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(1) R6661
DOE Research and Development Report

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**Specified Assurance Level
Sampling Procedure**

O. Willner

**Bettis Atomic Power Laboratory
West Mifflin, Pennsylvania 15122**

November 1980

**Prepared for the
U.S. Department of Energy
By Westinghouse Electric Corporation
Under Contract No. DE-AC11-76-PN00014**

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SAMPLING PROCEDURE

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Contract No. DE-AC11-76PN00014

November 1980

Printed in the United States of America
Available from the
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

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ABSTRACT

In the nuclear industry design specifications for certain quality characteristics require that the final product be inspected by a sampling plan which can demonstrate product conformance to stated assurance levels. The Specified Assurance Level (SAL) Sampling Procedure has been developed to permit the direct selection of attribute sampling plans which can meet commonly used assurance levels.

The SAL procedure contains sampling plans which yield the minimum sample size at stated assurance levels. The SAL procedure also provides sampling plans with acceptance numbers ranging from 0 to 10, thus, making available to the user a wide choice of plans all designed to comply with a stated assurance level.

SPECIFIED ASSURANCE LEVEL SAMPLING PROCEDURE

I. INTRODUCTION

In the nuclear industry specifications related to certain quality characteristics require that the final product be subjected to a sampling procedure which shall demonstrate product conformance by use of assurance statements. Assurance statements generally specify that there exists $\gamma\%$ assurance (or confidence) that at least $P\%$ of the individual items in the lot fall within the stated specification requirements. Values of γ and P most commonly used are 90, 95 or 99. For the sake of brevity, an assurance statement providing $\gamma\%$ confidence that at least $P\%$ of the items in a lot fall within stated intervals will be termed as a " γ/P " assurance statement.

In demonstrating compliance to specifications, sampling plans of either a variable type (where actual measurements are recorded) or an attribute type (where only go-no-go measurements are obtained) are used. Examples of commonly used variable type sampling plans are those furnished by MIL-STD-414⁽¹⁾ and by Bowker and Goode⁽²⁾. The most commonly used attribute sampling plans are those specified in MIL-STD-105D⁽³⁾ and by Dodge-Romig⁽⁴⁾. However, none of these plans are directly usable in finding sampling plans that meet specified assurance levels.

The Specified Assurance Level (SAL) sampling procedure is an attribute type sampling plan which is easily instituted and administered.

II. OBJECTIVE OF SAL SAMPLING PLAN PROCEDURE

The development of the SAL sampling plan was based on the objective of satisfying five basic sampling needs which exist in the nuclear industry. These needs which have not been previously fulfilled by existing sampling plans are as follows:

1. Index sampling plans to provide specified assurance levels.
2. Identify sampling plans which require the lowest possible sample sizes at the specified assurance levels.
3. Offer a selection of sampling plans which do not permit any defectives in the sample.
4. Present wider choice of optional sampling plans which offer the same specified assurance levels.
5. Employ a more exact probability distribution applicable to acceptance sampling, namely, the hypergeometric distribution.

III. DEVELOPMENT OF SAL SAMPLING PLAN

A. Description

The SAL sampling plan is a new and unique sampling plan. It differs from existing sampling plans in that it provides stated assurance level sampling plans, minimizes sample sizes and uses the hypergeometric distribution to develop sampling plans for small lot sizes. The SAL sampling plan has been developed for high assurance levels of 95/99, 95/95 and 90/90.

The hypergeometric distribution is the recognized applicable distribution when performing acceptance sampling where samples are drawn at random without replacement⁽⁵⁾. The use of this distribution for small lots, a task made easier by the use of high speed computers, results in sample sizes that are smaller than if either the binomial or Poisson distributions were employed. However, for large lots approximations by either the binomial or Poisson distributions are quite close to that obtained by the hypergeometric⁽⁶⁾. MTL-STD-105D and the Dodge Romig plans use either the binomial or Poisson distributions as approximations in generating the applicable sampling plans.

In the SAL plan separate sampling tables have been developed for small lots (using the hypergeometric distribution) and for large lots (using the binomial distribution). A lot has been designated as small if the use of the hypergeometric distribution resulted in a significant reduction of sample size at a stated assurance level from that obtained by the use of the binomial distribution.

Sampling plans applicable to small lot sizes (defined in the S-Tables of Appendix B) contain minimum sample sizes. The acceptance number (maximum number of defectives permitted in the sample resulting in lot acceptance) for these plans are equal to zero. Sampling plans applicable to large lots (greater than 1000 for 95/99 and 95/95 assurance levels and greater than 270 for 90/90 assurance levels) yield a wide choice of sampling plans at a stated assurance levels. The acceptance numbers for these plans range between zero and ten.

Operating characteristic (O.C.) curves used to describe the probability of accepting lots for various percent defectives and which are deemed necessary to judge the effectiveness of any given sampling plan are displayed in Appendix C for all SAL sampling plans.

B. Criteria Used For The Development Of Sampling Plans

Case I: Small (finite) lot size with acceptance number equal to zero.

For each lot size (N) and acceptance number of zero defectives ($c=0$), a sample size (n) was chosen such that the following condition employing the hypergeometric distribution, was satisfied.

Given γ , $P/100$ and $D/N = (100-P)/100$, choose n such that

$$P_a = \text{Prob} \{x = 0 \mid n, D, N\} = \frac{\binom{D}{x} \binom{N-D}{n-x}}{\binom{N}{n}} \leq (100-\gamma)/100 \quad (1)$$

where, P_a = Probability of accepting the lot.

N = lot size

D = number of defectives in the lot

n = sample size

x = number of defective found in the sample

$P/100$ = proportion of product in the lot which is acceptable

γ = confidence level

γ/P = assurance level evaluated at 95/99, 95/95 or 90/90

$$\binom{D}{x} = \frac{D!}{x!(D-x)!}, \quad \binom{N}{n} = \frac{N!}{n!(N-n)!}$$

$$\binom{N-D}{n-x} = \frac{(N-D)!}{(n-x)!(N-D-n+x)!}$$

Special difficulties arise, however, in the determination of the sample size n due to the fact that N , D and n can only assume integral values. The main difficulty consists in obtaining at times erratic values for n when using Equation (1). To overcome these difficulties the following three special restrictions had to be developed and imposed to ensure meeting the stated assurance level for more stable values of n .

