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MILITARY HANDBOOK

ENVIRONMENTAL STRESS SCREENING (ESS)
OF
ELECTRONIC EQUIPMENT

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DEPARTMENT OF DEFENSE

WASHINGTON DC 20301

ENVIRONMENTAL STRESS SCREENING OF ELECTRONIC EQUIPMENT

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Foreword

1. This Handbook provides techniques for planning and evaluating Environmental Stress Screening (ESS) programs. The guidance contained herein departs from other approaches to ESS in that quantitative methods are used to plan and control both the cost and effectiveness of ESS programs. Handbook procedures and methodology were developed under RADC contractual and in-house studies. Contractual efforts were performed by the Hughes Aircraft Company of Fullerton, California, under the direction of Mr. A. E. Saari. The Handbook includes the guidance contained in R&M 2000 ESS Policy Letter dated 25 Jun 86.

2. Environmental Stress Screening (ESS) programs, which are applied during the development and production phases, can yield significant improvements in field reliability and reductions in field maintenance costs. Application during development can reap significant savings in test time and costs as a result of eliminating or reducing the number of latent defects prior to qualification tests. The benefits for the manufacturer include: a high degree of visibility as to the sources of reliability problems in the product or process, better control of rework costs, and the opportunity to determine corrective actions which eliminate the sources of reliability problems from the product or process.

3. There are various approaches associated with the application of stress screens. Regardless of the approach used, the fundamental objective of ESS remains the same;i.e.,to remove latent defects from the product prior to field delivery. The quantitative methods, contained in this Handbook, extend this objective by focusing on the defects which remain in the product at delivery and their impact on field reliability. The goal of ESS programs thus becomes to reduce the latent defect population, at delivery, to a level which is consistent with the reliability requirements for the product. Reduction of the latent defect population in a production lot of electronic equipment, is accomplished by:

a. Use of ESS to precipitate flaws in the assembled hardware to a detectable level coupled with the use of thorough tests to facilitate their detection and removal.

b. Use of ESS results to isolate defect-failure causes followed by determining appropriate corrective actions. Effective corrective actions eliminate the source (cause) of the defect from the process or product, thereby improving manufacturing process capability.

4. General guidelines and supporting rationale in Section 4 and detailed guidelines in Section 5 provide the user with the procedures needed to plan, monitor and control the screening process so that quantitative goals can be achieved cost effectively. The five detailed procedures of Section 5 are entitled:

Procedure A - Part Fraction Defective - R&M 2000 Goals and Incoming Defect Density
Procedure B - Screen Selection and Placement
Procedure C - Failure-Free Acceptance Tests
Procedure D - Cost Effectiveness Analysis
Procedure E - Monitoring, Evaluation and Control

5. It should be noted that is is not possible to eliminate all defects from the hardware through stress screening. The vast majority of parts in the hardware have failure rates sufficiently low so that they never fail throughout the life of the product. Gross latent defects tend to fail early and dominate the reliability of fielded products during early life. The objective is to remove as many of the gross defects from the hardware as is technically and economically feasible so as to achieve the designed-in reliability. The Handbook implements these objectives through use of controls on the latent defects remaining in the hardware at delivery, the costs to precipitate and remove them, and the assurance needed that reliability objectives have been achieved.

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1. SCOPE

1.1 Purpose. This Handbook provides uniform procedures, methods and techniques for planning, monitoring and controlling the cost effectiveness of ESS programs for electronic equipment. It is intended to support the requirements of MIL-STD-785, Task 301, "Environmental Stress Screening" and to implement Air Force R&M 2000 ESS recommendations and guidelines.

1.2 Application. The Handbook is intended for use by procuring activities and contractors during development and production. It is not intended that the Handbook procedures and techniques be used in a cookbook fashion. Knowledge of the equipment and the manufacturing process is essential for a properly planned and tailored ESS program. The data base needed for a systematic approach to ESS application is not fully developed. Use of the Handbook by Government procuring agencies and equipment manufacturers will foster the development of an improved and broader data base.

1.3 General. A properly applied ESS program can significantly impact the quality and reliability of electronic products delivered to the Government. ESS is interrelated with the requirements set forth in MIL-Q-9858, and MIL-STD-785. Quality Control is a manufacturing function and Reliability Engineering is a design function. Although the Quality and Reliability disciplines are related, in practice, they are conducted as separate programs without common objectives. The Handbook uses the ESS program as a means for integrating Quality Control and Reliability Engineering tasks so as to assure achievement of reliability objectives during manufacture.

1.3.1 What is ESS? ESS is a process or series of processes in which environmental stimuli, such as rapid thermal cycling and random vibration, are applied to electronic items in order to precipitate latent defects to early failure. An equally important and inseparable aspect of the screening process is the testing which is done before, during and following the screen, so as to detect and properly identify the defects which have been precipitated to failure by a screen. The screening and testing process is basically a search for defects. Manufacturing techniques for modern electronic hardware consist of hundreds of individual operations and processes through which defects can be introduced into the product. Many of the defects can be detected without the need for stress screens by use of visual inspections, functional tests and other conventional quality assurance procedures. Such defects are termed patent defects. A small percentage of latent defects remain undetected by obvious means and, if not removed in the factory, will eventually manifest as early life failures during product use. The inability to find

latent defects by obvious means is a consequence of the increased complexity of modern electronic products and the processes which are used in their manufacture. ESS is the vehicle by which latent defects are accelerated to early failure in the factory. ESS can thus be viewed as an extension of the quality control inspection and testing process.

1.3.2 Organization of the Handbook. The Scope (Section 1) outlines the purpose of the Handbook and provides general introductory remarks pertaining to the quantitative approach to ESS. Section 2 lists applicable references and Section 3 defines terms and acronyms used. Section 4 contains general guidelines and provides the rationale and background for the detailed guidelines. Section 5 contains the detailed guidelines which are organized according to the sequence of events to be undertaken by the contractor in planning, monitoring and controlling a screening program. The detailed procedures are entitled:

- Procedure A - Part Fraction Defective - R&M 2000 Goals and Incoming Defect Density
- Procedure B - Screen Selection and Placement
- Procedure C - Failure-Free Acceptance Tests
- Procedure D - Cost Effectiveness Analysis
- Procedure E - Monitoring, Evaluation and Control

Appendix A contains the mathematical relations and model descriptions used in the Handbook. A review of Appendix A will help the interested reader in gaining a quick understanding of the rationale and methodology of the Handbook. Appendix B provides the rationale for establishing quantitative goals for the ESS program. The goals are derived from reliability requirements. Appendix C provides the mathematical foundation for the Failure-Free Acceptance Test.

Figure 1.1 shows the sequence of application of the various tasks contained in the Handbook. Reference to the applicable sections and procedures of the Handbook are provided in the figure. Quantitative goals for the screening program should be established in accordance with the methods outlined in Appendix B and paragraph 4.10.1. An ESS plan for the development phase should be submitted as part of the Reliability Program Plan. (paragraph 4.10.4) The product development phase is used to experiment with stress screens, using the R&M 2000 initial screening regimen, and to define and plan a cost effective screening program for the production phase. Controls are used to assure that the manufacturing process begins with a fraction defectives for electronic parts which is consistent with R&M 2000 goals. (paragraph 4.5, Procedure A1). The incoming latent defect density is estimated (Procedure A2) and screens are selectively placed at various assembly levels to develop a plan for achieving quantitative ESS goals cost-effectively (Procedures B, C, D and paragraph 4.10). An ESS plan for the production phase

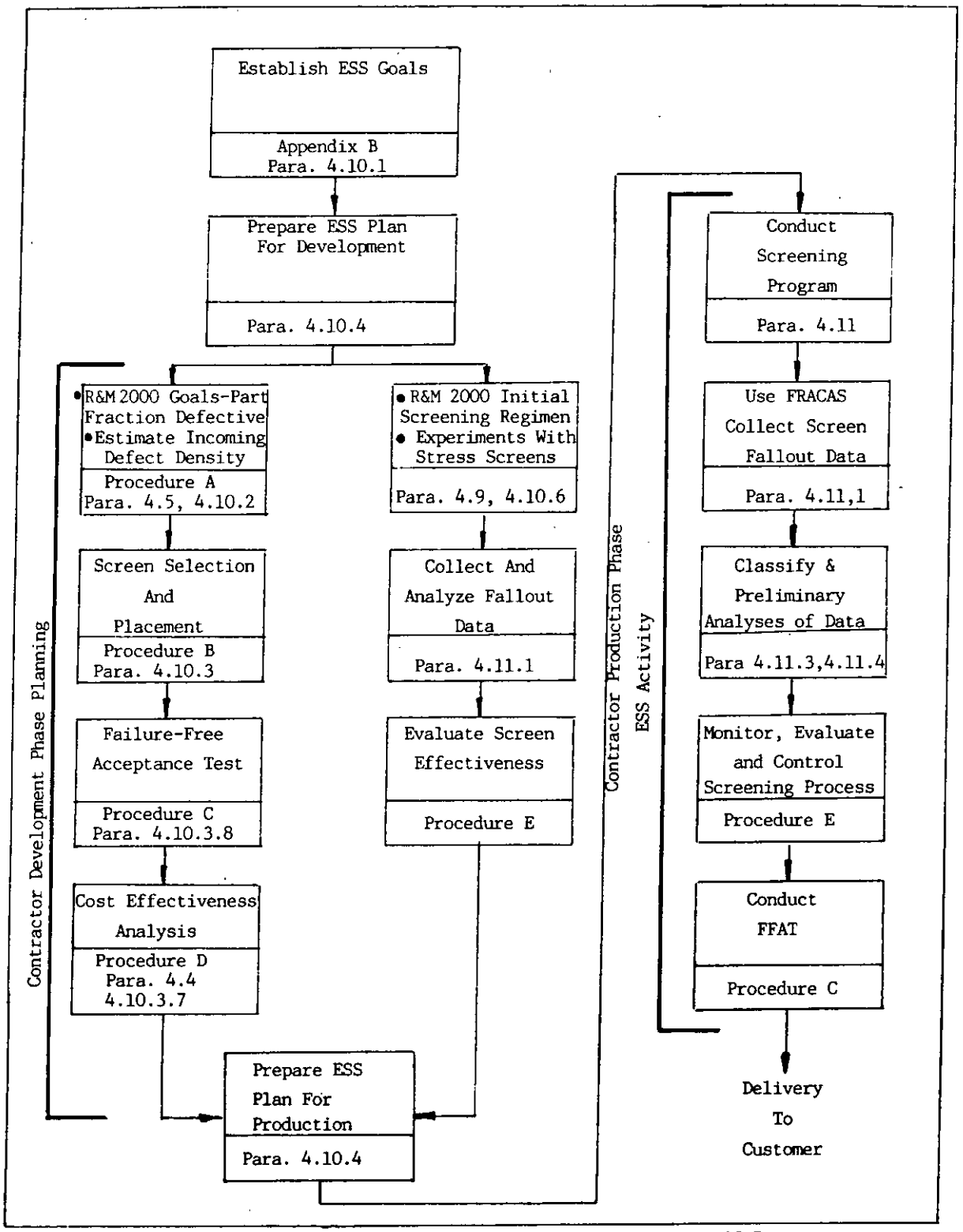


Figure 1.3 Task Sequence in Planning, Monitoring & Controlling an ESS Program

is submitted based upon the experimentation and analyses of cost-effectiveness (Para. 10.4). After the screening program is implemented during production, the fallout from the screens are used to evaluate the screening process and to establish whether ESS program objectives are being achieved (Paragraph 4.11, Procedure E). A Failure-Free Acceptance test is performed to provide assurance that quantitative objectives have been achieved prior to delivery to the customer. (Procedure C)

1.3.3 Development and production phase reliability assurance. ESS is not a substitute for a sound reliability program conducted during the design and development phases. The inherent reliability of the product is driven primarily by the design. However, without a viable reliability assurance program during production, the reliability which is designed into the product can be seriously degraded. An equipment will eventually pass a MIL-STD-781 reliability demonstration test, either during development or on a sample basis during production. A single equipment passing the MIL-STD-781 test does not imply that all other equipments in the production lot have the same reliability. A relatively few latent defects, contained in various equipments in the lot, can significantly reduce the field reliability, especially for equipments with high reliability requirements. A production reliability assurance program which complements the design/development reliability program, is therefore essential to achieving reliability objectives. A properly planned, monitored and controlled stress screening program, structured as part of a production reliability assurance program, is the vehicle through which product reliability in manufacture can be maintained. The procedures are oriented toward achieving reliability objectives through use of quantitative methods for stress screening and production reliability assurance.

1.3.4 ESS application and the quantitative approach. Historically there have been two basic approaches to the application of stress screens. In one approach, the Government explicitly specifies the screens and screening parameters to be used at various assembly levels. Failure-free periods are sometimes attached to the screens, as acceptance requirements, in order to provide assurance that the product is reasonably free of defects. Another approach is to have the contractor propose a screening program which is tailored to the product and is subject to the approval of the procuring activity. Although the latter approach is preferred, neither approach is adequate since explicit objectives and the relations between the screening program and quantitative reliability requirements are not always defined. Costs are also uncontrolled because some of the screens might be more efficiently performed at lower assembly levels where rework costs are lower. In addition, screening levels may far exceed the design limits of the product and result in damage to the equipment.

There are several unknowns associated with the application of stress screens. How effective are the screens? What is considered acceptable or unacceptable fallout from a screen? How does the quantity of defects remaining in the equipment after delivery to the customer impact field reliability? The aforementioned ESS approaches do not fully address these questions. For example, if the screen fallout is "low", it is not known whether the equipment is "good" (i.e., defect-free) or whether the screen is not effective. On the other hand, if the fallout is "high", it is not known whether the incoming defect levels are inordinately high or whether the screen might be causing non-defectives to fail.

Screens and tests are not perfect. At each stage of manufacture where screens and tests might be applied, from device level to the final system level, escapes to the next assembly stage occur and new opportunities for introducing defects are created. The number of latent defects which remain in the product at delivery and their impact on field reliability, however, is the primary concern.

1.3.4.1 The quantitative approach. The use of a quantitative approach to stress screening requires that the initial part latent defect levels, the defect level introduced during manufacture of the product, the effectiveness of the screens, and reasonably acceptable values for the number of latent defects which remain and escape into the field be addressed. Figure 1.2 illustrates the quantitative aspects of stress screening.

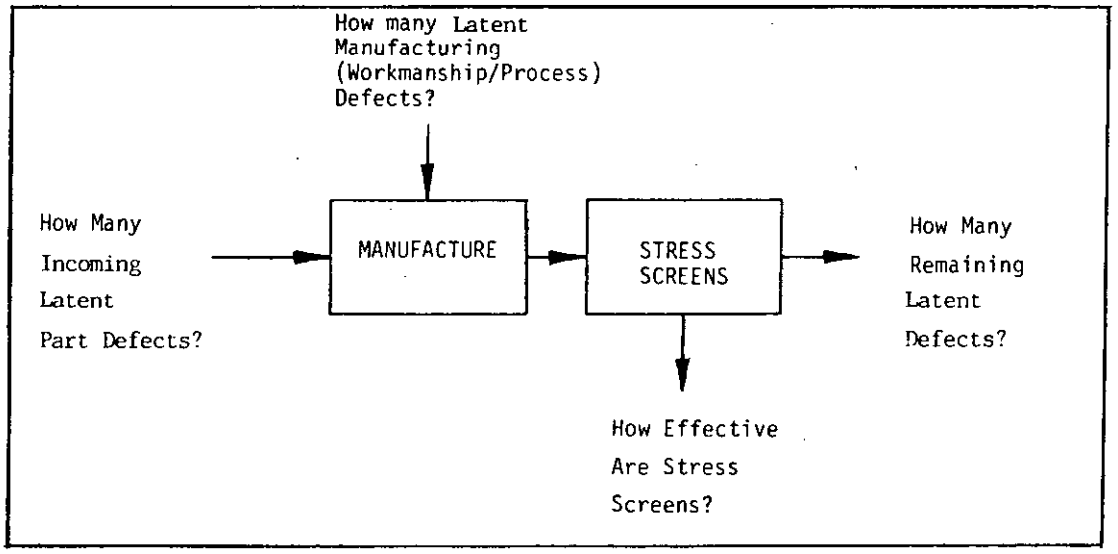


Figure 1.2 The Quantitative problem

When a quantitative approach to stress screening is used, the variables of interest are the average number of defects per product which enter the screen (D_{IN}), the screen/test effectiveness or test strength (TS) and the average number of defects per product which escape the screen/test (D_{out}). Figure 1.3 shows the relationships between these stress screening variables.

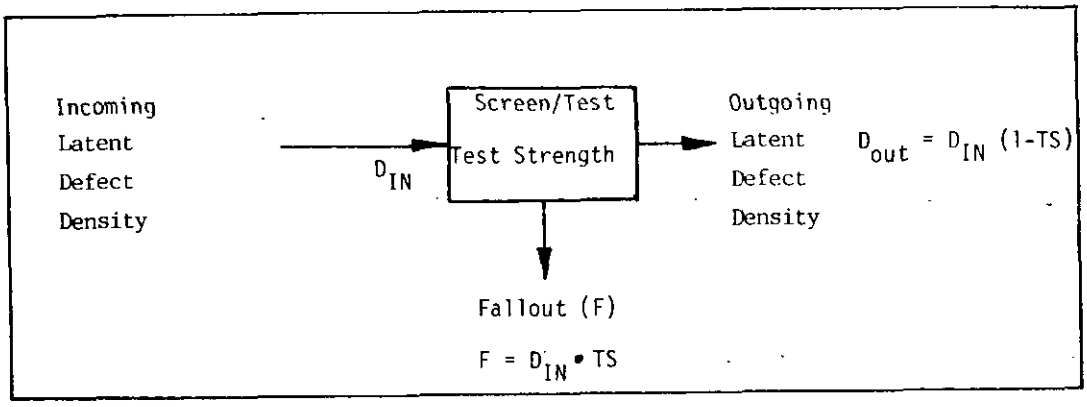


Figure 1.3 Stress Screening Variables

The number of defects remaining in the production lot at delivery is a function of three key factors:

a. The quantity of design, part and manufacturing (workmanship and process) defects which initially reside in the hardware prior to assembly level screening.

b. The capability of the screens to precipitate flaws in assemblies to a detectable level.

c. The thoroughness of the testing which is done, either during or after the screen, to assure detection and removal of the defects precipitated to failure by the screens.

None of the three factors which impact the reliability of delivered products is known with certainty. Without a basic knowledge of their quantitative value, however, effective screening programs cannot be properly planned and controlled. The procedures in the handbook are directed to obtaining both preliminary planning and measured estimates of the three factors in order to plan, monitor and control the screening process. Experience data gathered from previous screening programs, screening experiments conducted during the development phase and use of the handbook procedures provides the methodology and information needed to plan and conduct effective screening programs.

Once a screening program is implemented during production, the results must be monitored and appropriate changes made in the screening regimen to assure that goals on remaining defects are achieved. The basic mechanism for assuring control is to compare the screening results with established goals so as to determine the need for corrective actions. For example, corrective actions might be accomplished by increasing screening or test detection capability so that more defects can be precipitated and detected or by reducing incoming defect quantities through improved process controls. Changes which reduce or eliminate screening at some levels of assembly can also be taken to reduce costs, when it is found that the screens are ineffective or unnecessary.

1.3.5 Benefits of a quantitative approach. A quantitative approach to stress screening enables the establishment of explicit quantitative objectives and provides a basis for planning, monitoring and controlling the screening process to meet those objectives. A quantitative approach also facilitates Government and contractor communication on the status of the screening process and on the progress being made toward achieving objectives. Coupled with a good Failure Reporting Analysis and Corrective Action System (FRACAS), the quantitative approach also provides a more focused emphasis on the sources of latent reliability problems in the product or process as well as better control of costs.

1.3.6 Process capability and defect density. The use of a quantitative approach to stress screening requires addressing the capability of the manufacturing process to produce products which are reasonably free of defects. Defects are introduced into a lot of manufactured products through repeated assembly, handling and testing operations. The average number of defects per product (defect density) varies as a function of the degree of control which is exercised over the manufacturing process. When the variation is due only to random non-correctable causes, the process is said to be in control. The range over which such variability occurs is often referred to as the process capability. In quantitative terms, the process capability can be defined in terms of a process mean (average defect density) and a standard deviation. Process capability determines defect density and not vice versa. Quality control studies are often performed to establish process capability. However, rather than ask the question: What is the process capability?, one should ask: What must the process capability be in order to meet quantitative reliability objectives? The use of a quantitative approach to stress screening focuses attention on the latter question. Analyses of screening failures should be directed to determining root causes of defects and corrective actions so as to improve the process capability. Process capability is improved only through reducing the number of failure causes which are falsely deemed to result from non-correctable causes.

2. REFERENCED DOCUMENTS.

The documents cited in this section are for guidance and information.

2.1 Government documents.

SPECIFICATIONS

MIL-Q-9858 Quality Program Requirements

STANDARDS

MIL-STD-721 Definition of Terms for Reliability and Maintainability

Mil-Std-781 Reliability Design Qualification and Production Acceptance Tests: Exponential Distribution

MIL-STD-785 Reliability Program For Systems and Equipment Development and Production

MIL-STD-883 Test Methods and Procedures for Microelectronics

HANDBOOKS

MIL-HDBK-217 Reliability Prediction of Electronic Equipment

PUBLICATIONS

Air Force

AFWAL-TR-80-3086 Aug 80	Environmental Burn-In Effectiveness
RADC-TR-82-87 May 82 (AD-A118261)	Stress Screening of Electronic Hardware
RADC-TR-86-138	RADC Guide to Environmental Stress Screening
RADC-TR-86-149	Environmental Stress Screening

Navy

NAVMAT P-9492	Navy Manufacturing Screeing Program

(Copies of specifications, standards, handbooks, drawings, and publications required by contractors in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.)

2.2 Nongovernment documents.

Institute of Environmental Sciences (IES)

Environmental Stress Screening Guidelines, 1981

Environmental Stress Screening Guidelines for Assemblies, Sep 84

(Application for copies should be addressed to the Institute of Environmental Sciences, 940 East Northwest Highway, Mt Prospect IL 60056-3444)

Electronic Industries Association (EIA)

Interim Standard No. 18 Lot Acceptance Procedure for Verifying Compliance with the Specified Quality Level (SQL) in PPM

(Application for copies should be addressed to the Electronic Industries Association, 2001 Eye Street, NW, Washington DC 20006-5009)

2.2.1 Other nongovernment documents.

Fertig, K.W., Murthy, V.K., "Models for Reliability Growth During Burn-In", Proceedings of the 1978 Annual R&M Symposium, pp. 504-509.

Bateson, J.T., "Board Test Strategies - Production Testing in the Factory of the Future", Test and Measurement World, pp. 118-129, Dec 84.

Kube, F., Hirschberger, G., "An Investigation to Determine Effective Equipment Acceptance Test Methods", Grumman Aerospace Corporation, Report No., ADR 14-04-73, Apr 73

Brownlee, K.A. (1960), Statistical Theory and Methodology in Science and Engineering, New York, John Wiley and Sons

(Nongovernment documents are generally available for reference from libraries. They are also distributed among nongovernment standards bodies and using Federal agencies.)

3. DEFINITIONS AND ACRONYMS

3.1 Definitions. Definitions applicable to this Handbook are:

Assembly/Module	A number of parts joined together to perform a specific function and capable of disassembly, For example a printed circuit board. An assembly of parts designed to function in conjunction with similar or different modules when assembled into a unit. (i.e. Printed Circuit Assembly, power supply module, core memory module.)
Defect Density	Average number of latent defects per item. Symbols used: D_{IN}, D_{OUT}, D_R and D_O for incoming, outgoing, remaining and observed defect density, respectively.
Detectable Failure	A failure that can be detected with 100% test detection efficiency.
Escapes	A proportion of incoming defect density which is not detected by a screen and test and which is passed on to the next level. Symbol (D_{out})
Failure-Free Period	A contiguous period of time during which an item is to operate without the occurrence of a failure while under environmental stress.
Failure-Free Test	A test to determine if an equipment can operate without failure for a predetermined time period under specific stress conditions.
Failure Rate	The total number of failures within an item population, divided by the total number of life units expended by that population during a particular measurement interval under stated conditions. Symbol used λ. A reliability measure related to MTBF.
Fallout	Failures observed during, or immediately after, and attributed to stress screens. Symbol used F.
Latent Defect	An inherent or induced weakness, not detectable by ordinary means, which will either be precipitated to early failure under environmental stress screening conditions or eventually fail in the intended use environment.
Part	Any identifiable item within the product which can be removed or repaired (e.g., discrete semiconductor, resistor, IC, solder joint, connector).
Part Fraction Defective	The number of defective parts contained in a part population divided by the total number of parts in the population expressed in PPM.
Patent Defect	An inherent or induced weakness which can be detected by inspection, functional test, or other defined means without the need for stress screens.
Precipitation (of Defects)	The process of transforming a latent defect into a patent defect through the application of stress screens.
Production Lot	A group of items manufactured under essentially the same conditions and processes.
Screenable Latent Defect	A latent defect which has an inherent failure rate of greater than 10^{-3} failurs per hour under field stress conditions.
Screen Effectiveness	Generally, a measure of the capability of a screen to precipitate latent defects to failure. Sometimes used specifically to mean screening strength.
Screen Parameters	Parameters in screening strength equations which relate to screening strength, (e.g., vibration g-levels, temperature rate of change and time duration.)
Screening Regimen	A combination of stress screens applied to an equipment, identified in the order of application (i.e., assembly, unit and system screens).

