Standard Practice for Statements on Number of Specimens for Textiles[1]

This standard is issued under the fixed designation D 2905; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice provides a mechanism for calculating the number of specimens per laboratory sampling unit. It also provides recommended texts to be used in exceptional cases. Ordinarily, it is preferable to specify in the section on sampling a small fixed number of specimens for each laboratory sampling unit. Occasionally, however, the task group writing a test method may think that the variability among the observations on specimens within a laboratory sampling unit will probably differ significantly from laboratory to laboratory. It is in unusual cases of this sort that the recommended texts in this practice should be used.

1.1.1 Paragraph A14.8 of the *Recommendations on Form and Style* specifies that statements on the number of specimens be included in all test methods.

1.2 This practice covers six optional recommended texts which serve as guides for the preparation of statements on the number of specimens required to determine the average quality of each unit of the laboratory sample under various conditions. The choice of the text to be used in a specific method will depend on the purpose of the test and the available information. This practice covers the following six different conditions.

Recommended Text	Conditions	Sections
1	Standard Deviation with Two-sided Limits	10, 11
2	Standard Deviation with One-sided Limits	13, 14
3	Coefficient of Variation with Two-sided Limits	16, 17
4	Coefficient of Variation with One-sided Limits	19, 20
5	Variability Known, Fixed Number of Specimens	22
6	Variability Not Known, Fixed Number of Specimens	24

1.3 Recommended Texts 1 through 4 are preceded by examples. Each example states part of the data from an interlaboratory test and illustrates the decisions needed in the course of calculating the numerical values required for inclusion in a specific text. Each of these texts describes two conditions: (*1*) the procedure to be followed when the user has a reliable estimate of the variability of the method in his own laboratory, and (*2*) the fixed number of specimens required when the user does not have a reliable estimate of the variability of the method in his own laboratory.

1.4 The instructions in this practice are specifically applicable to methods based on the measurement of variates. The instructions are not generally applicable to data based on attributes, and as a result, are not usually used for methods based on “go, no-go” tests.

1.5 This practice does not specify or discuss sampling plans but assumes that sampling has been adequately covered in other sections of the test method under preparation. However, to obtain the total number of specimens on which to base a decision to accept or reject a lot when acceptance testing a commercial shipment, multiply the number of specimens for each unit or the laboratory sample by the total number of such units in the entire lot sample. Instructions on the number of units in the laboratory sample to be taken from each of the primary sampling units in the lot sample should be in the applicable material specification or other agreement between the purchaser and the supplier.

2. Referenced Documents

2.1 *ASTM Standards:*

D 123 Terminology Relating to Textiles[2]

D 2904 Practice for Interlaboratory Testing of a Textile Test Method that Produces Normally Distributed Data[2]

D 2906 Practice for Statements on Precision and Bias for Textiles[2]

D 4271 Practice for Writing Statements on Sampling in Test Methods for Textiles[3]

E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process[4]

E 456 Terminology Relating to Quality and Statistics[4]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[4]

2.2 *ASTM Adjuncts:*

TEX-PAC[5]

NOTE 1—Tex-Pac is a group of PC programs on floppy disks, available

[1] This practice is under the jurisdiction of ASTM Committee D13 on Textiles, and is the direct responsibility of Subcommittee D13.93 on Statistics.

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[2] *Annual Book of ASTM Standards*, Vol 07.01.

[3] *Annual Book of ASTM Standards*, Vol 07.02.

[4] *Annual Book of ASTM Standards*, Vol 14.02.

[5] PC programs on floppy disks are available through ASTM. Request ADJD2904.

through ASTM Headquarters, 100 Barr Harbor Drive, West Conshohocken, PA 19428, USA. The calculations for the numbers of specimens described in the various sections of this practice can be performed using one of the programs in this adjunct.

3. Terminology

3.1 *Definitions:*

3.1.1 *accuracy*, *n—of a test method*, the degree of agreement between the true value of the property being tested (or accepted standard value) and the average of many observations made according to the test method, preferably by many observers. See also *bias* and *precision*.

3.1.1.1 *Discussion*—Increased accuracy is associated with decreased bias relative to the true value; two methods with equal bias relative to the true value have equal accuracy even if one method is more precise than the other. The true value is the exact value of the property being tested for the statistical universe being sampled. When the true value is not known or cannot be determined, and an acceptable standard value is not available, accuracy cannot be established. No valid inferences on the accuracy of a method can be drawn from an individual observation.

3.1.2 *bias*, *n—in statistics*, a constant or systematic error in test results.

3.1.2.1 *Discussion*—Bias can exist between the true value and a test result obtained from one method; between test results obtained from two methods; or between two test results obtained from a single method, for example, between operators or between laboratories.

3.1.3 *coefficient of variation, CV*, *n*—a measure of the dispersion of observed values equal to the standard deviation for the values divided by the average of the values; may be expressed as a percentage of the average (CV %).