1) Let $N_i^* = \{N : (100-P)/100 \cdot N = I\}$

where $I = \{0, 1, 2, \dots\}$

such that the resulting sample size n_i^* satisfies Equation (1).

Then for all N , $N_i^* < N < N_{i+1}^*$, restrict n to interval

$$n_i^* \leq n \leq n_{i+1}^*$$

Purpose: To preclude the occurrence of sample sizes for lots with percent defectives approximately equal to D/N to fall outside of the band of sample sizes obtained for those lots with percent defective exactly equal to D/N .

For example, to prevent obtaining the following sample sizes for a 90/90 assurance level.

<u>Lot Size</u>	<u>No. of Defectives in Lot</u>	<u>Sample Size</u>
50	5	18
54	5	20
56	6	17
60	6	19

Restriction requires that for all lot sizes, within the lot interval such as 50 and 60, sample sizes are trapped between 18 and 19.

- 2) For all N_k, N_{k+1} in the interval $N_i^* < N_k < N_{i+1}^*$, restrict corresponding sample sizes n_k, n_{k+1} to the interval $n_i^* \leq n_k \leq n_{k+1} \leq n_{i+1}^*$ for all $k > 0$.

Purpose: To require that sample size will be a monotonically increasing function of lot size.

- 3) Group lot sizes into intervals (N_S, N_{S+1}) such that

$$\Pr \{x = 0 \mid n_S, D, N_S\} \leq \frac{(100-\gamma')}{100} \leq \frac{(100-\gamma)}{100} \quad (1a)$$

$$\text{for } D/N_S \leq (100-P')/100$$

$$\text{where } \gamma' \geq \gamma \text{ and } P' \geq P$$

$$\text{and } \Pr \{x = 0 \mid n_{S+1}, D, N_{S+1}\} < \frac{(100-\gamma^*)}{100} \leq \frac{(100-\gamma)}{100} \quad (1b)$$

$$\text{for } D/N_{S+1} \leq (100-P^*)/100$$

$$\text{where } \gamma^* \geq \gamma \text{ and } P^* \geq P.$$

Purpose: To permit lot sizes to be grouped into wider and more convenient categories without violating assurance levels.

The sampling plans resulting from the imposed boundary conditions are exhibited in Tables S-1, S-2 and S-3 of Appendix B for 95/99, 95/95 and 90/90 assurance levels, respectively. Operating characteristic curves for each of these sampling plans have been developed and are displayed in Appendix C.

Case II: Large lot size with acceptance numbers ranging from zero to ten.

Since the binomial distribution provides close approximation to the hypergeometric distribution for large lot sizes, the following calculational approach was used in the development of sampling plans dealing with large lots.

For each lot size N and acceptance numbers ranging from 0 to 10 ($c = 0$ to $c = 10$), a sample size n was chosen such that the following conditions were satisfied.

Given γ , P and c , choose n such that

$$P_a = \Pr_{(x \leq c/n, P)} = \sum_{x=0}^c \binom{n}{x} \left(\frac{100-P}{100} \right)^x \left(\frac{P}{100} \right)^{n-x} \leq \left(\frac{100-\gamma}{100} \right) \quad (2)$$

for $0 \leq c \leq 10$

where, $x = 0, 1, 2, \dots, c$ defectives in the sample

c = acceptance number

$P/100$ = proportion of product which is acceptable

γ = confidence level

The sampling plans resulting from the imposed boundary conditions of Equation (2) are exhibited in Tables L-1, L-2 and L-3 for 95/99, 95/95 and 99/99 assurance levels, respectively. Operating characteristic curves for each of these sampling plans have been developed and are displayed in the referenced charts.

C. Correspondence of Assurance Statements With Points On The Operating Characteristic Curve

The purpose of this section is to show the existence of a relationship between an assurance statement and points on the Operating Characteristic (O.C.) curve. This relationship is demonstrated for a 90/90 assurance level using the binomial distribution and is shown pictorially in Figure 1.

1. Points On The Operating Characteristic Curve

A point (x, y) on the O.C. curve signifies that a lot which is $x\%$ defective will be accepted with probability y . Specific points on the O.C. curve can be calculated in accordance with formula (2) which can be expressed as follows:

FIGURE 1
OPERATING CHARACTERISTIC CURVE
FOR SAMPLE SIZE = 22, ACCEPTANCE NUMBER = 0

$$P_a = \sum_{x=0}^c \binom{n}{x} p^x (1-p)^{n-x} \quad (3)$$

where, P_a = probability of accepting the lot
 $= \frac{(100-\gamma)}{100}$.

p = percent defective = $\frac{(100-P)}{100}$.

x = number of defectives found in the sample.

c = acceptance number.

n = sample size.

In calculating the O.C. curve, one fixes the values of c , n and p and solves for P_a . For example, if $c = 0$, $n = 22$ and $p = 10\%$ the calculated value of P_a is 0.10. This point appears on the O.C. curve plotted in Figure 1. Thus it can be stated that a 10% defective product will be accepted with a probability of 10%.

2. Assurance Statement

A γ/P assurance statement specifies that there exists $\gamma\%$ confidence that at least $P\%$ of all items in a lot are expected to fall within specification limits. This is equivalent to placing a confidence statement on the maximum percent defective of a lot (i.e. there exists $\gamma\%$ confidence that the true percent defective of a lot does not exceed p).

The determination of a confidence limit on the true lot percent defective is also accomplished by using formula (3). However, in this case the values of P_a , c and n are fixed and the value of p is minimized so that formula (3) holds.

In particular, if $P_a = 0.10$, $c = 0$ and $n = 22$ then $p \geq 0.10$ will satisfy formula (3)^a. Thus, it can be stated that there exists 90% confidence that the true percent defective does not exceed 0.10. Figure 1 shows the equivalence of a (p, P_a) point on the O.C. curve with a γ/P assurance statement. This correspondence is employed throughout the SAL plan.

From the above considerations the SAL procedures, tables and O.C. curves have been developed and are included in Appendices A, B and C of this report.

IV. DISCUSSION AND COMPARISON OF SAL AND MIL-STD-105D SAMPLING PLANS

A. Discussion of SAL

Many of the specifications in the nuclear industry require 95/95 or 95/99 assurance levels, i.e., there shall be 95% confidence that at least 95% or 99%, respectively, of the product fall within specification requirements. Moreover, the use of assurance levels provides a means of specifying the degree of criticality related to specific product characteristics and, hence, denotes the extent of manufacturing controls that must be exercised.

