

A Question of Accuracy: What does it mean to be Traceable?

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Do you ever wonder if the ACME gadgets that Wile E. Coyote used in his endless pursuit of the Road Runner were traceable? And if they were, to what and how were these gadgets traceable? But more importantly, would the traceability of the ACME gadgets have helped the Coyote catch the Road Runner? Probably, only animation director Chuck Jones knows, but for a metrologist these questions are all valid and should be for providers and consumers alike.

In its *International Vocabulary of Basic and General Terms in Metrology (VIM)*,¹ the International Organization for Standardization (ISO) defines **traceability** as the “property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties.” In basic terms this means that a claim of traceability is meaningless without three elements: (1) a declaration of the source of traceability (e.g., standards or measurements provided by the *Bureau International des Poids et Mesures* – BIPM, or the National Institute of Standards and Technology – NIST, or a state office of weights and measures), (2) a full description of the traceability chain from the source to the measurement of interest, and (3) an uncertainty claim with supporting data. The responsibility for providing support for an uncertainty claim rests with the entity making the claim (i.e., the provider), but the responsibility for assessing the validity of such a claim rests with the consumer.

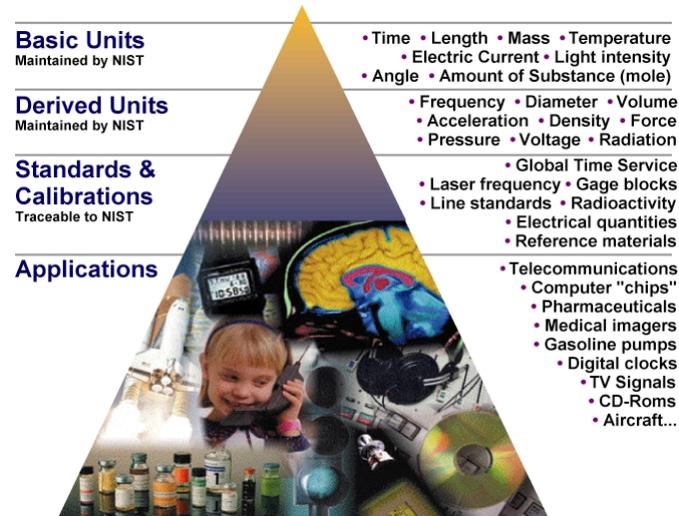


Figure 1. Measurement traceability pyramid in the U.S.

In many consumer-provider relationships, the accuracy of measurements is supported by a pyramid of traceability that starts with the basic, often national, measurement standards and ends in the realization of measurement system(s) appropriate for their needs. Such realization is often propagated through instrument manufacturers and providers of reference data and/or materials (see Figure 1). Many of the parameters of interest to the flow metrology community (e.g., flow, volume, density, viscosity, wind speed, etc.) are expressed in derived units of the *Système International d'Unités* (International System of Units, SI) and as such, they reside in the second tier of the traceability pyramid. The realization of these measurements places a special burden on metrologists given that a derived unit requires traceability to each of its individual basic unit components and yet its

realization may be in error due to a bias in it's the complete measurement system used. For such reasons, a second measurement characteristic known as **proficiency** – the demonstration of the measurement system competence – can be an important tool for the demonstration of traceability.

A measurement system (i.e., all elements required to make a measurement including metrologists, equipment, administration, etc.) demonstrates proficiency by using scientifically-sound measurement procedures and by confirming agreement among equivalent measurement systems via comparisons. These procedures and the results of comparisons are typically recorded in the laboratory's quality manual and supporting documentation and should be made available to the consumer upon request.² For instance, a secondary metrology flow laboratory calibrates a flow meter transfer standard, which is also calibrated by NIST. If the results from the two calibrations are in agreement within the expected uncertainty,³ the laboratory will have strengthened its claim of proficiency in that particular area of flow metrology.³ As this article does not deal specifically with proficiency testing, a more thorough treatment of the topic can be found in reference 4.