Screening Strength	The probability that a specific screen will precipitate a latent defect to failure, given that a latent defect susceptible to the screen is present. Symbol (SS)
Selection and Placement	The process of systematically selecting the most effective stress screens and placing them at the appropriate levels of assembly.
Stress Screening	The process of applying mechanical, electrical and/or thermal stresses to an equipment item for the purpose of precipitating latent part and workmanship defects to early failure.
System/Equipment	A group of units interconnected or assembled to perform some overall electronic function (e.g., electronic flight control system, communications system).
Test Detection Efficiency	A measure of test thoroughness or coverage which is expressed as the fraction of patent defects detectable, by a defined test procedure, to the total possible number of patent defects which can be present. Symbol (DE) used synonomously as the probability of detection.
Test Strength	The product of screening strength and test detection efficiency. The probability that a defect will be precipitated by a screen and detected in a test. Symbol (TS).
Thermal Survey	The measurement of thermal response characteristics at points of interest within an equipment when temperature extremes are applied to the equipment.
Unit	A self-contained collection of parts and/or assemblies within one package performing a specific function or group of functions, and removable as a single package from an operating system (i.e., autopilot computer, vhf communications, transmitter).
Vibration Survey	The measurement of vibration response characteristics at points of interest within an equipment when vibration excitation is applied to the equipment.
Yield	The probability that an equipment is free of screenable latent defects when offered for acceptance.

3.2 Acronyms/Abbreviations

3.2.1 Acronyms used in procedure A of section 5

Abbreviation	Description
AIC	Airborne Inhabited Cargo
AIT	Airborne Inhabited Trainer
AIB	Airborne Inhabited Bomber
AIA	Airborne Inhabited Attach
AIF	Airborne Inhabited Fighter
AUC	Airborne Uninhabited Cargo
AUT	Airborne Uninhabited Trainer
AUB	Airborne Uninhabited Bomber
AUA	Airborne Uninhabited Attack
AUF	Airborne Uninhabited Fighter
ARW	Airborne Rotary Wing
CL	Cannon Launch
GB	Ground Benign
GF	Ground Fixed
GM	Ground Mobile
ML	Missile Launch
MFF	Missile Free Flight
MFA	Airbreathing Missile Flight
MP	Manpack
NS	Naval Sheltered
NU	Naval Unsheltered
NUU	Naval Undersea Unsheltered
NSB	Naval Submarine
NH	Naval Hydrofoil
SF	Space Flight
USL	Undersea Launch

3.2.2 Other Acronyms

Abbreviation	Description
AOQL	Average Outgoing Quality Limit
BIT	Built In Test
CND	Cannot Duplicate
CDE	Chance Defective Exponential
ESD/EOS	Electrostatic Discharge/Electrical Overstress
ESS	Environmental Stress Screening
FFAT	Failure Free Acceptance Tests
FRACAS	Failure Reporting and Corrective Action System
FL	Fault Location
FMEA	Failure Mode & Effect Analysis
FBT	Functional Board Tester
IC	Integrated Circuit
ICT	In Circuit Tester
ICA	In Circuit Analyzer
LBS	Loaded Board Shorts
LRU	Line Replaceable Unit
LSI	Large Scale Integration
LTPD	Lot Tolerance Percent Defective
MTBF	Mean Time Between Failures
MLE	Maximum Likelihood Estimate
MSI	Medium Scale Integration
NFF	No Fault Found
OEM	Original Equipment Manufacturer
PEP	Production Engineering Phase
PCB	Printed Circuit Board
PPM	Parts Per Million
PWA	Printed Wiring Assembly
PM	Performance Monitoring
RTOK	Retest OK
SRU	Shop Replaceable Unit
SQL	Specified Quality Level
TAAF	Test Analyze & Fix

4. GENERAL GUIDELINES

4.1 Relation of ESS to MIL-STD-785 reliability program tasks. Planning an ESS program for the production phase is interrelated with many of the MIL-STD-785 reliability program tasks which are required to be performed during development and production. Every effort should be made to integrate the knowledge gained from MIL-STD-785 tasks into the planning of an ESS program for production. MIL-STD-785 reliability program tasks which have a particular bearing on ESS planning include: Reliability Prediction (Task 203), Reliability Allocation (Task 202), Qualification Tests (Task 303), Parts Program (Task 207), Failure Reporting Analysis and Corrective Action System (Task 104), Failure Modes, Effects and Criticality Analysis (Task 204), Reliability Growth Testing (Task 302), and of course, ESS (Task 301). Proper screen selection and placement is highly dependent on the reliability and stress design characteristics of the equipment. Information derived from reliability program tasks such as: predicted and demonstrated failure rates, quality level of parts, number and type of nonstandard and MIL-parts, number and type of interconnections, design capability, field stress environments, and critical items should be used in structuring an ESS program for production.

4.2 Contractual aspects of ESS. ESS must remain an adaptive process so that the screening regimen can be changed to improve cost-effectiveness. Contract provisions for ESS programs should have flexibility to effect necessary modification of stress screens. During the initial stages of production more severe stress screens may be required. As the product and process mature, the screens may require adjustment such as by reducing the number of temperature cycles, the number of axes of vibration or by eliminating unnecessary screens. In early production, a number of unknowns preclude adoption of optimum stress screening. Some of the more significant unknowns are:

a. Residual design deficiencies
b. Manufacturing planning errors
c. Worker training
d. New suppliers
e. Latent defects in new part lots
f. New process capability
g. Stress screening effectiveness
h. Testability (for defect detection)

The stress screening program, even if carefully planned, may produce unexpected results which should be addressed through modification of the screens. The principle of adaptive screening is to adjust the screens on the basis of observed screening results so that the screens are always most cost effective while meeting ESS program goals. Contract terms should be flexible enough to permit modification of screens or screen parameters when such modification can be shown to be beneficial.

In long term production the quantity and distribution of latent defects changes with time and therefore contract terms should contain provisions for periodically reassessing the individual screens and the overall screening program. The overriding criterion for change should be the most cost effective achievement of objectives. Contracting arrangements should be made which permit such changes without having to resort to extensive renegotiation.

4.3 Subcontractor and supplier stress screening. Items which are furnished by subcontractors or other equipment suppliers may require stress screening. There are several distinct advantages for the subcontractor or supplier to perform the stress screening rather than the prime contractor.

a. Subcontractor/supplier concern for yield can be translated to profits which may force process improvements to minimize latent defects.

b. Screening at receiving inspection/test, by the prime contractor, may involve returning defective items to the subcontractor/supplier and result in shortages and schedule slippages.

c. Special stress screening facilities and test equipment do not have to be purchased, supported and operated by the prime contractor.

The procedures and methodology contained in the Handbook can be imposed on the subcontractor/supplier. To assure that the subcontractor/supplier is able to perform the tasks required by the Handbook the intent must be made known prior to production. In this manner, the subcontractor/supplier can prepare a screening plan, acquire the necessary capability or arrange for an external laboratory to perform the screening.

4.3.1 Screening of spares. Spares should be subjected to a screening regimen equivalent to that used for the production hardware. Spares are either manufactured on the same production line or are produced separately to the same specifications as the production hardware. The spares are most often an LRU or SRU and consequently may not receive the exposure to additional screening at higher assembly levels that non-spare items might receive. Quantitative ESS goals for the system should be allocated down to the spare item. The procedures of Section 5 can be used to ensure that defect density for the spares does not exceed allocated goals. A costly and less desirable alternative would be to screen and test all spares in a mock-up configuration for the system.

4.4 Costs of ESS vs productivity improvement. The costs of conducting a screening program during the production phase can be high. To a large extent, the costs can be offset by the increased productivity which results through proper screen selection and placement. Screening at the lowest possible level of assembly will almost always be the least costly alternative in terms of rework costs. The time and effort required to test, troubleshoot and repair items increases by at least an order of magnitude at each subsequent level of assembly. Significant cost savings or avoidance can accrue to the manufacturer by analyzing the cost benefits of various screen selection and placement alternatives and by striving to find defects at the lowest possible level of assembly. The fixed and recurring costs to screen, instrument and test the hardware at lower assembly levels, especially with power applied, can possibly, negate any benefit from lower rework costs. Cost savings to the Government will result through improved field reliability and corresponding reductions in field repair costs. The benefits of a properly conducted ESS program to the Government go beyond field repair costs alone. Improved reliability during early life will also reduce over-buying of spares, since estimates of required spare quantities are based upon early life field performance. The opportunity for introducing new defect sources into the hardware during field maintenance and handling is also reduced.

There should be however, controls and constraints on the cost of conducting a screening program. Situations can arise where the cost of conducting a screening program far outweigh any benefits which may be derived. For example, for low complexity items the number of screenable defects which are likely to be present in the hardware may be relatively small. Conducting a full-scale screening program, in such cases, can result in very high costs per defect eliminated. Cost of $10K to $15K per defect eliminated may be justified for equipments which are used in critical missions with very high reliability requirements. On the other hand, such costs may be difficult to justify if the equipment is used in noncritical missions and if the costs of field maintenance are not severely effected by not screening. Each case, where a stress screening program is under consideration, must be judged individually as to the cost benefits to be derived from stress screening. Procedure D, in Section 5 is used to determine the cost-effectiveness of ESS programs.

4.5 Air Force R&M 2000 ESS policy-part fraction defective. Air Force R&M 2000 ESS studies recommend that the manufacturing process begin with piece parts having a remaining part fraction defective below 1000 PPM by FY87 and below 100 PPM by FY90. Procedure A1 of Section 5 and ESS results from first assembly screens are used in the Handbook procedures to evaluate the achivement of these goals. In terms of the reliability of delivered systems, the R&M 2000 ESS goals can be extended to include goals on remaining part fraction defective for the system at delivery. Appendix B of the Handbook discusses a method which uses a 50 PPM part fraction defective goal for delivered systems to establish quantitative ESS program goals.

4.6 Part vs assembly fraction defective. The part fraction defective can have a significant impact on the assembly fraction defective depending upon the number of parts contained in the assembly. The Poisson approximation is used in Figure 4.1 to illustrate the expected assembly fraction defective as a function of the remaining part fraction defective and the number of parts per assembly.

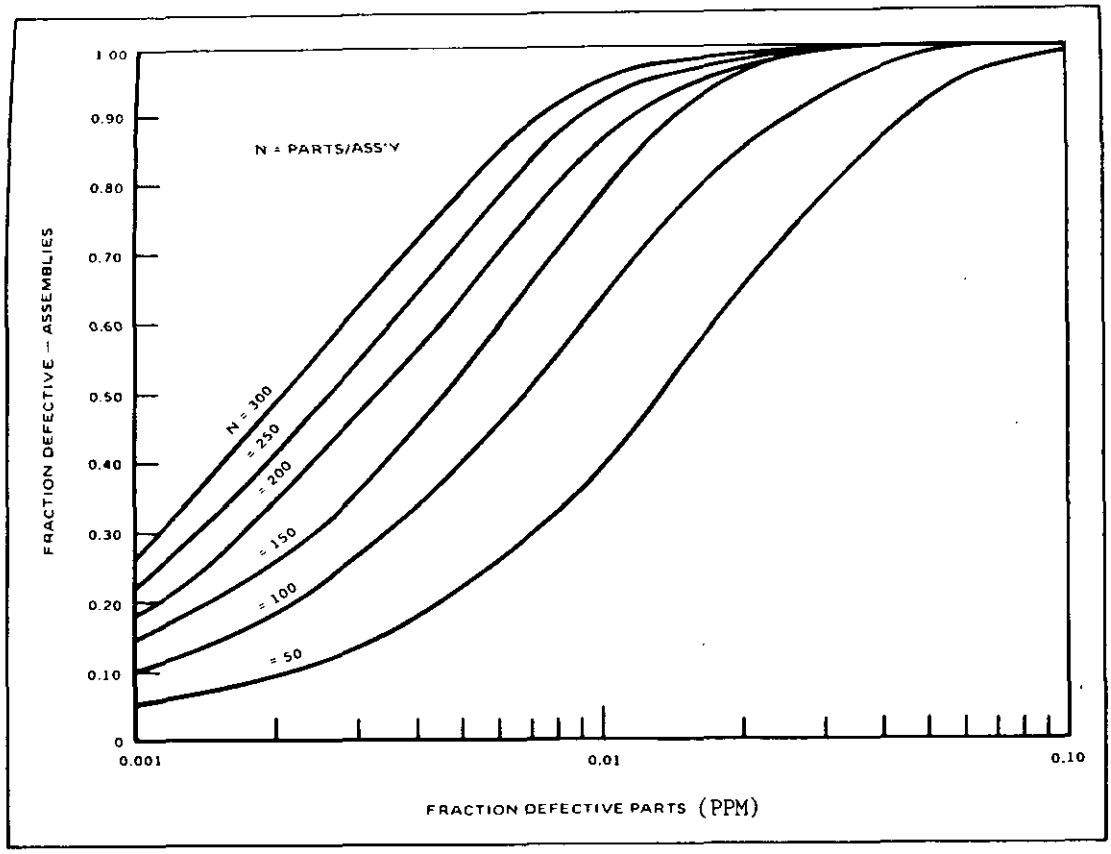


FIGURE 4.1. FRACTION OF DEFECTIVE ASSEMBLIES vs REMAINING PART FRACTION DEFECTIVE

As can be noted relatively small values of part fraction defective result in large values of assembly fraction defective depending upon the number of parts contained in the assembly. As an example, for a 150 part assembly containing parts with a fraction defective of .01 (10,000 PPM), the defect density is 1.5 and the assembly fraction defective is about .8. In terms of yield only about 20% of such assemblies, when subjected to first assembly test, would pass without failure. It is quite obvious that the part fraction defective must be much better than .01 if the costs of rework, retesting and handling of the assemblies are to be avoided. Elimination of defectives through part level screening is obviously the most cost effective course of action. However, the following questions can be posed: How much better must the remaining part fraction defective be?; What level of part fraction defective is needed for delivered systems? and, can such levels be achieved? A part fraction defective of .001 (1000 PPM) on a 300 part assembly, results in an assembly fraction of about .27. Although not shown in Figure 4.1, a part fraction defective of .001 (1000 PPM) on a 1000 part assembly or on a 10,000 part system gives an assembly/system fraction defective of .63 and .99995 respectively. The foregoing implies that for the 1000 part assembly, an average of 37 out of 100 assemblies would be defect free and for the 10,000 part system only about 5 systems in 100,000 would be defect free. Extending the same example to the case where the part fraction defective is .0001 (100 PPM), then an average of 99 of 100, 1000 part assemblies would be defect free and for the 10,000 part system an average of 37 out of 100 systems would be defect free. It would, therefore, appear that levels of part fraction defective of less than 100 PPM are needed or should at least be established as goals for delivered systems. The degree to which such goals can be achieved is dependent upon the emphasis placed on finding defects during screening and eliminating their cause(s) through corrective action. A method for establishing goals on remaining defect density at delivery, which is discussed in Appendix B, uses a 50 PPM goal on part fraction defective for each system delivered to the field.

4.7 Part level screening/rescreening. Screening at the part level is often the most cost effective alternative for eliminating defects prior to the parts being assembled into the production hardware. A population of parts, even those procured to high quality levels, may appear to contain inordinately high fraction defective levels when the parts are retested. For example, microelectronic devices procured to the quality requirements of MIL-STD-883 receive 100% final electrical testing by the part vendor. Nonetheless, one manufacturer has found that about 1%, and as much as 4% of the parts will not pass a similar electrical test performed at the OEM receiving inspection. There are several possible reasons for this including:

- the seller's and buyer's tests are different
- seller testing errors
- buyer testing errors
- device damage or degradation in handling
- inspection and sorting errors.

Table 4.1 shows the percent rejected for a large quantity of devices which were subjected to rescreening at the equipment manufacturers facility. The data indicate that the remaining part fraction defective (percent rejected column), after the initial screening was done by the part vendor, is clearly unacceptable. However, as is typical with such data, it is not known whether the parts are truly of poor quality or whether testing errors or handling damage could be the cause.

Table 4.1 Manufacturer Receiving Inspection Test Results

Part Type	Quantity	Average Quality	Rejects	Per Cent Rejected
Microcircuits	1,419,581	B-1	13,779	0.97(9706PPM)
Discrete Semiconductors	343,000	TX	2,008	0.59(5854PPM)
Passives	1,296,200	ER-M	8,539	0.66(6588PPM)

Reference RADC-TR-82-87

The quantities of remaining defects in a population of screened or rescreened parts is, at best, uncertain. Screens and tests are not perfect and if a lot of parts are subjected to a series of screens, rescreens and tests, on a 100% basis, the observed fraction defective does not provide information on the remaining fraction defective. In fact, poor screens and tests will indicate very low observed part fraction defectives. Part level screening should result in a remaining part fraction defective of no more than .01% (100 PPM) to avoid costly rework during manufacture and to ensure adequate reliability in the product. Most statistical sampling plans contain provisions which establish average outgoing quality, but the assumption underlying such plans is that the screens and tests are 100% effective.

To determine the fraction of incoming microcircuit test rejects that were actually defective, another manufacturer performed a retest of 525 rejects from a population of 75,981 tested devices. The results are shown in Table 4.2.

Table 4.2 Results of Retesting Incoming Receiving Test Microcircuit Rejects

Supplier	# of Lots	Total Qty.	Rejects		Verified (See Note)		
			Total	%	Pass	Fail	% Fail
A	25	8525	100	1.17	62	32	0.38
B	8	8435	22	.26	15	7	0.08
C	17	21826	166	.76	120	46	0.21
D	30	27295	144	.53	35	102	0.37
E	22	9471	96	1.01	31	63	0.67
F	2	429	6	1.40	4	2	0.47
TOTALS	104	75,981	534	0.70	267	258	0.34

Reference RADC-TR-82-87

NOTE: 525 of the 534 rejects were retested. Percent failed shown in last column is the percent of the total quantity tested.

As can be noted, about 50% of the rejects were found to be defective but 50% could not be verified as rejects;i.e. they passed the retest. Such large discrepancies can be the result of any one or a combination of the reasons listed above. On a lot basis, other data show that about 75-80% of the lots subjected to rescreening show zero failures and only 5% of the lots produce 90-95% of the failures. These data suggest that the differences are traceable primarily to lot problems and very likely would be found to correlate with chronic problems specific to particular device types or manufacturers. Corrective action for specific problems should be determined rather than resorting to retesting of reasonably defect-free lots with the attendant possibility of handling damage or testing errors.

Screening at the assembly level is a costly means of finding and eliminating part defects from the hardware. There are always uncertainties as to whether the part defects which are found during assembly level screening, are escapes from part level screens or whether they are newly introduced defects due to handling, test and assembly operations. The part fallout from early screening at the assembly level can provide much of the information needed for resolving such uncertainties and taking corrective action. If the part fallout at assembly level screening is greater than, at most 1000 PPM, then rejection of suspect lots, changing vendors, or negotiation of corrective action with the part vendors should be made. A thorough failure analysis of the part fallout from assembly level screening can help in determining the types of screens which should be used, at the part level, for eliminating specific defect types.

4.8 Development phase screening. Screening during the development phase is primarily intended as an experimental activity to gather information on the quantity and type of defects likely to be present in the production hardware and the effectiveness of screens which might be applied. The application of stress screening techniques prior to such development phase activities as qualification, reliability growth, and reliability acceptance tests can also be very beneficial. When stress screening is applied first, latent defets are weeded-out, thus enabling better use of test time and resources in achieving design maturity test objectives. When the development hardware is similar to the production configuration, the knowledge gained from screen experimentation can be invaluable for coping with the problem during production. However, the development hardware can, in some instances, be an advanced development model in which a technical concept is being validated and the hardware used bears little resemblance to the production hardware. In addition, for some high volume production programs, a production engineering phase (PEP) may follow development in which major hardware design changes are made to enhance producibility. Suppliers and vendors used during development may also change for production. The system may contain many nonstandard parts substituted due to lead time problems. Screening fallout data for nonstandard parts would not be representative of production. It would also be difficult to obtain a measure of workmanship or process latent defects because the hardware may have been fabricated in engineering laboratories. In addition, experience has shown that about one-half of development phase failures are design related. The lack of disciplined electrostatic discharge/electrical overstress (ESD/EOS) controls can result in failures during development testing, which may not occur under more controlled production conditions. The combination of one or more of these conditions during development will tend to overshadow information needed for planning a production screening program. Appropriate cautions should be used in interpreting development phase screening results when pre-production prototypes are not used in the development phase.

4.9 ESS experimentation - pre-production prototypes. Use of the procedures contained in the Handbook in conjunction with stress screen experimentation on pre-production prototype equipment can provide invaluable data for planning. Estimates of the type and quantity of defects likely to be present in the hardware can be evaluated against experimental data. Screens can be designed, based upon engineering evaluation, which provide the desired stess stimulation for suspected defect sites in the hardware. Test specifications can also be evaluated to ensure that possible failure modes, arising from various defect types and sources, can be detected by the tests performed either during or following the screens. Integration of the results from the MIL-STD-785 reliability program tasks can also be effectively accomplished. Early fallout from screens provides the maximum amount of information on likely defect sources and process capability. Corrective actions taken as a result of screen experimentation during development can aid significantly to stabilizing the process for production. Planning estimates of incoming density, screening strength and test detection efficiency can be refined. In addition, the use of the R&M 2000 initial screening regimen which includes high strength temperature cycling and random vibration screens will permit the establishment of incoming defect density with less uncertainty. The screen types, parameters and conditions are given in Table 4.10 of 4.10.6.

4.10 Planning a stress screening program for the production phase. Planning a stress screening program for production must begin early in the development phase. The success of a stress screening program is strongly dependent on knowledge of the product and the processes to be used in manufacture. The following must be kept in mind when planning a stress screening program using quantitative methods:

a. The defects which can potentially reside in the product and the effectiveness of screens in precipitating the defects to failure are not known with certainty. By comparison of planned estimates for defect fallout with actual screen fallout, the screening and manufacturing process can be adapted to achieve desired goals.

b. Screening experience data on equipment similar in composition, construction and degree of maturity, can provide very useful data for planning purposes. Information derived from the following sources should be used in planning an ESS program for production:

(1) Identification of hardware items (parts, assemblies) which have exhibited a high incidence of latent defectives on other programs.

(2) Identification of suppliers/vendors whose products have indicated high defect levels.

(3) Qualification test results.

(4) Supplier acceptance test results.

(5) Part receiving inspection, test and screening results.

(6) Screening and test records for previous programs.

(7) Reliability growth test results.

c. A viable screening program must be dynamic, i.e. the screening process must be continuously monitored to ensure that it is both technically and cost effective. Changes to the screening process should be made, as necessary, based on analysis of screening fallout data and failure analysis so that quantitative screening objectives can be achieved.

d. The basic questions which must be addressed in planning a stress screening program are:

(1) What are the quantitative objectives of the program?

(2) What are the stress screens to be used and what level of assembly should the screens be placed to achieve the desired objectives?

(3) What are the costs associated with each of the possible alternative screening sequences and how can the screening program be made cost effective?

(4) How will one know if the screening program is proceeding according to plan? What assurances can be provided that program objectives have been achieved?

(5) What corrective actions must be taken to achieve desired screening program goals if the screening fallout data indicate significant departures from the planned program?

e. An ESS program for the production phase should include the following major tasks:

(1) Establish Objectives/Goals
(2) Obtain Planning Estimates of Defect Density
(3) Selection and Placement of Screens
(4) Preparation of ESS Plan

A discussion of each of these major tasks which includes background, rationale and general guidelines for use of the detailed procedures is contained in 4.10.1 through 4.10.5.

4.10.1 Establishing objectives/goals. Expressed quantitatively, the objective of a stress screening program is to reduce the incoming latent defect density in a production lot of equipment to an acceptable remaining latent defect density in a cost effective manner. Methods discussed in Appendix B provide the basis for establishing goals on remaining defect density. A set of values of remaining defect density is shown in Table 4.3. Values of D_R corresponding to the predicted series failure rate λ_o (exponential model) for the system are shown.

Table 4.3 Remaining Defect Density Goals (D_R)

Predicted Series Failure Rate λ_o (Failures/Hour)	MTBF = $\frac{1}{\lambda_o}$	D_R
.1	10	10
.01	100	1
.005	200	.5
.002	500	.2
.001	1000	.1
.005	2000	.05
.002	5000	.02
.001	10000	.01
.00001	100000	.0001

A simple relation for obtaining goals for remaining defect density can be noted from the tabled values.

$$100\ \lambda_o = D_R$$

The remaining defect density D_R is directly related to yield, i.e. D_R = -ln yield. Yield or D_R is the goal at which planning, monitoring and controlling the screening process is aimed.

4.10.2 Obtaining planning estimates of defect density. The design of a stress screening program requires knowledge of the quantity and type of latent defects which are likely to reside in the hardware prior to assembly level screening. The part fraction defective tables contained in Procedure A of Section 5 are used to obtain planning estimates of defect density. Values in the tables are based upon studies of historical defect data from the factory and field for several part types. Extrapolations to other part types and field environments were made based upon correlations to MIL-HDBK-217 quality level and field environment factors. As more experience data on part fraction defective are gathered the estimates will be improved. Study results and methodology are contained in RADC-TR-86-149.

In accordance with R&M 2000 goals, the manufacturing process should begin with a part fraction defective of no greater than 1000 PPM by FY87 and 100 PPM by FY90. If it is determined that the part fraction defective exceed R&M 2000 goals, then corrective actions with the part vendor or by the OEM must be determined.

