Standard Test Method of Variables Sampling of Metallic and Inorganic Coatings[1]

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1. Scope

1.1 This test method provides sampling plans that are intended for use in the inspection of metallic and inorganic coatings on products for the purpose of deciding whether submitted lots of coated products comply with the specifications applicable to the coating.

1.2 The sampling plans are variables plans. In plans of this type, several articles of product are drawn from a production lot. A characteristic of the coating on the drawn articles is measured. The values obtained are used to estimate the number of articles in the lot that do not conform to a numerical limit, for example a minimum thickness. The number is compared to a maximum allowable.

1.3 Variables plans can only be used when the characteristic of interest is measurable, the test method gives a numerical measure of the characteristic, and the specification places a numerical limit on the measured value. It is also necessary that the variation of the characteristic from article to article in a production lot be normally distributed (see Appendix X2). Each article must be tested in the same way (for example, coating thickness must be measured at the same location, see X2.7) so that the values from article to article are comparable. If one or more of these conditions are not met, a variables plan cannot be used. Instead, an attributes plan must be used. These are given in Test Method B602 and Guide B697.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

B602 Test Method for Attribute Sampling of Metallic and Inorganic Coatings

B697 Guide for Selection of Sampling Plans for Inspection of Electrodeposited Metallic and Inorganic Coatings

2.2 *ANSI Standards:*[3]

ANSI/ASQC Z1.9-1979 Sampling Procedures and Tables for Inspection by Variables for Percent Non-Conformance

ANSI/ASQC Z1.4-1981 Sampling Procedures and Tables for Inspection by Attributes

2.3 *Military Standards:*[4]

MIL-STD-105 Sampling Procedures and Tables for Inspection by Attributes

MIL-STD-414 Sampling Procedures and Tables for Inspection by Variables for Percent Defective

3. Definitions

3.1 *destructive test*—test that destroys the tested article or makes it nonconforming to a requirement.

3.2 *nondestructive test*—test that neither destroys the tested article nor makes it nonconforming to a requirement.

3.3 *inspection lot*—collection of articles of the same kind that is submitted to inspection for acceptance or rejection as a group.

3.4 *sample*—articles randomly selected from an inspection lot whose quality is used to decide whether or not the inspection lot is of acceptable quality.

3.5 *standard deviation*—measure of dispersion equal to the square root of the mean of the squares of the deviations from the arithmetic mean of the distribution (see 9.2.6).

4. Summary of Test Method

4.1 The plans in this test method provide the same protection as the attributes plans in Tables 1, 2, and 3 of Test Method B602 and are interchangeable with them when the conditions necessary for variables sampling exist. This method has no plan comparable to Table 4 of Test Method B602, because variables plans are subject to an excessive probability of error when the number of nonconforming articles in a lot is expected

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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 American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[4] Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098.

to be approximately 1 % or less as it is for the Table 4 plan. Also for this reason, comparable variables plans are not given for the smallest lot sizes of Tables 1 and 2 of Test Method B602. The plans of Table 4, and Tables 1 and 2 in Test Method B602 are described as Level I, Level II, and Level III respectively. For consistency, Table 1 and Table 2 of this method are described as Level II since they are comparable to Table 1 of Test Method B602, and Table 3 and Table 4 are described as Level III.

4.2 The main advantage of a variables sampling plan over an attributes plan is that fewer articles need to be inspected to obtain the same protection. For example, a sample of 12 using variables can give the same protection as a sample of 50 using attributes. On the other hand, more expensive test methods may be required to yield the measurements required by variables sampling.

4.3 Generally, thickness is the only characteristic of a coating that meets the conditions of a variables plan given in 1.3. For that reason, the plans in this method are designed to be used when the specification for the characteristic in question is a minimum value, which is the usual case for coating thickness. Variables plans can be used when the limit is a maximum and when there are both a minimum and a maximum. Plans for these cases are given in the references.

4.4 The sampling plans in Tables 1 and 2 of this test method are considered to be standard for nondestructive testing and will be used unless the buyer specifies otherwise. Tables 5 and 6 will be used for destructive testing; these plans use smaller samples to reduce the cost of inspection with a resultant reduction of the ability to distinguish between conforming and nonconforming lots.

4.5 Additional variables plans are given in Appendix X3. Also found there are instructions for the calculation of plans for needs that are not covered.

5. Significance and Use

5.1 Sampling inspection permits the estimation of the overall quality of a group of product articles through the inspection of a relatively small number of product articles drawn from the group.

TABLE 1 Level II—Sampling Plans for Nondestructive Tests, Standard Deviation Known[A]

Inspection Lot Size	*n*	*k*	AQL	LQL	50/50 Point	AOQL
91 through 280	7	1.664	1.1	12	4.8	2.4
281 through 500	12	1.649	1.7	10	5.0	2.6
501 through 1 200	16	1.712	1.7	8.2	4.4	2.3
1 201 through 3 200	25	1.704	2.1	7.4	4.4	2.5
3 201 through 10 000	36	1.778	2.0	5.9	3.8	2.2
10 001 through 35 000	52	1.829	2.0	4.9	3.4	2.1
Over 35 000	82	1.893	1.9	4.0	2.9	1.9

[A] The AQL, LQL, 50/50 Point, and AOQL are in percent.