Faced with these requirements, current available sampling plans can not be used directly to obtain the required sampling plans. The SAL procedure has been developed primarily to enable the user to select sampling plans which can directly meet designated assurance levels. However, other important features contained in the SAL procedure are discussed below.

The SAL procedure contains sampling plans which minimizes the number of pieces to be inspected. This feature is especially vital where the cost of inspection is high. The sample minimization feature has been incorporated into the SAL plan for small lots by employing (1) the hypergeometric distribution and (2) sampling plans with acceptance numbers equal to zero.

An additional feature of the SAL plan is that for large lots a wide range of alternate sampling plans have been provided all of which offer equal assurance levels. A total of eleven alternate sampling plans are listed for each assurance level with acceptance numbers ranging from 0 to 10. These alternate plans furnish varying producer's risks but provide identical consumer's risks. For this reason a producer should consult the various O.C. curves shown in Appendix C and choose the plan which will decrease the producer's risk while inspecting at an economically acceptable sampling rate.

B. Discussion of MIL-STD-105D in Relationship with SAL

In discussing the SAL procedure it is appropriate to compare this plan with other sampling plans which are in common usage.

MIL-STD-105D is currently the most widely used sampling procedure. This plan is entered by means of (a) Lot Size, (b) Inspection Level, (c) AQL, (d) Choice of Normal, Tightened and Reduced Inspection and (e) Choice of Single, Double or Multiple Sampling. Experience over the years has indicated that areas of confusion exist in the real meaning of AQL and just how the Lot Size, Inspection Levels, Choice of Normal, Tightened and Reduced Inspection affect the protection provided to the consumer by MIL-STD-105D sampling plans.

1. Effect of AQL

As defined by the MIL-STD-105 procedure, AQL is the maximum percent defective that, for purposes of sampling inspection, can be considered satisfactory as a process average. It is designed so that lots submitted for sampling inspection at the AQL value are accepted with probabilities ranging from 85% to 99%.

The AQL concept can best be examined by means of an example. Suppose a lot of 50 pieces is submitted for sampling inspection for which MIL-STD-105D is used. If we specify the use of AQL = 1.5%, single sampling, normal inspection and Inspection Level II we can then determine the specific sampling plan to be used.

Based on Tables I and II-A of MIL-STD-105D we find that the sampling plan consists of taking eight pieces ($n = 8$) with an acceptance number of zero ($c = 0$). This means that eight pieces are to be selected at random from the lot of fifty pieces. If no defectives among the sample of eight pieces are found the lot is accepted; otherwise, it is rejected or 100% screened for the presence of defectives.

Let us investigate how effective this sampling plan is in detecting poor quality lots. This can best be accomplished by examining the O.C. (Operating Characteristic) curve of Figure 2 based on page 36 of MIL-STD-105D. This curve indicates the probability of accepting the lot under various conditions, i.e., that the lot contains various percent defectives.

Based on this curve the following statements can be made.

- (a) If the lot contains 1.5% defectives, it will be accepted with approximately 90% probability.
- (b) If the lot contains 10% defectives, it will be accepted with approximately 47% probability.
- (c) If the lot contains 30% defectives, it will be accepted with approximately 5% probability.

Thus, we can see that if a lot contains a percent defective equal to the AQL value (in this case 1.5%), the probability of the lot being accepted by this sampling plan is very high (in this case 90%). The producer's risk for this manufacturer is therefore 10%. However, if the lot contains 10% defectives it still is accepted 47% of the time. Thus, if the purchaser or consumer does not want to accept a 10% defective lot, then this sampling plan does not offer the consumer sufficient protection.

FIGURE 2
OPERATING CHARACTERISTIC CURVE
FOR $n=8, c=0$

It should be noted that this plan does offer good protection in rejecting a 30% defective lot since the probability of accepting a 30% defective lot is 5% (i.e. 95% probability of rejecting a 70% non-defective lot). In this report the assurance level offered by this plan is expressed as a 95/70 assurance level. Thus, it can be seen that although the AQL chosen for this sampling plan is 1.5%, the consumer's protection is limited to a 5% assurance of not buying a 30% defective lot or worse. The 5% probability of buying a poor lot is known as the consumer's risk.

In many of the specifications involving nuclear product, the requirements are stated in a manner which guarantees the meeting of the consumer's risk.

That is, the consumer (the purchaser) defines an unacceptable percent defective so that if the incoming lot contains the specified unacceptable percent defective it is assured that such a lot will be rejected with high probability. For example, a 95/99 specification requirement guarantees to the consumer (government) that if the incoming lot contains 1% defective it will be rejected with 95% probability. The SAL procedure is designed to furnish sampling plans at stated consumer's risks, whereas, the MIL-STD-105D procedure places emphasis on the producer's risk.

It should be noted that another popular sampling plan, Dodge Romig Plans⁽⁴⁾, is indexed by LTPD (Lot Tolerance Percent Defective) which corresponds to the percent defective which the consumer finds undesirable and wishes to reject. However, these plans are all stated at a single consumer's risk of 0.10 corresponding to only the 90% assurance level. Thus 95/99 or 95/95 plans are not referenced and therefore cannot be obtained from these tables. In addition, these plans require that one enter the table by the process average percent defective which the manufacturer has been producing in the past, a value frequently not known by the purchaser.

2. Effect of Lot Size

MIL-STD-105D uses Lot Size as a basic entry in determining sample size (See Table I of MIL-STD-195D).

Furthermore, the plan is formulated so that for a fixed AQL value and Inspection Level, both sample size and the acceptance numbers increase with increasing lot size. An example of this is shown in Table I below for AQL = 2.5%, Inspection Level II, Normal Inspection Plan and Single Sampling.

Table I

Use of MIL-STD-105D, AQL = 2.5%,
Inspection Level II Plan

<u>Lot Size</u>	<u>Sample Size</u>	<u>Acceptance Number</u>
20	5	0
75	13	1
200	32	2
1,000	80	5
3,000	125	7
20,000	315	14
40,000	500	21

Although lot size is used as a main determining factor in Table I of MIL-STD-105D to arrive at sample size, computations of O.C. curves are not based on lot size. (MIL-STD-105D uses the binomial and the Poisson distributions to determine values of the O.C. curve. These distributions are not dependent on the size of the lot.)