4.10.2.1 Latent vs patent defects. A common understanding of the nature of the defects which the screening program should be designed to precipitate is essential for proper planning. The factors which impact incoming defect density and the rationale for the procedures used in obtaining planning estimates of defect density should also be understood.

In a simple context, a defect can be defined in terms of an out-of-tolerance or specification condition which can be readily detected by an inspection or test procedure. Such defects are termed patent defects. Patent defects represent the majority of the defect population in an equipment and are readily detected without the need for stress screens. A smaller percentage of defects however, cannot be detected by conventional means. Such defects are termed latent defects. A latent defect is characterized as an inherent or induced weakness or flaw in a material which will manifest itself as a failure in the operational environment.

Both patent and latent defects are introduced into the product during fabrication, assembly, handling and test operations. The patent defects pass through various assembly stages until they are detected by a test or inspection of sufficient thoroughness and are subsequently eliminated from the product. When good quality control test and inspection procedures are applied, all but the most subtle patent defects should be detected and eliminated prior to shipment. Some examples of patent defects are:

a. Patent Defects

(1) Parts
- (a) Broken or damaged in handling
- (b) Wrong part installed
- (c) Correct part installed incorrectly
- (d) Failure due to electrical overstress or to electrostatic discharge
- (e) Missing parts

(2) Interconnections
- (a) Incorrect wire termination
- (b) Open wire due to handling damage
- (c) Wire short to ground due to misrouting or insulation damage
- (d) Missing wire
- (e) Open etch on printed wiring board
- (f) Open plated - through hole
- (g) Shorted etch
- (h) Solder bridge
- (i) Loose wire strand

Latent defects cannot be detected until they are transformed to patent defects by environmental stress applied over time. Stress screening is the vehicle by which latent defects are transformed into detectable failures. Some examples of latent defects are:

b. Latent Defects

(1) Parts
- (a) Partial damage through electrical overstress or electrostatic discharge
- (b) Partial physical damage during handling
- (c) Material or process induced hidden flaws
- (d) Damage inflicted during soldering operations (excessive heat)

(2) Interconnections
- (a) Cold solder joint
- (b) Inadequate/excessive solder
- (c) Broken wire strands
- (d) Insulation damage
- (e) Loose screw termination
- (f) Improper crimp
- (g) Unseated connector contact
- (h) Cracked etch
- (i) Poor contact termination
- (j) Inadequate wire stress relief

4.10.2.2 Categories of defects. The majority of parts and connections within an electronic equipment are "good" and will never fail over the product's lifetime. The failures which occur during product life are traceable to design or externally induced causes, or to latent defects which were introduced into the product during manufacture. Not all latent defects however, are screenable i.e., capable of being eliminated from the equipment in the factory by use of stress screens. It is only those latent defects, whose failure threshold can be accelerated by the stresses imposed by the screens, which are screenable. Such screenable defects, if not eliminated from the product in the factory, will result in premature or early-life failures in the field. It is the screenable early life failure which the stress screening program must be designed to remove. Figure 4.2 illustrates the categories of defects and their relationship to product life failures.

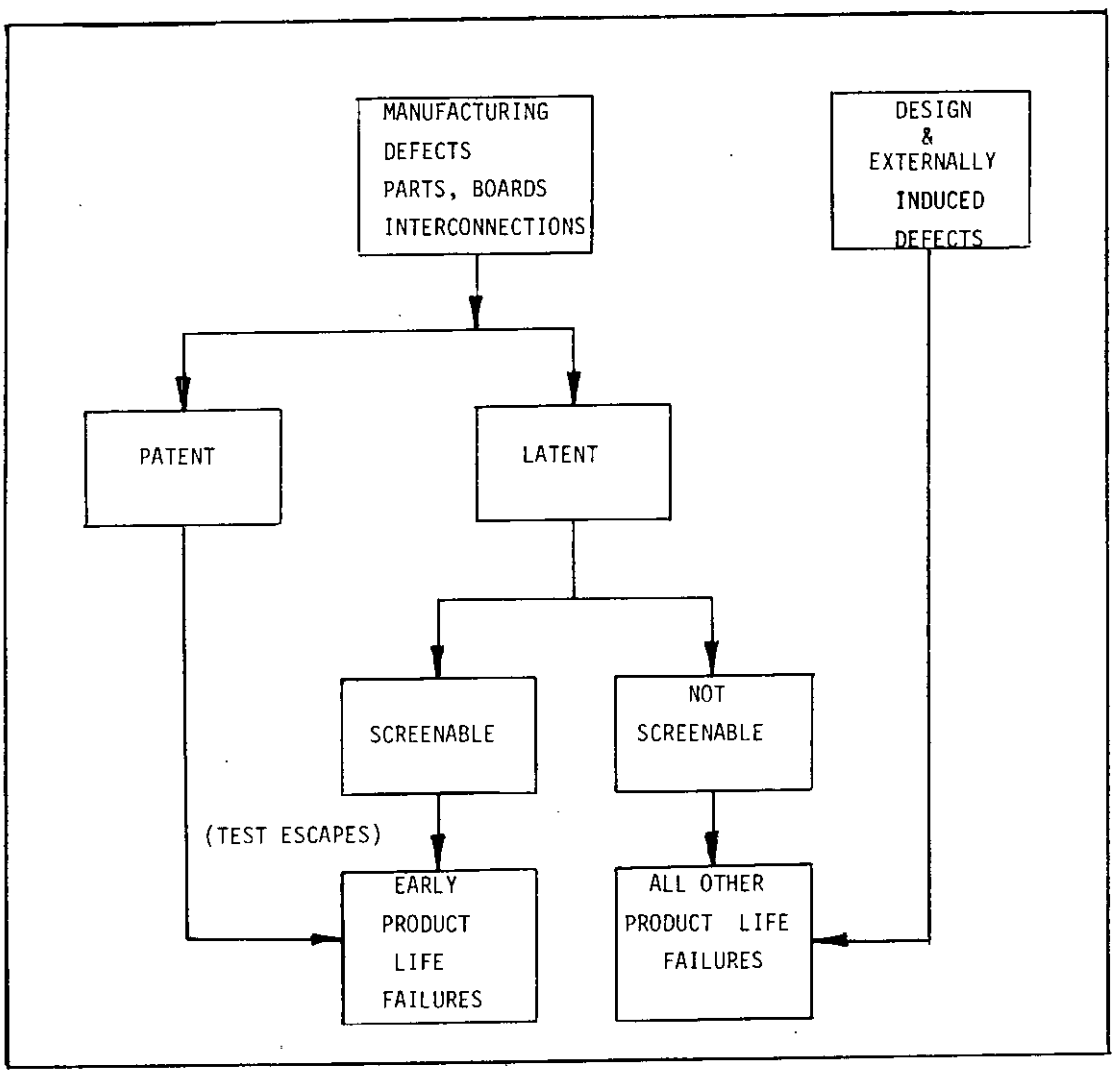


Figure 4.2 Defect Categories & Product Life Failures

4.10.2.3 Factors which impact defect density. The quantity and type of defects which are introduced into a product are dependent upon several factors. The first five factors, listed below, are related to product or program characteristics for which the manufacturing function within a company has little control. The last two factors are related to the manufacturing process for which the manufacturing function has direct control.

a. Complexity - The quantity and type of parts and interconnections used in the product effects defect density. Increased complexity creates more opportunities for defects.

b. Part Quality Level/Grade - The quality levels of parts are established by Mil-Std part screening requirements. The number of defects which remain in a lot of screened parts is determined by the type and extent of screening and testing to which the parts are subjected under Mil-Std screening requirements.

c. Field Stress Environment - The stress conditions to which the equipment will be exposed in the field environment will effect the proportion of defects which should be screened from the product. A defect may be precipitated to early failure in a harsh field operating environment, but may survive product life in a benign field environment.

d. Process Maturity - New production requires time to identify and correct planning and process problems, train personnel and to establish vendor and process controls. Maturity is dependent on volume and time. Low production volume over a long period would have a low maturity rate and will thus impact defect density.

e. Packaging Density - Electronic assemblies with high part and wiring density are more susceptible to process, workmanship and temperature induced defects due to smaller error margins, increased rework difficulty and thermal control problems.

The following factors are under the direct control of the manufacturing function. The degree of control exercised will determine defect density. Screen fallout data provide the necessary input for determining out-of-control conditions.

f. Manufacturing Process Controls - Good process controls will tend to reduce the number of defects which are introduced into the product. The criteria by which processes are considered to be in or out of control should be established by reliability requirements and monitored using the fallout from the screening process.

g. Workmanship Quality Standards - Stringent and properly enforced workmanship quality standards will enhance the reliability of the product through reduced introduction of workmanship defects into the product. The levels to which quality standards should be established and monitored must also be dictated by reliability requirements and made visible by the screening process.

4.10.2.3.1 Part fraction defective and MIL-STD quality levels. The number of defects which reside in electronic hardware is strongly dependent on the MIL-STD quality level of the parts used. An example, using microcircuit quality grades is presented to illustrate this idea. The failure rate of different populations of microcircuits, operating under identical conditions, can vary over an order of magnitude depending on quality level (e.g. Class S versus C-1). Major differences between the Class S die and the Class C-1 die include the visual inspection acceptance criteria, level of process controls, extent of screening and the electrical tests to which the dice are subjected. Screens and tests do not make devices more reliable. It is the lot quality which is improved by eliminating some latent defective parts. Therefore, it can be postulated that the difference in the failure rate of the two populations due solely to quality level, is also a direct measure of the difference in fraction defective of those populations.

To extend the example, consider a class S, hermetic flatpack MSI device of, say, 40 gates operating with T_j = 25°C in a benign ground environment. A failure rate of 0.0032 x 10^{-6} failures per hour is calculated using MIL-HDBK-217. Let 5,000 of such devices be used in an end item expected to operate 50,000 hours. The expected number of device failures during the end item life is less than 1. For this application, the device can be considered to be "good", i.e. free of latent defectives. If a class C-1 device were used on the end item instead of the class S device, an additional 20 failures could be expected to occur during the same end item life, due solely to the difference in quality grade. The additional 20 failures can be viewed as representing latent defectives in the population. If the class S parts were operated with T_j = 100°C instead of 25°C the increase in failure rate would result in an additional two failures during the 50,000 hours. This may indicate that the class S lot contains latent defectives that were precipitated by the increased operating temperature. There can be no precise definition for a latent defective part because the inherent flaw can range from a minor flaw, which may not be subjected to sufficient stress to cause degradation of the flaw to a hard failure, to a major flaw, which requires only a slight stress. The quality level of the parts, used in a product is a major factor affecting incoming defect density. Procedure A, in Section 5 uses the quality level as a factor in obtaining planning estimates of defect density.

4.10.2.3.2 Screenable latent defects and the field stress environment. The notion of screenable latent defects must be further examined to fully understand the rationale used for the procedures contained in the handbook. The population of latent defects within newly manufactured electronic items can be viewed as a continuum which ranges from minor defects of small size to major defects of large size. Defects of large size will tend to fail prematurely under normal field operating stress conditions. Defects of small size will either eventually manifest as failures, or not fail at all during product life. It is the major flaw or defect which stress screening is intended to precipitate to failure. Good manufacturing process controls will tend to reduce the number of latent defects which are introduced into the hardware.

However, it is important to note a somewhat controversial point, i.e., given the same manufacturing process, the number of screenable latent defects which may reside in the hardware will differ, dependent upon the operating environment to which the equipment will be exposed. The stress/time to which a latent defect is exposed will determine its time-to-failure or failure threshold. The probability of a latent defect's failure threshold being exceeded is much higher in a harsh environment than in a more benign environment. Figure 4.3 illustrates that a harsh uninhabited airborne environment has a smaller time-to-failure than a ground benign environment thus affecting the proportion of a latent defect population which should be screened from the equipment.

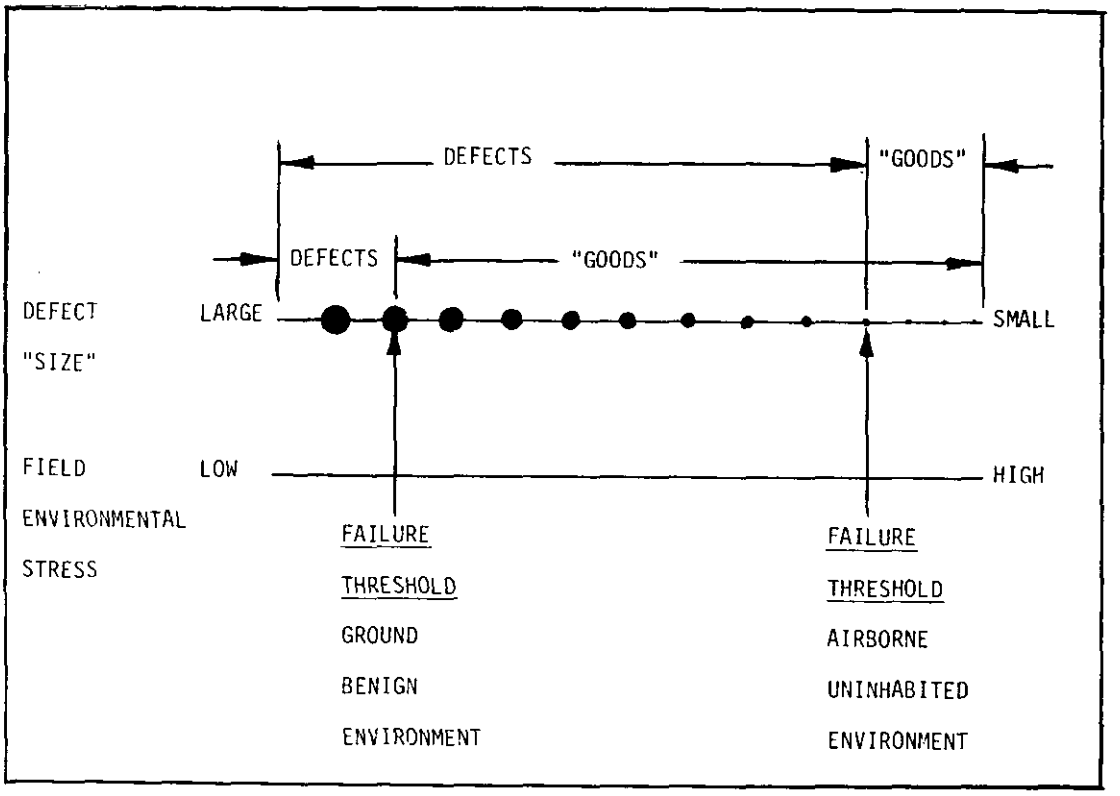


Figure 4.3 Latent Defects and the Field Stress Environment

Obtaining an initial estimate of defect density for an equipment must take into consideration the field operating environment to which the equipment will be exposed during product life. The methods contained in Procedure A of Section 5, use the environments of MIL-HDBK-217 (π_E Factors) as a defect density estimation factor.

4.10.2.3.3 Process maturity and defects. The maturity of both the product design and the manufacturing process can significantly impact the quantity and type of defects which can reside in the hardware. The data shown in Table 4.4 represent experience on several large development and production projects. As the data illustrate, the proportions of failures in a product which are traceable to design, part or manufacturing causes can differ substantially, depending upon the stage of maturity of the product and the manufacturing process. During the development phase, the major contributor to product failure is design (~50%), while parts may account for 20% of the failures. Unfortunately, design problems can still be present in the product when stress screens are being conducted during production. The proportion of failures in a product, attributable to design, would be expected to decrease as the process matures. As can be noted, part and manufacturing (workmanship & process) problems tend to dominate early and late production. The overall defect density in the product would also be expected to decrease as the process matures. Maturity of the product and process should be taken into account when planning estimates of defect density are being determined in accordance with the Procedure A of Section 5. In such cases, the user may decide to modify some of the incoming part fraction defective values in Tables 5.2 through 5.13, of Procedure A either upward or downward, depending upon past experience and assessments of maturity.

Table 4.4 Defect Types & Density vs Process Maturity

Maturity	Defect Type Distribution (percent)			Defect Density
	Design	Manufacturing	Parts	
Development	40-60	20-40	10-30	High
Early Production	20-40	30-50	20-40	Moderate
Late Production	5-15	20-30	60-70	Low

Reference RADC-TR-82-87

4.10.2.3.4 Packaging density. Assemblies with high part and wiring density are more likely to contain both patent and latent defects because of the proximity of devices and interconnections contained within a small volume. The effects of poor heat dissipation in densely packaged electronic assemblies can accelerate latent defects to early failure. Difficulties in initially assembling or reworking the hardware can also make such assemblies more defect prone. Procedure A in Section 5, for estimating defect density, does not directly take into account the packaging density factor. It is recommended however, for those assemblies in an equipment which are judged to have high packaging density, that the tabled values of part fraction defective be increased in accordance with the manufacturer's experience.

4.10.3 Screen selection and placement. The single most important task in planning a stress screening program is the selection of appropriate screens and their placement at various levels of assembly so as to achieve a cost effective screening program. Listed below are the factors which affect screen selection and placement. Each of the factors are discussed in more detail in following paragraphs.

a. Goals on remaining defect density - The extent of screening required during the production phase will depend on MTBF requirements and on the goals established for remaining defect density (D_R).

b. Incoming defect density - The quantity and type of defects which reside in the hardware at various assembly levels effects the type and extent of screening required.

c. Screen effectiveness - Prior knowledge of the effectiveness of the screens in precipitating defects to failure.

d. Test detection efficiency - The tests which can be economically and feasibly used to detect defects which have been precipitated to failure by the screens.

e. Thermal and vibration response characteristics - The structural, thermal and material properties of the items to be screened and their response to applied stress.

f. Design limits - The environmental stress design limits of the items to be screened.

g. Facilities - The screening, test and instrumentation facilities available to the manufacturer to perform screening and test operations.

h. Costs - The costs to achieve screening program goals on remaining defect density.

i. Failure-Free Acceptance Tests (FFAT) - The use of a FFAT as an integral part of a system level screen to verify that goals have been achieved.

4.10.3.1 Goals on remaining defect density. Equipments having high reliability requirements will have more stringent goals on remaining defect density and consequently more stressful screening regimens are needed. Methods for determining goals on remaining defect density are discussed in Appendix B. Achieving low defect densities may require 100% screening at all assembly levels and use of a failure-free acceptance screen/test at the system level to provide assurance that goals have been achieved.

4.10.3.2 Incoming defect density. A production program which begins with high levels of incoming defect density will require more extensive screening to reduce the defect density to acceptable levels. Every effort should be made to determine realistic estimates of incoming defect density based upon the manufacturers experience and use of the procedures contained in the handbook.

4.10.3.3 Screen effectiveness. Screen effectiveness is characterized as the "screening strength" which is defined as: the probability that a screen will precipitate a defect to a detectable state given that a defect susceptible to the screen stress is present. A basic premise of stress screening is that under specific screening stresses applied over time, the failure rates of defectives are accelerated from that which would occur under normal field operating stress conditions. By subjecting electronic items to accelerated stresses, i.e. rapid temperature cycling and random vibration, latent defects are thus precipitated to early failure. More severe stresses will tend to accelerate failure mechanisms and the rate of defect failure. For example, the failure rate of a latent defect increases with more rapid rates of temperature change and larger temperature extremes. The screening strength of a random vibration screen increases as a function of the level and duration of the applied excitation.

Stress screens are not all equally effective in transforming latent defects into detectable failures. The nature of defects varies with equipment type, manufacturer and time. Screen effectiveness is achieved through proper application of screens which can only be realized through prior experience and experimentation. Stress screens are intended to precipitate latent part and workmanship defects. In a very broad sense, vibration screens are considered to be more effective for workmanship defects and thermal screens are considered more effective for part defects. There are also classes of defects which are responsive to both vibration and thermal excitation. Table 4.5 provides a listing of latent defect types and the screens believed to be effective is precipitating them to failure. Table 4.5 may be used as an aid in the selection of a screen type when prior knowledge on workmanship or part defects for similar assemblies is available.

Table 4.5 Assembly Defect Types Precipitated by Thermal and Vibration Screens

Defect Type	Thermal Screen	Vibration Screen
Defective Part	X	X
Broken Part	X	X
Improperly Installed Part	X	X
Solder Connection	X	X
PCB etch, Shorts and Opens	X	X
Loose contact		X
Wire Insulation	X	
Loose wire termination	X	X
Improper crimp or mating	X	
Contamination	X	
Debris		X
Loose hardware		X
Chafed, pinched wires		X
Parameter drift	X	
Hermetic seal failure	X	
Adjacent boards/parts shorting		X

Reference RADC-TR-82-87

Table 4.5 indicates that vibration screens are generally more effective for loose contacts, debris and loose hardware while temperature cycling screens are not effective. Thermal screens are generally more effective for part parameter drift, contamination and improper crimp or mating type defects while vibration screens are not. For other defect classes listed in the table, both thermal and vibration screens are effective, but the relative degree of effectiveness of one screen type over the other is not precisely known. These are some of the uncertainties which must be dealt with in planning a screening program. Historically, on average, 20% of the defects are found to be responsive to vibration screens and 80% to temperature cycling screens. (Reference publication IES Environmental Stress Screening Guidelines for Assemblies).

4.10.3.3.1 Pre/post screen testing and screen effectiveness. In order to experimentally determine scress screen effectiveness, the following conditions are required:

a. The items subjected to stress screening must be tested thoroughly before the stress screen to assure that no detectable failures remain at the start of stress screening. When testing is not performed prior to stress screening, it is not known whether patent defects were present, which could have been detected without stress screening or whether latent defects were precipitated by the stress screen.

b. The items subjected to stress screening must be powered and exercised. Performance must be continuously monitored to assure that stress-dependent defects (e.g., intermittents, temperature and timing sensitive faults) are detected.

c. The items subjected to screening must be tested using the same test(s) both before and after the stress screen to assure that the failures detected are a result of the stresses imposed.

d. Data must be collected on defect fallout after the stress screen (i.e., during subsequent stress screens, tests, or early field operation) to obtain an estimate of the number of defects which were initially present.

When such data are available and assuming perfect tests, then the screen effectiveness can be determined by use of the observed fallout from the screen and the number of defects initially present i.e.:

$$\text{Screening Strength} = \frac{\text{Fallout}}{\text{Number of Initial Latent Defects}}$$

If the screen effectiveness was known precisely then the number of incoming defects could be calculated directly using the observed fallout from the screen. The remaining number of defects would also be known. Such idealized conditions are difficult, if not impossible, to realize in practice. We are thus compelled to use a modeling approach where screen effectiveness (strength) is based upon estimates derived from a combination of the actual screening program data, experiments, and the published literature. The screening strength models and values used in the handbook tables of Procedure B in Section 5, were developed using such an approach. The results and methodology used for these studies are contained in RADC TR-82-87 and RADC TR-86-149. Addition information is also provided in AFWAL TR-80-3086 and ADR 14-04-73. As more experience data on stress screening are gathered, the screening strength estimates will be refined and improved.

4.10.3.3.2 Pre and post screen testing during production. As was previously discussed, if an item is not tested prior to entering a screen it cannot be determined, even if a detailed failure analyses were performed, whether the defects were precipitated by the screen or whether they were present in the item (patent defects) before the screen. Testing items before they enter the screens and establishing that the items are functioning properly is essential. Evaluation and measurement of the effectiveness of the

screens and the overall screening process should be based upon only those defects which are precipitated to failure by the stressed imposed by the screen. Pre-screen testing should be done immediately prior to the screen to eliminate the uncertainties of latent defect introduction during such processes as cleaning, conformal coating and handling which may otherwise follow the pre-screen test. Relaxing pre-screen test requirements for economic reasons can be detrimental to achieving program objectives. If major changes take place during production such as in an assembly or fabrication process, personnel or production flow, then the defect density (both latent and patent) is likely to change and effect the fallout observed during screening. Under long term production, process improvements and other corrective actions taken as a result of the screening process are likely to change the quantity and distribution of latent defects present in the hardware. Workmanship and manufacturing process defects tend to dominate early production and part related defects dominate mature production. Screens have a different degree of effectiveness for different defect types and therefore screens which may have been effective during early production should be re-evaluated to ascertain their effectiveness. Without the use of pre-screen testing, evaluation and control of the screening process is not possible.

4.10.3.3.3 Screen parameters. Screening strength and the failure rate of defects are a function of specific screen stresses (parameters) and the time duration of the stress application. Tables 5.14 thru 5.18 in Procedure B of Section 5 provide values for screening strength and defect failure rates as a function of relevant screening parameters. Temperature cycle, constant temperature, random and swept-sine screening parameters are defined as follows:

a. Thermal cycle screen parameters

(1) Maximum temperature (Tmax) - The maximum temperature to which the screened assembly will be exposed. This should not exceed the lowest of the maximum ratings of all the parts and materials comprising the assembly. Note that nonoperating temperature ratings for parts are higher than operating ratings.

(2) Minimum temperature (Tmin) - The minimum temperature to which the screened item will be exposed. This should not exceed the highest of the minimum ratings of all the parts and materials comprising the assembly.

(3) Range (R) - The range is the difference between the maximum and minimum applied external (chamber) temperature (Tmax - Tmin). Temperatures are expressed in ^{o}C.