TABLE 2 Level II—Sampling Plans for Nondestructive Tests, Standard Deviation Unknown[A]

Inspection Lot Size	*n*	*k*	AQL	LQL	50/50 Point	AOQL
91 through 280	16	1.663	1.0	12	4.8	2.4
281 through 500	29	1.649	1.7	10	5.0	2.6
501 through 1 200	40	1.713	1.7	8.2	4.3	2.2
1 201 through 3 200	61	1.704	2.1	7.4	4.4	2.5
3 201 through 10 000	92	1.778	2.0	5.9	3.8	2.2
10 001 through 35 000	137	1.825	2.0	4.9	3.4	2.0
Over 35 000	223	1.893	1.9	4.0	3.0	1.9

[A] The AQL, LQL, 50/50 Point, and AOQL are in percent.

TABLE 3 Level III—Sampling Plans for Nondestructive Tests, Standard Deviation Known[A]

Inspection Lot Size	*n*	*k*	AQL	LQL	50/50 Point	AOQL
51 through 150	6	1.432	1.8	18	7.6	3.8
151 through 280	10	1.411	2.7	16	7.9	4.1
281 through 500	14	1.470	2.8	13	7.1	3.5
501 through 1 200	23	1.492	3.3	11	6.8	3.8
1 201 through 3 200	30	1.551	3.2	9.4	6.0	3.5
3 201 through 16 000	44	1.618	3.1	7.7	5.3	3.2
16 001 through 35 000	66	1.680	3.0	6.4	4.6	3.0
Over 35 000	103	1.719	3.0	5.6	4.4	2.9

[A] The AQL, LQL, 50/50 Point, and AOQL are in percent.

TABLE 4 Level III—Sampling Plans for Nondestructive Tests, Standard Deviation Unknown[A]

Inspection Lot Size	*n*	*k*	AQL	LQL	50/50 Point	AOQL
51 through 150	12	1.433	1.7	19	7.6	3.8
151 through 280	19	1.410	2.6	16	7.9	3.7
281 through 500	29	1.470	2.8	13	7.1	3.8
501 through 1 200	48	1.494	3.3	11	6.7	3.8
1 201 through 3 200	66	1.551	3.2	9.4	6.0	3.5
3 201 through 16 000	102	1.618	3.1	7.7	5.3	3.2
16 001 through 35 000	159	1.680	3.0	6.4	4.6	3.0
Over 35 000	248	1.717	3.0	5.6	4.3	2.9

[A] The AQL, LQL, 50/50 Point, and AOQL are in percent.

5.2 The specification of a sampling plan provides purchasers and sellers a means of identifying the minimum quality level that is considered to be satisfactory.

5.3 Because sampling plans yield estimates of the quality of a product, the results of the inspection are subject to error.

TABLE 5 Sampling Plans for Destructive Tests, Standard Deviation Known[A]

Inspection Lot Size	*n*	*k*	AQL	LQL	50/50 Point
26 through 1 200	5	1.262	2.3	25	10
1 201 through 35 000	10	1.411	2.7	16	7.9
Over 35 000	14	1.519	2.5	12	6.5

[A] The AQL, LQL, and 50/50 Point are in percent.

TABLE 6 Sampling Plans for Destructive Tests, Standard Deviation Unknown[A]

Inspection Lot Size	*n*	*k*	AQL	LQL	50/50 Point
26 through 1 200	9	1.181	2.8	27	12
1 201 through 35 000	19	1.412	2.5	16	7.9
Over 35 000	34	1.497	2.8	12	6.7

[A] The AQL, LQL, and 50/50 Point are in percent.

Through the selection of a sampling plan, the potential error is known and controlled.

5.4 Sampling inspection is used when a decision must be made about what to do with a quantity of articles. This quantity may be a shipment from a supplier, articles that are ready for a subsequent manufacturing operation, or articles ready for shipment to a customer.

5.5 In sampling inspection, a relatively small number of articles (the sample) is selected randomly from a larger number of articles (the inspection lot); the sample is inspected for conformance to the requirements placed on the articles. Based on the results, a decision is made whether or not the lot conforms to the requirements.

5.6 Since only a portion of a production lot is inspected, the quality of the uninspected articles is not known. The possibility exists that some of the uninspected articles are nonconforming. Therefore, basic to any sampling inspection plan is the willingness of the buyer to accept lots that contain some nonconforming articles. The number of nonconforming articles in accepted lots is controlled by the size of the sample and the criteria of acceptance that are placed on the sample.

5.7 Acceptance sampling plans are used for the following reasons:

5.7.1 When the cost of inspection is high and the consequences of accepting a nonconforming article are not serious.

5.7.2 When 100 % inspection is fatiguing and boring and, therefore, likely to result in errors.

5.7.3 When inspection requires a destructive test, sampling inspection must be used.

5.8 In acceptance sampling by variables, the coating characteristic of each article in the sample is measured. Using the arithmetic mean of these values, the standard deviation of the process, and the factor *k* that is found in the Tables, a number is calculated (see 9.3). If this number equals or exceeds the specified minimum, the inspection lot conforms to the requirements. If it is less, the lot does not conform. If the standard deviation of the process is not known, the standard deviation of the sample is calculated and used.

5.9 The use of a sampling plan involves the balancing of the costs of inspection against the consequences of accepting an undesirable number of nonconforming articles. There is always a risk that a random sample will not describe correctly the characteristics of the lot from which it is drawn, and that an unacceptable lot will be accepted or an acceptable lot will be rejected. The larger the sample, the smaller this risk but the larger the cost of inspection.

5.10 To understand the risks, consider that if every article in an inspection lot conforms to its requirements, every article in the sample will conform also. Such lots will be accepted (Note 1). If only a few articles in an inspection lot are nonconforming, the sample probably will indicate that the lot is acceptable; but there is a small probability that the sample will indicate that the lot is unacceptable. The larger the proportion of nonconforming articles in an inspection lot, the more likely it will be that the sample will indicate that the lot is unacceptable. If every article in an inspection lot is nonconforming, a sample will always indicate that the lot is unacceptable.

