1E. Metrological Traceability

Introduction:

Metrology is the science of measurements. A measurement result must be tied to a globally accepted standard to ensure uniformity and consistency of measurement results worldwide. Metrological traceability ties a measurement result made by a forensic science service provider (FSSP) to the International System of Units (SI).

Metrological Traceability Overview

Customers need work performed to be reliable and accurate. They also need to be assured that if the work is performed on a different day by the same provider or by another provider, the result will be similar and comparable within the stated measurement uncertainty. The need for reliability, uniformity, consistency, and comparability is the fundamental reason for establishing the traceability of a measurement result. The need for uniformity and consistency in measurements is not unique to forensic science but is also required in research, industry, and commerce.

Metrological traceability is only applicable to a measurement result. Measuring equipment and organizations do not have metrological traceability.

Sometimes the term metrological traceability is shortened to traceability. However, the entire term, metrological traceability, is preferred to avoid confusion with other concepts that use traceability to mean the history of an item, such as sample traceability, document traceability, equipment traceability, or material traceability.

Measurements

The measurement process may be a single step, such as a length measurement, or take many steps, such as quantifying the amount of a drug in blood. The measurement result may be reported, such as the weight of a seized drug, or the measurement may be part of a test, calibration, or inspection method where the reported result does not meet the definition of a measurement but instead meets the definition of a nominal property, such as a caliber of bullet (e.g., 9mm) or type of car (e.g., sedan/truck).

The International System of Units (SI)

The SI, commonly referred to as the metric system, is the international standard for measurement. The International Bureau of Weights and Measures (BIPM) is the organization that is tasked with ensuring worldwide uniformity of measurements traceable to the SI. Table 1 provides the seven base quantities in the SI, the base unit name, and the symbol.

Using these seven base units, users may make many more measurements from SI-derived units (e.g., kg·m/s2, which is a Newton), an SI prefix unit (e.g., giga, centi, milli), or by using a unit conversion (e.g., metric to U.S. customary units conversions).

Table 1: SI Base Units

BASE QUANTITY NAME	BASE UNIT NAME	SYMBOL
Time	second	s
Length	meter	m
Mass	kilogram	kg
Electric Current	ampere	A
Thermodynamic Temperature	kelvin	K
Amount Of Substance	mole	mol
Luminous Intensity	candela	cd

Source: NIST Special Publication 330:2019, Table 2

Metrological Traceability Chain

It is possible to tie a measurement result to the SI through a series of calibrations. This is called a metrological traceability chain. See Figure 1 for an example of a metrological traceability chain.



Provider Measurement Result
(e.g., weight, volume, length)

Provider Measuring Equipment
(e.g., balance, pipette, ruler)

Accredited Calibration Service Supplier
(1 or more between the provider and the NMI)

National Metrology Institute (NMI)
(e.g., National Institute of Standards and Technology (NIST)

International System of Units (SI)

Figure 1 Metrological Traceability Chain

In chemical analysis, metrological traceability is established through one or more calibration measurement standards called calibrators. If an FSSP prepares a calibrator, each piece of measuring equipment used in its preparation (i.e., pipette, volumetric flask, balance) will have been calibrated to establish metrological traceability of the measurement made using that measuring equipment. If the calibrator is a certified reference material, used exactly as provided by the reference material producer (RMP), the metrological traceability chain for the certified reference material will include the RMP and the calibration of the measuring equipment used in its production.

Establishing Metrological Traceability

Metrological traceability is established by considering and then ensuring the following[1]:

a) The measurand, the quantity to be measured, is defined.
b) A documented unbroken chain of calibrations is established between the measurement being made back to stated and appropriate references (appropriate references include national or international standards and intrinsic standards).
c) Measurement uncertainty for each step in the traceability chain is evaluated according to agreed methods.
d) Each step of the chain is performed in accordance with appropriate methods, with the measurement results and with associated, recorded measurement uncertainties.
e) The organizations performing one or more steps in the chain supply evidence of their technical competence.

Maintaining Metrological Traceability

It is not enough to merely establish metrological traceability for a measurement process. Maintenance of metrological traceability (i.e., continued metrological confirmation and statistical control of the measurement process) is necessary for subsequent measurement results to have this property.

A proper measurement assurance program, part of overall quality assurance, must be established to ensure the ongoing validity of the measurement process and the accuracy of the reference standard used at the time of the measurement.