(4) Temperature rate of change ($\dot{T}$) - This parameter is the average rate of change of the temperature of the item to be screened as it transitions between Tmax and Tmin and is given by:

$$\dot{T} = \left[\left(\frac{Tmax - Tmin}{t_1}\right) + \left(\frac{Tmax - Tmin}{t_2}\right)\right] \div 2$$

Where: t_1 is the transition time from Tmin to Tmax in minutes

t_2 is the transition time from Tmax to Tmin in minutes

(5) Dwell - Maintaining the chamber temperature constant, once it has reached the maximum (or minimum) temperature, is referred to as dwell. Dwell at the temperature extremes may be required to allow the item being screened to achieve the chamber temperature at the extremes. The duration of the dwell is a function of the thermal mass of the item being screened. For assemblies which have low thermal mass, part case temperatures will track chamber temperatures closely thereby eliminating the need for dwell. Units and systems may have a greater thermal lag and achieving high rates of temperature change may be difficult. Dwells at temperature extremes are required in such instances.

(6) Number of cycles - The number of transitions between temperature extremes (Tmax or Tmin) divided by two.

b. Constant Temperature Screen Parameters

(1) Temperature delta (Δ T) - The absolute value of the difference between the chamber temperature at which the equipment is being screened and 25°C.

$$\Delta T = \left|T - 25^{o}C\right|$$

Where T is the chamber temperature

(2) Duration - The time period over which the temperature is applied to the item being screened, in hours.

c. Vibration screen parameters

(1) grms level for random vibration - The rms value of the applied power spectral density over the vibration frequency spectrum.

(2) g-level for swept sine vibration - The constant rms acceleration applied to the equipment being screened throughout the frequency range above 40HZ. The g-level below 40HZ may be less.

(3) Duration - The time period over which the vibration excitation is applied to the item being screened, in minutes.

(4) Axes of vibration - This can be a single axes or multiple axes depending on the sensitivity of defects to particular axial inputs.

4.10.3.4 Test detection efficiency. Test detection efficiency is a measure of test thoroughness or coverage which is expressed as the fraction of patent defects detectable by a defined test procedure to the total possible number of patent defects which can be present. While stress screens may be effective in transforming a latent defect into a detectable failure, removal of the failed condition is dependent on the capability of the test procedures used to detect and localize the failure.

Modern electronic equipment comprised of microprocessors, large memory and LSI devices may contain defects so subtle that only the most thorough of tests can detect them. Printed wiring assemblies (PWA) have also become much more complex with associated higher defect densities. The costs of PWA fault isolation and repair at end item test and during field use can be 10 to 100 times greater than at the PWA level. Stress screening and testing at the PWA level even perhaps at the bare board level, thus becomes more cost effective. Investments in test equipment and in developing thorough tests with high test detection efficiency also becomes practical from an economic standpoint.

Care should be taken to ensure that tests have detection efficiencies as high as is technically and economically achievable. The screens may otherwise precipitate defects to failure which may go undetected by post screen tests. Effective screening at lower levels of assembly may not always be easily accomplished because of low test detection efficiency. The difficulty in accurately simulating functional interfaces or the inability to establish meaningful acceptance criteria may make the development of tests with high detection efficiency at the assembly level difficult and costly. A certain percentage of defects may only be detectable at the unit/system level when all or a majority of the system components are connected and operating as a system. Analysis and quantification of test detection efficiencies should be an integral part of the planning for a screening program.

4.10.3.4.1 Determining test detection efficiency. On some system procurements the probability of detection is a specified parameter for built-in-test (BIT), performance monitoring (PM) and fault location (FL) capability requirements. When the required BIT or PM/FL capability is used to verify performance of an item being screened, the specified values of detection efficiency should be used in developing the screening plan. On other system procurements, requirements to perform a failure modes and effects analysis (FMEA) are specified in the contract. In such cases, the FMEA should be used to estimate the fraction of defects detectable for a given test design.

When FMEA or BIT fault detection requirements are not specified in the contract, estimates of test detection efficiency should be made based upon experience data. The data should be gathered from fixed test positions and analyzed by test engineering personnel. Table 4.6 provides values of test detection efficiency for various tests which may be applied with stress screens. The values in the table were derived by production and engineering test personnel from a large DOD electronic system manufacturer. RADC TR-82-87

TABLE 4.6 DETECTION EFFICIENCY vs TEST TYPES

Level Assembly	Test Type	Detection Efficiency
Assembly	Production Line GO-NO GO Test	0.85
	Production Line In-Circuit Test	0.90
	High Performance Automatic Tester	0.95
Unit	Performance Verification Test (PVT)	0.90
	Factory Checkout	0.95
	Final Acceptance Test	0.98
System	On-Line Performance Monitoring Test	0.90
	Factory Checkout Test	0.95
	Customer Final Acceptance Test	0.99

Table 4.7 provides fault coverage estimates for various automatic test systems used by electronics system manufacturers.

TABLE 4.7 FAULT COVERAGE FOR AUTOMATIC TEST SYSTEMS

Circuit Type	Automatic Test System Type			
	Loaded Board Shorts Tester (LBS)	In-Circuit Analyzer (ICA)	In-Circuit Tester (ICT)	Functional Board Tester (FBT)
Digital	45% to 65%	50% to 75%	85% to 94%	90% to 98%
Analog	35% to 55%	70% to 92%	90% to 96%	80% to 90%
Hybrid	40% to 60%	60% to 90%	87% to 94%	83% to 95%

An illustration of fault coverage for a sample of 1000 PWA's subjected to various test strategies is also provided in Reference. The strategies employed include the use of each of four automatic testers independently and in combination. Table 4.8 provides a summary of the results.

TABLE 4.8 FAULT DETECTION FOR A 1000 PCB LOT SIZE*

Fault Classification	Actual	LBS	ICA	ICT	FBT	ICA-ICT	ICA-FBT	ICT-FBT	ICA-ICT-FBT
Shorts	261	261	261	261	261	261	261	261	261
Opens	5	5	5	5	5	5	5	5	5
Missing Components	30		25	28	25	29	27	29	30
Wrong Components	67		53	61	55	64	59	60	65
Reversed Components	28		26	23	25	27	28	25	28
Bent Leads	43		38	43	43	43	43	43	43
Analog Specifications	25		13	21	18	21	21	22	23
Digital Logic	27			20	27	20	27	27	27
Performance	26				26		26	26	26
Total No. of Faults	512	266	421	462	486	470	497	498	508
Fault Coverage	100%	52%	82%	90%	95%	92%	97%	97%	99%
Fault Coverage Increase	-	-	-	-	-	2.2%	2.3%	2.5%	4.5%
Rejected PCBs	398	223	345	370	385	374	391	393	394
Rework Yield		195	316	354	376	361	384	388	393
Undetected Faulty PCB		203	82	44	22	37	14	10	5
Rework Yield		49%	79%	89%	94%	91%	96%	97%	99%
Rework Yield Increase	-	-	-	-	-	2%	2.1%	3.2%	4.5%
Finished Units		805	918	956	978	963	986	990	995

As can be noted from the table, using only a Functional Board Tester (FBT) provides 95% fault coverage but combining an In-Circuit Tester (ICT) with the FBT increases coverage to 97% and adding an In-Circuit Analyzer (ICA) to the sequence, increases coverage to 99%.

The faults detected are typical patent defects and do not cover the spectrum of defect types of interest in stress screening. The statistics provided in the table, however, provide a basis for developing estimates of test detection efficiency when a stress screening program is being planned. The data should also be helpful in selecting test strategies for use with stress screens.

4.10.3.4.2 Power-on testing vs power-off. Application of power, exercising and monitoring equipment performance continuously during the screen will greatly enhance test detection efficiency. Subtle faults, such as contact intermittents or temperature sensitive parts, can only be detected with powered and monitored screens. With the increased complexity of modern electronics, fault sites may be confined to smaller areas and fault symptoms may appear only during certain tests or under a special set of external conditions. As a result, a greater incidence of "Cannot Duplicate" (CND), "No-Fault Found" (NFF) and "Retest OK" (RTOK) and similar intermittent or transient phenomena can occur. Latent defects which are precipitated to failure by stress screens can be categorized into three general types:

a. Type 1 Physical defects that are readily transformed from an inherent weakness to a hard failure by the stress screen.

b. Type 2 Physical defects that manifest as failures only while under thermal or mechanical stress. (e.g. intermittent caused by a cold solder joint)

c. Type 3 Functional defects that manifest as performance failures or anomolies only while under thermal or mechanical stress. (e.g. timing problems)

The type 1 defects are readily detected by post screen tests of sufficient thoroughness. Type 2 and Type 3 defects require thorough and continuously monitored tests so that they can be detected. Type 3 defects, which include problems such as timing, part parameter drift with temperature or tolerance build-up can only be detected with powered and monitored tests. Type 2 and Type 3 defects can comprise 50% and as much as 80% of the latent defects present in the hardware. (Reference RADC TR-86-149)

Developing tests and test strategies for use with stress screens and estimating their detection efficiency is a vitally important activity in planning a stress screening program. The use of tests with high detection efficiency is of equal importance to using effective screens in structuring a screening program for production.

4.10.3.5 Thermal and vibration response characteristics. All assembled hardware consists of many paths along which a stress might be transmitted. The selection of screening parameters and methods of stress application must be suited to the stress transmission characteristics of the hardware design. As a part of the screen selection and placement process, in which thermal or vibration screens are to be used, a stress response survey of the item to be screened should be performed. Care should be exercised to ensure that hardware responses are large enough to generate an effective screen while not exceeding hardware design capability. Environmental stresses should be applied to the hardware and the response of critical hardware elements measured to determine whether maximum or minimum temperature limits are being exceeded, and whether suspected defect sites (parts, interconnections etc.) are responsive to the screen stress. In addition, normal design provisions for isolating the hardware from stress such as the use of shock mounting, vibration isolators or cooling air should also be evaluated. Application of environmental stress screening in such instances, should require bypassing the normal stress isolation provisions or may dictate the need for screening at lower assembly levels which do not include the stress isolation design features.

4.10.3.6 Design limits. The use of screen parameters which impose stresses which exceed the design limits of the product is not recommended. Effective screening programs can be developed without having to resort to stresses which exceed the design capability of the hardware. Criteria for judging how much the design limits can be safely exceeded, without causing damage to the product, are non-existent or at least arbitrary. The impetus for exceeding the design limits is basically economic in nature because harsher screens tend to take less time to precipitate defects to failure. Using the procedures contained in the handbook, the manufacturer can focus on those items in which defects are most likely to reside in the hardware and determine safe screening levels, within appropriate cost constraints, for precipitating them to failure.

4.10.3.7 Facilities and costs. The facilities that the manufacturer has available for screening, instrumenting and testing the product effects screen selection and placement. A manufacturer may not have random vibration facilities or automatic test systems which can be used for the stress screening program. In such cases, the manufacturer may decide to impose less severe stresses for a longer duration or decide to use less expensive alternatives such as described in NAVMAT P-9492. The costs to purchase expensive screening or test equipment and perform screens at a given level of assembly may not be warranted, in terms of the number of defects which are likely to be found. The screening and test facilities which the manufacturer has available for screening must be addressed in preparing the screening program plan and in the screen selection and placement process. Costs versus the benefits to be derived from screening should be addressed.

The criterion used in the handbook to both limit costs and judge the cost effectiveness of the screening program is called the cost threshold. The cost threshold is based upon the average cost of repair in the field and can be viewed as a "not-to-exceed" cost. After determining the costs of conducting the screening program and estimating the expected fallout in accordance with the Procedures B

& C of Section 5, the manufacturer should compare the cost per defect eliminated against the cost threshold. If the cost per defect eliminated is found to be higher than the cost threshold, then the manufacturer should determine alternative methods which lower the costs of finding and eliminating the defects to a value which is less than or equal to the cost threshold. Alternatives might include reducing the incoming defect density by means other than assembly screening, (e.g., increase the quality level of parts used) increase the screening strength at lower assembly levels, or eliminate screens which may be of questionable value. In those cases, where field reliability is an overriding requirement, then the Government procuring activity must decide to what extent the cost threshold should be exceeded.

4.10.3.8 Failure-free acceptance screen/test. The use of failure-free periods or cycles, as a part of a stress screen, is intended to provide some degree of assurance for the user that screening is complete. A failure-free period is a time interval during which the equipment must operate without failure while exposed to environmental stress. Arbitrary selection of failure-free periods does not provide any quantitative assurance that the remaining defect density goals have been achieved. Prior knowledge of defect density, the effectiveness of the screens to be used, and a quantitative goal for the remaining defect density must be available in order to establish failure-free acceptance test requirements. The quantity of primary interest is the average number of defects remaining (defect density) per equipment at delivery. Yield, which is directly related to remaining defect density, can be verified by conducting a failure-free screen/test for a predetermined period of time. The length of the failure-free period is dependent on the yield requirement or goal, the degree and type of stresses applied during the failure-free period and the statistical confidence needed to provide assurance that the yield goal has been achieved.

The failure-free acceptance test can be used as an integral part of the system level screen or as part of a formal acceptance test for the system when a stress screen is not used at the system level. When a failure-free acceptance test is used, each system offered for acceptance must be subjected to the failure-free screen and test. Passing the test involves contiguous operation of the equipment for a time T, without failure while under screening stress. If a failure occurs, the failure is repaired and the equipment is again subjected to the same failure-free period starting at T=0. Appendix C of the Guidebook provides the mathematical derivation of the FFAT methods contained in the handbook. Procedure C in Section 5 contains the detailed procedures for tailoring a FFAT to program requirements.

4.10.4 Preparation of ESS plans. The contrator should prepare ESS plans for both the development and production phases. The purpose of the development phase plan is to describe the proposed application of ESS during development and production. The development phase plan should be submitted as part of the Reliability Program Plan. A detailed ESS plan should be submitted for approval by the procuring activity prior to production.

4.10.4.1 Development phase plan - The development phase plan should include the following:

a. Identification of the reliability requirements for the product and the quantitative goals for the ESS program.

b. Identification of the equipment to be screened and the respective production quantities.

c. Description of the initial screens which will be applied and the screening experiments which will be conducted.

d. Description of the data collection and analysis program which will be used.

e. Description of subcontractor and supplier stress screening to be performed.

f. Results of preliminary use of the handbook procedures.

g. Identification of the organization elements that will be responsible for ESS planning and experimentation, and the conduct of development phase screening activity.

4.10.4.2 Production phase plan. The production phase plan shall include the following:

a. Quantitative objectives of the ESS program.

b. Detailed breakdown to the assembly level of the equipment which will be screened.

c. Description of the screens which will be applied, including screen parameters and exposure time.

d. Description of the results in applying Procedures A, B, C and D of Section 5 including the rationale for achieving quantitative objectives in a cost effective manner.

e. Description of the FRACAS and the analyses procedures which will be used to evaluate and control the screening process.

f. Description of the Failure-Free Acceptance Test to be performed for each system to verify achievement of objectives.

g. Identification of the organizational elements responsible for conducting and evaluating the effectiveness of the production ESS program.

4.10.5 Guidelines for initial screen selection and placement. An initial screening regimen should be selected for experimental use during the development phase in conjunction with the use of the handbook procedures. Table 4.9 is recommended as an aid in selecting and placing screens for a starting regimen.

TABLE 4.9 GUIDELINES FOR INITIAL SCREEN SELECTION AND PLACEMENT

Level of Assembly	Selection				Placement	
	Temp Cycle	Const. Temp.	Rand Vib.	S.S. Vib.	Advantages	Disadvantages
Assy	E[1]	M[2]	M[3]	N	• Cost per flaw precipitated is lowest (unpowered screens) • Small size permits batch screening • Low thermal mass allows high rates of temperature change • Temperature range greater than operating range allowable	• Test detection efficiency is relatively low • Test equipment cost for powered screens is high
	E = Effective M = Marginally Effective N = Not Effective Notes: 1. Particularly if power is applied and performance is monitored at temperature extremes. 2. Effective where assemblies contain complex devices (RAMs, microprocessors, hybrids) 3. Effectiveness highly dependent on assembly structure. Not effective for small, stiff PWAs.					
Unit	E	M	E	M	• Relatively easy to power and monitor performance during screen • Higher test detection efficiency than assembly level • Assembly interconnections (e.g., wiring backplane) are screened	• Thermal mass precludes high rates of change, or requires costly facilities • Cost per flaw significantly higher than assembly level • Temperature range reduced from assembly level
System	E	M	E	M	• All potential sources of flaws are screened • Unit interoperability flaws detected • High test detection efficiency	• Difficult and costly to test at temperature extremes • Mass precludes use of effective vibration screens, or makes use costly • Cost per flaw is highest

4.10.6 R&M 2000 ESS initial regimen. R&M 2000 ESS studies recommend the screen types, parameters and placements outlined in Table 4.10 as an initial regimen. The screens contained in Table 4.10 have high screening strength. There are several advantages to beginning the screening regimen with high strength screens. Estimates of incoming defect density can be established with less uncertainty within tighter control bounds. In addition, after sufficient fallout has been observed and more cost effective alternatives determined, it is much simpler to reduce rather than increase the screening regimen.

TABLE 4.10 R&M 2000 ENVIRONMENTAL STRESS SCREENING INITIAL REGIMEN

SCREEN TYPE, PARAMETERS AND CONDITIONS	ASSEMBLIES (PRINTED WIRING ASSEMBLIES)(SRU) *	EQUIPMENT, OR UNIT (LRU/LRM)
THERMAL CYCLING SCREEN		
Temperature Range (Minimum) (See Note 1)	From -54°C To +85°C	From -54°C To +71°C
Temperature Rate of Change (Minimum) (See Note 2)	30°C/Minute (Chamber Air Temp)	5°C/Minute (Chamber Air Temp)
Temperature Dwell Duration (See Note 3)	Until Stabilization	Until Stabilization
Temperature Cycles (Minimum)	25	10
Power On/Equipment Operating	No	(See Note 5)
Equipment Monitoring	No	(See Note 6)
Electrical Testing After Screen	Yes (At Ambient Temperature)	Yes (At Ambient Temp)
QUAS-RANDOM VIBRATION (See Note 7)		
Spectral Density	(See Note 8)	6 Grms
Frequency Limits		100-1000 Hz
Axes Stimulated Serially or concurrently		3
Duration of Vibration (Minimum) -Axes stimulated serially -Axes stimulated concurrently		 10 Minutes/Axis 10 Minutes
Power On/Equipment Operation		(See Note 5)
Equipment Monitoring		(See Note 6)

* SRU - Snop Replaceable Unit
LRU - Line Replaceable Unit
LRM - Line Replaceable Module

NOTES:

1. Temperatures beyond stated minimums are acceptable.
2. Rapid transfers of the equipment between one chamber at maximum temperature and another chamber at minimum temperature are acceptable.
3. The temperature has stablilized when the temperature of the part of the test item considered to have the longest thermal lag is changing no more than 2 degrees centigrade per hour.
4. A minimum of 5 thermal cycles must be completed after the random vibration screen.
5. Shall occur during the low to high temperature excursion of the chamber and during vibration. If operating, equipment shall be at maximum power loading. Power will be OFF on the high to low temperature excursion until stabilized at the low temperature. Power will be turned ON and OFF a minimum of three times at temperature extremes on each cycle.
6. Instantaneous go/no-go performance monitoring during the stress screen is essential to identify intermittent failures when power is on.
7. Specific level may be tailored to individual hardware specimen based on vibration response survey and operational requirements.
8. When random vibration is applied at the equipment-level, random vibration is not required at the subassembly-level. However, subassemblies purchased at spares are required to undergo the same random vibration required for the equipment-level. A "LRU mock-up" or equivalent approach is acceptable.

4.11 Production phase - monitoring, evaluation and control. Once a screening program is implemented during the production phase, the screen fallout data and the screening process must be monitored and controlled to assure that program objectives are achieved. Use of a Failure Reporting Analysis, and Corrective Action System (FRACAS) should be an integral part of production phase monitoring and control tasks. The fallout from the screening process provides the necessary visibility regarding the sources of defects in the product and the manufacturing process. Finding defects, determining their root causes and ensuring that the sources of the defects are eliminated from either the process or product, is the basic mechanism by which process capability is improved.

Analyses of screen fallout data must be performed with specific objectives in mind. Well-defined monitoring, evaluation and control task objectives will ensure that the proper data is collected, classified and correctly analyzed to meet objectives. The objectives of the monitoring-evaluation and control tasks are to establish assurance that remaining defect density and reliability goals are achieved through implementing improvements in manufacturing, screening and test process capability. Manufacturing process capability is improved through taking corrective actions which reduce the number of defects that are introduced into the product. Screening process capability is improved by increasing the screening strength of screens and ensuring that potential sites for defects in the product are being adequately stimulated by the screen. Testing process capability is improved by increasing test detection efficiencies when it is found that latent defects, precipitated to failure by a lower level screen, are escaping and being detected by tests at upper assembly levels.

Another goal of monitoring and control tasks is related to cost effectiveness. The initial screening program might have been based upon planning estimates which were overly pessimistic. Corrective actions might also have been taken during production to reduce the number of defects introduced into the product. In either case, if the screening program is continued as planned, more screening than is necessary results, which impacts both cost and schedule. Decisions must be made to either reduce the screening regimen, resort to environmental stress testing on a sample basis or to completely eliminate the screen. In a sense, the goal of monitoring and control tasks is to make the screening program unnecessary.

4.11.1 Data collection. The importance of timely and accurate data collection to achieving screening program objectives cannot be overemphasized. The data elements listed below should be collected during the conduct of the screening program. Some of the data elements become available directly as observed events from the screening process. Other data elements will become available only after analysis of the failures and failure data, or after a batch of items have been exposed to screening.

a. Identification of the items exposed to the screen/test.

b. Number of like items exposed to the screen/test.

c. Number of like items passed/failed the screen/test.

d. Description of the type of defect found (part, workmanship/process, design)

e. Type and number of defects found in conjunction with the number of items exposed, passed/failed (data elements b, c, d).

f. Identification of the part, interconnection site where the defect was found.

g. Identification of the assembly level or manufacturing process operation where the defect was introduced.

h. Screen conditions under which the defect was found (e.g., high temperature, vertical axis of vibration etc.).

i. Time-to-failure relative to the start of the screen.

j. Failure analysis results which identifies the root cause of the defect.

h. Corrective action taken to eliminate the cause of the defect from the product and/or process.

4.11.2 Failure classification. In order to establish a basis for the analysis of the screening fallout data, the failures must be properly classified. The following classification scheme is recommended.

a. Part defect - A failure or malfunction which is attributable to a basic weakness or flaw in a part (diode, transistor, microcircuit, etc.).

b. Manufacturing defect - A failure or malfunction attributable to workmanship or to the manufacturing process (cold solder joint, cracked etch, broken wire strands, etc.).

c. Design Failure - A failure or malfunction attributable to a design deficiency. Note that electrical or thermal overstress failures due to inadequate derating, are design problems. One would expect that all or most design problems would have been eliminated from the hardware prior to production. Nonetheless, a substantial proportion of failures during early production ($\sim$30%) are found to be traceable to design.

d. Externally induced failures - A failure attributable to external influences such as prime power disturbances, test equipment, instrumentation malfunctions or test personnel.

e. Dependent failure - A failure which is caused by the failure of another associated item which failed independently.

f. Software failure - A failure attributable to an error in a computer program.

g. Unknown cause failure - An independent failure which requires repair and rework but which cannot be classified into any of the above categories.

4.11.3 Preliminary analysis of fallout data. A preliminary analysis of the fallout data should be performed to insure that failure causes are properly established and to categorize the failures so that more detailed analysis related to the ESS program objectives can be performed. The failure categories and recommended actions follow.

a. Part and interconnection defects - All failures traceable to part board and interconnection defects, which are precipitated and detected by a screen/test, should be considered to be latent defects provided that pre-screen testing was performed. These data should be used for monitoring and control purposes.

b. Design failures - A predominance of design problems which are discovered during production screening operations is a matter of serious concern. Every effort should be made to determine corrective actions for design problems very early in production. It does no good to speculate that the design problems should have been eliminated from the hardware during the development stage. Stress screening, on a 100% basis, is an expensive and time consuming method for finding design problems. If the fallout from screening indicates persistent evidence of design problems, methods other than 100% stress screening should be used. Reliability growth and Test-Analyze-And-Fix (TAAF) techniques are recommended.

c. Unknown cause failures - Special attention should be given to unknown cause failures. Sufficient investigation should be made to establish that an intermittent condition does not exist. The number of failures classified as "Unknown Cause" should be kept to a minimum. Every effort should be made to correlate the failure circumstance data with the other similar failure incidents, as well as to use failure analysis so as to establish the cause of failure.

d. Dependent and induced failures - Analyses of dependent and induced failures should be performed to determine necessary corrective actions.

4.11.4 Analysis of screen fallout data. The analysis of screening fallout data is directed toward evaluating the screening process so as to achieve screening program goals on remaining defect density D_R. Yield goals are achieved by both improving manufacturing process capability through corrective action and by improving the screening and test process capability when it is found to be needed.

Manufacturing, screening and test process capability will determine the remaining defect density. The capability of these processes are measured and controlled by use of two important quantities, the incoming defect density (D_{IN}) and the test strength (TS). Neither one of these quantities are directly observable as a result of the screening process. The only observable statistic is the fallout from the screen/test, from which inferences regarding D_{IN} and TS must be drawn. The basic approach used in the Procedure E of Section 5, is to obtain estimates of D_{IN} and TS, using the screen fallout data and to statistically compare the observed data against the planning estimates. Based upon the comparisons, corrective actions are determined to eliminate the source of the defect from the process and/or to change the screens so as to achieve stated objectives.