By contrast the SAL plan for small lots (S-Tables) is based on the hypergeometric distribution which is functionally dependent on the lot size (see Formula (1)). This serves to minimize the required sample size for stated assurance levels.

An example of how the use of the hypergeometric distribution can minimize the required sample size at stated confidence limits we can consider a lot of 100 pieces submitted for sampling inspection to attain a 95/95 assurance level. The use of the binomial distribution (which assumes sampling with replacement) results in a minimum sampling plan of $n = 59$, $c = 0$, whereas, use of the hypergeometric distribution reduces the required sample size to $n = 45$, $c = 0$.

Furthermore, additional sample savings can be realized by the SAL plan as compared to MIL-STD-105D when sampling to meet stated assurances since the latter plan only uses fixed sample sizes. Therefore, if MIL-STD-105D were used to select a sampling plan to meet a 95/95 assurance level for a lot size of 100 pieces the required sampling plan would be $n = 80$, $c = 0$ (since the next lower available plan consists of $n = 50$, $c = 0$ which falls short of meeting a 95/95 level). Thus, the actual savings in this example would be 44% ($n = 80$ vs. $n = 45$).

3. Effect of Inspection Level and Choice of Normal, Reduced or Tightened Inspection

The choice of Inspection Level is a necessary input in the determination of a MIL-STD-105D sampling plan. The most commonly

chosen levels are Inspection Levels I, II or III. Additional inspection levels mostly applicable to destructive testing are S-1, S-2, S-3 and S-4 levels. These are stated in Table I of MIL-STD-105D.

It should be clearly understood by the user that the greatest consumer protection is offered by Inspection Level III plans, that a lesser protection is offered by Inspection Level I plans and that the least protection is offered by the Inspection Level S-1 plans. It is therefore necessary to consult the O.C. curves applicable to the resultant sampling plans to determine the effect of specifying these alternate inspection levels.

Similarly, the choice of normal, reduced or tightened inspection will affect the O.C. curves and thereby the consumer protection applicable to these plans. Unfortunately, O.C. curves applicable to reduced inspection plans are unavailable in MIL-STD-105D. O.C. curves are furnished for the normal and tightened plans based on the binomial or Poisson assumptions and these should be consulted when using these plans.

C. Comparison of SAL and MIL-STD-105D Plans

A comparison of the assurance levels provided by MIL-STD-105D with those of the SAL procedure is shown in Figure 3. AQL values of 0.1%, 1.0%, 2.5%, 6.5% and 10.0% taken from MIL-STD-105D are compared to the 95/95 assurance level taken from the SAL plan. From this figure it can be noted that for the MIL-STD-105D plans

- (1) the percent of product assured increases with increasing lot sizes,
- (2) considerably less than 90% of the product is assured for all indicated AQL values and for all lots less than 150.
- (3) higher AQL values will in certain instances offer a higher lot assurance than for lower AQL values.

Figure 4 exhibits the comparison of the sample size required by MIL-STD-105D (AQL = 2.5%) vs. the SAL (95/95) sampling procedure. It is evident from this graph that the SAL (95/95) plan consistently offers a higher assurance level. This is true even for lot sizes of over 500 where the sampling rate required by MIL-STD-105D (AQL = 2.5%) is considerably higher than for the SAL plan. For example, for a lot size of 3,201 to 10,000, MIL-STD-105D requires a sample size of 200 pieces and offers a 95/92 assurance level ($n = 200$, $c = 10$) whereas under SAL (95/95) a sample size of only 59 is required ($n = 59$, $c = 0$, option 1) which offers a higher assurance level.

Figure 5 shows a similar comparison between MIL-STD-105D (AQL = 1.0%) vs. SAL (95/95) sampling rates. This graph shows that for lot sizes of 5,000 or less the SAL (95/95) plan offers a consistently higher assurance level than the MIL-STD-105D (AQL = 1.0%) plan. This is true even for lot sizes of 500 to 10,000 where a higher sampling rate prevails for the MIL-STD-105D (AQL = 1.0%) plan.

FIGURE 3
COMPARISON OF THE PERCENT OF PRODUCT ASSURED TO MEET
REQUIREMENTS MIL-STD-105D* (AQL) VS SAL (95/95) PLANS

FIGURE 4
COMPARISON OF SAMPLE SIZES MIL-STD-105D
(AQL=2.5%) VS SAL (95/95)

FIGURE 5
COMPARISON OF SAMPLE SIZES MIL-STD-105D
(AQL=1.0%) VS SAL (95/95)

V. EXAMPLES OF SAL APPLICATIONS

Use of the SAL procedure in selecting sampling plans for three specific cases with varying lot sizes which have been encountered in some of the nuclear program applications are shown in Table II.

Case I pertains to a lot size of 43,000 units and required the use of the L-Sampling Tables of Appendix B applicable to large lots. Cases II and III refer to lot sizes of 1,000 items and 140 items, respectively, and required the use of the S-Sampling Tables of Appendix B applicable to small lots. The resultant sample sizes for assurance levels of 95/99, 95/95 and 90/90 are presented in Table II below.

It should be noted that for Case I application, a choice of eleven separate sampling plans are indicated. For example, the following choices of sampling plans, shown in Table L-2 of Appendix B all provide a 95/95 assurance level:

(1)	n = 59,	c = 0
(2)	n = 93,	c = 1
(3)	n = 124,	c = 2
(4)	n = 153,	c = 3
(5)	n = 181,	c = 4
(6)	n = 208,	c = 5
(7)	n = 234,	c = 6
(8)	n = 260,	c = 7
(9)	n = 286,	c = 8
(10)	n = 311,	c = 9
(11)	n = 336,	c = 10

Only the first two sampling plan choices are shown in Table II.

For comparison purposes, Table II also displays the sampling plans which would be required per MIL-STD-105D using AQL values of 0.10%, 2.5% and 6.5%; the corresponding assurance levels are shown to the right of each sampling plan.

Based on Table II results, the following observations can be made:

- (1) The use of AQL in MIL-STD-105D does not result in achieving a specific assurance level. MIL-STD-105D was designed so that a product presented for sampling inspection at the AQL value will be accepted with high probability. It offers no stated protection against accepting a lot of poor quality.