NOTE 1—Throughout this method, it is assumed that no mistakes are made in sampling, measurement, and calculation.

5.11 The probability of accepting an inspection lot that contains nonconforming items is often described in terms of the Acceptable Quality Level (AQL) and the Limiting Quality Level (LQL). The AQL is the quality level that is considered to be acceptable. The LQL is a quality level that is considered to be barely tolerable. A sampling plan is selected that has a high probability of accepting lots of AQL quality and of rejecting lots of LQL quality. In this method, the AQL given for a sampling plan is the quality level of lots (expressed as the percentage of nonconforming articles) that have a 95 % probability of being accepted. The LQL is the quality level of lots that have a 10 % probability of being accepted or, in other words, a 90 % probability of being rejected. The tables in this method give the AQL and LQL of each plan. They also give the 50/50 point, the quality level of a lot that is just as likely to be accepted as rejected.

5.12 The disposition of nonconforming inspection lots is beyond the scope of this method because, depending on the circumstances, lots may be returned to the supplier, kept and used, put to a different use, scrapped, reworked, or dealt with in some other way. An alternative is rectifying inspection in which rejected lots are screened and used.

5.13 In rectifying inspection, when an inspection lot is rejected, all of the articles in the lot are inspected and nonconforming ones are removed. They may be replaced with conforming articles. The now 100 % conforming lot is accepted. With this practice, the average quality level for a series of lots taken as a whole will be better because of the addition of the 100 % conforming lots. When the incoming lots are of a good quality level, the average quality level of a series of lots will be even better when the rejected lots are screened and resubmitted. When incoming lots are of a poor quality level, the average quality of a series of accepted lots will again be good because many of the incoming lots will be rejected and upgraded. At intermediate quality levels of incoming lots, the average quality level of a series of accepted lots will again be improved, but it will not be improved as much as in either of the above cases; and there will be an intermediate quality level where the degree of improvement is the least. This improved quality level is called the Average Outgoing Quality Limit (AOQL). It is the worst condition that can occur under rectifying inspection. The tables give the AOQL for each plan. There is no AOQL for the plans used with destructive tests because destructive tests cannot be used to screen rejected lots.

NOTE 2—The AOQLs given in the tables are strictly correct only when the sample is small with respect to the lot. If this is not the case, the correct AOQL will be smaller than the tabulated value. The correct values are obtained by multiplying the tabulated values by the following equation:

$$1 - \text{sample size/lot size} \tag{1}$$

5.14 Rectifying inspection will substantially increase the cost of inspection if the incoming lots are much worse than AQL quality.

5.15 Rectifying inspection is used only when required by the purchaser.

6. Ordering Information

6.1 Unless otherwise specified by the purchaser, the sampling plans given in Tables 1 and 2 will be used for nondestructive testing, and the plans given in Tables 5 and 6 for destructive testing.

6.2 When either a nondestructive or a destructive test can be used to inspect an article for conformance to a particular requirement, the purchaser should specify which test is to be used. When a test is neither clearly nondestructive nor destructive, the purchaser should specify which it is considered to be.

NOTE 3—The nature of a destructive test can be such that the tested article can be reclaimed, for example by stripping and reapplying the coating. Other tests can destroy the coating in nonessential locations, in which case the article can still be functional. In these instances, the purchaser needs to decide and state whether the tests are to be considered destructive or nondestructive.

6.3 Rectifying inspection will be used only when specified by the purchaser. When rectifying inspection is used, nonconforming articles will be replaced with conforming ones only when specified by the purchaser.

7. Formation of Inspection Lot

7.1 An inspection lot shall be formed from articles that are of the same kind, that have been produced to the same specification, and that have been coated by a single supplier at one time or at approximately the same time under essentially identical conditions.

NOTE 4—These requirements are intended to ensure that the lot is homogeneous and that variations between articles in the lot are the result only of the inherent variation of the production process (see Appendix X1).

8. Sampling

8.1 *General*—A sample shall be selected randomly from the inspection lot. If the test method to be used is nondestructive, the sample size shall be that directed in 8.2. If the test method is destructive, the sample size shall be that directed in 8.3.

8.2 *Nondestructive Tests*—For nondestructive testing, the size of the sample shall be that specified for the sampling plan level that is required by the purchaser. The sampling plans are given for Level II in Tables 1 and 2 and for Level III in Tables 3 and 4. If the purchaser does not specify the level, Level II shall be used. The plans in Table 1 and Table 3 shall be used when the standard deviation of the coating process is known. Tables 1 and 2 plans shall be used when the standard deviation is not known and must be estimated from the sample values.

8.3 *Destructive Tests*—For destructive testing, the size of the sample shall be that specified in Table 5 when the standard deviation of the process is known and Table 6 when it is not known.

8.4 The sample shall be drawn randomly from the inspection lot, that is, in a manner that ensures each article an equal chance of being selected regardless of other considerations such as location in the inspection lot, appearance, quality, location on a fixture during coating, and chronological relationship to the other articles. Random sampling procedures are given in the Appendixes.

9. Calculations

9.1 Calculate the arithmetic mean of the measured characteristic by adding the values obtained for the articles and dividing the number of articles that were tested using the following equation:

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n} \tag{2}$$

where:

$\bar{X}$ = arithmetic mean of the measured values,
X_i = measured value,
$\sum_{i=1}^{n} X_i$ = sum of the measured values, and
n = number of articles tested.

