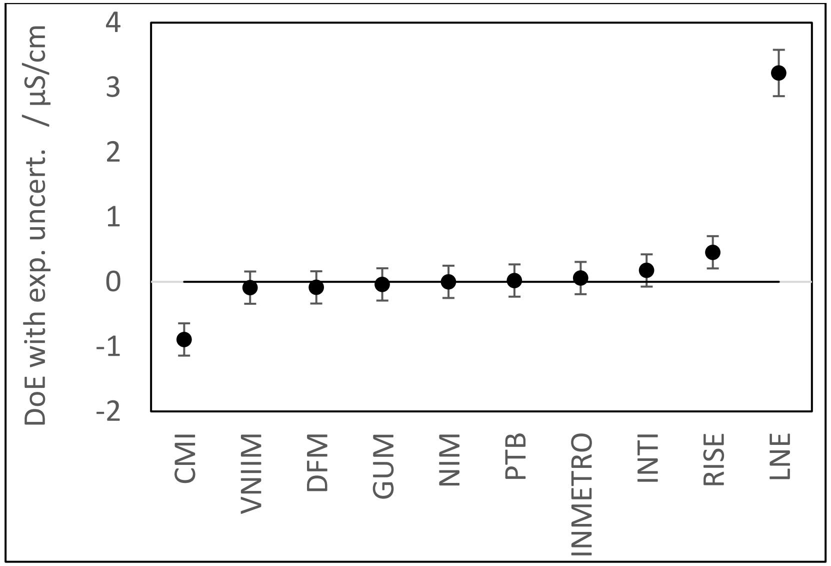


Table 9a Degrees of Equivalence for adjusted cell constants and their exp. uncertainties corresponding to 0.055 µS cm^{-1} nominal conductivity. The column on the right hand side indicates the minimal uncertainty consistent with the CRV.

Laboratory name	quantity value x_i 1/cm	standard uncertainty $u(x_i)$ 1/cm	expanded (95%) uncertainty 1/cm	DoE_i 1/cm	U(DoE) 1/cm	minimal exp. uncertainty consistent with CRV (relative)
RISE	0.00988	3.0E-04	6.0E-04	-7.0E-05	6.0E-04	6.1%
CMI	0.009881	4.1E-05	8.2E-05	-6.5E-05	7.9E-05	0.83%
NIM	0.009919	5.5E-05	1.1E-04	-2.7E-05	1.1E-04	1.1%
DFM	0.009943	1.5E-05	3.0E-05	-3.3E-06	1.8E-05	0.30%
PTB	0.009982	2.4E-05	4.7E-05	3.6E-05	4.1E-05	0.48%

Figure 9a corresponding to table 9a

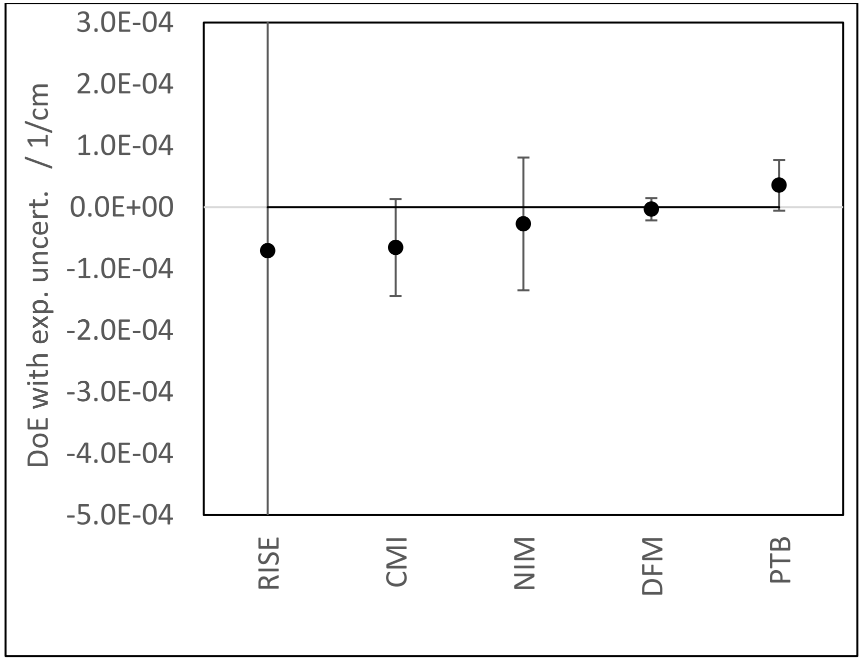


Table 9b Degrees of Equivalence of adjusted cell constants and their exp. uncertainties corresponding to 0.5 µS cm^{-1} nominal conductivity. The column on the right hand side indicates the minimal uncertainty consistent with the CRV.

