MEASURE FOR MEASURE

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Accuracy Matters

Understanding and communicating measurement uncertainties

Editor's note: This is part one of a two-part series that explores accuracy in measurement results. Look for part two in July's column.

MANY DECISIONS ARE based on accurate measurement results, such as: "Should medicine be prescribed for high cholesterol or high glucose?" or "Should a measuring instrument or standard be adjusted to meet tolerances?"

The answers are based on measurement results. And as a patient, scientist, citizen or policymaker, we make assumptions about the accuracy of measurement results in reports and calibration certificates. We assume they're good, right, or to say it more correctly, "They're accurate." But note that accuracy is often defined as hitting the center of a target or true value.

One of our colleagues regularly says, "The only true value is on a sign above a hardware store." But people who use measurements often trust the accuracy of their measurement results—usually without question, believing the results are "good and right."

A measurement result alone is incomplete without some assessment and measure of reported uncertainty. People can estimate the temperature outside on a warm spring day within a few degrees based on their experience. But if we use a thermometer, our first hope is that it's accurate and gives us the correct or right temperature. After this, we must consider the resolution of the standard: "Is the readability of the thermometer 1 degree Celsius, 0.1 degree or 0.01 degree?"

Our confidence that the results are right will depend on the readability or resolution of the standard or measuring instrument. Our confidence shouldn't be based on a calculator or spreadsheet giving us a calculated value to 15 decimal places when the resolution or uncertainty is a fraction of that.

Repeatability

Repeatability of an instrument or standard also is a variable of concern. Many people naturally repeat measurements to get a sense of whether multiple values agree. We use simple measurements in daily life, such as stepping on a scale to monitor your weight or checking a vehicle's mileage to calculate fuel efficiency.

Assigning uncertainty to a measurement result is a rigorous, documented and validated process that is assessed nearly as often as the measurement results themselves. Measurement scientists often use internationally accepted procedures to obtain standardized measurement results. They also use the *Guide to the Expression of Uncertainty in Measurement* for evaluating and reporting associated uncertainties.[1]

The readability (or resolution and repeatability) of measurement results gives a sense of confidence (or lack thereof), and these also have associated measures of uncertainty. It's a wise practice to ask for the measurement uncertainty and use it to assess the quality and precision of a measurement result. Uncertainty values provide confidence in the measurement result: It quantifies the boundaries or limits within which a measurement result should agree with a true quantity value.

Terms and communication

Accurate measurement results and associated uncertainties must be communicated. This could be in a newspaper, a scientific paper or on a calibration certificate. This also means it's critical to have accuracy in our words and measurement results.

Guiding documents help standardize communication: *The International Vocabulary of Metrology* (VIM) provides guidance on terms used with measurement and calibration results.[2] When measurement professionals use terms such as "accuracy," "traceability," "uncertainty" and "reference standards," they have specific meanings that should be used by every scientist.

For example, the VIM defines "accuracy"—as it's related to a measurement result—as the "closeness of agreement between a measured quantity value and a true quantity value of a measurand." According to the VIM, "measurand" is "the quantity intended to be measured." This definition of accuracy also includes three explanatory notes:

1. "The concept 'measurement accuracy' is not a quantity and is not given a numerical quantity value. A measurement is said to be more accurate when it offers a smaller measurement error."
2. "The term 'measurement accuracy' should not be used for measurement trueness, and the term 'measurement precision' should not be used for 'measurement accuracy', which, however, is related to both of these concepts."
3. "'Measurement accuracy' is sometimes understood as closeness of agreement between measured quantity values that are being attributed to the measurand."[3]

If measurement results between or among laboratories are compared, scientists must be able to talk about the same things. This is why standardized definitions are essential: They can prevent confusion in communicating measurement results.