Table II

Sampling Plans and Assurance Levels Provided by SAL and
MIL-STD-105D Plans

Case	Lot Size	Use of SAL Plan: Entered by Assurance Level						Use of MIL-STD-105D* Entered by AQL Value**					
		95/99		95/95		90/90		0.10%		2.5%		6.5%	
		Sample Plan	Assur. Level	Sample Plan	Assur. Level	Sample Plan	Assur. Level	Sample Plan	Assur. Level	Sample Plan	Assur. Level	Sample Plan	Assur. Level
I	43,000	n=299 c=0 or n=473 c=1 or others in the table. See Table L-1	95/ 99	n=59 c=0 or n=93 c=1 or others in the table. See Table L-2	95/ 95	n=22 c=0 or n=38 c=1 or others in the table. See Table L-3	90/ 90	n=800 c=2	95/ 99.2	n=500 c=21	95/ 94	n=200 c=21	95/ 85
II	1,000	n=268 c=0 See Table S-1	95/ 99	n=57 c=0 See Table S-2	95/ 95	n=22 c=0 See Table S-3	90/ 90	n=125 c=0	95/ 97.6	n=80 c=5	95/ 87	n=80 c=10	95/ 80
III	140	100% See Table S-1	N.A.	n=48 c=0 See Table S-2	95/ 95	n=21 c=0 See Table S-3	90/ 90	n=125 c=0	95/ 97.6	n=20 c=1	95/ 78	n=20 c=3	95/ 66

* Sampling Plans are in accordance with MIL-STD-105D using Single Sampling, Normal Inspection and Inspection Level II.

** AQL Value - Acceptable Quality Level Value. There exists a high probability level of accepting lots of this quality level.

N.A. Sampling Plan not applicable - Use 100% inspection.

- (2) Smaller sample sizes than those required by the MIL-STD-105D procedure are furnished in many instances by the SAL procedure and may result in higher assurance levels than those offered by MIL-STD-105D. In those cases where the sample size for MIL-STD-105D is less than what is available by SAL, a significantly lower assurance level prevails.

VI. SUMMARY

This report discusses the development of the Specified Assurance Level Sampling Procedure which was designed to satisfy needed sampling plan objectives. Examples of usage and comparison with MIL-STD-105D sampling plan are provided.

The report contains the necessary procedures, sampling plan tables and Operating Characteristic curves to enable the user to institute attribute (go no-go) sampling inspection plans. These plans are designed to offer the consumer (purchaser) a stated assurance (γ) that at least P percent of the items in a lot or group of lots meet the specification limits. Separate sampling plan tables are provided for small and large lots. In addition, sample sizes have been minimized which attain stated assurance levels.

REFERENCES

1. "Military Standard - Sampling Procedures and Tables for Inspection by Variables for Percent Defective," MIL-STD-414, June 11, 1957.
2. A. H. Bowker and H. P. Goode, "Sampling Inspection by Variables," McGraw Hill, New York, 1952.
3. "Military Standard - Sampling Procedures and Tables for Inspection by Attributes," MIL-STD-105D, April 29, 1963.
4. H. F. Dodge and H. G. Romig, "Sampling Inspection Tables Single and Double Sampling," John Wiley and Sons, 1959.
5. I. Miller and J. E. Freund, "Probability and Statistics for Engineers," Prentice Hall, Inc., 1965.
6. A. J. Duncan, "Quality Control and Industrial Statistics," Richard D. Irwin, Inc., 1974.

APPENDIX A

SAL Sampling Procedures

SAMPLING PROCEDURES1. SCOPE1.1 Purpose

This publication establishes sampling plans and procedures for inspection by attributes designed to meet specified statistical assurance levels.

1.2 Application

Sampling plans designated in this publication are applicable to any lot accept-reject inspection operation for which it is desired to have assurance at a stated level that at least a specified percentage of all items in the lot are in conformance with specification requirements. Assurance levels used in this document are 95/99, 95/95 and 90/90 levels where γ/P denotes that there exists $\gamma\%$ assurance that at least $P\%$ of all individual items in the lot conform to specified requirements.

Sampling plans are presented which range from small to large lots. Use of the hypergeometric distribution was made to determine sampling plans for small lots; use of the binomial distribution was made to determine sampling plans for large lots. A lot was designated as a "small" lot if the use of the hypergeometric distribution (which is the exact distribution for acceptance sampling plans) yielded an appreciably smaller sample size, at a specified assurance level, as opposed to the use of the binomial distribution.

The plans apply with equal validity to either isolated lots or lots coming from a continuous production process. For this reason, they are particularly useful for incoming inspection and for job-shop situations.

1.3 Inspection

The term inspection, as used in this procedure, consists of the process of examining, testing, measuring or otherwise comparing the unit of product to its specification requirements.

1.4 Attribute Inspection

These plans are intended for application to situations in which the quality of a unit of production may be judged on the basis of whether or not it complies with requirements. Thus, the quality of a group of such units, called a lot can be expressed in terms of "percent defective".

1.5 Unit of Product

The phrase unit of product, as used in this document, refers to any characteristic or part being inspected to determine its compliance with requirements. It may be a single article, a pair, a set, a length, an area, an operation, a volume, a component of an end product, or the product itself. The unit of product may or may not be the same as the unit of purchase, supply, production, or shipment. It is only necessary that the units of product that go together to make up a lot have in common at least the characteristic which is being inspected.

2. CLASSIFICATION OF CHARACTERISTICS

2.1 Characteristics

A characteristic refers to any dimensional, physical, chemical, function, mechanical or electrical feature which describes and establishes the design, manufacturing and assembly requirements of the product (assembly, subassembly, and individual parts). The term characteristic includes only those material features or properties that can be verified on the product by measurement or observation (e.g., characteristics such as dimensions, identification marking, surface finish, cleanliness, forms, features, proper part placement and orientation).

2.2 Critical Characteristics

Critical characteristics refer to those characteristics that directly affect functional capabilities, reliability and/or safety, such as those associated with high stress areas, wear surfaces, safety related features, pressure boundaries, operating clearances, interchangeability, sliding and translating features, interface features and locking features for which failure to meet the acceptance limit of the characteristic could cause failure of the component. Examples of criteria that may be used for determining critical characteristics are as follows:

- a. Characteristics that establish pressure boundary wall thickness.
- b. Characteristics associated with assembly, alignment or fitup.
- c. Characteristics that establish minimum/maximum clearances between moving parts.
- d. Characteristics which affect installation or use (interface dimensions).