Laboratory name	quantity value x_i 1/cm	standard uncertainty $u(x_i)$ 1/cm	expanded (95%) uncertainty 1/cm	DoE_i 1/cm	U(DoE) 1/cm	minimal exp. uncertainty consistent with CRV (relative)
INMETRO	0.00894	7.9E-04	1.6E-03	-1.1E-03	1.6E-03	17.7%
CMI	0.009942	2.0E-05	4.0E-05	-8.5E-05	9.5E-05	0.40%
NIM	0.009984	3.1E-05	6.3E-05	-4.2E-05	9.5E-05	0.63%
DFM	0.009997	1.4E-05	2.9E-05	-2.9E-05	9.5E-05	0.29%
VNIIM	0.010056	6.5E-05	1.3E-04	2.9E-05	9.5E-05	1.3%
RISE	0.010060	6.4E-05	1.3E-04	3.3E-05	9.5E-05	1.3%
PTB	0.010060	2.2E-05	4.4E-05	3.3E-05	9.5E-05	0.44%

Figure 9b corresponding to table 9b

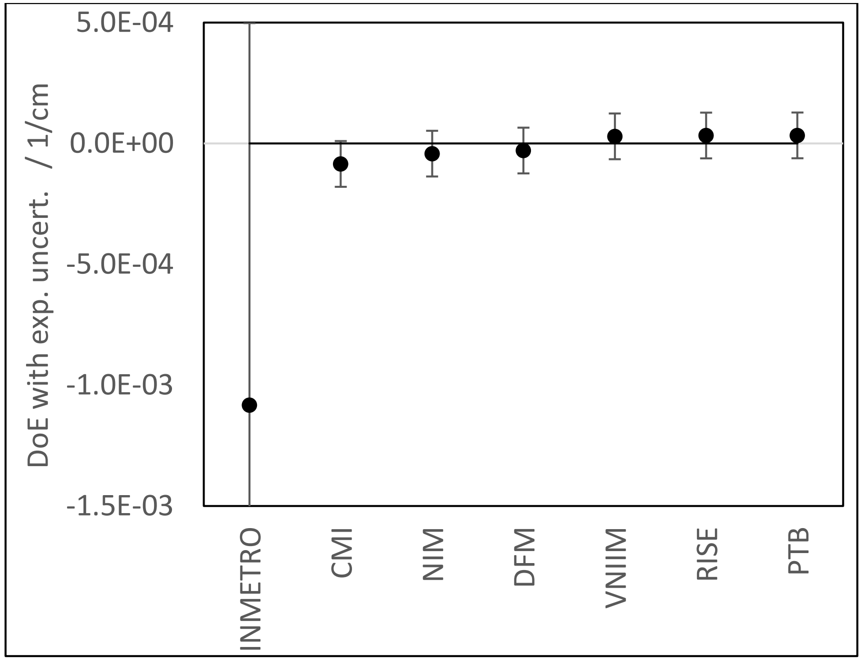


Table 9c Degrees of Equivalence of adjusted cell constants and their exp. uncertainties corresponding to 5 µS cm^{-1} nominal conductivity. The column on the right hand side indicates the minimal uncertainty consistent with the CRV.

Laboratory name	quantity value x_i 1/cm	standard uncertainty $u(x_i)$ 1/cm	expanded (95%) uncertainty 1/cm	DoE_i 1/cm	U(DoE) 1/cm	minimal exp. uncertainty consistent with CRV (relative)
CMI	0.009937	2.1E-05	4.1E-05	-7.5E-05	8.1E-05	0.4%
RISE	0.009984	5.2E-05	1.0E-04	-2.8E-05	8.1E-05	1.05%
NIM	0.0100060	8.9E-06	1.8E-05	-5.9E-06	8.1E-05	0.18%
VNIIM	0.010011	4.4E-05	8.8E-05	-1.1E-06	8.1E-05	0.88%
DFM	0.010013	1.2E-05	2.3E-05	1.1E-06	8.1E-05	0.23%
INMETRO	0.010040	3.6E-05	7.2E-05	2.8E-05	8.1E-05	0.7%
PTB	0.010049	2.2E-05	4.5E-05	3.7E-05	8.1E-05	0.44%
GUM	0.01016	1.8E-04	3.6E-04	1.5E-04	8.1E-05	3.6%
LNE	0.010399	5.4E-05	1.1E-04	3.9E-04	1.1E-04	3.7%