Units, symbols and results

Measurement results must communicate proper quantities, units and symbols. Many countries adopt the International System of Units (SI, also known as the metric system) as the reference basis for measurement results. There also is a reference document for presenting measurement units, symbols and results.[4]

The U.S. Metric Program of the National Institute of Standards and Technology (NIST), Office of Weights and Measures, helps implement the national policy to establish the SI as the preferred system of weights and measures for U.S. trade and commerce. It provides leadership and assistance on SI use and conversion to federal agencies, state and local governments, businesses, trade associations, standards-development organizations, educators and the general public.

NIST Special Publication (SP) 330[5] and NIST SP 811[6] provide the legal interpretation of and guidelines for SI use in the United States. These publications provide standardized guidance on how measurement units and results should be presented in writing.

Black dots

We like to ask, "If the measurement scientists don't get the communication of measurement results right, who will?" Regularly reviewing measurement results and uncertainties on calibration certificates and in laboratory documents yield numerous errors that can negatively affect interpretations of results by users.

Errors are often observed in the following situations:

- Measurement uncertainties are not included, are incomplete, are inaccurate, or are not properly rounded.
- Incorrect terminology is used.
- Typos are left uncorrected.
- Unit conversions are wrong.
- Incorrect units and symbols are presented, or correct units are inconsistently used.

We refer to these errors as "black dots." To customers, a black dot on a clear page is what they notice. This blemish is what they will remember, regardless of the other accurate information presented. Errors in reporting results can lead to confusion or bad decisions by users—often with critical effects. Black dots can destroy laboratory credibility.

> "Standardized definitions **are essential:** They can **prevent confusion in communicating** measurement results."

There are examples of black dots in daily life and news headlines, such as:

- In 1998, NASA's Mars climate orbiter was lost after a failure to communicate requirements and convert measurement units from two measurement systems.[7]
- In 2003, Disneyland Tokyo's Space Mountain roller coaster accident highlighted a scenario in which axle-and-bearing design specifications were converted to metric units and implemented in the ride. After time passed, routine maintenance called for bearing replacements. Instead of being replaced with metric-designed bearings, they were replaced with the incorrect size based on the original, nonmetric design. This created a gap between the axle and bearing. Eventually, the extra vibration and stress caused the axle to fail, derailing the roller coaster. Luckily, no passengers were injured.[8]

Document control, version control and archiving records are essential tools for ensuring changes made over time are effectively communicated to all personnel affected by a change. Failure to adequately control laboratory documents, such as calibration certificate templates, can be the root cause of black dots that are released to customers.

Avoiding black dots is fundamental to ensuring communication of accurate measurement results. Reviewing for typos, grammatical errors, accurate terminology, completeness, and use of appropriate measurement units and symbols is essential. The second part of this article will offer suggestions to improve the quality, accuracy and communication of measurement results. QP

REFERENCES

1. Joint Committee for Guides on Metrology (JCGM), *Evaluation of Measurement Data—Guide to the Expression of Uncertainty in Measurement*, first edition, 2008, http://tinyurl.com/evaluationofmeasurement.
2. JCGM, *International Vocabulary of Metrology—Basic and General Concepts and Associated Terms (VIM)*, third edition, 2012, http://tinyurl.com/vimterms.
3. Ibid.
4. The International Bureau of Weights and Measures, *The International System of Units (SI)*, eighth edition, 2006, http://tinyurl.com/international-si.
5. Barry N. Taylor and Ambler Thompson, eds., *The International System of Units (SI)—Special Publication 330*, 2008 edition, National Institute of Standards and Technology (NIST), http://tinyurl.com/nistsp330.
6. Barry N. Taylor and Ambler Thompson, eds., *Guide for the Use of International System of Units (SI)—NIST Special Publication 811*, 2008 edition, NIST, http://tinyurl.com/nist-sp811.
7. U.S. Metric Association, "Unit Mixups," www.us-metric.org/unit-mixups.
8. Ibid.

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Write It Right

Understanding nuances of metrics in technical writing

Editor's note: This is part two of a two-part series exploring accuracy in measurement results. Part one appeared in May 2016's QP.