2.3 Major Characteristics

Major characteristics refer to characteristics that, if deviated, do not directly affect the product to the extent that functional requirements are jeopardized. In general, all characteristics not classified as either critical or minor are considered to be major characteristics.

2.4 Minor Characteristics

Minor characteristics consist of any characteristics which, even if deviated, do not affect the intended function of the product. Characteristics such as fillet radii mating with air, nonfunctional transition radii or tapers, optional features, non-interfacing edge and corner breaks, tooling holes, lead-in chamfers, countersink angles, optional drill points and tapped hole lead diameter drill-throughs are examples of minor characteristics.

3. CLASSIFICATION OF DEFECTS AND DEFECTIVES

3.1 Method of Classifying Defects and Defectives

A defect is any nonconformance of a unit of product to its specified characteristics. A defective is a unit of product which contains one or more defects. Defectives will usually be classified as follows:

3.1.1 Critical Defective

A critical defective contains one or more critical defects and may also contain major and/or minor defects.

3.1.2 Major Defective

A major defective contains one or more major defects, and may also contain minor defects but contains no critical defect.

3.1.3 Minor Defective

A minor defective contains one or more minor defects but contains no critical or major defect.

4. MEASURES OF LOT QUALITY

4.1 Percent Defective

The quality of a lot can be measured in terms of the percent of the lot which is defective. This requires that each member of the lot is classified as either defective or non-defective. Defective means that it contains one or more instances of nonconformance to a specified characteristic. The plans described in this document are intended for use on lots whose quality is to be measured in terms of percent defective.

4.2 Assurance Level

The assurance level is a statistical confidence statement about a stated percentage of the individual units in a lot which is determined on the basis of inspecting a random sample of units from the lot. Thus, if a lot has successfully passed a 95/99 assurance level sampling plan it can be stated that with 95% confidence (assurance) at least 99% of all the units in the lot are acceptable.

Similarly, assurance levels can be stated to express the degree of protection which a sampling plan offers the purchaser in not accepting an undesirable percentage of defectives in the lot. Thus, a 95/99 designated sampling plan offers a 95% probability of rejecting a 1% defective lot.

4.3 Defects Per Unit

Alternatively, the quality of a lot can be measured in terms of the number of defects per unit. This implies that each member of the lot can have one or more defects. The plans described in this document were not developed for use when defects per unit is to be used as the measure of lot quality. Plans for defects per unit can be calculated using the Poisson probability distribution function or are available in MIL-STD-105D.

5. INDEXING PARAMETERS

5.1 Specified Assurance Level

The sampling plans in this document are indexed by assurance levels (95/99, 95/95 and 90/90). These plans are developed primarily to offer "consumer" or customer protection from buying lots deemed to be unacceptable, i.e. to protect against the beta risk. (Thus, a 95/99 sampling plan contains a beta risk of 5% of accepting a 1% defective lot, a 95/95 sampling plan contains a beta risk of 5% of accepting a 5% defective lot and a 90/90 sampling plan contains a beta risk of 10% of accepting a 10% defective lot).

NOTE: Since it is not possible to have all sampling points go through the desired assurance point, sampling plans were chosen which would offer at least the stated assurance level.

5.2 Acceptable Quality Level (AQL)

AQL, expressed as a percent, defines the maximum percent defective that, for purposes of sampling inspection, can be considered satisfactory as a process average. Tables L-1, L-2 and L-3 contain AQL levels which represent the percent defective which will be accepted with 95% probability by the applicable sampling plan.

6. SUBMISSION OF PRODUCT

6.1 Lot

The term lot shall mean "inspection lot", i.e., a collection of units of product from which a sample is to be drawn and inspected to determine conformance to prescribed characteristics and may differ from a collection of units designated as a lot for other purposes (e.g., production, shipment, etc.). Each lot shall, as far as practicable, consist of units of product of a single type, grade, class, size and composition, manufactured under essentially the same conditions.

6.2 Lot Size

The lot size is the number of units of product in a lot which is presented for sampling inspection at one time. It is represented in this document by "N".

6.3 Lot Formation and Sampling

The product shall be assembled into identifiable lots, sublots, batches, or in such other manner as may be prescribed. The formation of lots and the manner in which each lot is to be presented and identified by the supplier shall be designated or approved by the responsible authority. Evidence of process control is not a requirement for the use of these sampling plans since these sampling plans are designed to give specific protection against acceptance of lots of a given quality level or worse. However, if one suspects lack of control which could produce stratification of the material in the lot, then the method of random selection of samples should recognize this potential stratification. As with any statistical sampling plan, random sampling is presumed. Similarly, if the production sequence is suspected of having a relationship to quality, then the samples may be randomly drawn in a stratified manner, spaced throughout the run. In all cases, random sampling, such as assigning numbers to the units of the lot and selecting the sample by a random number table or another method designed to ensure randomness shall be employed. Randomization is a procedure which severs the causative connections between the act of selection and the quality characteristic being sampled.

As necessary, the supplier shall provide adequate and suitable storage space for each lot, equipment needed for proper identification and presentation, and personnel for all handling of product required for drawing of samples.

6.4 Sampling

It is possible and desirable to establish different assurance levels for various classes of defectives when using a sampling plan.

6.4.1 Sample Size

The sample size consists of the number of units of product which has been selected from the lot. Sample size is represented in this document by "n".

7. ACCEPTANCE OR REJECTION

7.1 Acceptability of Lots

Acceptability of a lot will be determined by the use of a sampling plan associated with the designated assurance level.

7.2 Defective Units

The right is reserved to reject any unit of product found to be defective whether that unit of product forms part of a sample or not, and whether the lot or batch as a whole is accepted or rejected. Rejected units may be repaired or corrected and resubmitted for inspection with the approval of, and in the manner specified by, the purchaser.

7.3 Resubmitted Lots

Lots found to be unacceptable shall be resubmitted for reinspection only after all units in the lot are re-examined, retested or repaired and all defective units are removed or defects corrected. The purchaser shall be informed when previously rejected lots are resubmitted for inspection.

8. SAMPLING PLANS

8.1 Sampling Plan

A sampling plan indicates the number of units of product from each lot which are to be inspected at random and the criteria for determining the acceptability of the lot. If the number of defective units found in the sample does not exceed the allowable number (acceptance number) the lot is accepted. If the number of defective units found in the sample exceeds the acceptance number the lot is rejected.