9.2 If the standard deviation of the coating process is known, continue the calculations as directed in 9.3. The symbol for the standard deviation for the process is σ. If the standard deviation for the process is not known, calculate an estimated value from the measurements obtained from the sample as directed in 9.2.1 through 9.2.6. The symbol for this estimated standard deviation is *s*.

9.2.1 Subtract the arithmetic mean from the first measured value using the following equation:

$$X_1 - \bar{X} \tag{3}$$

9.2.2 Calculate the square of the difference obtained in 9.2.1 using the following equation:

$$\left(X_1 - \bar{X}\right)^2 \tag{4}$$

9.2.3 Repeat 9.2.1 and 9.2.2 for each measured value.

9.2.4 Add all of the squares obtained in 9.2.2 and 9.2.3 using the following equation:

$$\left(X_1 - \bar{X}\right)^2 + \left(X_2 - \bar{X}\right)^2 + \ldots + \left(X_n - \bar{X}\right)^2 = \sum_{i=1}^{n} \left(X_1 - \bar{X}\right)^2 \tag{5}$$

9.2.5 Divide the sum obtained in 9.2.4 by one less than the number of articles that were tested using the following equation:

$$\frac{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)^2}{n-1} \tag{6}$$

9.2.6 Calculate the square root of the value obtained in 9.2.5 using Eq 6. This is standard deviation, *s*.

$$s = \sqrt{\frac{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)^2}{n-1}} \tag{7}$$

NOTE 5—The following equation can also be used:

$$s = \sqrt{\frac{\sum X_i^{\,2} - \frac{\left(\sum X_i\right)^2}{n}}{n-1}} \tag{8}$$

9.3 Using the *k* that is in the table and the standard deviation from 9.2, calculate the following number when the standard deviation is known:

$$\bar{X} - k\sigma \tag{9}$$

or, calculate the following when the standard deviation is not known:

$$\bar{X} - ks \tag{10}$$

10. Inspection and Lot Classification

10.1 *Inspection*—Each article in the sample shall be inspected as directed in the applicable coating standard.

10.2 *Lot Classification:*

10.2.1 The number calculated in 9.3 shall be compared to the minimum number stated in the coating specification. If the number in 9.3 equals or exceeds the specified minimum, the lot conforms to the requirements. If it is less than the specified minimum, the lot does not conform.

10.2.2 When specified by the purchaser, nonconforming lots shall be 100 % inspected, and nonconforming articles shall be removed. When required by the purchaser, the nonconforming articles shall be replaced with conforming articles.

APPENDIXES

(Nonmandatory Information)

X1. DRAWING OF SAMPLES

X1.1 The success of acceptance sampling is totally dependent on the sample being drawn from the lot at random. Random sampling means that the selection of an article for the sample is totally by chance and that every article in the lot is equally likely to be selected. If the articles in the inspection lot are thoroughly mixed, such as barrel-plated articles, a sample drawn from anywhere in the lot will be random (see X2.5). Rack-plated articles cannot be sampled this way unless thorough mixing is done before sampling, otherwise a random sampling procedure must be used. Methods of random sampling are described in the following paragraphs.

X1.2 When random numbers are used to select a sample, each article in the lot is identified by a different number. If the units have serial numbers, the serial numbers can be used. The numbers of the articles that are to be inspected are selected from a table of random numbers such as Table X1.1. Other tables of random numbers can be obtained from books on statistics. Some pocket calculators are designed to generate random numbers.

X1.3 As an example, assume that a sample of 12 articles is to be selected from an inspection lot of 80 articles. The articles are numbered 1 through 80. A pencil is allowed to fall blindly at some number in Table X1.1. Starting at this point, a coin is tossed to decide whether to go up or down the column; heads, up; tails, down. If the pencil falls on column 10, line 11, and the coin is tails; the decision is to read down the column until 12 numbers are chosen. Take the first two digits in each group of five digits. The selection of random numbers is made as follows: the 85's are rejected because they are over 80, and the second 06 is rejected because it has already appeared. The sample then consists of articles numbered 31, 20, 8, 26, 53, 65, 64, 46, 22, 6, 41, and 67.

X1.4 When product items are arranged in an order without regard to quality, such as articles in a tray, a sample can be drawn by using the constant interval procedure. Here, a constant interval is maintained between the items drawn for the sample. For example, every 9th, 19th, or 24th unit is selected. The first item drawn from the lot can be determined from the table of random numbers. All other items are then drawn at a constant interval following the first item. The constant interval is determined by dividing the lot size by the sample size.

X1.5 As an example, assume that a lot of 3000 items is to be inspected. In accordance with Table 3, a sample of 30 items is to be drawn. The constant interval is 100 (3000 divided by 30). A random number from 1 to 100 is selected either from a table or by another appropriate method. After the first item is taken, the remaining items in the required sample are drawn by selecting every 100th item from the lot until 30 are selected.

X1.6 References (**1 through 2**)[5] give additional information and procedures on random sampling.