Forensic Science Examples:

Table 2: Examples of Measuring Equipment Used by FSSPs and the Corresponding SI Base Quantity for the Measurement Made

MEASURING EQUIPMENT	SI BASE QUANTITY
Balances	Mass
Calipers	Length
Pipettes	Derived from Mass
Rulers/Tapes	Length
Thermometers	Temperature
Trigger-Pull Devices	Derived from Mass
Voltmeters	Derived from Electric Current
Volumetric Glassware	Derived from Mass

Measurements made by FSSPs include, but are not limited to, determinations of the following:

- Concentration (e.g., 0.187 g/dL ethanol in blood)
- Length (or height or size) (e.g., firearm barrel length of 16 inches)
- Refractive index (e.g., glass refractive index of 1.522409)
- Temperature (e.g., ethanol and water wet bath simulator temperature of 34.2^0 C)
- Volume (e.g., volume of liquid 67.4 mL)
- Weight (e.g., net weight 29.4 grams)

Key Takeaways

1. If the reported result is a measurement result, or if the measurement will affect the validity of the reported result, ensure:
   - Metrological traceability was established.
   - The measuring equipment was calibrated or certified reference material was provided by an appropriately accredited service provider.

Related Primers

Accreditation and Certification

Quality Assurance versus Quality Control

Measurement Uncertainty, Frequency Data and Error Rates

Learn More

Eurachem Education and Training Working Group's Terminology in Analytical Measurement: Introduction to VIM 3

International Bureau of Weights and Measures (BIPM), SI Brochure: The International System of Units (SI)

International Vocabulary of Metrology's (VIM), JCGM 200:2012

NIST Resources:
- SI Units
- Metrological Traceability: Frequently Asked Questions and NIST Policy
- GMP 13 – Good Measurement Practice for Ensuring Metrological Traceability

Footnote

1. International Organization for Standardization. (2017). General requirements for the competence of testing and calibration laboratories, Annex A. ISO/IEC 17025:2017. Geneva Switzerland.

Glossary: Primer 1E Metrological Traceability

Term	Definition	Reference	Primer Nos.
Calibration	The operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication	JCGM 200:2012, International vocabulary of metrology – Basic and general concepts and associated terms (VIM), Joint Committee for Guides in Metrology (JCGM)	1E Metrological Traceability
Calibrator	Measurement standard used in calibration	JCGM 200:2012, International vocabulary of metrology – Basic and general concepts and associated terms (VIM), Joint Committee for Guides in Metrology (JCGM)	1E Metrological Traceability
Certified reference material (CRM)	Reference material, accompanied by documentation issued by an authoritative body and providing one or more specified property values with associated uncertainties and traceabilities, using valid procedures	JCGM 200:2012, International vocabulary of metrology – Basic and general concepts and associated terms (VIM), Joint Committee for Guides in Metrology (JCGM)	1E Metrological Traceability
Measurement	Process of experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity	JCGM 200:2012, International vocabulary of metrology – Basic and general concepts and associated terms (VIM), Joint Committee for Guides in Metrology (JCGM)	1E Metrological Traceability; 2F Measurement Uncertainty, Frequency Data and Error Rates
Measurement result	Set of quantity values being attributed to a measurand together with any other available relevant information	JCGM 200:2012, International vocabulary of metrology – Basic and general concepts and associated terms (VIM), Joint Committee for Guides in Metrology (JCGM)	1E Metrological Traceability

Term	Definition	Reference	Primer Nos.
Metrological traceability	Property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty	JCGM 200:2012, International vocabulary of metrology – Basic and general concepts and associated terms (VIM), Joint Committee for Guides in Metrology (JCGM)	1E Metrological Traceability
Metrological traceability chain (traceability chain)	Sequence of measurement standards and calibrations that are used to relate a measurement result to a reference	JCGM 200:2012, International vocabulary of metrology – Basic and general concepts and associated terms (VIM), Joint Committee for Guides in Metrology (JCGM)	1E Metrological Traceability
Nominal property	Property of a phenomenon, body, or substance, where the property has no magnitude	JCGM 200:2012, International vocabulary of metrology – Basic and general concepts and associated terms (VIM), Joint Committee for Guides in Metrology (JCGM)	1E Metrological Traceability
Reference measurement standard (reference standard)	Measurement standard designated for the calibration of other measurement standards for quantities of a given kind in a given organization or at a given location	JCGM 200:2012, International vocabulary of metrology – Basic and general concepts and associated terms (VIM), Joint Committee for Guides in Metrology (JCGM)	1E Metrological Traceability