Tables S-1, S-2 and S-3 contain sampling plans where the acceptance number is zero and represent the minimum sample sizes to offer the stated assurance levels. Tables L-1, L-2 and L-3 contain a selection of various sample sizes and acceptance numbers which all offer the indicated assurance levels.

Tables S-1, S-2 and S-3 describe 95/99, 95/95 and 90/90 assurance level sampling plans, respectively. These tables are based on small lot sizes (lot size intervals appear in the tables), acceptance numbers equal to zero and make use of the hypergeometric distribution.

For large lots (greater than 1,000 for the 95/99 and 95/95 assurance levels and greater than 270 for the 90/90 assurance levels) use of Tables L-1, L-2 and L-3 should be made. Tables L-1, L-2 and L-3 can also be used for any lot size where sampling plans containing acceptance numbers ranging from 0 to 10 are desired. These plans may yield sample sizes equal to or greater than those that would be obtained by the hypergeometric distribution. Tables L-1, L-2, L-3 are based on the binomial distribution.

Sampling plans in this document are single sampling plans. Therefore, once a specific sampling plan (sample size and acceptance number) has been designated additional sampling is not permitted since that would tend to alter the specified assurance level.

8.2 Operating Characteristic Curves

The Operating Characteristic Curve is used to determine the probability of lot acceptance when various quality levels (percent defectives) are submitted for sampling inspection.

APPENDIX B

SAL Sampling Tables

1. Description of SAL Sampling Tables

The sampling plan tables consist of the S-Tables which are applicable to small lots and L-Tables which are applicable to large lots. The S-Tables contain sampling plans which yield the minimum sample sizes and contain acceptance numbers which are equal to zero. The L-Tables contain acceptance numbers ranging from 0 to 10 and therefore furnish not only the minimum sampling rates but also ten additional optional plans per table.

Three different assurance levels are provided. 95/99 assurances are furnished in Tables S-1 and L-1; 95/95 in Tables S-2 and L-2; 90/90 in Tables S-3 and L-3.

For lot sizes greater than 1,000 and assurance levels of 95/99 or 95/95 Tables L-1 or L-2 should be used. For lots greater than 270 and an assurance level of 90/90 use of Table L-3 should be made.

TABLE S-1

Sampling Plans Designed to Meet 95/99
Assurance Level Using Minimum Sample Size
 (All Acceptance Numbers are Zero)

<u>Lot Size</u>	<u>Sample Size*</u>	<u>Operating Characteristic Curves</u> <u>Plotted for Stated Lot Sizes</u>			<u>Chart</u>
		<u>N₁</u>	<u>N_c</u>	<u>N_h</u>	
1-155	A11	N.A.	N.A.	N.A.	N.A.
156-200	155	N.A.	N.A.	200	S-1A
201-300	194	201	250	300	S-1B
301-400	221	301	350	400	S-1C
401-500	236	401	450	500	S-1D
501-600	247	501	550	600	S-1E
601-700	254	601	650	700	S-1F
701-800	260	701	750	800	S-1G
801-900	264	801	850	900	S-1H
901-1,000	268	901	950	1,000	S-1I
Over 1,000	299	Refer to Table L-1			

N.A. - Not Applicable

* - Sampling Plans are based on the Hypergeometric Probability Distribution.

N₁ - Lowest curve on chart for stated lot size.

N_c - Center curve on chart for stated lot size.

N_h - Highest curve on chart for stated lot size.

TABLE S-2

Sampling Plans Designed to Meet 95/95
Assurance Levels Using Minimum Sample Size
 (All Acceptance Numbers are Zero)

Lot Size	Sample Size*	Operating Characteristic Curves Plotted for Stated Lot Sizes			Chart
		N_1	N_c	N_h	
1-40	All	N.A.	N.A.	N.A.	N.A.
41-60	38	41	50	60	S-2A
61-80	42	61	70	80	S-2B
81-100	45	81	90	100	S-2C
101-120	47	101	110	120	S-2D
121-140	48	121	130	140	S-2E
141-160	49	141	150	160	S-2F
161-180	50	161	170	180	S-2G
181-200	51	181	190	200	S-2H
201-240	52	201	220	240	S-2I
241-300	53	241	270	300	S-2J
301-360	54	301	330	360	S-2K
361-480	55	361	420	480	S-2L
481-700	56	481	590	700	S-2M
701-1,000	57	701	850	1,000	S-2N
Over 1,000	59	Refer to Table L-2.			

N.A. - Not Applicable.

* - Sampling plans are based on the Hypergeometric Probability Distribution.

N_1 - Lowest curve on chart for stated lot size.

N_c - Center curve on chart for stated lot size.

N_h - Highest curve on chart for stated lot size.

TABLE S-3

Sampling Plans Designed to Meet 90/90 Assurance
Levels Using Minimum Sample Size
 (All Acceptance Numbers are Zero)

Operating Characteristic Curves					
Plotted for Stated Lot Sized					
<u>Lot Size</u>	<u>Sample Size*</u>	<u>N_l</u>	<u>N_c</u>	<u>N_h</u>	<u>Chart</u>
1-20	All	N.A.	N.A.	N.A.	N.A.
21-30	16	21	25	30	S-3A
31-40	17	31	35	40	S-3B
41-50	18	41	45	50	S-3C
51-70	19	51	60	70	S-3D
71-120	20	71	95	120	S-3E
121-270	21	121	195	270	S-3F
Over 270	22	Refer to Table L-3.			

N.A. - Not Applicable.

* - Sampling plans are based on the Hypergeometric Probability Distribution.

N_l - Lowest curve on chart for stated lot size.

N_c - Center curve on chart for stated lot size.

N_h - Highest curve on chart for stated lot size.

TABLE L-1

Sampling Plans Designed to Meet 95/99
Assurance Levels
 (Acceptance Numbers ranging from 0 to 10)

<u>Options</u>	<u>Sample Size*</u>	<u>Acceptance Number</u>	<u>Operating Characteristic Curve Charts</u>	<u>Probability of Acceptance</u>	
				<u>.95 AQL**</u>	<u>.05</u>
(1)	299	0	L-1A	0.02% Def.	1.0% Def.
(2)	473	1	L-1A	0.08% Def.	1.0% Def.
(3)	628	2	L-1B	0.1% Def.	1.0% Def.
(4)	773	3	L-1B	0.2% Def.	1.0% Def.
(5)	913	4	L-1C	0.2% Def.	1.0% Def.
(6)	1049	5	L-1C	0.2% Def.	1.0% Def.
(7)	1182	6	L-1D	0.3% Def.	1.0% Def.
(8)	1312	7	L-1D	0.3% Def.	1.0% Def.
(9)	1441	8	L-1E	0.3% Def.	1.0% Def.
(10)	1568	9	L-1E	0.3% Def.	1.0% Def.
(11)	1693	10	L-1E	0.4% Def.	1.0% Def.