3.1.4 *determination value*, *n*—the numerical quantity calculated by means of the test method equation from the measurement values obtained as directed in a test method. (Syn. *determination*.)

3.1.5 *laboratory sample*, *n*—a portion of material taken to represent the lot sample, or the original material, and used in the laboratory as a source of test specimens.

3.1.6 *percentage point*, *n*—a difference of 1 % of a base quantity.

3.1.6.1 *Discussion*—A phrase such as "difference of *X* %" is ambiguous when referring to a difference in percentages. For example, a change in the moisture regain of a material from 5 % to 7 % could be reported as an increase of 40 % of the initial moisture regain or as an increase of two percentage points. The latter wording is recommended.

3.1.7 *precision*, *n*—the degree of agreement within a set of observations or test results obtained as directed in a method.

3.1.7.1 *Discussion*—The term "precision," delimited in various ways, is used to describe different aspects of precision. This usage was chosen in preference to the use of "repeatability" and "reproducibility" which have been assigned conflicting meanings by various authors and standardizing bodies.

3.1.8 *precision*, *n—under conditions of single-operator precision*, the single-operator-laboratory-sample-apparatus-day precision of a method; the precision of a set of statistically independent observations all obtained as directed in the method and obtained over the shortest practical time interval in one laboratory by a single operator using one apparatus and randomly drawn specimens from one sample of the material being tested.

3.1.8.1 *Discussion*—Results obtained under conditions of single-operator precision represent the optimum precision that can be expected when using a method. Results obtained under conditions of within-laboratory and between-laboratory precision represent the expected precision for successive test results when a method is used respectively in one laboratory and in more than one laboratory.

3.1.9 *precision*, *n—under conditions of within-laboratory precision with multiple operators*, the multi-operator, single-laboratory-sample, single-apparatus-day (within operator) precision of a method; the precision of a set of statistically independent test results all obtained in one laboratory using a single sample of material and with each test result obtained by a different operator, with each operator using one apparatus to obtain the same number of observations by testing randomly drawn specimens over the shortest practical time interval.

3.1.10 *precision*, *n—under conditions of between-laboratory precision*, the multi-laboratory, single-sample, single-operator-apparatus-day (within-laboratory) precision of a method; the precision of a set of statistically independent test results all of which are obtained by testing the same sample of material and each of which is obtained in a different laboratory by one operator using one apparatus to obtain the same number of observations by testing randomly drawn specimens over the shortest practical time interval.

3.1.11 *specimen*, *n*—a specific portion of a material or a laboratory sample upon which a test is performed or which is selected for that purpose. (Syn. *test specimen*.)

3.1.12 *standard deviation*, *s*, *n— of a sample*, a measure of the dispersion of variates observed in a sample expressed as the positive square root of the sample variance.

3.1.13 *test result*, *n*—a value obtained by applying a given test method, expressed as a single determination or a specified combination of a number of determinations.

3.1.14 *variance* s^2, *n— of a sample*, a measure of the dispersion of variates observed in a sample expressed as a function of the sum of the squared deviations from the sample average.

3.1.15 For definitions of other terms used in this practice, refer to Terminology D 123. For definitions of statistical terms refer to Terminology D 123 and Terminology E 456.

4. Significance and Use

4.1 *Standard Deviations versus Coefficients of Variation*—The term "standard deviation" is used throughout this section. Where it is applicable, the term "coefficient of variation" may be substituted. It should be realized, however, that the coefficient of variation should be used in a test method to describe variability only when the standard deviation has been found to increase in direct proportion to the average for determinations at different levels of the property of interest.

4.2 *Fixed Number of Determinations*— For most test methods, the variability for individual determinations will be relatively constant from laboratory to laboratory. For this reason, it is usually advisable to specify some small fixed number of determinations to be made on each laboratory sampling unit rather than to use the procedures given in this practice. The task group can determine the value of the fixed number of specimens per laboratory sampling unit using Eq 2 or Eq 3.

4.2.1 A small fixed number of determinations on each laboratory sampling unit is practical because the estimated variance for averages of all determinations on the entire lot sample is based on Eq 1:

$$V(A) = V(L)/n + V(T)/mn + V(E)/kmn \quad (1)$$

where:

$V(A)$	=	estimated variance for the average of all determinations on the entire lot sample,
$V(L)$	=	component of variance due to lot sampling units,
$V(T)$	=	component of variance due to laboratory sampling units within lot sampling units,
$V(E)$	=	component of variance due to specimens within laboratory sampling units,
n	=	number of lot sampling units in the lot sample,
m	=	number of laboratory sampling units per lot sampling unit, and
k	=	number of specimens (determinations) per laboratory sampling unit.

4.2.2 Eq 1 shows that only $V(E)$, the component of variance due to specimens, is affected by the number of specimens per laboratory sampling unit. Instead of testing a relatively large number of specimens per laboratory sampling unit, it is usually more cost effective to increase the divisor for $V(E)$ by increasing m, the number of laboratory sampling units per lot sampling unit, or n, the number of lot sampling units in the lot sample, or both. Increasing m or n or both not only decreases the contribution of $V(E)$, but also decreases the contribution of $V(T)$ or of both $V(L)$ and $V(T)$.