MANY QUESTIONS ARISE while you're writing laboratory documents, clarifying measurement results or implementing measurement system best practices. The proper use of measurement units and symbols in laboratory documents—such as calibration reports, control charts, uncertainty tables or standard operating procedures—is critical to effectively communicate technical information.

The National Institute of Standards and Technology (NIST) was delegated the responsibility to interpret or modify the International System of Units (SI, also known as the metric system) for use in the United States. To accomplish this, NIST provides several SI resources to support sectors of science, technology, trade and commerce. It also serves as the U.S. technical representative to the International Bureau of Weights and Measures (BIPM) that defines the SI. These publications are used to guide the measurement unit style in technical and documentary standards.

NIST Special Publication (SP) 330 and *NIST SP 811* provide the legal interpretation of and guidelines for SI use in the United States. *NIST SP 811* also provides detailed rules for SI writing style, including a useful editorial checklist.[1, 2]

Striving for zero errors

NIST SP 811 is written for technical audiences, such as engineers, scientists and academics. Appendix B provides rounding guidance and unit-conversion factors for a broad set of measurement units. NIST published several similar technical guides, including the *Metric Style Guide for the News Media*, which provides condensed SI content to highlight commonly used measurement information.[3] A convenient hub of SI style guidance also is available on the NIST metric program's website.[4]

Use a leading zero: For numbers less than one, a zero is written before the decimal point.[5] This ensures a quantity is appropriately interpreted and helps avoid consequences of a misplaced decimal point. Without a leading zero, a value like .25, for example, could be misinterpreted as 25, an error that makes it 100 times greater in magnitude. Such an error could seriously harm a patient if the quantity represented a medication dose.

> “There are **many resources** that can help you **avoid being responsible** for inaccuracies in measurement reporting.”

Avoid unit-conversion errors: Using the SI reduces the number of errors associated with measurement conversions between U.S. customary units and the SI. Eliminating conversions altogether negates the need to document which conversion factors are being used and their sources. Conversion calculations require rigorous software validation, which is a time-consuming process. At best, conversion-calculation errors can cause expensive mistakes. At worst, their consequences can be a matter of life and death.

Ground control to accuracy

The 1999 crash of NASA's $125 million NASA Mars climate orbital spacecraft served as a wake-up call for potential errors related to working with multiple measurement systems. The mishap occurred because the spacecraft entered the Mars atmosphere on a trajectory that was too low.[6]

NASA later identified the root cause of the erroneous trajectory and velocity calculations: A contractor failed to use SI units of force (Newton, or N) as specified by NASA in the coding of a ground software file used in trajectory models. One corrective action that NASA recommended was to perform software audits to evaluate specification compliance on all data transferred between NASA and the contractor.[7]

Language arts

Several helpful conversion-factor resources have been made available on the NIST metric program's website.[8] Caution is recommended to organizations developing unit-conversion software or using online calculators for technical purposes. It's important to conduct a rigorous validation and verification analysis before using unit-conversion software.

Spelling and pronunciation of measurement units—This can be challenging. Advantages of the SI over the many other historic and customary measurement unit systems is that the SI provides a coherent set of internationally accepted unit symbols that can be used to communicate across all languages. Table 1 provides examples of how unit names are translated in several languages:

In *NIST SP 811*, words are spelled in accordance with the *U.S. Government Printing Office Style Manual* (U.S. Government Publishing Office, 2008), which follows *Webster's Third New International Dictionary of the English Language* (Merriam-Webster, 1993). The spellings "meter," "liter" and "deka" are used rather than "metre," "litre," and "deca" as in the original BIPM English text of the SI brochure.

The BIPM SI brochure is the definitive international reference on the SI.[9] The text is published in French and English, and has been translated into many other languages.

Capitalization of units, symbols and prefixes—Unit names start with a lowercase letter except at the beginning of the sentence or title, such as "pascal," "becquerel," "newton" or "tesla." For degrees Celsius (symbol °C), the unit "degree" is lowercase. But the modifier "Celsius" is capitalized because it's a person's name. A space is left between the numerical value and the unit symbol, and values are not hyphenated. For example: 20 °C and 10 kg are correct; 20°C, 20° C, 10-kg or 10kg are incorrect. If a unit name is spelled out during use, normal grammar rules apply.

