NVLAP®	**DEPARTMENT OF COMMERCE** National Institute of Standards and Technology National Voluntary Laboratory Accreditation Program	**ISSUE DATE:** August 24, 2017
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		LAP: Calibration
SUBJECT: Laboratory Bulletin for Calibration Laboratories for Flow and Related Quantities		

The purpose of this bulletin is to advise each laboratory that performs calibrations of flow and related quantities about specific NVLAP policies and requirements for onsite assessments. This bulletin covers information required for a laboratory's description of its calibration and measurement capabilities on its NVLAP scope of accreditation; provides detail about determination of uncertainty in flow measurements; and provides detail about proficiency testing for flow and related quantities. Review of these three areas is an integral part of the NVLAP assessment of a laboratory performing calibrations of flow and related quantities.

Note there are new requirements in this document which laboratories must address by December 31, 2017.

Scope of Accreditation

The scope of accreditation, calibration and measurement capability (CMC), and associated notes are to inform customers and assessors of the accredited capabilities of the laboratory, including the range of conditions (i.e. fluid type, pressure, temperature) the laboratory provides during the calibration of a customer's device. Laboratories shall provide a complete list of the ranges of pertinent parameters that are accredited for the facility. Scopes for flow laboratories shall include:

1. **Measurand**: The NVLAP list of measurands for accredited flow calibrations are: liquid flow, gas flow, air speed, liquid volume, and hydrometer correction.

2. **Range of Measurand**: The minimum and maximum values of the measurand over which a laboratory is accredited shall be listed in the CMC table.

3. **CMC Uncertainty:** The 95% confidence level expanded uncertainty for the output of the calibration, including uncertainties related to the device under test (i.e. not the uncertainty of the reference standard alone) shall be listed in the CMC table. The CMC lists the smallest uncertainty of measurement that is normally available to the laboratory's customers for a nearly ideal flow meter (usually called the best existing device). The CMC uncertainty can be

presented as a single figure, a range of values, an equation, or a table, but it must apply for the range of measurement. The uncertainty related to the device under test shall include a contribution due to repeatability based on the normal number of measurements performed at each flow set point, corrected for the finite sample size using the Welch-Satterthwaite method as described in the GUM [1] or appropriately applied *t*-values. The uncertainty in customer calibration reports will nearly always be larger than the uncertainty stated in the CMC table because of extra uncertainty components that arise when the meter under test is not the best existing device (see section below entitled Uncertainty for a Customer Calibration Report). More information on these topics and references to example uncertainty analyses for flow can be found in Working Group for Fluid Flow Guidelines [2]. The WGFF Guidelines are applied to National Metrology Institutes when they generate CMCs for the Bureau International des Poids et Mesures.

4. **Instrument Type**: In some cases, a laboratory is only qualified to calibrate particular meter types, for instance, its own product. In those cases, the types of devices that the laboratory is accredited to calibrate shall be stated as a note on the scope of accreditation, for example, "Stated CMC uncertainty is for calibration of electromagnetic flow meters. Calibration of other flow meter types is available at higher uncertainty."

5. **Fluid Type**: Example entries are: water, dry air, nitrogen, natural gas, carbon dioxide, mineral oil, gasoline, non-toxic and non-flammable gases, etc. For liquid calibration services, the range of kinematic viscosity that the laboratory can provide is recommended.

6. **Pressure of Fluid**: Minimum and maximum values of pressure in the fluid applied to the device under test during calibration.

7. **Temperature of Fluid**: Minimum and maximum values of temperature in the fluid applied to the device under test during calibration.

Fluid type, pressure, temperature, and kinematic viscosity of the fluid shall be entered in the Remarks section of the CMC table or in the Notes section.

Uncertainty for a Customer Calibration Report

The uncertainty listed in the NVLAP scope of accreditation will nearly always be smaller than the uncertainty in a calibration report for a customer's instrument. The extra uncertainty components in a calibration certificate vary with the measurand and the type of meter being calibrated and must be understood, quantified, and reported by a laboratory accredited to calibrate that meter type.

[1] *Guide to the Expression of Uncertainty in Measurement*, JCGM 100:2008.
[2] *WGFF Guidelines for CMC Uncertainty and Calibration Report Uncertainty*, Working Group for Fluid Flow, October 21, 2013, http://www.bipm.org/utils/en/pdf/ccm-wgff-guidelines.pdf.

Some of the extra uncertainty components that arise in a meter calibration can be categorized as 1) repeatability or short-term reproducibility for the customer's meter under test, 2) extra instrumentation used to acquire data from the meter under test (like frequency, pressure, or temperature sensors), and 3) fluid properties.

Example 1: In the simplest case, the meter under test (MUT) has a flow computer that indicates flow in the same units as the calibration laboratory's reference standard. If the laboratory's system for recording the output from the MUT has negligible uncertainty (e.g. a digital interface), then the only significant extra uncertainty component beyond the CMC uncertainty is the difference in repeatability (or reproducibility) between the MUT and the best existing device used to calculate the CMC uncertainty.

Example 2: In some cases, calibration results for the meter under test are reported as a "performance indicator" such as discharge coefficient, meter factor, flow coefficient, or some dimensionless quantity appropriate for the meter type. In such a case, the calibration report shall give the uncertainty of the performance indicator, which in most cases will be larger than the CMC uncertainty. Extra uncertainty components arise in a performance indicator due to instrumentation associated with the meter under test or fluid properties. An example of an uncertainty analysis with significant associated instrumentation uncertainty can be found in the Appendix of the NIST Special Publication 250-80 *Gas Flow Meter Calibrations with the Working Gas Flow Standard* [3]. In that example (a laminar flow meter calibration), the reference standard measures standard volumetric flow with expanded uncertainty of 0.1 %, but the uncertainty of the performance indicator in the calibration report has uncertainty as large as 0.52 %, primarily due to uncertainty in the differential pressure measurement for the laminar flow meter.