The **uncertainty** of the result of a measurement reflects the degree to which the true value of the measurand is known. It is estimated via a detailed assessment of all possible sources of variability in the measurement system. In 1993, the ISO standardized the way in which we estimate and express the uncertainty of measurement systems in their publication *Guide to the Expression of Uncertainty in Measurement* (referred to as the *Guide* or the GUM).⁵ Although a detailed description of the GUM is beyond the scope of this article there are a few main points that should be discussed. Following the procedure outlined in the GUM, the many sources of uncertainty in the result of a measurement are classified in two groups: Type A and Type B sources. *Type A* sources are those evaluated by statistical methods and *Type B* are those evaluated by other means. For example, a Type A uncertainty could be obtained from the standard deviation of repeated instrument observations, e.g., a thermometer, while a Type B uncertainty could arise from use of a first-order calculation of the change in the volume of a tank due to thermal expansion, when a higher order model more accurately reproduces tank characteristics. Once all the sources of uncertainty have been estimated, they are combined using a “root-sum-of-squares” method to obtain the *combined uncertainty* of the measurement. This number is then expanded by a *coverage factor* (*k*), which reflects the desired level of confidence to be associated with the interval provided by the final uncertainty number. This final number is referred to as the *expanded uncertainty*. In 1994, NIST prepared a brief interpretation of the GUM.⁶ This document is available online in the Technical Notes & Publications section of the NIST Fluid Flow Group web site, http://www.nist.gov/fluid_flow.

Flow Traceability

In the U.S., custody of the national flow standards the responsibility of the NIST Fluid Flow Group. In its laboratories in Gaithersburg, Maryland, the NIST Fluid Flow Group maintains standards for gas flow, water flow, hydrocarbon liquid flow, liquid volume and density, and wind speed. These standards are disseminated to the U.S. flow metrology community via: (a) calibration services (see Table 1), and (b) proficiency testing programs (also known as measurement assurance programs or MAPs). Laboratories may also participate in voluntary accreditation activities as a means of demonstrating competence and capability to its customers.

Service	Range		Expanded Uncertainty (k=2)	Units
	Min	Max		
Gas flow	1	78,000	0.20%	slm
Water flow	36	38,000	0.10%	slm
Hydrocarbon liquid flow	0.05	530	0.10%	slm
Liquid volume	1	7,600	25 ppm	liters
Liquid density	600	2,000	4 ppm	kg/m ³
Air speed	0.2	75	1.00%	m/s

Table 1. Calibration services provided by the NIST Fluid Flow Group.

An instrument **calibration** is the most convenient way of obtaining direct flow traceability to NIST. Using the services outlined in Table 1, NIST calibrates master flow instruments, which are then used elsewhere to calibrate instruments for field use. An advantage of this approach is that the customer obtains traceability to the national flow standards in one step. This compares favorably with the calibration of the same instrument at a secondary flow metrology laboratory where the resulting traceability chain is, by definition, at least two steps long (*i.e.*, NIST → secondary metrology laboratory → consumer’s instrument).

Measurement assurance programs enable participants to ascertain the long-term performance of their metrology programs – they provide traceability and demonstrate proficiency. A typical MAP starts with a careful study of the metrological needs of the participant. Based on such findings, participant personnel and NIST metrologists and statisticians design a robust testing program that makes use of a stable transfer instrument package. The transfer package may initially be tested at NIST to ascertain its precision, repeatability, and reproducibility.¹ Once the metrology team is satisfied that the transfer package meets the requirements of the MAP, the package is circulated among the participants, including NIST, the participating laboratories, and any other interested parties. The raw data obtained during testing is sent to NIST, as the MAP coordinator, for analysis and reports are issued on a prescribed schedule. Long duration MAPs may benefit participants to a greater degree because the longer-term stability of a metrology

program is documented. Since MAPs involve testing of the transfer package at the customers laboratory and at NIST, the results help demonstrate metrological proficiency. The typical cost of these programs in flow metrology is about one order of magnitude more than a conventional NIST calibration.