4.3 *Calculated Number of Determinations*—In those cases where the authors of a test method think that the variability for individual determinations is likely to vary significantly from laboratory to laboratory, they may wish to specify a number of specimens per laboratory sampling unit, k, that is a function of the observed variability. This practice provides a procedure for determining the value of k under such conditions.

4.3.1 In cases where k is to be calculated, the task group needs also to specify a fixed value of k to be used when an estimate of the variability for determinations within a laboratory sampling unit is not available. In the absence of the necessary information, it is advisable for such a fixed value of k to be somewhat larger than would ordinarily be obtained from an estimate of the variability of determinations in a user's laboratory. Such a fixed value of k is normally obtained by using a value of the variability, that is 1.414 times the best estimate for a typical value of the variability. This procedure will result in a calculated value of k that is twice what would be obtained from the typical value of the variability. See 12.1.2, 15.1.2, 18.1.2, and 21.1.2 for examples of calculations of a fixed number of specimens per laboratory sampling unit when there is not a good estimate of variability which was obtained in the user's laboratory.

5. Basis for Calculations

5.1 In order to determine the number of specimens required, information is needed on the variability of individual observations made as directed in the method to be used. The variability of individual observations depends upon the test method itself, upon the experience and training of the operator, upon the calibration and maintenance of the apparatus used, and especially upon the variability of the property in the material being tested. For this reason, it is preferable for the user of the test to determine the variability of individual observations experimentally under the actual test conditions of interest and upon specimens from the types of material to be tested by use of the method. Less satisfactorily, the user may act on information obtained by using the proposed method on typical materials before the method was published. Such general information is usually obtained as directed in Practice D 2904 or Practice E 691 and is reported in the section of the method on Precision and Bias as directed in Practice D 2906.

5.2 In addition to the variability of individual observations, the required number of specimens depends upon the values *chosen* for the allowable variation and probability level. Both of these factors are based on engineering judgment, but the original recommendations of the task group preparing the method must be approved by the members of the subcommittee.

5.3 The recommendations in this standard consider only the variability of individual observations made under conditions of single-operator precision. Other sources of variation, such as differences between instruments, operators, laboratories, or differences with time may also have to be taken into account when certain test methods are being written or revised. For a general discussion of the precision that can be expected with different numbers of specimens, both within and between laboratories, refer to Practice D 2906.

5.4 When a specified number of specimens are tested as directed in a method, the mean of the resulting observations is an *estimate* of the true average of the property being tested when measured as directed in the method. The larger the number of observations and the smaller the variability among the observations, the nearer the test result (the average of the observations) will tend to approach the true average.

NOTE 2—The term "true average" as used here refers to the average that would be obtained by testing the entire laboratory sampling unit as directed in the specified method.

5.5 The required number of specimens per unit of the laboratory sample is usually calculated using either Eq 2 or Eq 3 which are as follows:

$$k = (ts/E)^2 \quad (2)$$

TABLE 1 Values of Student's *t* for One-Sided and Two-Sided Limits and the 95 % Probability[A]

df	One-Sided	Two-Sided	df	One-Sided	Two-Sided	df	One-Sided	Two-Sided
1	6.314	12.706	11	1.796	2.201	22	1.717	2.074
2	2.920	4.303	12	1.782	2.179	24	1.711	2.064
3	2.353	3.182	13	1.771	2.160	26	1.706	2.056
4	2.132	2.776	14	1.761	2.145	28	1.701	2.048
5	2.015	2.571	15	1.753	2.131	30	1.697	2.042
6	1.943	2.447	16	1.746	2.120	40	1.684	2.021
7	1.895	2.365	17	1.740	2.110	50	1.676	2.009
8	1.860	2.306	18	1.734	2.101	60	1.671	2.000
9	1.833	2.262	19	1.729	2.093	120	1.658	1.980
10	1.812	2.228	20	1.725	2.086	∞	1.645	1.960

[A] Values in this table were calculated using Hewlett Packard HP 67/97 Users' Library Programs 03848D, "One-Sided and Two-Sided Critical Values of Student's *t*" and 00350D," Improved Normal and Inverse Distribution." For values at other than the 95 % probability level, see published tables of critical values of Student's *t* in any standard statistical text **(2)**, **(3)**, **(4)**, and **(5)**.

$$k = (tv/A)^2 \tag{3}$$

where:

- k = number of test specimens per unit of the laboratory sample required, rounded to the next higher whole number or to the next higher multiple of five depending on the judgment of the task group preparing the method.
- s = standard deviation of individual observations, in units of the property being evaluated (Note 3),
- v = coefficient of variation of individual observations, expressed as percent of the average.
- t = constant depending upon the desired probability level and equal to Student's t for the degrees of freedom associated with the measure of variability, s or v (see Table 1),
- E = allowable difference or the smallest difference of practical importance in the test results expressed in units of the property being evaluated, which in some cases may be percentage points, (Notes 3 and 4), and
- A = allowable difference or the smallest difference of practical importance in the test results expressed as a percent of the average (Note 4).