Example 3: In some cases, the uncertainty in the fluid properties *directly* impacts the uncertainty of the performance indicator. Returning to the laminar flow meter example, the viscosity of the calibration fluid is needed to calculate the flow coefficient. If there is significant uncertainty associated with the values of viscosity, perhaps due to the impurity of the fluid, uncertainty in temperature measurements, or the uncertainty of literature viscosity data, this must be included in the uncertainty of the flow coefficient.

Example 4: In some cases, the uncertainty in the fluid properties *indirectly* impacts the uncertainty of the performance indicator. For example, calibration data for a turbine meter is often presented as Strouhal number St versus Roshko number Ro. The Roshko number is defined as $Ro = fD^2/\nu$

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[3] Wright, J. D., Kayl, J.-P., Johnson, A. N., and Kline, G. M., *Gas Flowmeter Calibrations with the Working Gas Flow Standard*, NIST Special Publication 250-80, National Institute of Standards and Technology, Gaithersburg, MD, November 23, 2009, https://www.nist.gov/publications/gas-flowmeter-calibrations-working-gas-flow-standard.

where f is the rotor frequency of the meter under test, D is the diameter of the meter, and ν is the fluid kinematic viscosity. If the change in St with respect to Ro is large (the slope of the calibration curve is large), uncertainty in the Roshko number due to kinematic viscosity can cause significant uncertainty in the Strouhal number. Where the calibration curve is flat, the sensitivity coefficient $\partial St/\partial Ro$ is zero, but if it is not flat ($\partial St/\partial Ro$ is non-zero), uncertainty in the kinematic viscosity leads to uncertainty in the Roshko number, which must be considered in the uncertainty in Strouhal number. A similar situation can occur for other plots of performance indicator, e.g. discharge coefficient plotted versus Reynolds number.

Requirements for Proficiency Testing

A NVLAP-accredited laboratory is required to provide the results of proficiency tests (PT) to assessors to demonstrate that it achieves its uncertainty specifications. The accredited laboratory is responsible for obtaining PT results. An acceptable proficiency test shall use a transfer standard and be performed with other PT participants with uncertainty comparable to that of the accredited laboratory (i.e. within a factor of 2).

The accredited laboratory is responsible for performing internal comparisons between systems with overlapping measurement ranges and maintaining records (including graphical representations) of the results of these internal comparisons. The accredited laboratory is also responsible for maintaining control charts that show the stability of calibration results from periodic calibration of check standards using the same reference standard. Internal comparison and check standard data should be used to reduce the proficiency testing (external comparison) workload. For example, an accredited laboratory that maintains five reference standards is not required to perform proficiency testing (external comparisons) with each of the five reference standards. Rather, one proficiency test will suffice if there are successful internal comparison results that connect that one reference standard to the other four.

A NVLAP-accredited laboratory is not required to perform proficiency testing with a National Metrology Institute (NMI), nor is it required to use NIST. However, each NVLAP-accredited laboratory is *encouraged* to use NIST for proficiency tests except 1) when the laboratory has CMC uncertainty *greater than twice* the NIST uncertainty specified for the measurand in the BIPM Key Comparison Data Base (www.bipm.org) or 2) when the measurand or needed range is not supported by NIST. If NIST or another NMI is not used, PT providers offering PT at the appropriate level and accredited to ISO 17043 by an ILAC Mutual Recognition Arrangement signatory accrediting body may be used. Also, proficiency testing can be done between accredited laboratories with comparable uncertainty (i.e. within a factor of 2).

This laboratory bulletin does not nullify the following two clauses from NIST Handbook 150-2-2016:

3.4.3.1 Calibration proficiency tests may be organized by NVLAP in consultation with NIST experts for parameters where laboratories are operating at or near NIST uncertainties.

3.4.4 a) Where NVLAP provides coordination for PT, a laboratory accredited for the parameter and range within the specified uncertainty for the test shall participate.

Specific proficiency test requirements for flow laboratories are:

1) Comparisons will be performed at least every five years, generally following the "Guidelines for CIPM Key Comparison" [4].
2) An unstable transfer standard can lead to inconclusive proficiency test results. Preliminary tests shall be conducted to assess the stability of the transfer standard to be used and its sensitivity to transport, environmental conditions, fluid properties, etc. The transfer standard shall be demonstrated to have reproducibility less than the accredited laboratory's uncertainty through preliminary testing or (if such a device does not exist) the transfer standard must have the best commercially available calibration stability. At minimum, calibration results for the transfer standard from the beginning and the end of the proficiency test done by one of the participants shall be used to quantify transfer standard stability.
3) The comparison will be blind, i.e. the pilot laboratory or some third party will not share measurement results with the accredited laboratory until all measurements are completed. Results cannot be altered to improve agreement.
4) For PT results to be considered successful, the standardized degrees of equivalence at all test flows, defined as the difference between the accredited laboratory and the NMI (or other PT provider) divided by the root-sum-square of the two laboratory uncertainties and the uncertainty introduced by the transfer standard, shall be less than or equal to 1 for 95 % or more of the proficiency test set points.
5) The comparison shall be performed at 2 or more values of the measurand differing by at least a factor of 5. Wider ranges are encouraged if the transfer standard is capable.
6) Normally, a laboratory will have ranges of measurand in on its scope that cannot be covered by a single transfer standard. Therefore, the accredited laboratory should choose different ranges of the measurand for different comparisons, so that over time, proficiency is demonstrated over the entire range of the measurand.

[4] Guidelines for CIPM Key Comparisons, March 1, 1999, http://www.bipm.org/utils/en/pdf/guidelines.pdf.