Unit symbols are written in lowercase letters (such as "m" for meter, "s" for second or "kg" for kilogram). But symbols for units derived from the name of a person are capitalized—such as W for watt, V for volt, Pa for pascal or K for kelvin. The recommended symbol for "liter" in the United States also is capitalized as L to avoid misinterpreting "l" with the number one. A period should not be used following a unit symbol or abbreviation. For example, gram is represented as "g" not "g." Symbols of prefixes that mean a million or more are capitalized, and those that are less than a million are lowercased. For example, M for mega (millions) and "m" for milli (thousandths).

U.S. customary units—After the SI was developed, many style requirements were applied to non-SI measurement systems, including U.S. customary units—such as inch, foot, yard, mile, ounce, pound, gill or gallon. Although NIST does not publish a style resource for U.S. customary units, appendix C of NIST's Handbook 44, "General Tables of Units of Measurement," is a good resource for U.S. customary units used in trade and commerce, their relationships, and unit-conversion factors.[10]

Because the SI is critical as an international standard, its use in product design, manufacturing, marketing and labeling is essential for the U.S. industry's success in the global marketplace. NIST's metric program encourages using the SI in all facets of education, including honing workers' skills.

The successful voluntary transition of the United States to the SI is a critical factor in the competitive economic success of industry.[11] Accuracy in terminology use, measurement results and measurement units is necessary to avoid the embarrassment of having others find your "black dots" (errors that can negatively affect interpretations of your results in scientific communications). There are many resources that can help you avoid being responsible for inaccuracies in measurement reporting. **QP**

Unit name translations / TABLE 1

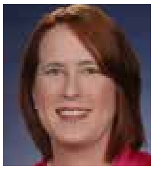
	Unit symbol		
Language	**m**	**s**	**kg**
English (U.S.)	meter	second	kilogram
Spanish	metro	segundo	kilogramo
Italian	metro	secóndo	chilogrammo

Source: James R. Frysinger, "SI Crosses All Language Barriers," Metricmethods.com, http://tinyurl.com/si-crosses-language.

Note: SI refers to the International System of Units, also known as the metric system.

REFERENCES AND NOTE

1. Barry N. Taylor and Ambler Thompson, eds., *The International System of Units (SI)—Special Publication 330*, 2008 edition, National Institute of Standards and Technology (NIST), http://tinyurl.com/nistsp330.
2. Barry N. Taylor and Ambler Thompson, eds., *Guide for the Use of International System of Units (SI)—NIST Special Publication 811*, 2008 edition, NIST, http://tinyurl.com/nist-sp811.
3. NIST, *Metric Style Guide for the News Media*, 1997, http://tinyurl.com/metric-style-guide.
4. "Writing With SI (Metric) Units," NIST.gov, http://tinyurl.com/si-writing.
5. Taylor, *Guide for the Use of International System of Units (SI)—NIST Special Publication 811*, see reference 2.
6. Robin Lloyd, "Metric Mishap Caused Loss of NASA Orbiter," CNN.com, Sept. 30, 1999, http://tinyurl.com/mars-metric.
7. "Mars Climate Orbiter Mishap Investigation Board Phase I Report," NASA, Nov. 10, 1999, http://tinyurl.com/nasa-orbiter-report.
8. "Unit Conversion," NIST.gov, http://tinyurl.com/nist-unit-conversion.
9. International Bureau of Weights and Measures, *The International System of Units (SI)*, eighth edition, 2006, http://tinyurl.com/bipm-si-brochure.
10. Tina Butcher, Steve Cook, Linda Crown and Rick Harshman, eds., *Specifications, Tolerances, and Other Technical Requirements for Weighting and Measuring Devices—NIST Handbook 44*, NIST, 2012.
11. If you have a question about metric system use, style or related publications, send it to thesi@nist.gov.



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