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Standard Guide for Preparing and Interpreting Precision and Bias Statements in Test Method Standards Used in the Nuclear Industry¹

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INTRODUCTION

Test method standards are required to contain precision and bias statements. This guide contains a glossary that explains various terms that often appear in these statements as well as an example illustrating such statements for a specific set of data. Precision and bias statements are shown to vary according to the conditions under which the data were collected.

1. Scope

1.1 This guide covers terminology useful for the preparation and interpretation of precision and bias statements. This guide does not recommend a specific statistical method. It provides awareness of terminology and approaches and options to use for precision and bias statements.

1.2 In formulating precision and bias statements, it is important to understand the statistical concepts involved and to identify the major sources of variability that affect results. [Appendix X1](#) and [Appendix X2](#) provide a brief summary of these concepts.

1.3 To illustrate the statistical concepts and to demonstrate some sources of variability, a hypothetical data set has been analyzed in [Appendix X2](#). Reference to this example is made throughout this guide.

1.4 It can be difficult to ship nuclear materials for interlaboratory testing. When this is the case, precision statements may reflect only within-laboratory variability.

1.5 No units are used in this statistical analysis.

1.6 This guide does not involve the use of materials, operations, or equipment and does not address any risk associated.

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recom-*

mendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 *ASTM Standards:*²

[C859 Terminology Relating to Nuclear Materials](#)

[E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods](#)

[E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method](#)

[E2586 Practice for Calculating and Using Basic Statistics](#)

[E2655 Guide for Reporting Uncertainty of Test Results and Use of the Term Measurement Uncertainty in ASTM Test Methods](#)

2.2 *Joint Committee for Guides in Metrology Standards:*³

[JCGM 100:2008 Evaluation of Measurement Data—Guide to the Expression of Uncertainty in Measurement \(GUM 1995 with Minor Corrections\)](#)

3. Terminology

3.1 For definitions of terms used in this guide but not defined herein, see Terminology [C859](#).

3.2 *Terminology for Precision and Bias Statements:*

3.2.1 *accuracy, n*—the closeness of agreement between a measurement result and an accepted reference. [C859](#)

3.2.2 *analysis of variance (ANOVA), n*—the body of statistical theory, methods, and practices in which the variability in a set of data is partitioned into identifiable sources of variability.

¹ This guide is under the jurisdiction of ASTM Committee [C26](#) on Nuclear Fuel Cycle and is the direct responsibility of Subcommittee [C26.08](#) on Quality Assurance, Statistical Applications, and Reference Materials.

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ Available from Bureau International des Poids et Mesures (BIPM), www.bipm.org.

3.2.2.1 *Discussion*—Sources of variability may include analysts, instruments, samples, time and laboratories. To use the analysis of variance, the data collection method must be carefully designed based on a model that includes all the sources of variability of interest. (See Example, X2.1.6.)

3.2.3 *bias, n*—the difference between the expectation of the test results and an accepted reference value. **E177**

3.2.4 *precision, n*—the closeness of agreement between independent test results obtained under stipulated conditions. **E177**

3.2.5 *propagation of variance, n*—a procedure by which the mean and variance of a function of one or more random variables can be expressed in terms of the mean, variance, and covariances of the individual random variables themselves (Syn. *variance propagation, propagation of error*).

3.2.5.1 *Discussion*—There are a number of simple exact formulas and Taylor series approximations which are useful here (1 and 2).⁴

3.2.6 *random error, n*—a component of the error that, in the course of a number of measurement results of the same measurand, varies in a random way (adapted from Guide E2655).

3.2.7 *random sample (measurements), n*—a set of measurements taken on a single item or on similar items in such a way that the measurements are independent and have the same probability distribution.