X1.7 The numbers of a random sample can be generated by the following microsoft BASIC computer program:

[5] The boldface numbers in parentheses refer to the list of references at the end of the standard.

```
10   REM—Program to select random samples for testing
30   PRINT “ENTER LOT SIZE”
40   INPUT L
50   PRINT “ENTER SAMPLE SIZE”
60   INPUT S
70   DIM A(L)
80   FOR K = 1 TO L
90   A(K) = 0
100  NEXT K
110  PRINT “MATRIX ZEROED”
120  RANDOMIZE PEEK(11)
130  FOR K = 1 TO L
140  N = INT(L*RND(1) + 1)
150  IF A(N)<>0 THEN 140
160  A(N) = K
170  NEXT K
180  PRINT “MATRIX LOADED”
190  PRINT “FOR A LOT SIZE OF ”;L:LPRINT “FOR A LOT SIZE OF” ;L
200  PRINT “AND A SAMPLE SIZE OF” ;S:LPRINT “AND A SAMPLE SIZE
     OF ”;S
205  PRINT “THE SAMPLE NUMBERS ARE:”:LPRINT “THE SAMPLE
     NUMBERS ARE:”
210  FOR R = 1 TO S
220  M = INT(L*RND(1) + 1)
230  IF A(M) = 0 THEN 220
240  PRINT A(M);“,”;:LPRINT A(M);“,”;
250  NEXT R
260  PRINT “END OF SAMPLE LIST”:LPRINT “END OF SAMPLE LIST”
270  END
```

TABLE X1.1 Table of Random Numbers

Line	Column													
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
1	10480	15011	01536	02011	81647	91646	69179	14194	62590	36207	20969	99570	91291	90700
2	22368	46573	25595	85393	30995	89198	27982	53402	93965	34095	52666	19174	39615	99505
3	24130	48360	22527	97265	76393	64809	15179	24830	49340	32081	30680	19655	63348	58629
4	42167	93093	06243	61680	07856	16376	39440	53537	71341	57004	00849	74917	97758	16379
5	37570	39975	81837	16656	06121	91782	60468	81305	49684	60672	14110	06927	01263	54613
6	77921	06907	11008	42751	27756	53498	18602	70659	90655	15053	21916	81825	44394	42880
7	99562	72905	56420	69994	98872	31016	71194	18738	44013	48840	63213	21069	10634	12952
8	96301	91977	05463	07972	18876	20922	94595	56869	69014	60045	18425	84903	42508	32307
9	89579	14342	63661	10281	17453	18103	57740	84378	25331	12566	58678	44947	05585	56941
10	85475	36857	53342	53988	53060	59533	38867	62300	08158	17983	16439	11458	18593	64952
11	28918	69578	88231	33276	70997	79936	56865	05859	90106	31595	01547	85590	91610	78188
12	63553	40961	48235	03427	49626	69445	18663	72695	52180	20847	12234	90511	33703	90322
13	09429	93969	52636	92737	88974	33488	36320	17617	30015	08272	84115	27156	30613	74952
14	10365	61129	87529	85689	48237	52267	67689	93394	01511	26358	85104	20285	29975	89868
15	07119	97336	71048	08178	77233	13916	47564	81056	97735	85977	29372	74461	28551	90707
16	51085	12765	51821	51259	77452	16308	60756	92144	49442	53900	70960	63990	75601	40719
17	02368	21382	52404	60268	89368	19885	55322	44819	01188	65255	64835	44919	05944	55157
18	01011	54092	33362	94904	31273	04146	18594	29852	71585	85030	51132	01915	92747	64951
19	52162	53916	46369	58586	23216	14513	83149	98736	23495	64350	94738	17752	35156	35749
20	07056	97628	33787	09998	42698	06691	76988	13602	51851	46104	88916	19509	25625	58104
21	48663	91245	85828	14346	09172	30168	90229	04734	59193	22178	30421	61666	99904	32812
22	54164	58492	22421	74103	47070	25306	76468	26384	58151	06646	21524	15227	96909	44592
23	32639	32363	05597	24200	13363	38005	94342	28728	35806	06912	17012	64161	18296	22851
24	29334	27001	87637	87308	58731	00256	45834	15398	46557	41135	10367	07684	36188	18510
25	02488	33062	28834	07351	19731	92420	60952	61280	50001	67658	32586	86679	50720	94953
26	81525	72295	04839	96423	24878	82651	66566	14778	76797	14780	13300	87074	79666	95725
27	29676	20591	68086	26432	46901	20849	89768	81536	86645	12659	92259	57102	80428	25280
28	00742	57392	39064	66432	84673	40027	32832	61362	98947	96067	64760	64584	96096	98253
29	05366	04213	25669	26422	44407	44048	37937	63904	45766	66134	75470	66520	34693	90449
30	91921	26418	64117	94305	26766	25940	39972	22209	71500	64568	91402	42416	07844	69618
31	00582	04711	87917	77341	42206	35126	74087	99547	81817	42607	43808	76655	62028	76630
32	00725	69884	62797	56170	86324	88072	76222	36086	84637	93161	76038	65855	77919	88006
33	69011	65795	95876	55293	18988	27354	26575	08625	40801	59920	29841	80150	12777	48501
34	25976	57948	29888	88604	67917	48708	18912	82271	65424	69774	33611	54262	85963	03547
35	09763	83473	73577	12908	30883	18317	28290	35797	05998	41688	34952	37888	38917	88050
36	91567	42595	27958	30134	04024	86385	29880	99730	55536	84855	29080	09250	79656	73211
37	17955	56349	90999	49127	20044	59931	06115	20542	18059	02008	73708	83517	36103	42791
38	46503	18584	18845	49618	02304	51038	20655	58727	28168	15475	56942	53389	20562	87338
39	92157	80634	94824	78171	84610	82834	09922	25417	44137	48413	25555	21246	35509	20468
40	14577	62765	35605	81263	39667	47358	56873	56307	61607	49518	89656	20103	77490	18062
41	98427	07523	33362	64270	01638	92477	66969	98420	04880	45585	46565	04102	46880	45709
42	34914	63976	88720	82765	34476	17032	87589	40836	32427	70002	70663	88863	77775	69348
43	70060	28277	39475	46473	23219	53416	94970	25832	69975	94884	19661	72828	00102	66794
44	53976	54914	06990	67245	68350	82948	11398	42878	80287	88267	47363	46634	06541	97809
45	76072	29515	40980	07391	58745	25774	22987	80059	39911	96189	41151	14222	60697	59583
46	90725	52210	83974	29992	65831	38857	50490	83765	55657	14361	31720	57375	56228	41546
47	64364	67412	33339	31926	14883	24413	59744	92351	97473	89286	35931	04110	23726	51900
48	08962	00358	31662	25388	61642	31072	81249	35648	56891	69352	48373	45578	78547	81788
49	95012	68379	93526	70765	10592	04542	76463	54328	02349	17247	28865	14777	62730	92277
50	15664	10493	20492	38391	91132	21999	59516	81652	27195	48223	46751	22923	32261	85653
51	16408	81899	04153	53381	79401	21438	83035	92350	36693	31238	59649	91754	72772	02338
52	18629	81953	05520	91962	04739	13092	97662	24822	94730	06496	35090	04822	86774	98289
53	73115	35101	47498	87637	99016	71060	88824	71013	18735	20286	23153	72924	35165	43040
54	57491	16703	23167	49323	45021	33132	12544	41035	80780	45393	44812	12515	98931	91202
55	30405	83946	23792	14422	15059	45799	22716	19792	09983	74353	68668	30429	70735	25499
56	16631	35006	85900	98275	32388	52390	16815	69298	82732	38480	73817	32523	41961	44437
57	96773	20206	42559	78985	05300	22164	24369	54224	35083	19687	11052	91491	60383	19746