Figure 9c corresponding to table 9c

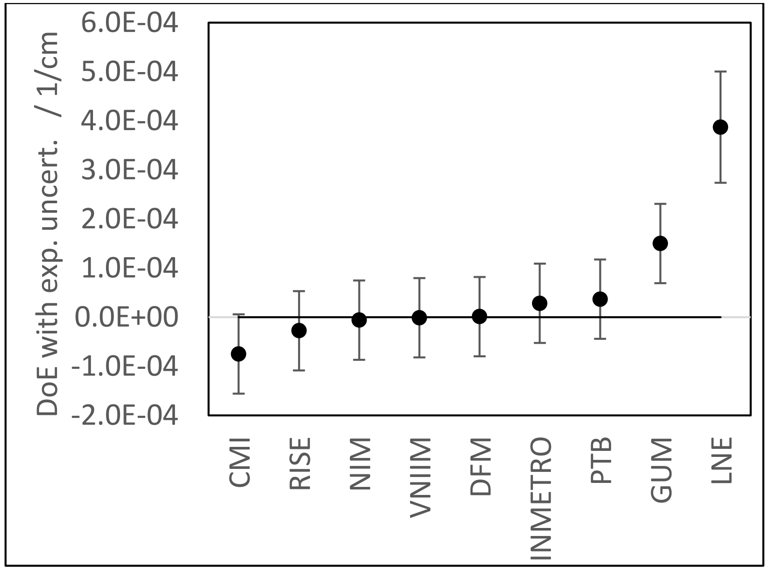
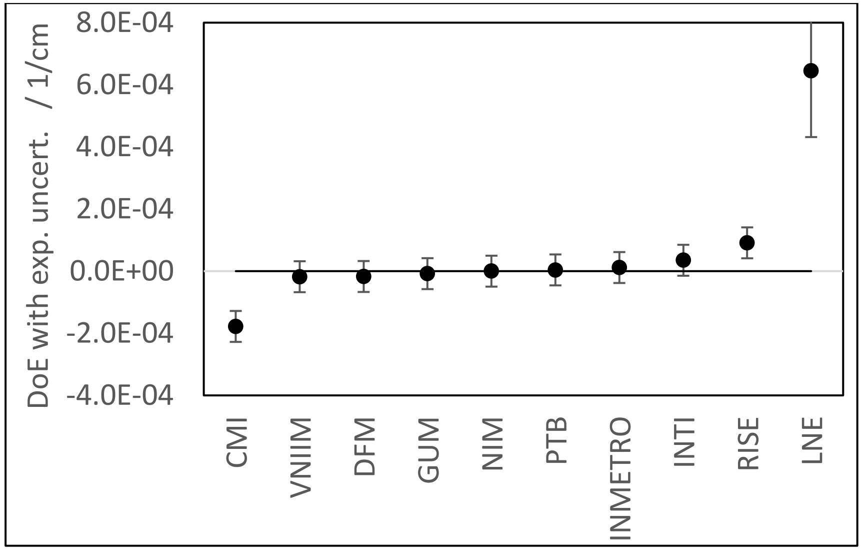


Table 9d Degrees of Equivalence of adjusted cell constants and their exp. uncertainties corresponding to 50 µS cm^{-1} nominal conductivity. The column on the right hand side indicates the minimal uncertainty consistent with the CRV.