Four complementary procedures are presented in Procedure E for performing monitoring and analyses tasks. Procedures E1 and E4 use Quality Control Charts and control intervals for monitoring and control. Procedures E2 and E3 use maximum likelihood and graphical techniques, applied to the Chance Defective Exponential model, to estimate D_{IN} and TS.

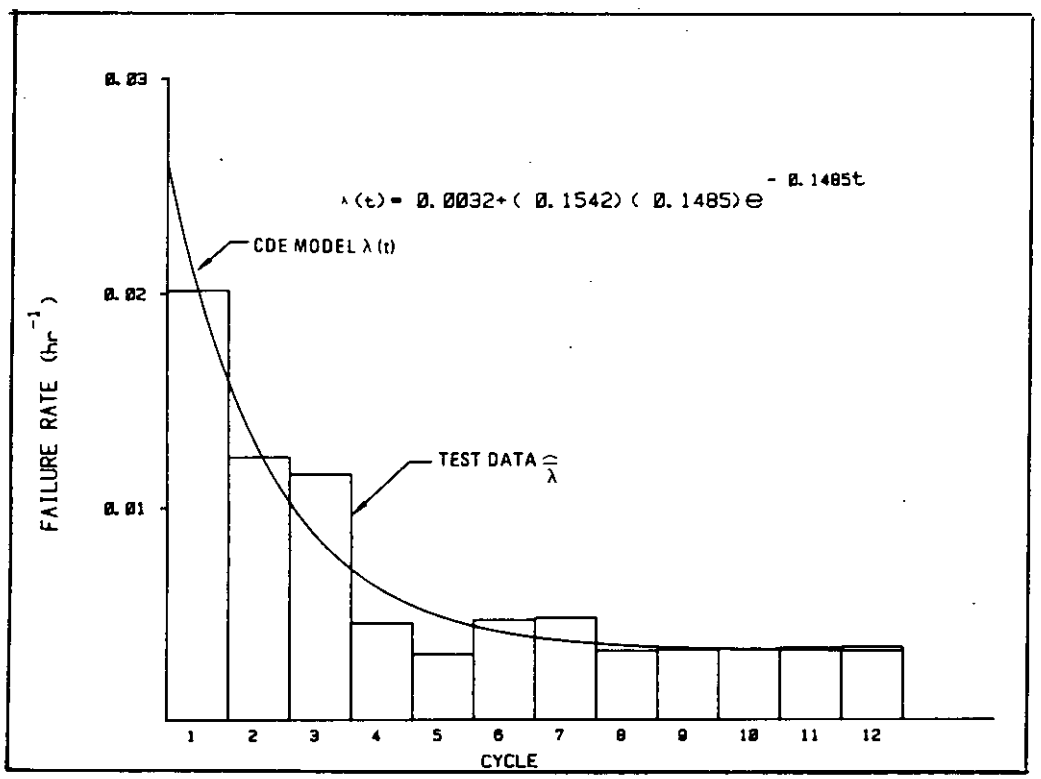
4.11.4.1 Quality control charts. The use of control charts for defect control is a standard quality assurance technique. Control charts are used in Procedure E1 which are based upon the Poisson Probability distribution; i.e.,

$$P(x=x) = \frac{e^{-D} D^x}{x!}$$

Where: D = defect density
x = number of defects in an item
P(X=x) = probability of x defects in an item

The mean of the Poisson distribution is D and the standard deviation is $\sqrt{D}$. When the true defect density is D, 99% of the time the number of defects(x) in an item, will lie between the control chart limits established by $D \pm 3\sqrt{D}$. The primary purpose of the control chart technique is to establish baselines against which the process can be monitored and by which out-of-control conditions can be identified. Part fraction defective and defect density are calculated, using the fallout data, and compared against the control chart baselines. Part and workmanship (process) problems are rank ordered and corrective actions are required which eliminate the source of the defects from the product. Procedure E1 of Section 5 contains the detailed methodology for implementing the control chart technique.

4.11.4.2 Use of the CDE model to evaluate screening results. The Chance Defective Exponential (CDE) model was developed by Fertig and Muthy and is discussed in a paper contained in the 1978 Annual R&M Symposium. Appendix A of the guidebook, provides a description of the CDE model. The failure rate function of the CDE model can be fitted to the observed fallout data for a given screen so as to obtain estimates of the model parameters. The parameters of the CDE model provide estimates of the incoming defect density D_{IN}, the screening strength (SS) and the failure rate of the "good" part population for an equipment. Figure 4.4 is an extract from study report which shows a histogram of the screen fallout from a 12 cycle -54°C to 71°C temperature cycle screen. The fallout per cycle is used to obtain maximum likelihood estimate (MLE) for the parameters of the CDE model.



Reference AFWAL-TR-80-3086

Figure 4.4 Temperature Cycling Data Fitted To The Chance Defective Exponential Model

As the figure shows, the CDE model parameters estimated by the MLE procedure, are: incoming defect density (D_{IN}) equal to .1542 defects per item, the failure rate of a defect ($\bar{\lambda}_D$) equal to .1485 failures per hour (which corresponds to a screening strength of .95) and a value of .0032 for the failure rate of the main population (λ_o). The MLE estimates of the model parameters should be compared against the planning estimates of D_{IN} and SS to determine appropriate corrective action. The parameter estimation procedure should be applied to several batches of screened items, and/or confidence limits should be calculated for the MLE parameters to verify that significant differences from planning estimates exist. Caution should be exercised in interpreting the MLE estimates of the CDE model parameters. In most instances, the time duration of a screen/test is insufficient to obtain any precision in the estimate of λ_o, the failure rate of the "nondefective" population. It is therefore recommended, as a first step, that λ_o be set to zero, or that a prior estimate of λ_o be used. Prior estimates of λ_o can be obtained from development phase reliability tasks, i.e., from a MIL-HDBK-217 prediction or from the results of a MIL-STD-781 demonstration test.

4.11.4.3 Comparing observed and planning estimates of D_{IN} and TS. In practice the "true" values of incoming defect density and test strength can differ significantly from planning estimates. When significant difference exist , both the outgoing defect density and costs are effected. Under certain conditions, differences from planning estimates will jeopardize achieving goals on remaining defect density, whereas in other cases, the differences will have more of an impact on costs. The corrective action required to assure achievement of screening program goals will differ, depending upon the degree of departure from planned values and whether D_{IN}, TS or both are higher or lower than planning estimates. It must also be recognized that, given effective corrective actions, good process control and the removal of defects from the product, D_{IN} would be expected to decrease rather rapidly during the initial stages of screening. It is, therefore, necessary to establish monitoring schedules and lot sampling techniques, which correlate with major corrective action changes so that reductions in D_{IN} and the effectiveness of corrective actions can be measured.

5. DETAILED GUIDELINES

5.1 ESS planning, monitoring and control procedures. Detailed procedures and methodologies for performing the major tasks involved in planning, monitoring and controlling the screening program are contained in the following paragraphs. There are five basic procedures as follows.

a. Procedure A entitled, "Part Fraction Defective - R&M 2000 goals and Incoming Defect Density" is used to control the part fraction defective and to obtain initial estimates of D_{IN}. Two procedures are contained in Procedure A. Procedure A1 provides control of incoming defect density for electronic components (diodes, transistors, etc.) by limiting the part fraction defective to the R&M 2000 goals of no greater than 1000 PPM and 100 PPM. Methods for sampling part lots to determine if the part fraction defective exceeds the R&M 2000 goals are included in the procedure. Procedure A2 contains tabled values of part, board and connection fraction defective as a function of quality level and field environmental stress. The tables are used to estimate incoming defect density. Other factors which impact incoming defect density, such as maturity and packaging density, should be factored into the estimates based upon experience and the recommendations contained in the handbook.

b. Procedure B entitled, "Screen Selection and Placement" uses the results obtained from Procedure A, to plan a screening program to achieve objectives on remaining defect density. The procedure contains tabled values of screening strength and defect failure rates as a function of the screen parameters and duration. Other factors which effect screen selection and placement, such as the quantity of defect type susceptible to temperature versus vibration screens, must be factored into the procedure based upon the manufacturer's experience and the recommendations contained in the handbook. Procedure B must be performed in conjunction with the following two procedures C and D, to develop a screening plan.

c. Procedure C entitled, "Failure-Free Acceptance Test" is used to establish failure-free acceptance periods which provide a lower confidence bound on yield or equivalently, the remaining defect density. The failure-free acceptance test can be made a part of the end item (system) level screen or used as part of a separate acceptance test procedure. In either case, the costs of conducting the FFAT must be factored into the screen selection and placement and cost estimating procedures.

d. Procedure D entitled, "Cost Effectiveness Analysis" is used to estimate and compare the costs of various screen selection and placement alternatives in order to arrive at a cost effective screening program. The manufacturer's cost of conducting the screening program is normalized to a cost per defect eliminated. Comparison of the cost per defect eliminated by the screening program against a cost threshold value is used to determine cost effectiveness.

e Procedure E entitled, "Monitoring, Evaluation and Control" is used to obtain estimates of the defect density based upon the observed screen fallout data and to establish whether the observed defect density falls within or outside of predetermined control limits. Comparisons of observed part fraction defective and defect density are made against baseline criteria to prioritize and determine the need for corrective actions which improve manufacturing or screening process capability.

5.2 Procedure A - Part fraction defective - R&M 2000 goals and incoming defect density

5.2.1 Objective. Provide assurance that the manufacturing process begins with electronic parts (diodes, transistors, etc.) with R&M 2000 part fraction defective goals of below 1000 PPM by FY87 and below 100 PPM by FY90. Obtain planning estimates of incoming defect density which will serve as a basis for planning a stress screening program.

5.2.2 Procedure A1. R&M 2000 goals on electronic part fraction defective. The methodology uses either an industry accepted lot acceptance procedure for verifying compliance with the Specified Quality Level (SQL) in PPM (EIA Interim Standard No. 18) or a lot acceptance procedure based on a constant Average Outgoing Quality Limit (AOQL). There are several ways that the SQL or AOQL can be applied.

a. The parts vendors can use process control and testing with sufficient documentation of their product's quality to the original equipment manufacturer (OEM) or Air Force agency buying their parts to assure both the OEM and the government that the parts do in fact meet the defective rate requirements.

b. The OEM can perform receiving inspection and screening to assess the defective rate of the purchased parts.

c. The OEM can use the results of first assembly screening to assess the defect rate of the purchased parts. (See Procedures E1, Step 5).

The lot sampling approach contained in the EIA Interim Standard (No. 18) employs essentially a constant Lot Tolerance Percent Defective (LTPD) for a given SQL and therefore provides good buyer protection. Alternatively, a constant AOQL approach permits smaller sample sizes for the higher quality vendors and still assures the accepted product meets the quality requirements. The sample sizes for lower quality products would be slightly larger than those in the EIA Standard. Therefore, Table 5 has been prepared as an alternative to the EIA Standard. While Table 5 contains sampling plans only for 100 PPM and 1,000 PPM levels, the sample sizes are linearly related to defective rates so plans for other defective levels are easily obtained. For example, for 500 PPM the sample sizes for 1,000 PPM are doubled and the number of defectives permitted is unchanged.

The values in Table 5 are based on using the Binomial distribution to approximate the exact probability of acceptance. This approximation is not accurate for cases where the number of samples is a large fraction of the total lot. Therefore, it is necessary that the sampling plan selected maintain the lot size to sample size ratio above five to one. For example, for the 1,000 PPM requirement and a lot size of 5,000 items, only the sampling for zero or one defective may be used.

5.2.2.1 Procedure steps:

Step 1. For Air Force programs, all lots must be sampled by either the vendor or the OEM using one of the following plans:

a. Sample in accordance with the EIA Interim Standard with an SQL of 2,500 for the 1,000 PPM requirement and an SQL of 250 for the 100 PPM requirement. (Table I of the EIA Standard must be extended for an SQL of 250.)

b. Sample in accordance with Table 5 herein.

Step 2. Parts suppliers should retain and provide test data to validate that their manufacturing process is providing a product with a defective rate of less than the allowed level and, if the EIA Interim Standard (No. 18) is being used for lot sampling, the appropriate sample sizes are being selected.

Step 3. If the supplier defective level meets or is less than the required level, no further rescreening or sampling of the lot by the OEM is needed. However, if a supplier's defective level exceeds the goal, or the supplier is unable to provide satisfactory evidence of the quality levels, additional acceptance testing should be performed during OEM receiving inspection. The OEM should test the parts in accordance with the established military specifications for the part type utilizing sample sizes from Table 5. Further, the Air Force or its contractor may check part defective rates of any lot at their discretion. The various parts will be tested in accordance with the established military specifications for that part type. The tests should, as a minimum, include thermal cycling, as outlined below, and full electrical characterization.

Minimum Temperature Range	From -54^{o} to $100^{o}C$
Minimum Temperature Rate of Change	The total transfer time from hot to cold or cold to hot should not exceed one minute. The working zone recovery time should be five minutes maximum after introduction of the load from either extrme in accordance with MIL-STD-883C.
Temperature Dwell Duration	Until Stablilization (see Note 1)
Minimum Temperature Cycles	25
Power On/Equipment Operating	No
Equipment Monitoring	No
Electrical Testing After Screen	Yes (At high and low temperatures)

Note 1. Temperature has stabilized when the temperature rate or change is no more than two degrees celsius per hour.

Step 4. As with the EIA Standard, when Table 5 is used, any rejected lot should be screened 100 percent in accordance with the military specifications for that part type.

Step 5. For lots that are smaller than the smallest sample sizes given in Table 5, all items in the lot should be tested.

Table 5 Defectives Permitted Vs. Sample Size

.10% AOQL (1000 PPM)		.01% AOQL (100 PPM)	
No of Defectives	Sample Size	No. of Defectives	Sample Size
0	368	0	3680
1	840	1	8400
2	1371	2	13,710
3	1942	3	19,420
4	2544	4	25,440
5	3168	5	31,680
6	3812	6	38,120

5.2.3 Procedure A2 - Planning estimates of incoming defect density

5.2.3.1 Methodology. The methodology is similar to the procedures used in MIL-HDBK-217 for estimating failure rates. Tables 5.2 through 5.13 are used in the procedure to obtain incoming defect density estimates as a function of the number of parts, boards and connections contained in the product, their quality level and the field stress environment to which the parts will be exposed. Other factors which may effect estimates of incoming defect density, such as the product or process maturity, packaging density or prior experience should be used, as may be appropriate, to tailor the estimate to the unique characteristics of a given product and process. Estimates can be scaled upward or downward when prior knowledge or experience data on specific part types or manufacturing processes are available. The

proportion of incoming defect density which are responsive to either vibration or temperature screens should also be estimated. Historical data has shown that approximately 20% of the defects in a production lot are sensitive only to vibration type screens and 80% to temperature screens. Each situation, however, must be judged individually. The defect density estimates, obtained by this procedure, should be viewed as being representative of the user's (manufacturer's) average process capability. It should be recognized that the estimates obtained by this procedure are planning estimates only which are required for establishing a baseline screening program. Comparison of the planned estimates of defect density against observed values using Procedure E, is the vehicle by which defect density is controlled and the screening program objectives and production reliability assurance are achieved.

The procedure uses a three-level equipment breakdown structure, i.e. System, Unit and Assembly, to illustrate the methodology for planning a stress screening program. Other equipment breakdown structures are, of course, possible and can be adapted to the structure used herein. Stress screening, excluding part level screening, is generally confined to three levels. However, if more levels are used, the methodology is equally applicable, requiring only the expansion of the three-level-worksheets.

5.2.3.2 Equipment breakdown. The equipment to be screened should be depicted in chart form down to the assembly level as illustrated in Figures 5.1 and 5.2. Figure 5.1 shows the breakdown of a system to be screened into three units. Figure 5.2 shows the breakdown of one of the units into its constituent assemblies.

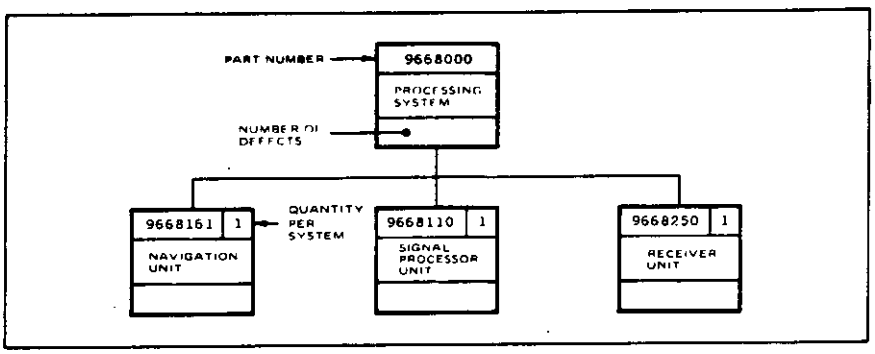


Figure 5.1 System Breakdown Chart

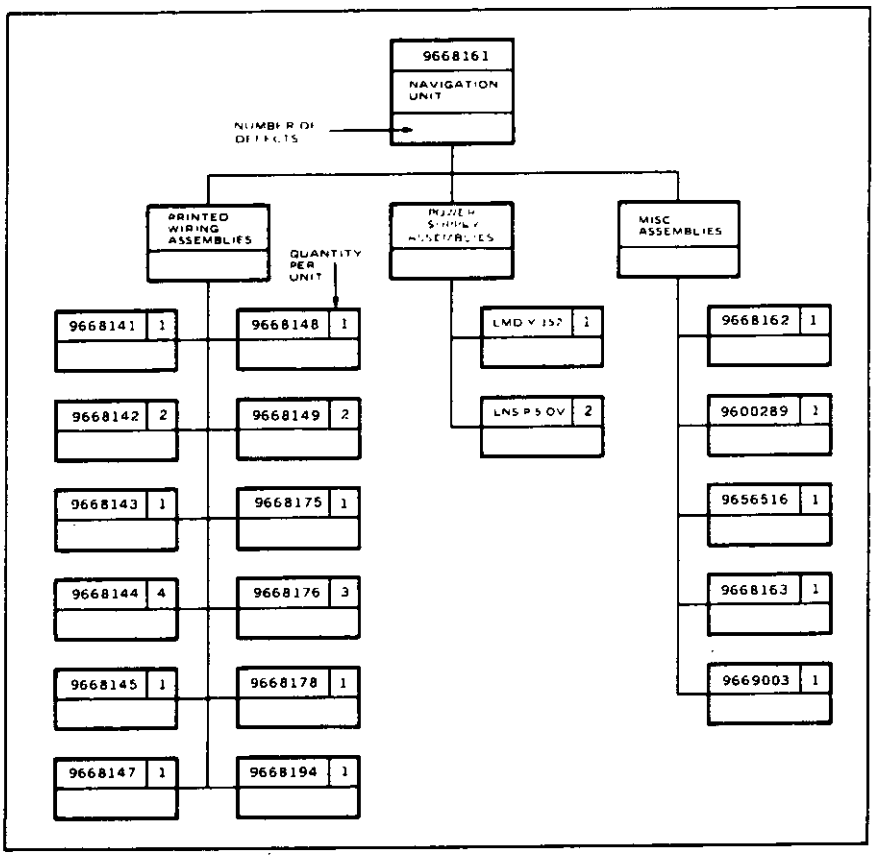


Figure 5.2 Unit Breakdown To Assembly Level

5.2.3.3 Procedure steps. Using the equipment breakdown charts and the defect estimation worksheets (Figure 5.3) the following steps should be performed.

Step 1. Assembly defect estimates. For each assembly identified in the equipment breakdown, as in Figure 5.2., a defect estimation worksheet as shown in Figure 5.3 should be completed.

DEFECT ESTIMATION WORKSHEET

Program/Project	System Nomenclature		
Unit Identifier	Assembly Identifier	Prepared By	Date

Part Type	Quality Level/ Grade	Quantity	Fraction Defective	Estimated Defects
Microelectronic Devices				
Transistors				
Diodes				
Resistors				
Capacitors				
Inductive Devices				
Rotating Devices				
Relays				
Switches				
Connectors				
Printed Wiring Boards				
Connections, Hand Solder				
Connections, Crimp				
Connections, Weld				
Connections, Solderless Wrap				
Connections, Wrapped and Soldered				
Connections, Clip Termination				
Connections, Reflow Solder				
			Defect Density/Assembly	
			Defect Density Total	

Figure 5.3 Worksheet for Estimating Defect Density

Step 2. Part type. Determine the part types used in the item. Part types shown on the worksheet are the standard types included in MIL-HDBK-217. Miscellaneous part types can be added as necessary.

Step 3. Quality level/grade. Enter the appropriate quality level or grade for the part types as indicated by Table 5.1.

Table 5.1 Quality Levels and Grades

Quality Grade	Equivalent Quality Levels*		
	Microcircuits	Semiconductors	Passive Parts
0	S	JANS	T
1	B	JANTXV	S
2	B-0	JANTX	R
3	B-1	$\frac{1}{3}$ JAN, $\frac{2}{3}$ JANTX**	P
4	B-2	$\frac{2}{3}$ JAN, $\frac{1}{3}$ JANTX**	$\frac{1}{2}$ M, $\frac{1}{2}$ P **
5	C	JAN	M
6	C-1	$\frac{1}{2}$ JAN, $\frac{1}{2}$ LOWER**	$\frac{1}{2}$ L, $\frac{1}{2}$ M **
7	D	LOWER	L
8	D-1	PLASTIC	COMMERCIAL

* as defined in MIL-HDBK-217.

** Mixture of quality levels to obtain quality grade

Step 4. Quantity. Enter the quantity of each part and connection type.

Step 5. Fraction defective. Determine the fraction defective in parts per million (PPM) for each part, connection, board and connector type using Tables 5.2 through 5.13. The field environment under which the equipment is intended to operate must be known.

Step 6. Estimated defects. Determine the estimated defects by multiplying the Quantity in Step 4 by the fraction defective in Step 5 and enter on the worksheet.

Step 7. Defect density. Enter the Defect Density for the Assembly by adding all the estimated defects for all the parts in the assembly. Enter the total Defect Density by multiplying the assembly Defect Density by the number of identical assemblies contained in the equipment.

Step 8. Unit defect estimates. For each unit identified in Figure 5.1, a Unit Breakdown chart as shown in Figure 5.2 should be prepared. A Defect Estimation Worksheet should be completed for each unit, as was done for the assemblies, including only those parts and interconnections that were not included in the assemblies. Determine the estimated number of defects for each unit by summing the estimated defects for all the assemblies comprising the unit and the estimated unit flaws. Note that the quantity of identical assemblies or units in the system must be used in calculating defect density. Enter the totals on the System Breakdown Chart in the spaces provided.

Step 9. System defect estimates. A defect estimation worksheet should be completed for the system to estimate the number of defects not included in the Unit or Assembly level estimates. Determine the total estimated number of defects in the system by summing the unit defect estimates and the quantity from the system defect estimates. This total is the incoming defect density for the system which is used as the planning estimate D_{IN}.

Step 10. Total defects production lot. The total defects for the production lot should be calculated by multiplying the system defect density obtained in Step 9 by the number of systems to be produced.