3.2.7.1 *Discussion*—Some authors refer to this as a simple random sample. One must then be careful to distinguish between a simple random sample from a finite population of N items and a simple random sample from an infinite population. In the former case, a simple random sample is a sample chosen in such a way that all samples of the same size have the same chance of being selected. An example of the latter case occurs when taking measurements. Any value in an interval is considered possible and thus the population is conceptually infinite. The definition given in 3.2.7 is then the appropriate definition. (See *representative sample* and Appendix X4.)

3.2.8 *range, n*—maximum value minus the minimum value in a sample. **E2586**

3.2.9 *relative standard deviation, n*—the sample standard deviation divided by the sample mean.

3.2.9.1 *Discussion*—The RSD can be expressed as a percent by multiplying by 100 %. The RSD is calculated using the following equation,

$$RSD = \frac{s}{\bar{x}} \quad (1)$$

where:

s = sample standard deviation, and
 $\bar{x}$ = sample mean.

3.2.9.2 *Discussion*—The use of the RSD (RSD, %) to describe precision implies that the uncertainty is a function of the measurement values.

3.2.10 *repeatability, n*—intrinsic variability due solely to the measurement procedure, excluding all variability from factors such as analyst, time and laboratory.

3.2.11 *representative sample, n*—a generic term indicating that the sample is typical of the population with respect to some specified characteristic(s).

3.2.11.1 *Discussion*—Taken literally, a representative sample is a sample that represents the population from which it is selected.

3.2.12 *reproducibility, n*—variability in the measurement results due to factors such as analyst, apparatus, environmental conditions and laboratory.

3.2.13 *standard deviation, n*—of a population, σ , the square root of the average or expected value of the squared deviation of a variable from its mean; of a sample, s , the square root of the sum of the squared deviations of the observed values in the sample from their mean divided by the sample size minus 1. **E2586**

3.2.13.1 *Discussion*—The practice of associating the $\pm$ symbol with standard deviation (or RSD) is not recommended. The $\pm$ symbol denotes an interval. The standard deviation is not an interval and it should not be treated as such. If the $\pm$ notation is used as in, “The fraction of uranium was estimated as 0.88 ± 0.01 ,” a footnote should be added to clearly explain what is meant.

3.2.14 *standard deviation of the mean (sample), n*—the sample standard deviation divided by the square root of the number of measurements used in the calculation of the mean (Syn. *standard error of the mean*).

3.2.14.1 *Discussion*—The equation for standard deviation of the mean is:

$$s_{\bar{x}} = \frac{s}{\sqrt{n}} \quad (2)$$

where:

$s_{\bar{x}}$ = standard deviation of the mean of a set of measurements,
 s = standard deviation of the set, and
 n = number of measurements in the set.

3.2.15 *systematic error, n*—a constant deviation that is present in all members of a set of measurements.

3.2.15.1 *Discussion*—Systematic error is sometimes confused with intermediate deviations which are constant within a given subgroup of the population, but differ between subgroups. For example, in the case of a set of measurements performed by a single analyst over a number of days, the systematic deviation is constant on all days, while an intermediate deviation is constant within a given day but differs for each day.

3.2.16 *uncertainty, n*—an indication of the magnitude of error associated with a value that takes into account both systematic errors and random errors associated with the measurement or test process. **E2655**

3.2.16.1 *Discussion*—Uncertainty applies to a given set of measurements, not to a method, contrasted with precision and bias which pertain to a method. Furthermore, precision and bias may be incorporated into the estimate of uncertainty.

⁴ The boldface numbers in parentheses refer to the list of references at the end of this guide.

a measurement, but the combined uncertainty may include other contributors in addition to precision and bias. As of the publication of this standard, the accepted way to estimate uncertainty is defined in The Guide to the Expression of Uncertainty in Measurement (GUM).

3.2.17 *variance (sample)*, n —square of the standard deviation of the sample. **E2586**

3.2.17.1 *Discussion*—The equation that expresses this definition is as follows:

$$s^2 = \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2 \quad (3)$$

where:

s^2 = sample variance,
 n = number of results obtained,
 x_i = i th individual result, and
 $\bar{x}$ = sample mean ($\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i$).