NOTE 3—When the property being evaluated is measured as a percentage of a specified value, for example, elongation measured as a percentage of the original gage length, the allowable variation and the standard deviation should be expressed in percentage points.

NOTE 4—The arbitrarily chosen values for both E and A refer to the allowable difference or the smallest difference of practical importance in a test result based on observations still to be carried out under conditions of single-operator precision.

5.6 For a detailed discussion of the calculation of the number of specimens and of the estimation of the standard deviation, refer to Practice D 2904 and Recommended Practice E 122.

6. Criteria for Selection of the Recommended Text

6.1 The selection of the appropriate recommended text will normally be based upon decisions on the following matters: (*1*) choice between the standard deviation or the coefficient of variation as the appropriate measure of variability, (*2*) choice between one-sided or two-sided limits for the property being evaluated, and (*3*) determination if special circumstances dictate specifying a prescribed number of specimens.

6.2 On the basis of data for materials having a wide range of values, determine if the standard deviation is relatively independent of the mean values reported. If the standard deviation does not seem to increase in proportion to the mean value of the observations, select the standard deviation as the measure of variability and use either Text 1 or Text 2 depending on whether one-sided or two-sided limits are required. If the standard deviation seems to increase in proportion to the mean value of the observations, select the coefficient of variation as the measure of variability and use either Text 3 or Text 4 depending on whether one-sided or two-sided limits are needed.

6.2.1 If the individual observations have a frequency distribution that is markedly skewed or if the standard deviation seems to be correlated with the mean of the observations but does not vary proportionally to the mean, consider making a transformation of the original data which will result in a normally distributed variate with a standard deviation which is independent of the mean. Arbitrary grades or classifications, scores for ranked data, and counts of an observed condition are among the types of data that normally require transformation.

NOTE 5—An empirically chosen transformation is often considered satisfactory if a cumulative frequency distribution of the transformed data gives a reasonably straight line when plotted on normal probability graph paper.[6] A number of articles and standard statistical texts discuss the choice of suitable transformations **(1)**, **(2)**, **(3)**, **(4)**, and **(5)**.[7]

NOTE 6—Use of the coefficient of variation when the standard deviation is the more appropriate measure of variability can cause serious errors. Likewise, the use of the standard deviation when the coefficient of variation is the more appropriate measure of variability can result in serious errors. In both cases, an erroneous answer will be obtained when calculating the number of specimens required for a material having an average value significantly different from the average of the material from which the variability was originally estimated.

6.3 If the property being evaluated ought to be controlled in both directions, select one of the recommended texts which specifies two-sided limits. If the property being evaluated

[6] Normal Probability Graph Paper may be bought from most suppliers. The equivalent of Keuffel and Esser Co. Style 46-8000 or of Codex Book Co., Inc., Norwood, MA 02062, Style 3127, is acceptable.

[7] The boldface numbers in parentheses refer to references listed at the end of this practice.

needs to be controlled in only one direction, select one of the recommended texts which specifies one-sided limits.

6.3.1 *Examples*—Yarn number is an example of a property that ought to be controlled in both directions and requires two-sided limits. Fabric strength need have no maximum limit while shrinkage must only stay below a permissible value. Both fabric strength and shrinkage are examples of properties which need to be controlled in only one direction and require one-sided limits.

6.4 Special circumstances sometimes make it desirable to specify a prescribed number of observations. Among the reasons for requiring a specific number of specimens and suggested courses of action are the following:

6.4.1 If an allowable variation which is substantially below normal industry requirements requires one or fewer observations by an experienced operator at the 95 % probability level; specify one observation.

6.4.2 If an allowable variation that is substantially below normal industry requirements requires no more than *n* observations by an experienced operator at the 95 % probability level; and if observations are very inexpensive or very quickly done; specify at least the next higher multiple of five observations.

6.4.3 If information about test precision is incomplete, but there is wide industry acceptance of a certain number of observations in a test result; specify that number of observations.

6.5 Consider the use of Text 5, Variability Known, Fixed Number of Specimens, Section 22, when realistic values of the allowable variation, the selected probability, and the measure of single operator variability obtained in the interlaboratory test used in Recommended Texts 1, 2, 3, or 4 specify fewer than half the number of specimens customarily tested in the trade.

7. Selection of an Allowable Difference

7.1 Select an allowable difference, that is, the smallest difference of practical importance, small enough to ensure that the variability of the test results will not exceed the normal needs of the trade but not so small that an unrealistically large number of observations are required. (See 1.5.) There are no formal rules for selecting such values. Base the selection on a knowledge of the probable use of the test results and the approximate cost of testing. Values of E are expressed in units of measure (Note 3), values of A in percent of the average (see Eq 2 and Eq 3). In both cases, values between 2.5 and 7.0 % of the expected average are often recommended.