* Sampling plans are based on the Binomial Probability Distribution.

** AQL = the percent defective which will be accepted with 95% probability by the sampling plan.

TABLE L-2

Sampling Plans Designed to Meet 95/95
Assurance Levels
 (Acceptance Numbers Ranging from 0 to 10)

<u>Options</u>	<u>Sample Size*</u>	<u>Acceptance Number</u>	<u>Operating Characteristic</u> <u>Curve Charts</u>	<u>Probability of Acceptance</u>	
				<u>.95</u> <u>AQL**</u>	<u>.05</u>
(1)	59	0	L-2A	0.1% Def.	5.0% Def.
(2)	93	1	L-2A	0.3% Def.	5.0% Def.
(3)	124	2	L-2B	0.6% Def.	5.0% Def.
(4)	153	3	L-2B	0.9% Def.	5.0% Def.
(5)	181	4	L-2C	1.1% Def.	5.0% Def.
(6)	208	5	L-2C	1.3% Def.	5.0% Def.
(7)	234	6	L-2D	1.4% Def.	5.0% Def.
(8)	260	7	L-2D	1.5% Def.	5.0% Def.
(9)	286	8	L-2E	1.6% Def.	5.0% Def.
(10)	311	9	L-2E	1.8% Def.	5.0% Def.
(11)	336	10	L-2E	1.8% Def.	5.0% Def.

* Sampling Plans are based on the Binomial Probability Distribution.

** AQL = the percent defective which would be accepted with 95% probability by the sampling plan.

TABLE L-3

Sampling Plans Designed to Meet 90/90
Assurance Levels
 (Acceptance Numbers ranging from 0 to 10)

<u>Options</u>	<u>Sample Size*</u>	<u>Acceptance Number</u>	<u>Operating Characteristic Curve Charts</u>	<u>Probability of Acceptance</u>	
				<u>.95 AQL**</u>	<u>.10</u>
(1)	22	0	L-3A	0.2% Def.	10.0% Def.
(2)	38	1	L-3A	0.9% Def.	10.0% Def.
(3)	52	2	L-3B	1.6% Def.	10.0% Def.
(4)	65	3	L-3B	2.1% Def.	10.0% Def.
(5)	78	4	L-3C	2.6% Def.	10.0% Def.
(6)	91	5	L-3C	2.9% Def.	10.0% Def.
(7)	104	6	L-3D	3.2% Def.	10.0% Def.
(8)	115	7	L-3D	3.5% Def.	10.0% Def.
(9)	123	8	L-3E	3.7% Def.	10.0% Def.
(10)	140	9	L-3E	3.9% Def.	10.0% Def.
(11)	152	10	L-3E	4.1% Def.	10.0% Def.

* Sampling Plans are based on the Binomial Probability Distribution.

** AQL = the percent defective which will be accepted with 95% probability by the sampling plan.

APPENDIX C

Operating Characteristic Curves
For SAL Plan

1. Description of SAL Operating Characteristic Curves

Operating Characteristic (OC) curves are furnished in this section for each sampling plan appearing in Appendix B.

The S-Charts pertain to the sampling plans in Appendix B related to small lot sizes. For these charts three separate OC curves appear. The lowest OC curve refers to the largest lot size of the stated lot size interval and the highest OC curve refers to the smallest lot size of that interval. None of these OC curves were permitted to extend above the $(1-\gamma, 1-P)$ point of the curve.

The L-Charts refer to the large lot sampling plans identified in Appendix B as L-Tables. Each OC curve is identified with a corresponding n, c (sample size, acceptance number) which corresponds to the applicable plan shown in Appendix B.

Chart S-1A

95/99 SAMPLING PLANS

Chart S-1B

95/99 SAMPLING PLANS

Chart S-1C
95/99 SAMPLING PLANS

95/99 SAMPLING PLANS

Chart S-1E

95/99 SAMPLING PLANS

Chart S-1F
95/99 SAMPLING PLANS

Chart S-1G

95/99 SAMPLING PLANS

95/99 SAMPLING PLANS

Chart S-11

95/99 SAMPLING PLANS

95/95 SAMPLING PLANS

Chart S-2B

95/95 SAMPLING PLANS

Chart S-2C

95/95 SAMPLING PLANS

Chart S-2D

95/95 SAMPLING PLANS

95/95 SAMPLING PLANS

Chart S-2F

95/95 SAMPLING PLANS

95/95 SAMPLING PLANS

Chart S-2H

95/95 SAMPLING PLANS

Chart S-2I

95/95. SAMPLING PLANS

Chart S-2J

95/95 SAMPLING PLANS

95/95 SAMPLING PLANS

Chart S-2L

95/95 SAMPLING PLANS

95/95 SAMPLING PLANS

- 09 -

Chart S-2N

95/95 SAMPLING PLANS

Chart S-3A

90/90 SAMPLING PLAN - HYPERGEOMETRIC DIST

Chart S-3B

90/90 SAMPLING PLAN - HYPERGEOMETRIC DIST

90/90 SAMPLING PLAN - HYPERGEOMETRIC DIST

Chart S-3D

90/90 SAMPLING PLAN - HYPERGEOMETRIC DIST

Chart S-3F

95/99 SAMPLING PLANS

Chart L-1B

95/99 SAMPLING PLANS

95/99 SAMPLING PLANS

Chart L-1D

95/99 SAMPLING PLANS

95/99 SAMPLING PLANS

Chart L-2A

95/95 SAMPLING PLANS

95/95 SAMPLING PLANS

Chart L-2C

95/95 SAMPLING PLANS

95/95 SAMPLING PLANS

Chart L-2E

95/95 SAMPLING PLANS

Chart L-3A

90/90 SAMPLING PLAN

Chart L-3B

90/90 SAMPLING PLAN

Chart L-3C

90/90 SAMPLING PLAN

Chart L-3D

90/90 SAMPLING PLAN