4. Significance and Use

4.1 To describe the performance of a standard test method, precision and bias statements are required.⁵ Committee E11 on Probability and Statistics has published standards addressing these terms and the preparation of precision and bias statements; these include Practices **E177** and **E691**. These practices should not be used in cases where small numbers of test results do not support statistical normality.

4.2 The intent of this guide is to help analysts prepare and interpret precision and bias statements. It is essential that, when the terms are used, their meaning should be clear and easily understood.

4.3 **Appendix X1** and **Appendix X2** provide the theoretical foundation for precision and bias concepts and Practice **E691** addresses the problem of sources of variability. To illustrate the interplay between sources of variability and formulation of precision and bias statements, a hypothetical data set is analyzed in **Appendix X2**. This example shows that depending on how the data was collected, different precision and bias statements are possible. Reference to this example will be found throughout this guide.

4.4 There has been much debate inside and outside the statistical and metrological community on the exact meaning of some statistical terms. Thus, following a number of the terms in Section 3 is a list of several ways in which that term has been used. This listing is not meant to indicate that these meanings are equivalent or equally acceptable. The purpose here is more to encourage clear definition of terms used than to take sides. When these terms are used, they should be defined clearly.

4.5 This guide is intended as an aid to understanding the statistical concepts used in precision and bias statements. There is no intention that this be a self-contained introduction to statistics. Since many analysts have no formal statistical training, it is advised that a trained statistician be consulted for further clarification if necessary.

5. Precision and Bias Considerations

5.1 Bias:

NOTE 1—Bias represents a constant error as opposed to a random deviation.

5.1.1 A method bias can be estimated by the difference between a measured average and an accepted reference value. The data from which the estimate is obtained should be statistically analyzed to establish bias in the presence of random deviations. The effects of random deviations are minimized by taking the average of a large set of test results (Practice **E177** recommends greater than 30). The basic test for bias is if the difference between the measured average value and the accepted reference value is statistically significant. The test must include all sources of measurement variability and uncertainty of reference values.

5.1.2 The bias of a test method is also commonly indicated by analytical chemists as percent recovery. A number of repetitions of the test method on a reference material are performed, and an average percent recovery is calculated. This average provides an estimate of the test method bias, which is multiplicative in nature, not additive.

5.1.3 If no material with an accepted reference value exists, then a bias statement cannot be made.

5.2 Precision:

5.2.1 It is important that some quantitative measure be used to specify precision. A statement such as, “The precision is 1.54 g” is useless. Measures frequently used to express precision are standard deviation, relative standard deviation, variance, repeatability, reproducibility, confidence interval, and range. In addition to specifying the measure and the precision, it is important that the number of repeated measurements upon which the precision estimated is based also be given. (See Example, **Appendix X2**.)

5.2.1.1 It is strongly recommended that a statement on precision of a measurement procedure include the following:

- (1) A description of the procedure used to obtain the data,
- (2) The number of repetitions, n , of the measurement procedure,
- (3) The sample mean and standard deviation of the measurements,
- (4) The measure of precision being reported,
- (5) The computed value of that measure,
- (6) The applicable range or concentration, and
- (7) The conditions under which the test results are obtained.

NOTE 2—The importance of items (3) and (4) lies in the fact that with these a reader may calculate a confidence interval or relative standard deviation as desired.

5.2.2 Precision is sometimes measured by repeatability and reproducibility.

5.2.2.1 Repeatability can be measured by the standard deviation, s_r , of n consecutive measurements by the same operator on the same instrument over a short period of time. Repeatability may be calculated over longer periods of times as the pooled standard deviation (refer to Practice **E691**). Reproducibility can be measured by the standard deviation, s_R , of m measurements, one obtained from each of m independent

⁵ Refer to Form and Style for ASTM Standards, 8th Ed., 1989, ASTM.