8. Selection of a Desired Probability Level

8.1 Selection of a probability level is largely a matter of engineering judgment. Experience has shown that for both one-sided and two-sided limits, a 95 % probability level is often a reasonable one.

NOTE 7—Numerically, the value of t for a one-sided limit at a 95 % probability level is equal to the value of t for two-sided limits at the 90 % probability level. The fact that the same numerical value is associated with two probability levels under two different sets of circumstances should not be allowed to influence the choice of a probability level. The consequences of error, not the choice between one-sided and two-sided limits, should be used as the basis for selecting a probability level.

9. Use of Illustrative Examples and Recommended Texts

9.1 Although Eq 2 or Eq 3 should be used during the preparation of most test methods involving the measurement of a variable, the first four recommended texts are appropriate only in cases where the task group thinks that the variability among specimens from a laboratory sampling unit will differ significantly among laboratories.

9.2 Each of the first four recommended texts is preceded by an example illustrating the reasoning and the calculations required prior to using the text. The examples do not refer to a specific method of test. The allowable difference and selected probability level used in the different examples have been varied for illustrative purposes and should not be used as guides by task groups preparing methods of test for similar properties. See previous sections for suggestions on selecting an allowable variation and a selected probability level.

9.3 Each of the first four recommended texts shows numerical values for some or all of the following terms which are based on the example which immediately precedes the recommended text: (*1*) the selected probability level, (*2*) the allowable difference, and (*3*) the fixed number of specimens with the value of the measure of variability used to calculate the fixed number of specimens *when there is no reliable estimate of single-operator precision for the user's laboratory.* The correct numerical values for the method in preparation must be substituted for the values used in the recommended text.

9.4 If widely different values of the measure of variability are applicable to different types of materials, or if the number of specimens is being specified for more than one property within a single section of a method, expand the recommended text to list the appropriate values for each type of material or each property being considered. The appropriate numerical values may be tabulated to conserve space.

9.5 In each of the recommended texts, the modified decimal number of the sections and the numbers of the equation are incidental and are not to be copied since they will vary from one method to another.

RECOMMENDED TEXT 1—STANDARD DEVIATION WITH TWO-SIDED LIMITS

10. Example 1—Moisture in Textile Materials

10.1 *Initial Choice of Recommended Text*— From the results of an interlaboratory test, it was concluded that variability was not proportional to the level of moisture in the samples. The single-operator component of variance expressed as a standard deviation was calculated to be 0.20 percentage point. Since moisture should be controlled in both directions, two-sided limits are required. Recommended Text 1 is initially indicated.

10.2 *Initial Choice of Allowable Difference and Selected Probability Level*—Based on its judgment of industry requirements, the task group might initially choose 0.25 percentage point as E, the allowable difference, and 95 % as the selected probability level.

10.3 *Calculation of Numerical Values for Use in the Recommended Text Selected*—Perform the following operations:

10.3.1 Select from Table 1 the value of $t = 1.960$, corresponding to two-sided limits and an infinite number of degrees of freedom at the 95 % probability level.

10.3.2 For those situations where the user has no reliable estimate of s, calculate a value of s that is somewhat larger than is usually found in practice by multiplying the typical value of $s = 0.20$ percentage points by 1.4 to get 0.28 percentage points.

NOTE 8—The factor 1.4 is arbitrary and was chosen because it gives a value of s (or v) that approximately doubles the number of specimens calculated by the equations in 5.5 when the user estimates the value of s (or v) based on a very large number of degrees of freedom. Doubling the number of specimens is likely to assure that the test result does not exceed the allowable variation at the selected probability level even when the user is inexperienced.

10.3.3 Using Eq 2, the value of t selected in 10.3.1, and the value of s calculated in 10.3.2, calculate $k = (1.960 \times 0.28/0.25)^2 = 4.8$ specimens. Round this value to five specimens.

NOTE 9—The task group must decide on the basis of industry practice and the cost of sampling and testing, whether to round the calculated value of the number of specimens upward to the next whole number or to the next multiple of five. Rounding instructions may be included with the equations in Recommended Texts 1 through 4.

10.4 *Evaluation of Preliminary Results*— After determining the values based upon the initial choices of text, allowable difference, and probability level, the task group must decide whether to: (*1*) accept the recommended text initially chosen and the calculated number of specimens as satisfactory, or (*2*) if the calculated number of specimens are considered unsatisfactory for any reason, modify the initial choice of allowable difference, selected probability level, or both and calculate values on the revised basis, or (*3*) use Recommended Text 5.

11. Recommended Text 1—Standard Deviation with Two-Sided Limits

11.1 Use the text illustrated in 12.1, 12.1.1, and 12.1.2.

NOTE 10—In recommended texts, the numbers of sections, notes, and equations are for illustrative purposes and are not intended to conform to the numbers assigned to the other parts of this practice. In correspondence, they can best be referenced by such phrases as "the illustrative text numbered as 12."