5.2.4 Part fraction defective tables. Tables 5.2 through 5.13 contain the part fraction defective as a function of the part quality level and the field stress environment to which the equipment will be exposed. Part types included in the tables are:

a.	Microelectronic Devices	g.	Rotating Devices
b.	Transistors	h.	Relays
c.	Diodes	i.	Switches
d.	Resistors	j.	Connections
e.	Capacitors	k.	Connectors
f.	Inductive Devices	l.	Printed Wiring Boards

TABLE 5.2 PART FRACTION DEFECTIVE, MICROELECTRONIC DEVICES PPM

Environment	Quality Level								
	S	B	B-0	B-1	B-2	C	C-1	D	D-1
GB	9.2	18.3	36.6	54.9	119.0	146.4	237.9	320.3	640.6
GF	19.4	38.7	77.4	116.1	251.6	309.6	503.2	677.3	1354.6
GM	27.5	55.1	110.1	165.2	357.9	440.5	715.8	963.6	1927.2
MP	25.6	51.2	102.4	153.6	332.9	409.7	665.8	896.3	1792.5
NSB	26.6	53.1	106.3	159.4	345.4	425.1	690.8	929.9	1859.9
NS	26.6	53.1	106.3	159.4	345.4	425.1	690.8	929.9	1859.9
NU	34.7	69.5	139.0	208.5	451.7	556.0	903.5	1216.2	2432.5
NH	35.7	71.4	142.8	214.3	464.3	571.4	928.5	1249.9	2499.9
NUU	37.6	75.3	150.5	225.8	489.3	602.2	978.6	1317.3	2634.6
ARW	48.2	96.4	192.9	289.3	626.9	771.6	1253.8	1687.8	3375.6
AIC	19.4	38.7	77.4	116.1	251.6	309.6	503.2	677.3	1354.6
AIT	21.8	43.5	87.0	130.5	282.9	348.1	565.7	761.5	1523.1
AIB	31.4	62.8	125.5	188.3	408.0	502.1	815.9	1098.4	2196.7
AIA	26.6	53.1	106.3	159.4	345.4	425.1	690.8	929.9	1859.9
AIF	36.2	72.4	144.8	217.2	470.5	579.1	941.0	1266.8	2533.5
AUC	21.8	43.5	87.0	130.5	282.9	348.1	565.7	761.5	1523.1
AUT	26.6	53.1	106.3	159.4	345.4	425.1	690.8	929.9	1859.9
AUB	43.4	86.8	173.6	260.5	564.3	694.6	1127.7	1519.4	3038.8
AUA	36.2	72.4	144.8	217.2	470.5	579.1	941.0	1266.8	2533.5
AUF	50.6	101.3	202.5	303.8	658.2	810.1	1316.4	1772.0	3544.0
SF	11.7	23.3	46.6	69.9	151.5	186.4	303.0	407.9	815.7
MFF	26.1	52.2	104.4	156.5	339.2	417.4	678.3	913.1	1826.2
MFA	33.3	66.6	133.2	199.8	433.0	532.9	866.0	1165.7	2331.4
USL	60.3	120.5	241.0	361.5	783.3	964.0	1566.6	2108.8	4217.7
ML	69.9	139.8	279.5	419.3	908.4	1118.0	1816.8	2445.7	4891.3
CL	1065.9	2131.8	4263.7	6395.5	13857.0	17054.8	27714.0	37307.4	74614.7

TABLE 5.3 PART FRACTION DEFECTIVE, TRANSISTORS PPM

	Quality Level				
Environment	JANTXV	JANTX	JAN	Lower	Plastic
GB	10.9	21.9	109.3	546.6	1093.2
GF	34.6	69.2	346.0	1730.2	3460.4
GM	98.8	189.5	947.7	4738.5	9477.0
MP	65.2	130.4	651.8	3259.0	6518.0
NSB	54.3	108.7	543.3	2716.5	5433.1
NS	54.3	108.7	543.3	2716.5	5433.1
NU	109.6	219.1	1095.7	5478.3	10956.6
NH	99.7	199.4	997.0	4985.1	9970.2
NUU	104.6	209.3	1046.3	5231.7	10463.4
ARW	139.2	278.3	1391.6	6957.8	13915.6
AIC	52.9	105.7	528.5	2642.6	5285.1
AIT	80.0	160.0	799.8	3998.8	7997.5
AIB	178.6	357.2	1786.1	8930.5	17860.9
AIA	104.6	209.3	1046.3	5231.7	10463.4
AIF	203.3	406.5	2032.7	10163.4	20326.8
AUC	80.0	160.0	799.8	3998.8	7997.5
AUT	129.3	258.6	1292.9	6464.6	12929.2
AUB	301.9	603.8	3019.0	15095.1	30190.1
AUA	178.6	357.2	1786.1	8930.5	17860.9
AUF	326.6	653.1	3265.6	16328.0	32656.0
SF	8.0	15.9	79.7	398.6	797.3
MFF	65.2	130.4	651.8	3259.0	6518.0
MFA	89.8	179.7	898.4	4491.9	8983.9
USL	183.5	367.1	1835.4	9177.0	18354.1
ML	208.2	416.4	2082.0	10410.0	20819.9
CL	3408.9	6817.7	34088.7	170443.3	340886.7

TABLE 5.4 PART FRACTION DEFECTIVE, DIODES PPM

	Quality Level					
Environment	JANS	JANTXV	JANTX	JAN	Lower	Plastic
GB	1.2	5.9	11.8	59.2	296.2	592.3
GF	1.7	8.6	17.2	86.0	430.0	860.0
GM	4.3	21.6	43.2	216.2	1080.8	2161.5
MP	3.2	16.1	32.2	160.8	803.8	1607.7
NSB	1.9	9.4	18.9	94.2	471.5	943.1
NS	1.9	9.4	18.9	94.3	471.5	943.1
NU	4.9	24.4	48.8	243.8	1219.2	2438.5
NH	4.5	22.5	45.1	225.4	1126.9	2253.8
NUU	4.7	23.5	46.9	234.6	1173.1	2346.2
ARW	6.0	29.9	59.8	299.2	1496.2	2992.3
AIC	3.8	18.8	37.7	188.5	942.3	1884.6
AIT	4.7	23.5	46.9	234.6	1173.1	2346.2
AIB	6.5	32.7	65.4	326.9	1634.6	3269.2
AIA	5.6	28.1	56.2	280.8	1403.8	2807.7
AIF	7.5	37.3	74.6	373.1	1865.4	3730.8
AUC	5.6	28.1	56.2	280.8	1403.8	2807.7
AUT	6.5	32.7	65.4	326.9	1634.6	3269.2
AUB	10.2	51.2	102.3	511.5	2557.7	5115.4
AUA	8.4	41.9	83.8	419.2	2096.2	4192.3
AUF	10.2	51.2	102.3	511.5	2557.7	5115.4
SF	1.2	5.9	11.8	59.2	296.2	592.3
MFF	3.2	16.1	32.2	160.8	803.8	1607.7
MFA	4.1	20.7	41.4	206.9	1034.6	2069.2
USL	7.6	38.2	76.5	382.3	1911.5	3823.1
ML	8.6	42.8	85.7	428.5	2142.3	4284.6
CL	128.4	641.9	1283.8	6419.2	32096.2	64192.3

TABLE 5.5 PART FRACTION DEFECTIVE, RESISTORS PPM

	Quality Level					
Environment	S	R	P	M	MIL-SPEC	Lower
GB	0.4	1.2	3.7	12.3	61.4	184.2
GF	0.6	2.0	6.1	20.3	101.7	305.2
GM	1.5	5.1	15.4	51.5	257.4	772.3
MP	1.7	5.7	17.2	57.2	286.2	858.7
NSB	0.9	3.1	9.2	30.7	153.6	460.9
NS	1.0	3.4	10.1	33.6	168.1	504.2
NU	2.6	8.7	26.2	87.2	436.2	1308.5
NH	2.6	8.7	26.2	87.2	436.2	1308.5
NUU	2.8	9.3	27.9	93.0	465.0	1395.0
ARW	3.5	11.6	34.8	116.1	580.3	1740.9
AIC	0.6	2.1	6.3	20.9	104.6	313.9
AIT	0.7	2.4	7.1	23.8	119.0	357.1
AIB	1.3	4.4	13.2	44.0	219.9	659.8
AIA	1.2	4.1	12.3	41.1	205.5	616.6
AIF	1.8	5.8	17.5	58.4	292.0	876.0
AUC	1.4	4.7	14.1	46.9	234.4	703.1
AUT	1.3	4.4	13.2	44.0	219.9	659.8
AUB	2.8	9.3	27.9	93.0	465.0	1395.0
AUA	2.8	9.3	27.9	93.0	465.0	1395.0
AUF	3.7	12.2	36.5	121.8	609.1	1827.4
SF	0.3	0.9	2.6	8.8	44.1	132.3
MFF	1.7	5.8	17.3	57.8	289.1	867.4
MFA	2.3	7.6	22.7	75.7	378.5	1135.5
USL	4.7	15.6	46.9	156.4	782.1	2346.3
ML	5.4	17.9	53.8	179.5	897.4	2692.2
CL	88.4	294.7	884.1	2947.0	14735.0	44205.0

TABLE 5.6 PART FRACTION DEFECTIVE, CAPACITORS PPM

Environment	Quality Level						
	S	R	P	M	L	MIL-SPEC	Lower
GB	1.2	3.8	11.5	38.4	115.3	115.3	384.4
GF	1.8	6.2	18.4	61.5	184.5	184.5	615.0
GM	9.0	30.0	89.9	299.8	899.4	899.4	2998.1
MP	12.7	42.3	126.8	422.8	1268.4	1268.4	4228.1
NSB	5,8	19.2	57.7	192.2	576.6	576.6	1921.9
NS	6.3	21.1	63.4	211.4	634.2	634.2	2114.1
NU	14.3	47.7	143.0	476.6	1429.9	1429.9	4766.2
NH	18.4	61.5	184.5	615.0	1845.0	1845.0	6150.0
NUU	20.8	69.2	207.6	691.9	2075.6	2075.6	6918.7
ARW	27.7	92.2	276.7	922.5	2767.5	2767.5	9225.0
AIC	3.5	11.5	34.6	115.3	345.9	345.9	1153.1
AIT	3.5	11.5	34.6	115.3	345.9	345.9	1153.1
AIB	5.8	19.2	57.7	192.2	576.6	576.6	1921.9
AIA	3.5	11.5	34.6	115.3	345.9	345.9	1153.1
AIF	6.9	23.1	69.2	230.6	691.9	691.9	2306.2
AUC	8.6	28.8	86.5	288.3	864.8	864.8	2882.8
AUT	9.2	30.7	92.2	307.5	922.5	922.5	3075.0
AUB	11.5	38.4	115.3	384.4	1153.1	1153.1	3843.7
AUA	9.2	30.7	92.2	307.5	922.5	922.5	3075.0
AUF	17.3	57.7	173.0	576.6	1729.7	1729.7	5765.6
SF	0.9	3.1	9.2	30.7	92.2	92.2	307.5
MFF	12.7	42.3	126.8	422.8	1268.4	1268.4	4228.1
MFA	17.3	57.7	173.0	576.6	1729.7	1729.7	5765.6
USL	36.9	123.0	369.0	1230.0	3690.0	3690.0	12300.0
ML	41.5	138.4	415.1	1383.7	4151.2	4151.2	13837.5
CL	703.4	2344.7	7034.1	23446.9	70340.6	70340.6	234468.6

TABLE 5.7 PARTS FRACTION DEFECTIVE, INDUCTIVE DEVICES PPM

	Quality Level	
Environment	MIL-SPEC	Lower
GB	537.2	1790.7
GF	1222.9	4076.4
GM	1996.1	7140.1
MP	2142.0	6653.8
NSB	1135.4	3784.6
NS	1222.9	4076.4
NU	2433.8	8112.7
NH	2725.6	9085.3
NUU	3017.4	10058.0
ARW	3892.7	12975.8
AIC	1047.8	3492.8
AIT	1266.7	4222.3
AIB	1266.7	4222.3
AIA	1266.7	4222.3
AIF	1704.4	5681.2
AUC	1339.6	4465.4
AUT	1339.6	4465.4
AUB	1485.5	4951.7
AUA	1485.5	4951.7
AUF	1850.3	6167.5
SF	537.2	1790.7
MFF	1996.1	6653.8
MFA	2579.7	8599.0
USL	5059.9	16866.2
ML	5643.4	18811.5
CL	89385.3	297951.1

TABLE 5.8 PART FRACTION DEFECTIVE, ROTATING DEVICES PPM

Environment	Fraction defective (Defects/10^6)
GB	5935.2
GF	11663.1
GM	30168.5
MP	27965.5
NSB	14967.6
NS	16289.4
NU	34574.6
NH	38980.6
NUU	43386.7
ARW	56604.8
AIC	12544.3
AIT	13645.8
AIB	15848.8
AIA	13645.8
AIF	23559.4
AUC	14747.3
AUT	18051.9
AUB	20254.9
AUA	18051.9
AUF	25762.5
SF	5935.2
MFF	27965.5
USL	74229.1
ML	83041.2
CL	********

TABLE 5.9 PART FRACTION DEFECTIVE, RELAYS PPM

	Quality Level	
Environment	MIL-SPEC	Lower
GB	142.5	210.9
GF	231.4	388.8
GM	635.1	1784.5
MP	1510.8	4384.3
NSB	621.4	1716.0
NS	621.4	1716.0
NU	1031.9	2673.9
NH	2263.4	6642.0
NUU	2400.2	6915.7
ARW	3221.2	9652.3
AIC	450.3	724.0
AIT	484.5	1100.3
AIB	758.2	1442.4
AIA	587.2	1100.3
AIF	758.2	1784.5
AUC	621.4	1442.4
AUT	689.8	1784.5
AUB	1100.3	2810.7
AUA	758.2	2126.5
AUF	1100.3	3152.8
SF	142.5	210.9
MFF	1510.8	4384.3
MFA	2058.1	5684.2
USL	4315.8	13073.1
ML	4931.6	14441.4
CL	N/A	N/A

TABLE 5.10 PART FRACTION DEFECTIVE, SWITCHES PPM

	Quality Level	
Environment	MIL-SPEC	Lower
GB	1.4	24.4
GF	2.4	44.0
GM	8.8	158.4
MP	12.8	230.6
NSB	5.3	95.5
NS	5.3	95.5
NU	12.2	220.3
NH	19.1	344.1
NUU	20.3	364.7
ARW	27.1	488.4
AIC	5.4	96.6
AIT	5.4	96.6
AIB	9.4	168.8
AIA	9.4	168.8
AIF	12.2	220.3
AUC	6.5	117.2
AUT	6.5	117.2
AUB	12.2	220.3
AUA	12.2	220.3
AUF	15.1	271.9
SF	1.4	24.4
MFF	12.8	230.6
MFA	17.4	313.1
USL	36.9	663.7
ML	41.5	746.2
CL	688.3	12388.6

TABLE 5.11 PART FRACTION DEFECTIVE, CONNECTIONS PPM

Environment	Connection Type									
							Crimp			
	Hand Solder	Weld	Solderless Wrap	Wrapped and Soldered	Clip Term	Reflow Solder	Auto	Man., Upper	Man., Std.	Man., Lower
GB	12.	0.2	0.02	1.	1.	0.3	1.2	1.2	2.5	24.8
GF	26.	0.5	0.03	1.	1.	0.7	2.6	2.6	5.2	52.0
GM	90.	1.7	0.12	5.	4.	2.4	9.0	9.0	18.1	180.8
MP	90.	1.7	0.12	5.	4.	2.4	9.0	9.0	18.1	180.8
NSB	43.	0.8	0.06	2.	2.	1.1	4.3	4.3	8.7	86.7
NS	54.	1.0	0.07	3.	3.	1.4	5.4	5.4	10.9	109.0
NU	123.	2.4	0.16	7.	6.	3.3	12.3	12.3	24.5	245.1
NH	136.	2.6	0.18	7.	6.	3.6	13.6	13.6	27.2	272.4
NUU	149.	2.9	0.20	8.	7.	3.9	14.9	14.9	29.7	297.1
ARW	198.	3.8	0.27	11.	9.	5.3	19.8	39.6	39.6	396.2
AIC	31.	0.6	0.04	2.	1.	0.8	3.1	3.1	6.2	61.9
AIT	56.	1.1	0.07	3.	3.	1.5	5.6	5.6	11.1	111.4
AIB	68.	1.3	0.09	4.	3.	1.8	6.8	6.8	13.6	136.2
AIA	62.	1.2	0.08	3.	3.	1.6	6.2	6.8	12.4	123.8
AIF	93.	1.8	0.12	5.	4.	2.5	9.3	9.3	18.6	185.7
AUC	37.	0.7	0.05	2.	2.	1.0	3.7	3.7	7.4	74.3
AUT	74	1.4	0.10	4.	3.	2.0	7.4	7.4	14.9	148.6
AUB	93.	1.8	0.12	5.	4.	2.5	9.3	9.3	18.6	185.7
AUA	87.	1.7	0.12	5.	4.	2.3	8.7	8.7	17.3	173.3
AUF	118.	2.3	0.16	6.	5.	3.1	11.8	11.8	23.5	235.2
SF	12.	0.2	0.02	1.	1.	0.3	1.2	2.5	2.5	24.8
MFF	90.	1.7	0.12	5.	4.	2.4	9.0	9.0	18.1	180.8
MFA	124.	2.4	0.17	7.	6.	3.3	12.4	12.4	24.8	247.6
USL	272.	5.2	0.37	15.	13.	7.2	27.2	27.2	54.5	544.8
ML	310.	6.0	0.42	17.	14.	8.2	31.0	31.0	61.9	619.0
CL	5200.	100.0	7.0	280.	240.	138.0	520.0	520.0	1040.0	10400.0

TABLE 5.12 PART FRACTION DEFECTIVE, CONNECTORS PPM

	Quality Level	
Environment	MIL-SPEC	Lower
GB	73.7	97.3
GF	83.2	248.1
GM	417.7	1204.6
MP	427.1	827.7
NSB	219.8	408.3
NS	276.3	544.9
NU	639.2	1298.9
NH	639.2	1251.8
NUU	686.3	1346.0
ARW	921.9	1770.1
AIC	120.9	497.8
AIT	168.0	497.8
AIB	238.7	733.4
AIA	215.1	733.4
AIF	332.9	969.0
AUC	262.2	733.4
AUT	403.6	733.4
AUB	497.8	969.0
AUA	474.3	969.0
AUF	733.4	1440.2
SF	73.7	97.3
MFF	427.1	827.7
MFA	592.1	1157.5
USL	1204.6	2382.7
ML	1393.1	2759.6
CL	23115.8	45733.8

TABLE 5.13 PART FRACTION DEFECTIVE, PRINTED WIRING BOARDS PPM

	Quality Level	
Environment	MIL-SPEC	Lower
GB	425.0	4250.0
GF	690.3	6903.2
GM	1792.4	17924.3
MP	1629.2	16291.5
NSB	1057.7	10576.9
NS	1302.6	13026.0
NU	2670.0	26700.3
NH	2874.1	28741.2
NUU	3078.2	30782.2
ARW	4098.7	40986.9
AIC	731.1	7311.4
AIT	1139.3	11393.2
AIB	1853.7	18536.5
AIA	1567.9	15679.2
AIF	2261.8	22618.4
AUC	1751.6	17516.1
AUT	3282.3	32823.1
AUB	5323.3	53232.5
AUA	4302.8	43027.8
AUF	7364.2	73641.9
SF	425.0	4250.0
MFF	1996.5	19965.2
MFA	2670.0	26700.3
USL	5527.3	55273.5
ML	6139.6	61396.3
CL	102267.9	*******

5.3 Procedure B - Screen selection and placement

5.3.1 Objective. The objective of this procedure is to select and place screens at appropriate levels of assembly so as to develop a screening program plan for achieving program objectives in a cost effective manner.

5.3.2 Methodology. Procedure steps, outlined below, should be performed iteratively and in conjunction with Procedures C & D.

Iterative application of the procedure should be as follows:

a. Initial Screen Selection and Placement (Based upon engineering evaluation, available facilities and procedure B)
b. Failure-Free Acceptance Tests (Procedure C)
c. Cost Effectiveness Analysis (Procedure D)
d. Remaining Defect Density Calculations
e. Screen Selection and Placement Modification
f. Goals on remaining defect density achieved within given cost constraints

Table 4.9 should be used as a guide for initial screen selection and placement. A diagram of similar defect flow chart, as shown in Figure 5.4, should be used in calculating the remaining defects for various possible screening sequences.

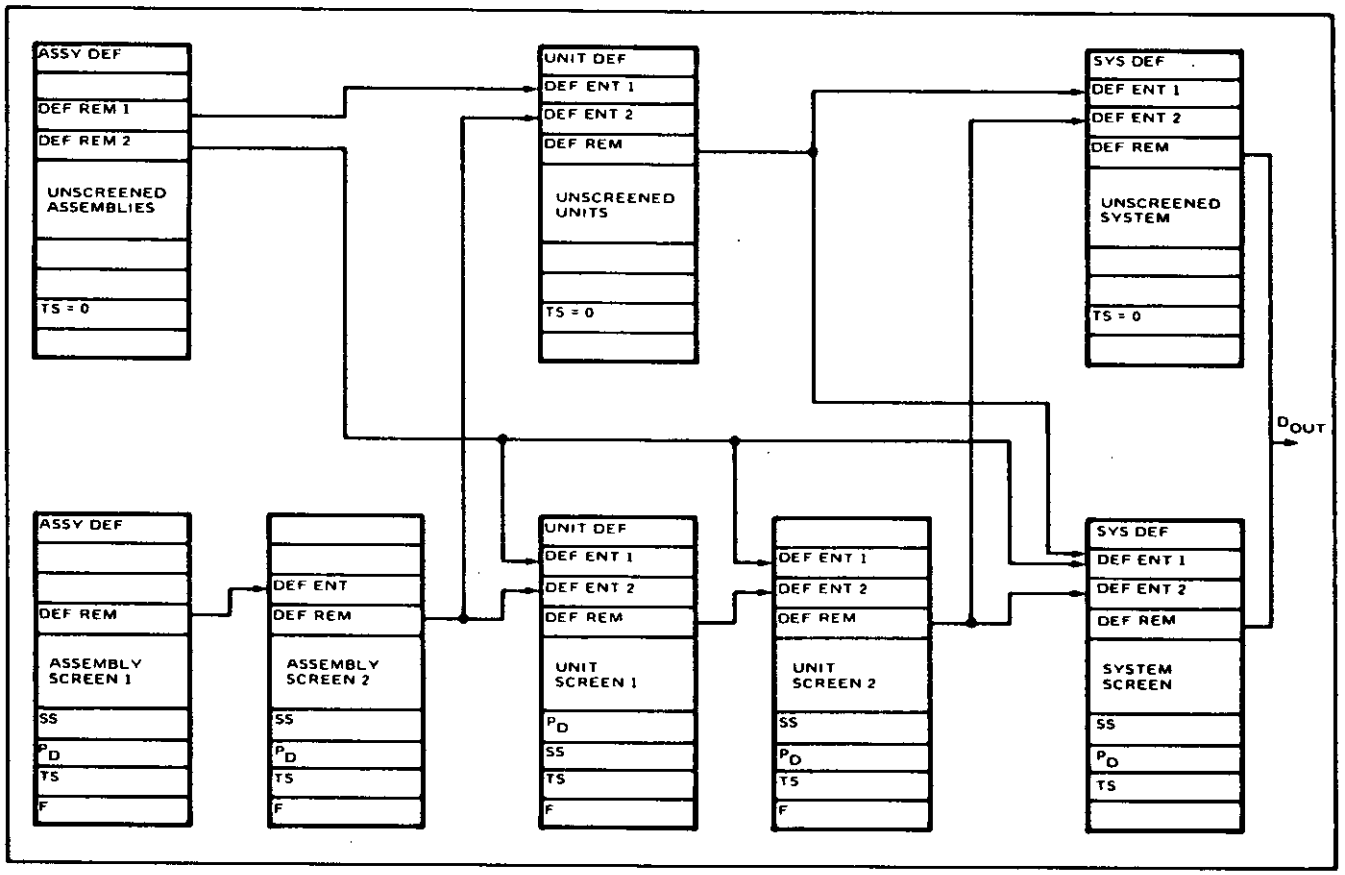


Figure 5.4 Multilevel Screening Flow Chart

5.3.3 Procedure steps. Instructions for use of the flow chart in Figure 5.4 are as follows:

Step 1. For each trial screening sequence, identify the units and assemblies that will be screened at their respective levels and those that will not be screened. (See Figure 5.5)

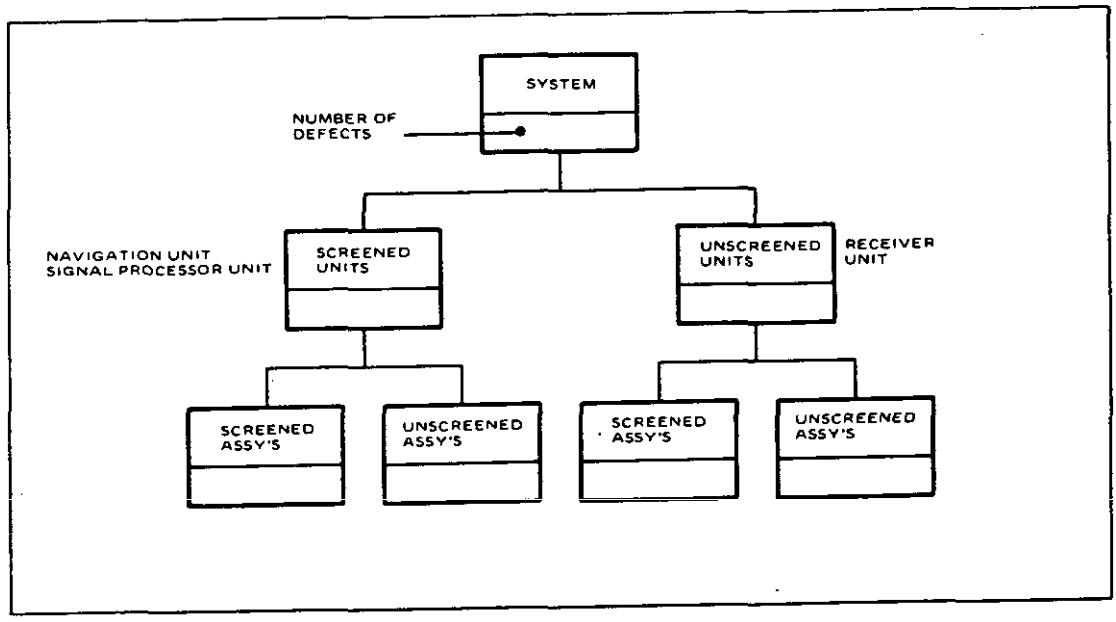


Figure 5.5 Identification of Equipment to be Screened

Step 2. From the Defect Estimation Worksheets of Procedure A, or from the Unit Breakdown Charts, total the estimated number of defects in assemblies to be screened and enter in the block "ASS'Y DEF" for ASSEMBLY SCREEN 1.

Step 3. Similarly, total the estimated number of defects in assemblies that are not to be screened and enter in the block "ASS'Y DEF" for UNSCREENED ASSEMBLIES.

Step 4. Repeat Steps 2 and 3 for Unit and System levels.

Step 5. Select candidate screens using the guidelines. Determine screening strengths for selected screens from Tables 5.14 through 5.18.

Step 6. Determine and enter the Detection Efficiency (D_E) of the tests to be performed during and after screening. For guidance, see Section 4.10.3.4 of the guidebook.

Step 7. Compute test strengths by multiplying screening strengths by their respective detection efficiencies (SS x D_E) and enter.

Step 8. Identify the unscreened assemblies that are installed in unscreened units and enter the total estimated number of defects for those assemblies in the UNSCREENED ASSEMBLIES block DEF REM 1 and in the block DEF ENT 1 of UNSCREENED UNITS. Enter the balance of estimated defects for unscreened assemblies in DEF REM 2.

