Uncertainty: Part 1, Relation to Precision

By Neil Ullman and John Carson

Q How are precision and uncertainty related?

A ASTM mandates that every new or existing test method should provide a statistical estimate of the degree of variation in results due to the test method. This should be recognized as an essential asset for both laboratories and users of the test results. Within ASTM this variation is described in the precision statement for the test method and is generally estimated through an interlaboratory study.

The measures of precision called for in *Form and Style for ASTM Standards* (A21.2) involve (1) repeatability, which examines typical random variation that a hypothetical "average analyst" in an "average laboratory" would experience when performing the test multiple times in the shortest period, and (2) reproducibility, which attempts to estimate the random variation among different laboratories with different operators, equipment, and training, executing the same test with the same stable reference material. The terms repeatability and reproducibility are defined in E177, Practice for Use of the Terms Precision and Bias in ASTM Test Methods. Implementing an interlaboratory program to obtain actual estimates of repeatability and reproducibility is described in E691, Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method.

The estimates of repeatability and reproducibility from an ILS are only as good as the number and appropriateness of the participants who contribute actual measurements. These precision values are truly statistical in nature and depend on having sufficient numbers of laboratories involved in the study. When the ILS includes a variety of laboratories engaged in routine use of the test method without major modification, then the estimates of reproducibility and repeatability will also have incorporated different operators with different training, different equipment in different environmental settings, and other relevant possible causes of variation. The result will be improved quality in these estimates of precision.

MEASUREMENT UNCERTAINTY

In 1993 the international organizations involved in metrology developed a standard called the "Guide to the Expression of Uncertainty in Measurement," generally referred to as the GUM.[1] This originated through the national laboratories who administer the official SI units of measurement and as such need to examine how errors might crop into the national physical standards such as the meter and volt.

The GUM presents methods for estimating precision of measurement that include all causes of variation that a laboratory might encounter over time. It describes estimates using actual data from the laboratory (Type A estimates) and estimates based on assumptions rather than actual data (Type B estimates). The final output is uncertainty of measurement, which can then be used to provide an interval around a future measurement that should include, with pre-specified probability, the true value you are interested in. The uncertainty formally applies to a specific laboratory implementing a

specified test method, and the interval applies to a specific measurement carried out in a specific laboratory implementing a specified test method. ASTM members will find ASTM E2655, Guide for Reporting Uncertainty of Test Results and Use of the Term Measurement Uncertainty in ASTM Test Methods, to be a useful reference.

In 1999, ISO/IEC 17025 was adopted, which instituted accreditation requirements for the competence of testing and calibration laboratories. This required establishing measurement uncertainty estimates for all test methods. Today this is a major reason for laboratories to address the issue of measurement variability.

For ASTM standards, *Form and Style* **(A22.1) states:**

> Measurement uncertainty is an estimate of the magnitude of systematic and random measurement errors that may be reported along with the measurement result. An uncertainty statement relates to a particular result obtained in a laboratory carrying out the test method, as opposed to precision and bias statements which are mandatory parts of the method itself and normally derived from an interlaboratory study conducted during development of the test method.

PRECISION, REPEATABILITY, AND UNCERTAINTY

A single analyst/instrument at your laboratory will get varying results from testing a stable reference material over a short period of time. This is repeatability specific to your laboratory. Because of changing environmental conditions, calibrations, and other factors, the expected variation for measurements over time is greater than that for repeated measurements over a short period of time. However, your lab may have several instruments and/or operators. This again increases the expected variation for measurements of a stable reference material. ASTM's committee on quality and statistics (E11), calls this within-laboratory variation over time, combining different sources of variation, "intermediate precision." Others call it "laboratory precision" or "site precision." This is a property not of the test method itself but of the test method as implemented by a particular laboratory.

Remember, an ILS requires the participation of many laboratories, which we hope are representative of all of those that typically use the test method. Thus, the repeatability estimate from an ILS only provides an expectation of repeatability for a typical laboratory. The repeatability estimated by conducting a suitable study in a particular laboratory will necessarily be different from that estimated in an ILS. We expect that the standard deviation under intermediate precision conditions at any particular laboratory should be smaller than the reproducibility standard deviation as reported in an ILS but larger than the repeatability standard deviation published in the test method. But exceptions to this are not too unusual, especially if only a small number of laboratories participated in the ILS or if the ILS was not recent, since instrumentation tends to improve over time.

Measurement uncertainty expressed as a standard deviation is essentially intermediate precision. It is the responsibility of every laboratory accredited under ISO/IEC 17025 to evaluate its own uncertainty associated with its tests. E11 has recommended that only results of studies conducted with real data, Type A estimates, should be utilized. E11 recommends, where possible, determining repeatability and intermediate precision in your lab using control charts, as described in ASTM E2554, Practice for Estimating and Monitoring the Uncertainty of Test Results of a Test Method Using Control Chart Techniques. This approach is useful as you can also monitor measurement uncertainty and use the chart as a tool for improving your measurement process and reducing the uncertainty of your lab measurements.

The next installment in this series discusses the role of studies and Bayes' Rule in estimating measurement uncertainty.

REFERENCE

1. Joint Committee for Guides in Metrology, 100:2008. Evaluation of measurement data – Guide to the expression of uncertainty in measurement, Geneva, Switzerland, Joint Committee for Guides in Metrology, 2008.

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