An additional form of verification of a laboratory's capability to provide measurement services traceable to the national standards is **laboratory accreditation**. A laboratory accreditation program entails a full evaluation of the customer's metrological capabilities. It requires a technical and administrative evaluation of their documented quality systems plus some form of proficiency testing. At NIST, the National Voluntary Laboratory Accreditation Program (NVLAP) provides accreditation services. Once an application for accreditation is received, NVLAP personnel assign a quality systems expert and a qualified technical assessor to perform the evaluation of the laboratory. The procedure typically takes about one year and the assessment is conducted on a cost-reimbursable basis. Accreditation differs from a measurement assurance program in a number of ways. First, the laboratory must operate under the umbrella of a well-structured quality system (see reference 2 as an example). Second, the laboratory provides uncertainty statements for its claimed measurement capabilities and these statements must be structured in accordance to some recognized standard (see reference 5 and 6 for guidance and reference 7 as an example). Third, the laboratory is required to have well documented traceability for all its instrumentation. Fourth, the laboratory agrees to correct any deficiencies that are encountered during the assessment prior to accreditation. Finally, the laboratory undergoes re-certification on a prescribed schedule. Aside from the obvious metrological benefits, laboratory accreditation brings the added benefit of international recognition of the laboratory's metrological capabilities. This international recognition is promoted through a number of Mutual Recognition Arrangements (MRAs) that NVLAP has signed with other accreditation bodies worldwide. For more information on laboratory accreditation and/or NVLAP, the reader is referred to the NVLAP web site <http://www.ts.nist.gov/nvlap> and reference 8.



The acceptance internationally of calibration certificates issued by NIST is promoted by *The Mutual Recognition Arrangement on National Measurement Standards and Calibration and Measurement Certificates Issued by National Metrology Institutes* (refer to as the MRA). To date, 43 countries, economies and international organizations have signed the agreement (see <http://www.bipm.fr> for more details). The main objectives of the MRA are: (1) establishing the degree of equivalence of national measurement standards maintained by National Metrology Institutes (NMIs); (2) providing for the mutual recognition of calibration and measurement certificates issued by NMIs; (3) providing governments and other parties with a secure technical foundation for wider agreements related to international trade, commerce and regulatory affairs.

Supporting the technical integrity of the MRA is a structure of national measurement standard comparisons between the signatory NMIs. These comparisons are organized under the auspices of the Consultative Committees of the *Comité International des Poids et Mesures* (CIPM – see <http://www.bipm.fr> for more details) and various Regional Metrology Organizations. As the NMI for the United States, NIST participates in these comparisons to confirm that the measurements of the same measurand conducted in two different countries agree within well quantified levels (i.e., demonstration of the degree of equivalence of national standards and proficiency among NMIs).

I suppose that at this point you must feel as confused and bewildered as Wile E. Coyote often did, but do not despair. The fundamental message is simple – there is more to traceability than claiming that you are traceable. A credible traceability claim is always followed by a declaration of the traceability chain, supported by data verifying the claim, and by a numerical value for the uncertainty of the measurement. There is more to good metrology than traceability – metrological proficiency is important, too. NIST provides instrument calibrations, measurement assurance programs, and laboratory accreditation programs to help you compete in the global economy with internationally recognized measurements. Metrological pyramids similar to that in Figure 1 in each country and the CIPM comparisons provide a measure of equivalence in the summits of such pyramids. NIST is not the ultimate metrological arbitrator, but it projects a strong and active voice among a group of international peers through ongoing comparisons to prove the proficiency of its metrological programs. Since the NIST calibration measurement capabilities

constantly change and improve, the most current information can be found at the NIST Fluid Flow Group web site, http://www.nist.gov/fluid_flow, and in the *NIST Calibration Services User's Guide*.⁹

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