Step 9. Determine which unscreened assemblies (DEF REM 2) will be installed in units that will first enter UNIT SCREEN 1, UNIT SCREEN 2., or SYSTEM SCREEN. Enter the number of estimated defects into the corresponding DEF ENT 1 block(s).

Step 10. In the ASSEMBLY SCREEN 1 block, calculate the screening fallout, F, by multiplying the ASS'Y DEF by test strength, TS, and enter in block F. Subtract F from ASS'Y DEF and enter difference in DEF REM and DEF ENT in ASSEMBLY SCREEN 2.

NOTE: If a second assembly screen is not considered, the test strength for ASSEMBLY SCREEN 2 is zero and the defects remaining (DEF REM) will be the same as the defects entering (DEF ENT).

Step 11. If TS $\neq$ 0 for ASSEMBLY SCREEN 2, calculate F by multiplying DEF ENT by TS. Subtract F from DEF ENT and enter in DEF REM.

Step 12. Determine which of the screened assemblies will be installed in Units that will enter UNIT SCREEN 1 and those that will be installed in unscreened units. Enter the number of estimated defects into the corresponding DEF ENT 2 block(s).

Step 13. In the UNIT SCREEN 1 block, calculate F by multiplying the sum of DEF ENT 1 and DEF ENT 2 by TS subtract F from the sum of DEF ENT 1 and DEF ENT 2 and enter in DEF REM and in the block DEF ENT 2 of UNIT SCREEN 2.

Step 14. In the UNIT SCREEN 2 block, repeat step 13. Enter the value in DEF REM 2 in the block DEF ENT 2 of SYSTEM SCREEN if the System is to be screened or in the corresponding block in UNSCREENED SYSTEM, if the system is not to be screened.

Step 15. In the UNSCREENED UNITS block, add the values in UNIT DEF, DEF ENT 1, and DEF ENT 2 and enter the sum in DEF REM.

Step 16. Determine which unscreened units will be screened as part of the system screen. Add the estimated defects for those units to the value in DEF ENT 1 of the SYSTEM SCREEN block. Enter the balance of estimated defects for unscreened units in DEF ENT 1 of the UNSCREENED SYSTEM block.

Step 17. In the SYSTEM SCREEN block, calculate F and subtract from the sum of DEF ENT 1 and DEF ENT 2. Enter the difference in DEF REM.

Step 18. In the UNSCREENED SYSTEM block, add the values in DEF ENT 1 and DEF ENT 2 and enter the sum in DEF REM.

Step 19. Add the values in the DEF REM blocks of UNSCREENED SYSTEM and SYSTEM SCREEN blocks. The sum is D_{out}, an estimate of the number of defects remaining after completing the candiate screening sequence. The value of D_{out} must be equal to or less than D_R to satisfy the specified yield requirement.

The above 19 steps complete the initial process of screen selection/placement and remaining defect calculation. The process must be repeated with alternate or modified screens since more than one screening sequence may qualify as a candidate for subsequent cost tradeoff analysis.

5.3.4 Screening strength tables. Tables 5.14 through 5.18 contain the screening strength of various screen types as a function of the screening parameters and time duration of the screen. The failure rates for defects, as a function of the stress level is also provided. Screen types included are:

a. Random Vibration
b. Temperature Cycling
c. Swept-Sine Vibration
d. Constant Temperature

TABLE 5.14 SCREENING STRENGTH AND FAILURE RATES $\bar{\lambda}_D$, RANDOM VIBRATION SCREENS

Duration (minutes)	Acceleration Level (G-RMS)													
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
5	0.007	0.023	0.045	0.072	0.104	0.140	0.178	0.218	0.260	0.303	0.346	0.389	0.431	0.473
10	0.014	0.045	0.088	0.140	0.198	0.260	0.324	0.389	0.452	0.514	0.572	0.627	0.677	0.723
15	0.021	0.067	0.129	0.202	0.282	0.363	0.444	0.522	0.595	0.661	0.720	0.772	0.816	0.854
20	0.028	0.088	0.168	0.260	0.356	0.452	0.543	0.626	0.700	0.764	0.817	0.861	0.896	0.923
25	0.035	0.109	0.206	0.314	0.424	0.529	0.625	0.708	0.778	0.835	0.880	0.915	0.941	0.959
30	0.041	0.129	0.241	0.363	0.484	0.595	0.691	0.772	0.836	0.885	0.922	0.948	0.966	0.979
35	0.048	0.149	0.275	0.409	0.538	0.651	0.746	0.822	0.878	0.920	0.949	0.968	0.981	0.989
40	0.055	0.168	0.308	0.452	0.586	0.700	0.791	0.860	0.910	0.944	0.966	0.981	0.989	0.994
45	0.061	0.187	0.339	0.492	0.629	0.742	0.829	0.891	0.933	0.961	0.978	0.988	0.994	0.997
50	0.068	0.205	0.369	0.529	0.668	0.778	0.859	0.915	0.951	0.973	0.986	0.993	0.996	0.998
55	0.074	0.224	0.397	0.563	0.702	0.809	0.884	0.933	0.964	0.981	0.991	0.996	0.998	0.999
60	0.081	0.241	0.424	0.595	0.734	0.836	0.905	0.948	0.973	0.987	0.994	0.997	0.999	1.000
$\bar{\lambda}_D$	0.084	0.276	0.552	0.903	1.322	1.806	2.351	2.954	3.613	4.327	5.092	5.905	6.776	7.692

TABLE 5.15 SCREENING STRENGTH TEMPERATURE CYCLING SCREENS

Number of Cycles	Temp Rate of Change $^{o}C/Min$	Temperature Range R (^{o}C)								
		20.	40.	60.	80.	100.	120.	140.	160.	180.
2	$\dot{T}$									
	5	.1633	.2349	.2886	.3324	.3697	.4023	.4312	.4572	.4809
	10	.2907	.4031	.4812	.5410	.5891	.6290	.6629	.6920	.7173
	15	.3911	.5254	.6124	.6752	.7232	.7612	.7920	.8175	.8388
	20	.4707	.6155	.7034	.7636	.8075	.8407	.8665	.8871	.9037
4	$\dot{T}$									
	5	.2998	.4147	.4939	.5543	.6027	.6427	.6765	.7054	.7305
	10	.4969	.6437	.7308	.7893	.8312	.8624	.8863	.9051	.9201
	15	.6292	.7748	.8498	.8945	.9234	.9430	.9567	.9667	.9740
	20	.7198	.8522	.9120	.9441	.9629	.9746	.9822	.9873	.9907
6	$\dot{T}$									
	5	.4141	.5522	.6400	.7025	.7496	.7864	.8160	.8401	.8601
	10	.6431	.7873	.8603	.9033	.9306	.9489	.9617	.9708	.9774
	15	.7742	.8931	.9418	.9657	.9788	.9864	.9910	.9939	.9958
	20	.8517	.9432	.9739	.9868	.9929	.9960	.9976	.9986	.9991
8	$\dot{T}$									
	5	.5098	.6574	.7439	.8014	.8422	.8723	.8953	.9132	.9274
	10	.7469	.8731	.9275	.9556	.9715	.9811	.9871	.9910	.9936
	15	.8625	.9493	.9774	.9889	.9941	.9967	.9981	.9989	.9993
	20	.9215	.9781	.9923	.9969	.9986	.9994	.9997	.9998	.9999
10	$\dot{T}$									
	5	.5898	.7379	.8178	.8674	.9005	.9237	.9405	.9529	.9623
	10	.8204	.9242	.9624	.9796	.9883	.9930	.9956	.9972	.9982
	15	.9163	.9759	.9913	.9964	.9984	.9992	.9996	.9998	.9999
	20	.9585	.9916	.9977	.9993	.9997	.9999	.9999	.9999	.9999
12	$\dot{T}$									
	5	.6568	.7994	.8704	.9115	.9373	.9544	.9661	.9744	.9804
	10	.8726	.9548	.9805	.9906	.9952	.9974	.9985	.9991	.9995
	15	.9490	.9886	.9966	.9988	.9996	.9998	.9999	.9999	.9999
	20	.9780	.9968	.9993	.9998	.9999	.9999	.9999	.9999	.9999

TABLE 5.16 FAILURE RATES λ_D, TEMPERATURE CYCLING SCREENS

Temp. Rate of Change $^{o}C/Min$	Temperature Range R (^{o}C)								
	20.	40.	60.	80.	100.	120.	140.	160.	180.
$\dot{T}$									
5	0.0891	0.1339	0.1703	0.2020	0.2308	0.2573	0.2821	0.3055	0.3278
10	0.1717	0.2580	0.3281	0.3893	0.4447	0.4958	0.5436	0.5888	0.6317
15	0.2480	0.3726	0.4739	0.5623	0.6423	0.7161	0.7852	0.8504	0.9125
20	0.3181	0.4779	0.6077	0.7212	0.8237	0.9184	1.0070	1.0906	1.1702

TABLE 5.17 SCREENING STRENGTH AND FAILURE RATES λ_D, SWEPT-SINE VIBRATION SCREENS

Duration (minutes)	G Level													
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
5	0.0020	0.0036	0.0051	0.0066	0.0080	0.0093	0.0107	0.0120	0.0132	0.0145	0.0157	0.0169	0.0181	0.0193
10	0.0040	0.0072	0.0103	0.0131	0.0159	0.0186	0.0212	0.0238	0.0263	0.0287	0.0312	0.0335	0.0359	0.0382
15	0.0060	0.0108	0.0154	0.0196	0.0238	0.0278	0.0316	0.0354	0.0391	0.0428	0.0464	0.0499	0.0534	0.0568
20	0.0080	0.0144	0.0204	0.0261	0.0316	0.0368	0.0420	0.0470	0.0519	0.0566	0.0614	0.0660	0.0705	0.0750
25	0.0099	0.0180	0.0255	0.0325	0.0393	0.0458	0.0522	0.0584	0.0644	0.0703	0.0761	0.0818	0.0874	0.0929
30	0.0119	0.0216	0.0305	0.0389	0.0470	0.0547	0.0623	0.0696	0.0768	0.0838	0.0906	0.0973	0.1039	0.1104
35	0.0139	0.0251	0.0355	0.0452	0.0546	0.0636	0.0723	0.0807	0.0890	0.0970	0.1049	0.1126	0.1201	0.1275
40	0.0159	0.0287	0.0404	0.0515	0.0621	0.0723	0.0822	0.0917	0.1010	0.1101	0.1189	0.1276	0.1361	0.1444
45	0.0178	0.0322	0.0454	0.0578	0.0696	0.0810	0.0919	0.1026	0.1129	0.1230	0.1328	0.1424	0.1517	0.1609
50	0.0198	0.0357	0.0503	0.0640	0.0770	0.0895	0.1016	0.1133	0.1246	0.1357	0.1464	0.1569	0.1671	0.1771
55	0.0217	0.0392	0.0552	0.0701	0.0844	0.0980	0.1112	0.1239	0.1362	0.1482	0.1598	0.1711	0.1822	0.1930
60	0.0237	0.0427	0.0600	0.0763	0.0917	0.1065	0.1207	0.1344	0.1476	0.1605	0.1730	0.1852	0.1970	0.2085
$\bar{\lambda}_D$	0.0240	0.0436	0.0619	0.0793	0.0962	0.1126	0.1286	0.1443	0.1597	0.1749	0.1899	0.2048	0.2194	0.2339

TABLE 5.18 SCREENING STRENGTH & FAILURE RATES $\bar{\lambda}_D$, CONSTANT TEMPERATURE SCREENS

Time in Hours	Temperature Delta (ΔT)								
	0.	10.	20.	30.	40.	50.	60.	70.	80.
10	0.0124	0.0677	0.0991	0.1240	0.1452	0.1639	0.1809	0.1964	0.2108
20	0.0247	0.1308	0.1885	0.2326	0.2693	0.3010	0.3290	0.3542	0.3772
30	0.0368	0.1896	0.2689	0.3278	0.3754	0.4156	0.4504	0.4810	0.5084
40	0.0488	0.2445	0.3414	0.4112	0.4661	0.5114	0.5498	0.5830	0.6121
50	0.0606	0.2956	0.4067	0.4842	0.5436	0.5915	0.6312	0.6649	0.6938
60	0.0723	0.3433	0.4655	0.5481	0.6099	0.6584	0.6979	0.7307	0.7584
70	0.0839	0.3877	0.5185	0.6042	0.6665	0.7144	0.7525	0.7836	0.8093
80	0.0953	0.4292	0.5663	0.6533	0.7149	0.7612	0.7973	0.8261	0.8495
90	0.1065	0.4678	0.6093	0.6963	0.7563	0.8004	0.8339	0.8602	0.8812
100	0.1176	0.5038	0.6480	0.7339	0.7917	0.8331	0.8640	0.8877	0.9063
110	0.1286	0.5374	0.6829	0.7669	0.8219	0.8605	0.8886	0.9097	0.9260
120	0.1394	0.5687	0.7144	0.7958	0.8478	0.8833	0.9087	0.9275	0.9416
130	0.1501	0.5979	0.7427	0.8211	0.8699	0.9025	0.9252	0.9417	0.9539
140	0.1607	0.6251	0.7682	0.8433	0.8888	0.9184	0.9388	0.9532	0.9636
150	0.1711	0.6505	0.7912	0.8628	0.9049	0.9318	0.9498	0.9624	0.9713
160	0.1814	0.6742	0.8119	0.8798	0.9187	0.9430	0.9589	0.9697	0.9774
170	0.1916	0.6962	0.8305	0.8947	0.9305	0.9523	0.9663	0.9757	0.9821
180	0.2017	.7168	0.8473	0.9077	0.9406	0.9602	0.9724	0.9805	0.9859
190	0.2116	0.7360	0.8625	0.9192	0.9492	0.9667	0.9774	0.9843	0.9889
200	0.2214	0.7538	0.8761	0.9292	0.9566	0.9721	0.9815	0.9874	0.9912
$\bar{\lambda}_D$	0.0013	0.0070	0.0104	0.0132	0.0157	0.0179	0.0199	0.0219	0.0237

5.4 Procedure C - Failure-Free Acceptance Test (FFAT).

5.4.1 Objective. The objective of this procedure is to determine the length T of a failure-free period which provides a given statistical confidence that the yield goal (remaining defect density) has been achieved.

5.4.2 Methodology. The values of three parameters should be determined in establishing failure-free acceptance test requirements.

a. λ_o - The predicted or specified failure rate for the system (per MIL-HDBK-217)

b. $\bar{\lambda}_D$ - The average failure rate of a defect under the stress screen to be used in the FFAT. (Tables 5.14 to 5.18 in Procedure B)

c. $\frac{\bar{\lambda}_D}{\lambda_o}$ - The ratio of the failure rate of a defect and the predicted failure rate of the system.

Tables 5.19 through 5.28 provide 90, 80, 70, 60 and 50% lower confidence bounds on yield as a function of the parameters defined above and T, the length of the failure-free period.

5.4.3 Procedure steps. The following outlines the procedural steps involved in determining the failure-free period.

Step 1. Determine the predicted failure rate for the system in accordance with MIL-HDBK-217. The prediction should be based upon the more detailed MIL-HDBK stress analysis procedures rather than simple part count estimation procedures.

Step 2. Establish the average defect density entering the system level screen, D_{IN_3} based upon prior screening results.

Step 3. Determine the screen type most appropriate for use at the system level, based upon prior knowledge of screen effectiveness and the type of defects expected to be present.

Step 4. Translate the yield requirement or goal into a defect density which will remain in the equipment upon completion of the failure-free acceptance test. (i.e. D_R = -ln yield).

Step 5. Determine the required test strength for the screen/test to reduce D_{IN_3} to D_R. i.e.,

$$D_R = D_{IN_3} (1-TS)$$

and

$$TS = 1 - \frac{D_R}{D_{IN_3}}$$

Step 6. Use the estimated test detection efficiency (DE) for the tests which will be applied at the system level.

Step 7. Determine the required screening strength SS for the screen which will be used during the failure-free acceptance test. i.e.,

$$SS = \frac{TS}{DE}$$

Step 8. Select a screen with the required SS determined in the previous step (7) from the Tables 5.14 through 5.18 of Procedure B. Note that the screen should not be selected based upon screening strength alone. The FFAT screen should be selected based upon analyses of screen fallout data at lower assembly levels, the quantity and type of defects expected to be present in the final system product prior to the FFAT and the screen type believed to be most effective for those defects.

Step 9. Determine the failure rate of a defect ($\bar{\lambda}_D$) for the screen selected in Step 8, using the same Tables 5.14 through 5.18 of Procedure B.

Step 10. Determine the failure rate ratio $\frac{\bar{\lambda}_D}{\lambda_o}$ and the statistical confidence required for verifying the yield requirement.

Step 11. Using Tables 5.19 through 5.28, select the table corresponding to the statistical confidence desired.

Step 12. Find the column in the table corresponding to the ratio $\frac{\bar{\lambda}_D}{\lambda_o}$ and proceeding down that column, find the value of yield which corresponds to the requirement or goal.

Step 13. Find the value of $\bar{\lambda}_D$ in the left most column of the table which corresponds to the yield value found by Step 12.

Step 14. Divide the value of $\bar{\lambda}_D T$ found in Step 13 by $\bar{\lambda}_D$, the defect failure rate of Step 9, to determine the length of the failure-free period T.

Step 15. Successful completion of the failure-free acceptance test will provide x% confidence that the actual yield is not less than the required value.

5.4.4 Tables for % lower confidence bound on yield. Tables for 50, 60, 70, 80, and 90% lower confidence bound on yield are provided. The x % lower confidence bound is given in the table as a function of the failure rate ratio $\bar{\lambda}_D/\lambda_o$, and the product of failure rate of a defect ($\bar{\lambda}_D$) and the time duration of the screen (T). Failure rate ratios $\bar{\lambda}_D/\lambda_o$ ranging from .1 to 1, in increments of .1 and from 2 to 60 or more, in increments of 1 and 10 are used in the tables.

TABLE 5.19 90 PERCENT LOWER CONFIDENCE BOUND ON YIELD $\frac{\bar{\lambda}_D}{\lambda_o}$ (.1-1.0)

$\bar{\lambda}_D T$	Failure Rate Ratio $\bar{\lambda}_D/\lambda_o$									
	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.2	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3	1.00	0.10	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00
0.4	1.00	0.54	0.14	0.07	0.05	0.04	0.03	0.03	0.02	0.02
0.5	1.00	1.00	0.38	0.20	0.13	0.10	0.09	0.08	0.07	0.06
0.6	1.00	1.00	0.69	0.38	0.26	0.21	0.17	0.15	0.14	0.13
0.7	1.00	1.00	1.00	0.58	0.41	0.33	0.28	0.24	0.22	0.21
0.8	1.00	1.00	1.00	0.78	0.56	0.45	0.39	0.35	0.32	0.29
0.9	1.00	1.00	1.00	0.96	0.71	0.58	0.50	0.45	0.41	0.38
1.0	1.00	1.00	1.00	1.00	0.84	0.69	0.60	0.54	0.50	0.47
1.1	1.00	1.00	1.00	1.00	0.95	0.79	0.69	0.63	0.58	0.55
1.2	1.00	1.00	1.00	1.00	1.00	0.88	0.78	0.71	0.66	0.62
1.3	1.00	1.00	1.00	1.00	1.00	0.95	0.85	0.78	0.73	0.69
1.4	1.00	1.00	1.00	1.00	1.00	1.00	0.91	0.83	0.78	0.74
1.5	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.88	0.83	0.79
1.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.93	0.88	0.84
1.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.91	0.87
1.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.94	0.91
1.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.93
2.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.95

TABLE 5.20 90 PERCENT LOWER CONFIDENCE BOUND ON YIELD $\frac{\bar{\lambda}_D}{\lambda_o}$ (1-60)

$\bar{\lambda}_D T$	Failure Rate Ratio $\frac{\bar{\lambda}_D}{\lambda_o}$												
	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	20.00	40.00	60.00 or More
1.0	0.47	0.35	0.32	0.30	0.29	0.29	0.28	0.28	0.28	0.28	0.27	0.27	0.26
1.1	0.55	0.42	0.38	0.36	0.35	0.35	0.34	0.34	0.34	0.33	0.33	0.32	0.32
1.2	0.62	0.48	0.44	0.42	0.41	0.40	0.40	0.40	0.39	0.39	0.38	0.38	0.37
1.3	0.69	0.54	0.50	0.48	0.47	0.46	0.45	0.45	0.45	0.44	0.43	0.43	0.43
1.4	0.74	0.59	0.55	0.53	0.52	0.51	0.50	0.50	0.50	0.49	0.48	0.48	0.47
1.5	0.79	0.64	0.60	0.57	0.56	0.55	0.55	0.54	0.54	0.54	0.53	0.52	0.52
1.6	0.84	0.68	0.64	0.62	0.61	0.60	0.59	0.59	0.58	0.58	0.57	0.56	0.56
1.7	0.87	0.72	0.68	0.66	0.64	0.64	0.63	0.63	0.62	0.62	0.61	0.60	0.60
1.8	0.91	0.76	0.71	0.69	0.68	0.67	0.67	0.66	0.66	0.66	0.65	0.64	0.64
1.9	0.93	0.79	0.75	0.73	0.71	0.71	0.70	0.70	0.69	0.69	0.68	0.67	0.67
2.0	0.95	0.82	0.77	0.75	0.74	0.73	0.73	0.73	0.72	0.72	0.71	0.70	0.70
2.2	0.99	0.86	0.82	0.80	0.79	0.79	0.78	0.78	0.77	0.77	0.76	0.76	0.75
2.4	1.00	0.90	0.86	0.84	0.83	0.83	0.82	0.82	0.82	0.81	0.80	0.80	0.80
2.6	1.00	0.92	0.89	0.88	0.87	0.86	0.86	0.85	0.85	0.85	0.84	0.84	0.83
2.8	1.00	0.94	0.92	0.90	0.89	0.88	0.88	0.88	0.88	0.87	0.87	0.87	0.86
3.0	1.00	0.96	0.93	0.92	0.91	0.91	0.91	0.90	0.90	0.90	0.89	0.89	0.89
3.5	1.00	0.98	0.97	0.96	0.95	0.95	0.95	0.94	0.94	0.94	0.94	0.93	0.93
4.0	1.00	0.99	0.98	0.98	0.97	0.97	0.97	0.97	0.97	0.97	0.96	0.96	0.96
5.0	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
6.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99
7.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 5.21 80 PERCENT LOWER CONFIDENCE BOUND ON YIELD $\frac{\bar{\lambda}_D}{\lambda_o}$ (.1-1.0)

	Failure Rate Ratio, $\frac{\bar{\lambda}_D}{\lambda_o}$									
$\bar{\lambda}_D T$	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.2	1.00	0.06	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.3	1.00	0.73	0.18	0.09	0.06	0.04	0.03	0.03	0.03	0.02
0.4	1.00	1.00	0.57	0.29	0.19	0.15	0.12	0.10	0.09	0.09
0.5	1.00	1.00	1.00	0.57	0.39	0.30	0.25	0.22	0.20	0.18
0.6	1.00	1.00	1.00	0.88	0.61	0.48	0.40	0.35	0.32	0.29
0.7	1.00	1.00	1.00	1.00	0.81	0.65	0.55	0.48	0.44	0.41
0.8	1.00	1.00	1.00	1.00	0.99	0.80	0.68	0.61	0.56	0.52
0.9	1.00	1.00	1.00	1.00	1.00	0.93	0.80	0.72	0.66	0.62
1.0	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.81	0.75	0.70
1.1	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.89	0.82	0.78
1.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.89	0.84
1.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.89
1.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.93
1.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97

TABLE 5.22 80 PERCENT LOWER CONFIDENCE BOUND ON YIELD $\frac{\bar{\lambda}_D}{\lambda_o}$ (1-60)

	Failure Rate Ratio $\frac{\bar{\lambda}_D}{\lambda_o}$												
$\bar{\lambda}_D T$	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	20.00	40.00	60.00 or More
1.0	0.70	0.52	0.48	0.45	0.44	0.43	0.43	0.42	0.42	0.42	0.40	0.40	0.40
1.1	0.78	0.59	0.54	0.51	0.50	0.49	0.48	0.48	0.48	0.47	0.46	0.45	0.45
1.2	0.84	0.65	0.59	0.57	0.55	0.54	0.54	0.53	0.53	0.53	0.51	0.51	0.50
1.3	0.89	0.70	0.64	0.62	0.60	0.59	0.59	0.58	0.58	0.57	0.56	0.55	0.55
1.4	0.93	0.74	0.69	0.66	0.65	0.64	0.63	0.63	0.62	0.62	0.60	0.60	0.60
1.5	0.97	0.78	0.73	0.70	0.69	0.68	0.67	0.66	0.66	0.66	0.64	0.64	0.63
1.6	1.00	0.81	0.76	0.74	0.72	0.71	0.71	0.70	0.70	0.69	0.68	0.67	0.67
1.7	1.00	0.84	0.79	0.77	0.75	0.74	0.74	0.73	0.73	0.72	0.72	0.71	0.71
1.8	1.00	0.87	0.82	0.79	0.78	0.77	0.77	0.76	0.76	0.75	0.74	0.73	0.73
1.9	1.00	0.89	0.84	0.82	0.81	0.80	0.79	0.79	0.78	0.78	0.77	0.76	0.76
2.0	1.00	0.91	0.86	0.84	0.83	0.82	0.81	0.81	0.80	0.80	0.79	0.78	0.78
2.2	1.00	0.94	0.90	0.88	0.86	0.86	0.85	0.85	0.84	0.84	0.83	0.83	0.82
2.4	1.00	0.96	0.92	0.90	0.89	0.89	0.88	0.88	0.87	0.87	0.86	0.86	0.86
2.6	1.00	0.98	0.94	0.93	0.92	0.91	0.91	0.90	0.90	0.90	0.89	0.88	0.88
2.8	1.00	0.99	0.96	0.94	0.93	0.93	0.92	0.92	0.92	0.92	0.91	0.91	0.90
3.0	1.00	0.99	0.97	0.96	0.95	0.94	0.94	0.94	0.94	0.93	0.93	0.92	0.92
3.5	1.00	1.00	0.99	0.98	0.97	0.97	0.97	0.96	0.96	0.96	0.96	0.95	0.95
4.0	1.00	1.00	0.99	0.99	0.98	0.98	0.98	0.98	0.98	0.98	0.97	0.97	0.97
5.0	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
6.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 5.23 70 PERCENT LOWER CONFIDENCE BOUND ON YIELD $\frac{\bar{\lambda}_D}{\lambda_o}$ (.1-1.0)