TABLE X1.1 *Continued*

Line	Column (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
58	38935	64202	14349	82674	66523	44133	00697	35552	35970	19124	63318	29686	03387	59846
59	31624	76384	17403	53363	44167	64486	64758	75366	76554	31601	12614	33072	60332	92325
60	78919	19474	23632	27889	47914	02584	37680	20801	72152	39339	34806	08930	85001	87820
61	03931	33309	57047	74211	63445	17361	62825	39908	05607	91284	68833	25570	38818	46920
62	74426	33278	43972	10119	89917	15665	52872	73823	73144	88662	88970	74492	51805	99378
63	09066	00903	20795	95452	92648	45454	09552	88815	16553	51125	79375	97596	16296	66092
64	42238	12426	87025	14267	20979	04508	64535	31355	86064	29472	47689	05974	52468	16834
65	16153	08002	26504	41744	81959	65642	74240	56302	00033	67107	77510	70625	28725	34191
66	21457	40742	29820	96783	29400	21840	15035	34537	33310	06116	95240	15957	16572	06004
67	21581	57802	02050	89728	17937	37621	47075	42080	97403	48626	68995	43805	33386	21597
68	55612	78095	83197	33732	05810	24813	86902	60397	16489	03264	88525	42786	05269	92532
69	44657	66999	99324	51281	84463	60563	79312	93454	68876	25471	93911	25650	12682	73572
70	91340	84979	46949	81973	37949	61023	43997	15263	80644	43942	89203	71795	99533	50501
71	91227	21199	31935	27022	84067	05462	35216	14486	29891	68607	41867	14951	91696	85065
72	50001	38140	66321	19924	72163	09538	12151	06878	91903	18749	34405	56087	82790	70925
73	65390	05224	72958	28609	81406	39147	25549	48542	42627	45233	57202	94617	23772	07896
74	27504	96131	83944	41575	10573	08619	64482	73923	36152	05184	94142	25299	84387	34925
75	37169	94851	39117	89632	00959	16487	65536	49071	39782	17095	02330	73401	00275	48280
76	11508	70225	51111	38351	19444	66499	71945	05422	13442	78675	84081	66938	93654	59894
77	37449	30362	06694	54690	04052	53115	62757	95348	78662	11163	81651	50245	34971	52924
78	46515	70331	85922	38329	57015	15765	97161	17869	45349	61796	66345	81073	49106	79860
79	30986	81223	42416	58353	21532	30502	32305	86482	05174	07901	54339	58861	74818	46942
80	63798	64995	46583	09785	44160	78128	83991	42865	92520	83531	80377	35909	81250	54238
81	82486	84846	99254	67632	43218	50076	21361	64816	51202	88124	41870	52689	51275	83556
82	21885	32906	92431	09060	64297	51674	64126	62570	26123	05155	59194	52799	28225	85762
83	60336	98782	07408	53458	13564	59089	26445	29789	85205	41001	12535	12133	14645	23541
84	43937	46891	24010	25560	86355	33941	25786	54990	71899	15475	95434	98227	21824	19585
85	97656	63175	89303	16275	07100	92063	21942	18611	47348	20203	18534	03862	78095	50136
86	03299	01221	05418	38982	55758	92237	26759	86367	21216	98442	08303	56613	91511	75928
87	79626	06486	03574	17668	07785	76020	79924	25651	83325	88428	85076	72811	22717	50585
88	85636	68335	47539	03129	65651	11977	02510	26113	99447	68645	34327	15152	55230	93448
89	18039	14367	61337	06117	12143	46609	32989	74014	64708	00533	35398	58408	13261	47908
90	08362	15656	60627	36478	65648	16764	53412	09013	07832	41574	17639	82163	60859	75567
91	79556	29068	04142	16268	15387	12856	66227	38358	22478	73373	88732	09443	82558	05250
92	92608	82674	27072	32534	17075	27698	98204	63863	11951	34648	88022	56148	34925	57031
93	23982	25835	40055	67006	12293	02753	14827	23235	35071	99704	37543	11601	35503	85171
94	09915	96306	05908	97901	28395	14186	00821	80703	70426	75647	76310	88717	37890	40129
95	59037	33300	26695	62247	69927	76123	50842	43834	86654	70959	79725	93872	28117	19233
96	42488	78077	69882	61657	34136	79180	97526	43092	04098	73571	80799	76536	71255	64239
97	46764	86273	63003	93017	31204	36692	40202	35275	57306	55543	53203	18098	47625	88684
98	03237	45430	55417	63282	90816	17349	88298	90183	36600	78406	06216	95787	42579	90730
99	86591	81482	52667	61582	14972	90053	89534	76036	49199	43716	97548	04379	46370	28672
100	38534	01715	94964	87288	65680	43772	39560	12918	86537	62738	19636	51132	25739	56947