NOTE 11—For illustrative purposes in the recommended texts, a name as been arbitrarily given the laboratory sampling units. In adapting the recommended texts to a specific test method, the appropriate name of the laboratory sampling units for that test method should be substituted for the name in the recommended text. Typical names for the laboratory sampling units include such terms as: "bundle of fiber," "package," "swatch," and "garment."

12. Number of Specimens

12.1 Take a number of specimens per bundle of fiber such that the user may expect at the 95 % probability level that the test result for a bundle of fiber is no more than 0.25 percentage points above or below the true average for the bundle of fiber. Determine the number of specimens per bundle of fiber as follows:

12.1.1 *Reliable Estimate of s*—When there is a reliable estimate of s based upon extensive past records for similar materials tested in the user's laboratory as directed in the method, calculate the required number of specimens per bundle of fiber using Eq 4 (same as Eq 2, but renumbered to coincide with section number).

$$k = (ts/E)^2 \qquad (4)$$

where:
- k = number of specimens per bundle of fiber (rounded upward to a whole number),
- s = reliable estimate of the standard deviation of individual observations or similar materials in the user's laboratory under conditions of single-operator precision,
- t = the value of Student's t for two-sided limits, a 95 % probability level, and the degrees of freedom associated with the estimate of s, and
- E = 0.25 percentage points, the value of the allowable difference.

12.1.2 *No Reliable Estimate of s*—When there is no reliable estimate of s for the user's laboratory, Eq 4 should not be used directly. Instead, specify the fixed number of five specimens per bundle of fiber. This number of specimens per bundle of fiber is calculated using $s = 0.28$ percentage point which is a somewhat larger value of s than is usually found in practice. When a reliable estimate of s for the user's laboratory becomes available, Eq 4 will usually require fewer than five specimens per bundle of fiber.

RECOMMENDED TEXT 2—STANDARD DEVIATION WITH ONE-SIDED LIMITS

13. Example 2—Impurity in a Fiber

13.1 *Initial Choice of Recommended Text*— From the results of an interlaboratory test, it was concluded that variability was not proportional to the level of the impurity in a sample of fiber. The single-operator component of variance expressed as a standard deviation was calculated to be 0.45 percentage point. Since the presence of an impurity needs to be controlled only to detect materials with an unacceptably high impurity content, one-sided limits are required. Recommended Text 2 is initially indicated.

13.2 *Initial Choice of Allowable Difference and Selected Probability Level*—Based on their judgment of industry requirements, the task group might initially choose 0.25 percentage point as E, the allowable difference, and 95 % as the selected probability level.

13.3 *Calculation of Numerical Values for Use in the Recommended Text Selected*—Perform the following operations:

13.3.1 Select from Table 1 the value of $t = 1.645$ corresponding to one-sided limits and an infinite number of degrees of freedom at the 95 % probability level.

13.3.2 For those situations where the user has no reliable estimate of s, calculate a value of s that is somewhat larger than is usually found in practice by multiplying the typical value of $s = 0.45$ percentage points by 1.4 to get 0.63 percentage points (Note 8).

13.3.3 Using Eq 2, the value of t selected in 13.3.1, and the value of s calculated in 13.3.2, calculate $k = (1.645 \times 0.63/0.25)^2 = 17.2$ specimens. Round this value upward to 20 specimens (Note 9).

13.4 *Evaluation of Preliminary Results*— See 10.4 for instructions on alternative courses of action to be considered at this point.

14. Recommended Text 2—Standard Deviation with One-sided Limits

14.1 Use the text illustrated in 15.1, 15.1.1, and 15.1.2 (Notes 10 and 11).

15. Number of Specimens

15.1 Take a number of specimens per garment such that the user may expect at the 95 % probability level that the test result for a garment is not more than 0.25 percentage points below the true average for the garment. Determine the number of specimens per garment as follows:

15.1.1 *Reliable Estimate of s*—When there is a reliable estimate of s based upon extensive past records for similar materials tested in the user's laboratory as directed in the method, calculate the required number of specimens per garment using Eq 5 (same as Eq 2, but renumbered to coincide with section number).

$$k = (ts/E)^2 \tag{5}$$

where:

k = number of specimens per garment (rounded upward to a multiple of five),
s = reliable estimate of the standard deviation of individual observations on similar materials in the user's laboratory under conditions of single-operator precision.
t = the value of Student's t for one-sided limits, a 95 % probability level, and the degrees of freedom associated with the estimate of s, and
E = 0.25 percentage points, the value of the allowable difference.

15.1.2 *No Reliable Estimate of s*—When there is no reliable estimate of s for the user's laboratory, Eq 5 should not be used directly. Instead, specify the fixed number of 20 specimens per garment. This number of specimens per garment is calculated using $s = 0.63$ percentage point which is a somewhat larger value of s than is usually found in practice. When a reliable estimate of s for the user's laboratory becomes available, Eq 5 will usually require fewer than 20 specimens per garment.