Laboratory name	quantity value x_i 1/cm	standard uncertainty $u(x_i)$ 1/cm	expanded (95%) uncertainty 1/cm	DoE_i 1/cm	U(DoE) 1/cm	minimal exp. uncertainty consistent with CRV (relative)
CMI	0.009828	2.0E-05	4.1E-05	-1.8E-04	5.0E-05	1.8%
VNIIM	0.009988	3.9E-05	7.7E-05	-1.8E-05	5.0E-05	0.77%
DFM	0.009989	1.2E-05	2.3E-05	-1.7E-05	5.0E-05	0.23%
GUM	0.009998	1.8E-05	3.7E-05	-8.0E-06	5.0E-05	0.37%
NIM	0.010006	2.7E-05	5.3E-05	0.0E+00	5.0E-05	0.53%
PTB	0.010010	2.2E-05	4.4E-05	4.0E-06	5.0E-05	0.44%
INMETRO	0.0100177	8.0E-06	1.6E-05	1.2E-05	5.0E-05	0.16%
INTI	0.01004	1.6E-04	3.3E-04	3.5E-05	5.0E-05	3.2%
RISE	0.010097	5.6E-05	1.1E-04	9.1E-05	5.0E-05	1.1%
LNE	0.01065	1.1E-04	2.1E-04	6.4E-04	2.1E-04	6.0%

Figure 9d corresponding to table 9d



HFDTLS Statement

The results of this comparison can be used to support conductivity CMC claims of a participating institute in the following conductivity ranges:

0.05 - 0.15 µS cm^{-1}
0.15 - 1.5 µS cm^{-1}
1.5 - 15 µS cm^{-1}
15 - 150 µS cm^{-1}

provided that the participant has reported a measurement result in the respective range.

The comparison will provide support for the kind of solutions stated in table 2. If this solution can reasonably be considered representative for other kinds of solutions, an CMC may be claimed for such solutions. Further evidence might be necessary to justify the corresponding uncertainty claim, which must not be smaller than the minimal uncertainties stated in this comparison.

Furthermore, this comparison may serve as support for CMC claims of cell constant calibration. The conductivity range of the calibration and the kind of solution used for the calibration must comply with the results of this comparison, i.e. tables 2 and 9, and must be added as additional information to a CMC claim of cell constant calibration.

References

[1] CCQM/13-22 “CCQM Guidance note: Estimation of a consensus KCRV and associated Degrees of Equivalence”, version 10, available at the CCQM members area of the BIPM webpage, 2013, https://www.bipm.org/cc/CCQM/Restricted/WorkingDocuments.jsp

Annex1 - Summary Measurement Report Form

Institute

Laboratory/department

Contact person / email

Reference conductivity ☐ primary measurement in flow through system
☐ measurement standard, state type of solution(s):
☐ other:

Measurement results

Nominal conductivity µS cm^{-1}	Date measured	Reference temperature		Tempera-ture	Reference conductivity				Conductivity indicated by Thornton 200CR	
		value / °C	potential deviation (*) Δt_{me} /°C	indicated by 200CR /°C	Reference value / µS cm^{-1}	Standard uncertainty / µS cm^{-1}	Coverage factor	Expanded (95.45% level) uncertainty / µS cm^{-1}	Indicated value / µS cm^{-1}	Stability / µS cm^{-1}
0.055 (upw)										
0.5										
5										
50										

(*) Estimated maximal deviation between the temperature in the circulated cell and the temperature at the actual position of solution temperature measurement.

Annex 2 – Dates of shipment

Round Robin shipment scheme

Institute	arrivel of instrument confirmed	targeted measurement period	afterwards, send instrument to	dispatch due at the latest	actual dispatch
	yes/not yet	calendar week	institute	date	date
PTB	n/a	50	LNE	04.01.2019	03.01.2019
LNE	yes	3	RISE	25.01.2019	28.01.2019
RISE	yes	6	DFM	15.02.2019	13.02.2016
DFM	yes	9	CMI	08.03.2019	05.03.2019
CMI	yes	12	LNE	29.03.2019	26.03.2019
LNE	yes	15	GUM	19.04.2019	15.04.2019
GUM	yes	18	PTB	03.05.2019	29.04.2019
PTB	yes	21	NIM	31.05.2019	13.05.2019
NIM	yes	24	VNIIM	21.06.2019	24.06.2019
VNIIM	yes	27	INTI	12.07.2019	21.10.2019
INTI	yes	30	INMETRO	02.08.2019	10.12.2019
INMETRO	yes	33	PTB	23.08.2019	03.02.2020
PTB	yes (*)	36	DFM		20.03.2020 (**)
DFM	yes	38	PTB		03.04.2020
PTB	arrival 08.04.2020				

(*) actual arrival at PTB 11.03.2020, due to customs issues

(**) dispatch delayed due to COVID-19 issues

Annex – 3 Contacts

Coordinating laboratory

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EURAMET Project 1462 Electrolytic conductivity at pure water level

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EURAMET Project 1462 Electrolytic conductivity at pure water level

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