X2. NORMAL DISTRIBUTION

X2.1 Articles produced by a manufacturing process are never identical. Minor variations in the process occur that affect the characteristics of the articles. Such variations often occur at random and tend to cancel each other out. Under these conditions, the articles are quite similar to each other. Less often, the chance variations do not cancel out as expected and some articles will differ from the typical. As a result, it often is the case that most of the articles produced by a controlled process are closely grouped around an average condition, while smaller numbers deviate more from the average, and the greater the deviation the fewer articles there are. Frequently this distribution of the articles can be closely described by a mathematical equation which, when plotted, gives the bell-shaped curve shown in Fig. X2.1. This is called a normal or Gaussian distribution.

NOTE X2.1—There is also a random variation introduced by the measurement method. This normally is small relative to the product variation and, thus, of little consequence.

X2.2 Along the horizontal, *X*axis in Fig. X2.1 is plotted the numerical value of the characteristic that is being considered, for example, the thickness of the coating. The area beneath the curve and above the *X*axis represents all of the articles in a production lot. The arithmetic mean thickness is $\bar{X}$, which is at the middle of the curve. The vertical line at $\bar{X}$ divides the curve in half so that half of the area is to the left, thicknesses less than the mean, and half is to the right, thicknesses greater than the mean. It can be seen that if a plating thickness specification is given as a minimum value, and if the mean thickness of the lot equals the specification value, the thickness of the plating on half of the parts will be below the specification limit; that is, half of the article will be nonconforming. Usually, it is required that most of the articles be conforming, which means that the mean thickness has to exceed the specified minimum. The

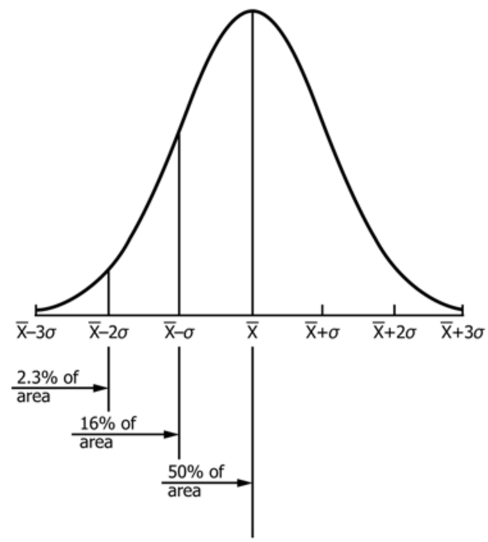

FIG. X2.1 Normal Distribution

standard deviation can be used to determine by how much.

X2.3 If the mean thickness is one standard deviation higher than the specified minimum thickness, the thickness will be less than the specified minimum on 16 % of the articles. If the mean is two standard deviations above the specification value, there will be about 2.3 % nonconforming articles in the lot. Hence, if the standard deviation of the process is known, a mean thickness can be calculated that will ensure that no more than a given percentage (for example, the AQL) of a lot will be nonconforming. Once a lot of articles is produced, a random sample of the articles can be inspected and their mean calculated. If the mean is equal to or larger than the required mean, it is known that the percentage of nonconforming articles in the lot is no more than the AQL. Actually, the mean of the sample can be different from that of the lot. In variables plans, an additional factor is placed in the calculation to allow for this. In processes where the standard deviation is not known and the sample standard deviation is used in the calculation, there is another potential error. This is guarded against by using larger samples.

X2.4 It is important to remember that variables sampling plans are based on the normal curve. If the product of a manufacturing process is not distributed normally, the use of a variables plan based on the normal curve will give invalid results. Therefore, statistical tests should be made of a process to confirm that the product characteristic is approximately normally distributed before a variables plan is used in the sampling inspection of the product. Tests for normality are described in Ref. (**3**).

X2.5 The distribution of plating thickness on barrel-plated articles tends to be normal, provided good barrel plating practices are observed. A production lot that consists of several barrel loads will also be normal if the loads are produced under essentially the same conditions. But if two or more loads that have different average thicknesses are mixed, the mixed lot may not conform to the normal distribution.

X2.6 The distribution of coating thickness on products that are processed on racks may or may not be normal. Tests of normality are required to determine if a variables plan can be used in these cases.

X2.7 The thickness of the coating must be measured at the same location on every article in the sample. If this is not done, the variation in thickness that occurs naturally over the surface of a product will result in invalid values for the average and the standard deviation.