15.2 Recommended Text 2, above, is written for the situation in which only an upper limit for test results is required. For the situation in which only a lower limit is required, substitute the word "above" for the word "below" in the first sentence of Section 15.1. Note that "above" is used when a *lower* limit is required and that "below" is used when an *upper* limit is required.

RECOMMENDED TEXT 3—COEFFICIENT OF VARIATION WITH TWO-SIDED LIMITS

16. Example 3—Yarn Number of Spun Yarns

16.1 *Initial Choice of Recommended Test*— From the results of an interlaboratory test, it was concluded that variability of yarn number was proportional to the level of yarn number. The single-operator component of variance expressed as a coefficient of variation was found to fall between 2 and 4 % of the average yarn number over a wide range of yarn numbers. A value of 3.0 % of the average was selected as typical. Since yarn number should be controlled in both directions, two-sided limits are required. Recommended Text 3 is initially indicated.

16.2 *Initial Choice of Allowable Difference and Selected Probability Level*—Based on their judgment of industry requirements, the task group might initially choose 2.0 % of the average as A, the allowable difference, and 95 % as the selected probability level.

16.3 *Calculation of Numerical Values for Use in the Recommended Text Selected*—Perform the following operations:

16.3.1 Select from Table 1 the value of $t = 1.960$, corresponding to two-sided limits and an indefinite number of degrees of freedom at the 95 % probability level.

16.3.2 For those situations where the user has no reliable estimate of v, calculate a value of v that is somewhat larger than is usually found in practice by multiplying the typical value of $v = 3.0$ % of the average by 1.4 to get 4.2 % of the average (Note 8).

16.3.3 Using Eq 3, the value of t selected in 16.3.1, and the value of v calculated in 16.3.3, calculate $k = (1.960 \times 4.2/2.0)^2 = 16.9$ specimens. Round this value upward to 17 specimens (Note 9).

16.4 *Evaluation of Preliminary Results*— See 10.4 for instructions on alternative courses of action to be considered at this point.

17. Recommended Text 3—Coefficient of Variation with Two-sided Limits

17.1 Use the text illustrated in 18.1, 18.1.1, and 18.1.2 (Notes 10 and 11).

18. Number of Specimens

18.1 Take a number of specimens per package such that the user may expect at the 95 % probability level that the test result for a package is not more than 2.0 % of the average above or below the true average of the package. Determine the number of specimens per package as follows:

18.1.1 *Reliable Estimate of v*—When there is a reliable estimate of v based upon extensive past records for similar materials tested in the user's laboratory as directed in the method, calculate the required number of specimens per package using Eq 6 (same as Eq 3, but renumbered to coincide with section number).

$$k = (tv/A)^2 \tag{6}$$

where:

k = number of specimens per package (rounded upward to a whole number),
v = reliable estimate of the coefficient of variation of individual observations on similar materials in the user's laboratory under conditions of single-operator precision,
t = the value of Student's t for two-sided limits, a 95 % probability level, and the degrees of freedom associated with the estimate of v, and
A = 2.0 % of the average, the value of the allowable difference.

18.1.2 *No Reliable Estimate of v*—When there is no reliable estimate of v for the user's laboratory, Eq 6 should not be used directly. Instead, specify the fixed number of 17 specimens per package. This number of specimens is calculated using $v = 4.2$ % of the average which is a somewhat larger value of v than is usually found in practice. When a reliable estimate of v for the user's laboratory becomes available, Eq 6 will usually require fewer than 17 specimens per package.

RECOMMENDED TEXT 4—COEFFICIENT OF VARIATION WITH ONE-SIDED LIMITS

19. Example 4—Fabric Tensile Strength

19.1 *Initial Choice of Recommended Text*— From the results of an interlaboratory test, it was concluded that variability of fabric strength was proportional to the level of fabric strength. Over a wide variety of fabrics, the single-operator component of variance expressed as a coefficient of variation was found to vary from 2 to 11 % of the average fabric strength. There was no apparent correlation between the coefficient of variation and the level of fabric strength. A value of 5.5 % of the average was selected as typical. Since fabric strength should only be controlled to detect materials with low strength, one-sided limits are required. Recommended Text 4 is initially indicated.

19.2 *Initial Choice of Allowable Difference and Selected Probability Level*—Based on their judgment of industry requirements, the task group might initially choose 4.0 % of the average as A, the allowable difference, and 95 % as the selected probability level.

19.3 *Calculation of Numerical Values for Use in the Recommended Text Selected*—Perform the following operations:

19.3.1 Select from Table 1 the value of $v = 1.645$ corresponding to one-sided limits and an infinite number of degrees at the 95 % probability level.

19.3.2 For those situations when the user has no reliable estimate of v, calculate a value of v that is somewhat larger than is usually found in practice by multiplying the typical value $v = 5.5$ % of the average by 1.4 to get 7.7 % of the average (Note 8).

19.3.3 Using Eq 3, the value of t selected in 19.3.1, and the value of v calculated in 19.3.2, calculate $k = (1.645 \times 7.7/4.0)^2 = 10.0$ specimens. Use this value as ten specimens (Note 9).

19.4 *Evaluation of Preliminary Results*— See 10.4 for instructions on alternative courses of action to be considered at this point.

20. Recommended Text 4—Coefficient of Variation with One-sided Limits

20.1 Use the text illustrated in 21.1, 21.1.1, and 21.1.2 (Notes 10 and 11).

21. Number of Specimens

21.1 Take a number of specimens per swatch such that the user may expect at the 95 % probability level that the test result for a swatch is no more than 4.0 % of the average above the true average for the swatch. Determine the number of specimens per swatch as follows:

21.1.1 *Reliable Estimate of v*—When there is a reliable estimate of v based upon extensive past records for similar materials tested in the user's laboratory as directed in the method, calculate the required number of specimens per swatch using Eq 7 (same as Eq 3, but renumbered to coincide with section number).

$$k = (tv/A)^2 \tag{7}$$

where:

k = number of specimens per swatch, (rounded upward to a whole number),
v = reliable estimate of coefficient of variation of individual observations on similar materials in the user's laboratory under conditions of single-operator precision,
t = the value of Student's t for one-sided limits, a 95 % probability level, and the degrees of freedom associated with the estimate of v, and
A = 4.0 % of the average, the value of the allowable difference.

21.1.2 *No Reliable Estimate of v*—When there is no reliable estimate of v for the user's laboratory, Eq 7 should not be used directly. Instead specify the fixed number of ten specimens per swatch. This number of specimens per swatch is calculated using $v = 7.8$ % of the average which is a somewhat larger value of v than is usually found in practice. When a reliable estimate of v for the user's laboratory becomes available, Eq 7 will usually require fewer than ten specimens per swatch.

21.2 Recommended Text 4, above, is written for the situation in which only a lower limit for test results is required. For the situation in which only an upper limit is required, substitute the word "below" for the word "above" in the first sentence of Section 21.1. Note that "above" is used when a *lower* limit is required and that "below" is used when an *upper* limit is required.

RECOMMENDED TEXT 5—VARIABILITY KNOWN, FIXED NUMBER OF SPECIMENS

22. Text 5—Variability Known

22.1 If information is available about the single-operator precision of the method but special circumstances, such as those described in 6.4.1 or 6.4.2, make it advisable to specify a fixed number of specimens, use a text similar to that illustrated in 23.1. Derive the numerical values used in the text as shown in Examples 1, 2, 3, or 4. Select the specific example to be used as a guide based on whether the standard deviation or the coefficient of variation has been chosen to measure variability and whether one-sided or two-sided limits are required. If one-sided limits are required, delete the words "above or below'' from the second sentence of the suggested text and (*1*) substitute the word "above" when only a *lower* limit is required for the test result, or (*2*) substitute the word "below" when only an *upper* limit is required for the test result. The term" percent of the average'' will be used instead of the unit of measure when the coefficient of variation is used (Notes 10 and 11).

23. Number of Specimens

23.1 Take five specimens per spool. If it is assumed that s = 0.028 percentage points, which is a somewhat larger value of s than is usually found in practice, it is expected at the 95 % probability level that the average of five specimens per spool is not more than 0.025 percentage points above or below the true average of the spool.

NOTE 12—To calculate the number of specimens per spool for other values of the allowable variation or for other probability levels, refer to Practice D 2905.

RECOMMENDED TEXT 6—VARIABILITY UNKNOWN, FIXED NUMBER OF SPECIMENS

24. Text 6—Variability Unknown

24.1 Use the text illustrated in 25.1. If applicable, follow the text with a note explaining the basis for selecting the fixed number of specimens specified in the text (Notes 10 and 11).

25. Number of Specimens

25.1 Take two specimens per zipper.

NOTE 13—While data on single-operator precision are not available, the use of two specimens per zipper is generally accepted in the trade.

26. Keywords

26.1 number of specimens; precision; statistics; writing statements

REFERENCES

(**1**) Bartlett, M. S., "The Use of Transformations," *Biometrics,* March, 1947, Vol 3, p. 39–52.

(**2**) Brownlee, K. A., *Industrial Experimentation*, Chemical Publishing Co., Brooklyn, NY, 1949.

(**3**) Davies, O. L., *The Design and Analysis of Industrial Experiments,* Oliver and Boyd, London: Hafner Publishing Co., New York, NY, 1954.

(**4**) Hald, A., *Statistical Theory with Engineering Applications,* John Wiley & Sons, Inc., New York, NY; Chapman & Hall, Ltd., London, 1952.

(**5**) Snedecor, G. W., *Statistical Methods,* Iowa State College Press, Ames, Iowa, 1946.