X3. ADDITIONAL SAMPLING PLANS

TABLE X3.1 Sampling Plans, Standard Deviation Known

LQL, %	AQL, %															
	1				2				5				10			
	n	k	50/50 Point	AOQL	n	k	50/50 Point	AOQL	n	k	50/50 Point	AOQL	n	k	50/50 Point	AOQL
5	18	1.943	2.6	1.4	51	1.824	3.4	2.1	...	...	...	...	...	...	...	...
10	8	1.740	4.1	2.0	14	1.619	5.3	2.8	65	1.441	7.5	4.9	...	...	...	...
15	5	1.600	5.5	2.8	8	1.481	6.9	3.5	23	1.303	9.6	5.6	142	1.144	13	9.5
20	4	1.493	6.8	3.4	6	1.373	8.5	4.3	13	1.193	12	6.3	44	1.034	15	9.9
25	3	1.396	8.1	4.2	5	1.283	10	5.0	7	1.009	14	6.9	23	0.940	17	11

TABLE X3.2 Sampling Plans, Standard Deviation Unknown

LQL, %	AQL, %															
	1				2				5				10			
	n	k	50/50 Point	AOQL	n	k	50/50 Point	AOQL	n	k	50/50 Point	AOQL	n	k	50/50 Point	AOQL
5	53	1.943	2.6	1.4	136	1.824	3.4	2.1	...	...	...	...	...	...	...	...
10	20	1.739	4.1	2.1	33	1.620	5.3	2.7	132	1.441	7.5	4.9	...	...	...	...
15	14	1.601	5.5	2.7	17	1.482	6.9	3.5	43	1.303	9.6	5.6	236	1.144	13	9.5
20	8	1.492	6.8	3.5	11	1.372	8.5	4.3	23	1.193	12	6.3	68	1.034	15	10
25	6	1.398	8.1	4.3	8	1.278	10	5.0	15	1.099	14	7.1	34	0.940	17	11

X3.1 Table X3.1 and Table X3.2 provide additional sampling plans that may be useful in situations where the standard plans of Tables 2-6 are unsuitable. The plans of Table X3.1 are to be used when the standard deviation of the process is known. The plans of Table X3.2 are to be used when the standard deviation is not known.

X3.2 The plans in Table X3.1 and Table X3.2 provide AQL's of 1, 2, 5, and 10 % and LQL's of 5, 10, 15, 20, and 25 %. To select a plan, go to the table, find the column headed with the desired AQL, read down to the row headed by the desired LQL, and note the sample size (*n*) and *k*.

X4. CALCULATIONS OF VARIABLES SAMPLING PLANS

X4.1 The equations in this appendix can be used to calculate the sample size (*n*) and the *k* value of variables sampling plans where:

X4.1.1 The coating requirement is stated as a lower limit;

X4.1.2 The probability of accepting product of AQL quality is 0.95 (95 %); and

X4.1.3 The probability of accepting product of LQL quality is 0.10 (10 %).

X4.2 First, select the AQL and LQL values. Next, go to Table X4.1 and find the values of *z* that correspond to the AQL and LQL. For AQL's and LQL's that are not given in the table, the*z*'s can be calculated by interpolation. The *z* corresponding to the AQL isz_1, and the one corresponding to the LQL is z_2.

TABLE X4.1 Values of *z* Used in Designing Variables Sampling Plans

AQL or LQL %Nonconforming	z
1	2.326
2	2.054
3	1.889
4	1.751
5	1.645
6	1.555
7	1.476
8	1.405
9	1.341
10	1.282
12.5	1.150
15	1.036
20	0.8416
25	0.6745

X4.3 Using z_1 and z_2, calculate *n* and *k*. Round the value of *n* to the nearest whole number. Use Eq X4.1 and Eq X4.2 when the standard deviation is known and Eq X4.3 and Eq X4.4 when the standard deviation is not known. The equations are derived in Ref (**3**), Chapters 11 and 12.

X4.3.1 Standard deviation known:

$$\eta = 8.564/(z_1 - z_2)^2 \qquad (X4.1)$$

$$k = \left(\sqrt{n}(z_1 + z_2) - 0.3633\right)/2\sqrt{n} \qquad (X4.2)$$

Use the rounded value of *n* to calculate *k*.

X4.3.2 Standard deviation unknown:

$$k = 0.4379\,z_1 + 0.5621\,z_2 \qquad (X4.3)$$

$$n = 4.2822\,(2 + k^2)/(z_1 - z_2)^2 \qquad (X4.4)$$

X4.4 Sample calculations are as follows:

Desired AQL = 2 %
Desired LQL = 10 %
Standard Deviation of Process Known
Select z's from Table X4.1
For AQL of 2 % $z_1 = 2.054$
For LQL of 10 % $z_2 = 1.282$

X4.4.1 Calculate n as follows:

$$n = 8.564/(2.054 = 1.282)^{2} = 14.4 \quad (X4.5)$$

Round to 14.

X4.4.2 Calculate k as follows:

$$k = \left(\sqrt{14}\,(2.054 + 1.282) - 0.3633\right)/2\sqrt{14} = 1.619 \quad (X4.6)$$

X4.4.3 Note that these are the values of n and k given in Table X4.1 for an AQL of 2 %, an LQL of 10 %, and a known standard deviation.

REFERENCES

(1) Military Handbook MIL-HDBK-53, "Guide for Sampling Inspection."

(2) Manual on Presentation of Data and Control Chart Analysis, *ASTM STP15D*, ASTM, 1983.

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(4) General Services Administration Handbook FSS P4440.1, *Guide for the Use of MIL-STD-105*.

(5) Duncan, Acheson J., "Acceptance Sampling Plans,"*Standardization News*, ASTM, Vol 3, No. 9, September 1975, pp. 8–9.

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