	Failure Rate Ratio $\frac{\bar{\lambda}_D}{\lambda_o}$									
$\bar{\lambda}_D T$	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.1	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.2	1.00	0.40	0.09	0.04	0.03	0.02	0.02	0.01	0.01	0.01
0.3	1.00	1.00	0.56	0.27	0.18	0.13	0.11	0.09	0.08	0.08
0.4	1.00	1.00	1.00	0.66	0.44	0.34	0.28	0.24	0.21	0.20
0.5	1.00	1.00	1.00	1.00	0.73	0.56	0.47	0.41	0.37	0.34
0.6	1.00	1.00	1.00	1.00	1.00	0.78	0.66	0.58	0.52	0.48
0.7	1.00	1.00	1.00	1.00	1.00	0.96	0.82	0.72	0.66	0.61
0.8	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.85	0.77	0.72
0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.87	0.81
1.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.89
1.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95

TABLE 5.24 70 PERCENT LOWER CONFIDENCE BOUND ON YIELD $\frac{\bar{\lambda}_D}{\lambda_o}$ (1-60)

	Failure Rate Ratio $\frac{\bar{\lambda}_D}{\lambda_o}$												
$\bar{\lambda}_D T$	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	20.00	40.00	60.00 or More
1.0	0.89	0.66	0.60	0.57	0.56	0.55	0.54	0.53	0.53	0.53	0.51	0.50	0.50
1.1	0.95	0.72	0.66	0.63	0.61	0.60	0.59	0.59	0.58	0.58	0.56	0.56	0.55
1.2	1.00	0.77	0.71	0.68	0.66	0.65	0.64	0.63	0.63	0.63	0.61	0.60	0.60
1.3	1.00	0.81	0.75	0.72	0.70	0.69	0.68	0.68	0.67	0.67	0.65	0.64	0.64
1.4	1.00	0.85	0.79	0.76	0.74	0.73	0.72	0.71	0.71	0.71	0.69	0.68	0.68
1.5	1.00	0.88	0.82	0.79	0.77	0.76	0.75	0.75	0.74	0.74	0.72	0.72	0.71
1.6	1.00	0.90	0.84	0.82	0.80	0.79	0.78	0.78	0.77	0.77	0.75	0.74	0.74
1.7	1.00	0.92	0.87	0.84	0.82	0.81	0.81	0.80	0.80	0.79	0.78	0.77	0.77
1.8	1.00	0.94	0.89	0.86	0.85	0.84	0.83	0.82	0.82	0.82	0.80	0.79	0.79
1.9	1.00	0.96	0.90	0.88	0.87	0.86	0.85	0.84	0.84	0.84	0.82	0.82	0.81
2.0	1.00	0.97	0.92	0.90	0.88	0.87	0.87	0.86	0.86	0.85	0.84	0.83	0.83
2.2	1.00	0.99	0.94	0.92	0.91	0.90	0.90	0.90	0.89	0.89	0.88	0.87	0.86
2.4	1.00	1.00	0.96	0.94	0.93	0.92	0.92	0.91	0.91	0.91	0.90	0.89	0.89
2.6	1.00	1.00	0.97	0.96	0.95	0.94	0.94	0.93	0.93	0.93	0.92	0.91	0.91
2.8	1.00	1.00	0.98	0.97	0.96	0.95	0.95	0.95	0.94	0.94	0.93	0.93	0.93
3.0	1.00	1.00	0.99	0.98	0.97	0.96	0.96	0.96	0.96	0.95	0.95	0.94	0.94
3.5	1.00	1.00	1.00	0.99	0.98	0.98	0.98	0.98	0.97	0.97	0.97	0.97	0.96
4.0	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98
5.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99
6.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 5.25 60 PERCENT LOWER CONFIDENCE BOUND ON YIELD $\frac{\bar{\lambda}_D}{\lambda_o}$ (.1-1.0)

	Failure Rate Ratio $\frac{\bar{\lambda}_D}{\lambda_o}$									
$\bar{\lambda}_D T$	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.1	1.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.2	1.00	1.00	0.32	0.15	0.10	0.07	0.06	0.05	0.04	0.04
0.3	1.00	1.00	1.00	0.62	0.40	0.30	0.25	0.21	0.19	0.17
0.4	1.00	1.00	1.00	1.00	0.79	0.60	0.50	0.43	0.38	0.35
0.5	1.00	1.00	1.00	1.00	1.00	0.88	0.73	0.64	0.57	0.53
0.6	1.00	1.00	1.00	1.00	1.00	1.00	0.93	0.82	0.74	0.68
0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.87	0.81
0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.91
0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99

TABLE 5.26 60 PERCENT LOWER CONFIDENCE BOUND ON YIELD $\frac{\bar{\lambda}_D}{\lambda_o}$ (1-60)

	Failure Rate Ratio $\frac{\bar{\lambda}_D}{\lambda_o}$												
$\bar{\lambda}_D T$	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	20.00	40.00	60.00 or More
1.0	1.00	0.78	0.71	0.68	0.66	0.65	0.64	0.63	0.63	0.62	0.60	0.60	0.59
1.1	1.00	0.83	0.76	0.73	0.71	0.69	0.68	0.68	0.67	0.67	0.65	0.64	0.64
1.2	1.00	0.87	0.80	0.77	0.75	0.73	0.73	0.72	0.71	0.71	0.69	0.68	0.68
1.3	1.00	0.91	0.83	0.80	0.78	0.77	0.76	0.75	0.75	0.74	0.73	0.72	0.72
1.4	1.00	0.93	0.86	0.83	0.81	0.80	0.79	0.78	0.78	0.78	0.76	0.75	0.75
1.5	1.00	0.95	0.89	0.86	0.84	0.83	0.82	0.81	0.81	0.80	0.79	0.78	0.77
1.6	1.00	0.97	0.91	0.88	0.86	0.85	0.84	0.83	0.83	0.83	0.81	0.80	0.80
1.7	1.00	0.99	0.92	0.90	0.88	0.87	0.86	0.85	0.85	0.85	0.83	0.82	0.82
1.8	1.00	1.00	0.94	0.91	0.90	0.89	0.88	0.87	0.87	0.86	0.85	0.84	0.84
1.9	1.00	1.00	0.95	0.93	0.91	0.90	0.89	0.89	0.88	0.88	0.87	0.86	0.86
2.0	1.00	1.00	0.96	0.94	0.92	0.91	0.91	0.90	0.90	0.89	0.88	0.87	0.87
2.2	1.00	1.00	0.98	0.96	0.94	0.93	0.93	0.93	0.92	0.92	0.90	0.90	0.90
2.4	1.00	1.00	0.99	0.97	0.96	0.95	0.94	0.94	0.94	0.93	0.92	0.92	0.92
2.6	1.00	1.00	1.00	0.98	0.97	0.96	0.96	0.95	0.95	0.95	0.94	0.93	0.93
2.8	1.00	1.00	1.00	0.99	0.98	0.97	0.97	0.96	0.96	0.96	0.95	0.95	0.95
3.0	1.00	1.00	1.00	0.99	0.98	0.98	0.97	0.97	0.97	0.97	0.96	0.96	0.96
3.5	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.97	0.97
4.0	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98
5.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99
6.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 5.27 50 PERCENT LOWER CONFIDENCE BOUND ON YIELD $\frac{\bar{\lambda}_D}{\lambda_o}$ (.1-1.0)

	Failure Rate Ratio $\frac{\bar{\lambda}_D}{\lambda_o}$									
$\bar{\lambda}_D T$	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.1	1.00	0.16	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.00
0.2	1.00	1.00	0.89	0.42	0.27	0.20	0.16	0.14	0.12	0.11
0.3	1.00	1.00	1.00	1.00	0.77	0.58	0.47	0.40	0.36	0.33
0.4	1.00	1.00	1.00	1.00	1.00	0.95	0.78	0.68	0.60	0.55
0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.81	0.74
0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.89

TABLE 5.28 50 PERCENT LOWER CONFIDENCE BOUND ON YIELD $\frac{\bar{\lambda}_D}{\lambda_o}$ (1-60)

	Failure Rate Ratio $\frac{\bar{\lambda}_D}{\lambda_o}$												
$\bar{\lambda}_D T$	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	20.00	40.00	60.00 or More
1.0	1.00	0.89	0.81	0.77	0.75	0.74	0.73	0.72	0.71	0.71	0.69	0.68	0.67
1.1	1.00	0.93	0.85	0.81	0.79	0.78	0.77	0.76	0.75	0.75	0.73	0.72	0.71
1.2	1.00	0.96	0.88	0.84	0.82	0.81	0.80	0.79	0.79	0.78	0.76	0.75	0.75
1.3	1.00	0.98	0.91	0.87	0.85	0.84	0.83	0.82	0.81	0.81	0.79	0.78	0.78
1.4	1.00	1.00	0.93	0.89	0.87	0.86	0.85	0.84	0.84	0.83	0.82	0.81	0.80
1.5	1.00	1.00	0.95	0.91	0.89	0.88	0.87	0.86	0.86	0.86	0.84	0.83	0.83
1.6	1.00	1.00	0.96	0.93	0.91	0.90	0.89	0.88	0.88	0.87	0.86	0.85	0.84
1.7	1.00	1.00	0.97	0.94	0.92	0.91	0.90	0.90	0.89	0.89	0.87	0.86	0.86
1.8	1.00	1.00	0.98	0.95	0.94	0.93	0.92	0.91	0.91	0.90	0.89	0.88	0.88
1.9	1.00	1.00	0.99	0.96	0.95	0.94	0.93	0.92	0.92	0.92	0.90	0.89	0.89
2.0	1.00	1.00	1.00	0.97	0.96	0.95	0.94	0.93	0.93	0.93	0.91	0.90	0.90
2.2	1.00	1.00	1.00	0.98	0.97	0.96	0.95	0.95	0.95	0.94	0.93	0.92	0.92
2.4	1.00	1.00	1.00	0.99	0.98	0.97	0.97	0.96	0.96	0.96	0.94	0.94	0.94
2.6	1.00	1.00	1.00	1.00	0.99	0.98	0.97	0.97	0.97	0.97	0.96	0.95	0.95
2.8	1.00	1.00	1.00	1.00	0.99	0.99	0.98	0.98	0.98	0.97	0.96	0.96	0.96
3.0	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.98	0.98	0.98	0.97	0.97	0.97
3.5	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.98	0.98	0.98
4.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99
5.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

5.5 Procedure D - Cost effectiveness analysis

5.5.1 Objective. The objective of this procedure is to perform cost analyses so as to identify the screen selection and placement sequences from among many possible alternatives, which provide a cost effective screening program.

5.5.2 Methodology. Fixed, recurring, and rework costs are identified for each candidate screening sequence determined from Procedure B. Costs are determined for each level of assembly, including a failure-free acceptance test at the system level. The fixed, recurring, and rework costs at each level of assembly are used in a cost tradeoff analysis to find a cost effective screening regimen. The total costs of screening and the number of defects to be eliminated are used to determine the cost per defect eliminated for various candidate screening regimens. Comparison of the cost per defect eliminated by screening against a cost threshold of $1000 is the criterion used for judging cost effectiveness.

5.3.3 Procedure steps. The worksheet shown in Figure 5.6 or a similar aid should be used. Instructions for completing the worksheet follow.

COST WORKSHEET

System/Project

Prepared by Date

ASSEMBLY SCREENING COST
1. Fixed Screening Cost .....$_____
2. Variable Screening Cost .....$_____
3. Expected Assembly Level Fallout.....
4. Average Cost per Repair (if unknown use $40).....$_____
5. Screening Repair Cost (multiply line 3 by line 4).....$_____
6. Assembly Level Screening Cost (add lines 1,2 and 5).....$_____

UNIT SCREENING COST
1. Fixed Screening Cost.....$_____
2. Variable Screening Cost.....$_____
3. Expected Unit Level Fallout.....
4. Average Cost per Repair (if unknown use $375).....$_____
5. Screening Repair Cost (multiply line 3 by line 4).....$_____
6. Unit Level Screening Cost (add lines 1,2 and 5).....$_____

SYSTEM SCREENING COST
1. Fixed Screening Cost.....$_____
2. Variable Screening Cost.....$_____
3. Expected System Level Fallout.....
4. Average Cost per Repair (if unknown use $750).....$_____
5. Screening Repair Cost (multiply line 3 by line 4).....$_____
6. System Level Screening Cost (add lines 1,2 and 5).....$_____

TOTAL SCREENING COSTS
7. Total Fixed Cost.....$_____
8. Total Variable Cost.....$_____
9. Total Screening Repair Cost.....$_____
10. Total Expected Fallout.....
11. Total Number of Systems to be Produced.....
12. Total Screening Cost (add lines 7,8 and 9).....$_____
13. Total Screening Cost per System (divide 12 by 11).....$_____

COST PER DEFECT ELIMINATED (divide line 12 by 10).....$_____
THRESHOLD COST.....$_____

Figure 5.6 Cost Analyses Worksheet

Step 1 Fixed screening costs. (Lines 1) Determine the fixed screening costs for each level of assembly. These costs are one time expenditures necessary to conduct screening at a particular assembly level and include:

a. Cost of screening facilities
b. Cost of test equipment and fixtures
c. Cost of screening program planning and the preparation of procedures
d. Cost of training

Note that the cost of screening facilities, test equipment and fixtures should be apportioned to the program for which the cost analysis is to be performed. Costs of facilities and equipment which will also be used on other programs should be allocated in accordance with the internal cost accounting procedures of the manufacturer.

Step 2 Variable screening costs. (Lines 2) Determine the variable screening costs for the total number of items to be screened at each assembly level. These costs are recurring costs which are different for each level of assembly and which depend upon the number of items to be screened/rescreened and tested. During early production when defect density would be expected to be higher, a large cost driver of (stress 3,4, and 5) would be repair and rework costs. During late production when defect density would be expected to be lower, the primary driver would be the cost of labor to conduct the screens and their associated tests. The latter situation would be expected when failure-free screens and tests are employed at the system level. The costs to conduct failure-free acceptance tests and associated screens would thus be heavily dependent on the labor costs for screening and testing. Recurring costs include:

a. Cost of labor to conduct screens and tests
b. Cost of labor for screening program management
c. Cost of labor to conduct failure analysis (if not already accounted for by MIL-Q-9858A paragraph 3.5 corrective action)
d. Cost to record and analyze screening program data (if not already accounted for by MIL-STD-785B Task 104 requirements for a closed-loop Failure Reporting, Analysis and Corrective Action System (FRACAS).

Step 3 Expected fallout. (Lines 3) Determine the expected fallout for the total number of items to be screened at each level of assembly and for each candidate screening sequence using Procedure B (Figure 5.4).

Step 4 Average cost of repair. (Lines 4) Establish the average in-house cost of labor and materials to repair a failed item. These cost estimates are dependent on the type of equipment being screened, the manufacturer's repair and rework facilities and the level of assembly where the defect is found. When estimates are not available, an approximate value is given in the worksheet.

Step 5 Screening repair costs. (Lines 5) Calculate as indicated on the worksheet. (Multiply the expected fallout and the average cost of repair).

Step 6 Screening costs. (Lines 6) Calculate as indicated on the worksheet. (Add lines 1, 2 and 5).

Step 7 Total fixed costs. (Lines 7) Add the fixed costs for screening for each level of assembly. (Add all line 1 costs).

Step 8 Total variable costs. (Lines 8) Add the variable costs for screening for each level of assembly (Add all line 2 costs).

Step 9 Total screening repair costs. (Lines 9) Add the screening repair costs for each level of assembly. (Add all line 5 costs).

Step 10 Total expected fallout. (Line 10) Add the expected fallout for each level of assembly. (Add all line 3 entries). This estimate represents the total number of defects precipitated and detected by a candidate screening sequence.

Step 11 Total number of systems to be produced. (Line 11) Enter the total number of systems to be produced and/or exposed to stress screening.

Step 12 Total screening costs. (Line 12) Calculate as indicated on the worksheet. (Add lines 7, 8 and 9 entries).

Step 13 Average screening cost per system. (Line 13) This is the screening cost per system obtained by dividing Line 12 by Line 11 entries.

Step 14 Average cost per defect eliminated. Calculate the in-house average cost to eliminate a defect in the factory by dividing Line 12 by Line 10 entries.

Step 15 Threshold cost. (C_T) A threshold cost of $1000 is used in the procedure. The threshold cost is related to the field cost of repair and should be viewed as a not-to-exceed cost.

Step 16 After completion of the worksheet cost analyses, a comparison of the cost threshold (C_T) and the cost per defect eliminated by the screening process (C_D) should be made. If $C_D > C_T$ then the planned screening process should be re-evaluated to determine alternative screening methods to reduce costs, so that $C_D \leq C_T$. Cost reduction is achieved through analysis of alternative screening regimens which might include more extensive screening at the assembly level where rework costs are lower.

5.6 Procedure E - Monitoring, evaluation and control

5.6.1 Objective. This procedure is used to monitor, evaluate and control the screening and manufacturing process so as to assure achievement of goals on remaining defect density (yield). Objectives are to:

a. Obtain estimates of the defect density, based upon the observed screen fallout data, and establish whether the observed defect density falls within or outside of predetermined control limits.

b. Compare the observed part fraction defective with planning estimates to prioritize the need for corrective actions.

c. Determine and implement corrective actions to improve manufacturing and screening process capability. Four complementary procedures are used to accomplish the objective.

5.6.2 Procedure E1 - Quality control charts for defect control - Methodology. Consider a batch of screened items with the following data available:

a. Estimates of D_{IN} and TS in accordance with Procedure A and B.
b. Number of items in the batch.
c. Observed number of defects as fallout (F) from the screen.

Figure 5.7 illustrates the screened items and the parameters of interest. The screened items can represent boards, assemblies or units.

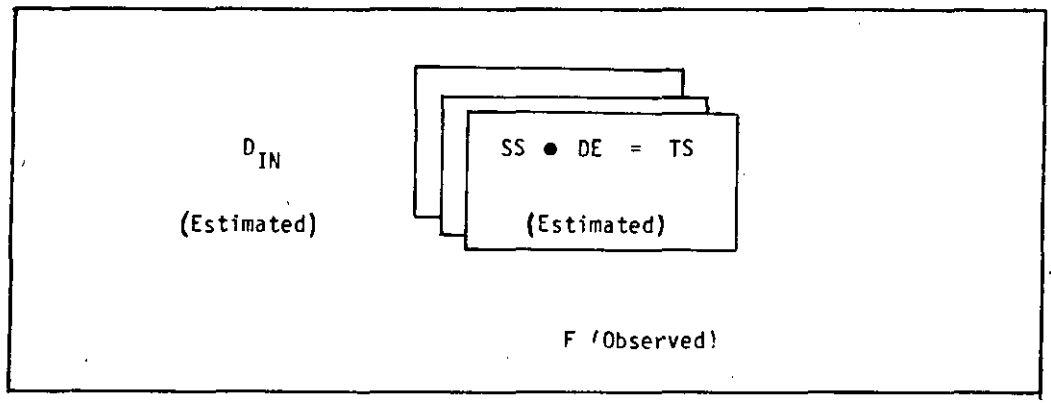


Figure 5.7 Screen Fallout Data Sample

The observed fallout can be above, below or within established control limits depending upon the degree to which the actual or "true" values of D_{IN} and TS differ from the planning estimates. The worst case situation, in terms of the effect on remaining defect density goals, is where D_{IN} is higher than the planning estimate and TS is lower. D_{IN} is reduced only through corrective actions which reduce future incoming defect density and thereby improves process capability. TS is increased by changing the screen type, stress levels or duration of the screen and by increasing the thoroughness of tests which are performed in conjunction with the screen. Table 5.29 illustrates the various possible conditions that can exist when the "true" values of D_{IN} and TS are compared against planning estimates. The conditions are ranked according to severity and grouped into four categories dependent upon whether outgoing defect density or costs are effected. The corrective actions required for each category are also shown in the table. Note that regardless of the outcome of the comparisons, corrective actions should always be taken to reduce D_{IN} when opportunities to do so are presented.

Table 5.29 Comparison of Actual vs Planned Defect Density (D_{IN}) and Test Strength (TS) Values

CONDITION		COMPARISON: Actual Vs Planned D_{IN}	COMPARISON: Actual Vs Planned TS	EFFECT ON: Remaining Defect Density Goal (D_R)	EFFECT ON: Future Screening Costs	ACTIONS REQUIRED: D_{IN} Reduce D_{IN} By Corrective Actions	ACTIONS REQUIRED: TS Changes to Screen/Test
I	a	HI	LO	Higher than Expected	Increase	Essential	Increase Screening Strength
	b	HI	OK				
	c	OK	LO				
II	d	HI	HI	Uncertain If Higher			
	e	LO	LO	Uncertain If Lower			
III	f	OK	HI	Lower than Expected	Reduce	By Opportunity*	Reduce Screening Strength
	g	LO	OK				
	h	LO	HI				
IV	i	OK	OK	Likely to be Achieved	Reduce	By Opportunity*	No Change or Eventually Reduce

* Corrective actions should always be taken when the opportunity presents itself and the costs to take actions are reasonable

5.6.3 Procedure steps.

Step 1 Using the observed number of defects and the quantities of parts and interconnection by type (from Procedure A) for the batch of screened items, calculate an observed part fraction defective for each part and interconnection type in the screened items.

Step 2 Calculate also the observed latent defect density using the relations:

$$\bar{P}_o = \frac{n_1 p_1 + n_2 p_2 + \ldots + n_k p_k}{\sum_{i=1}^{k} n_i}$$

and: $\sum_{i=1}^{k} n_i = N \qquad D_o = N\bar{P}_o$

Where: $\bar{P}_o$ = observed average part fraction defective per item

N = the total number of parts and interconnections per item

n_i = number of parts/interconnections of type i per item (i.e., diodes, transitors, hand soldered connection etc.)

p_i = observed part fraction defective calculated from step 1 for each part type

D_o = observed latent defect density per item.

Step 3 Rank the observed part fraction defective for each part and interconnection type i from the largest to the smallest.

Step 4 Determine D_{IN}, the expected incoming defect density for the batch of items subjected to the screen (from Procedure A).

Step 5 Compare the part fraction defective based upon observed fallout, calculated from step 1 against the planning estimates obtained from Procedure A, to determine those part types which show the largest (statistically significant) difference from planning estimates. The comparison should be based on a statistical test of significance which takes into account the sample size. Values of observed part fraction defective which exceed 1000 PPM should be specifically cited for corrective action.

Step 6 Determine the cause(s) for those part types showing the greatest differences and the corrective actions necessary to eliminate the sources of the defects from the product or process. Corrective actions might include, rejection of a suspect lot of parts, changing vendors, rescreening of the parts at incoming or changes to the manufacturing process.

Step 7 Prepare three control charts with the following trial values for the mean and standard deviation, $D_{IN} \pm 3\sqrt{D_{IN}}$, $D_{IN} \cdot TS \pm 3\sqrt{D_{IN} \cdot TS}$ and $D_{IN}(1-TS) \pm 3\sqrt{D_{IN}(1-TS)}$. Illustrations of the charts are shown in Figure 5.8 through Figure 5.10 with values of $D_{IN} = 3$ and $TS = .7$ as an example. The charts are shown separately, but note that the control limits overlap.

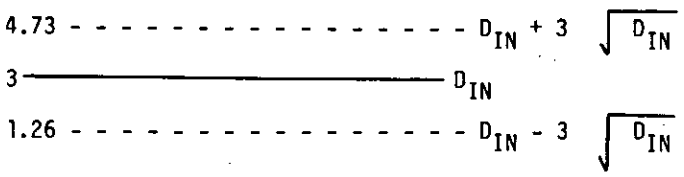


Figure 5.8 Control Chart I, Incoming Defect Density

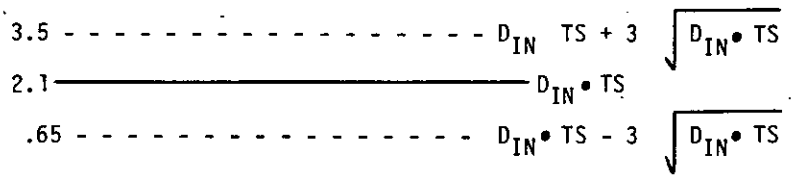


Figure 5.9 Control Chart II, Fallout

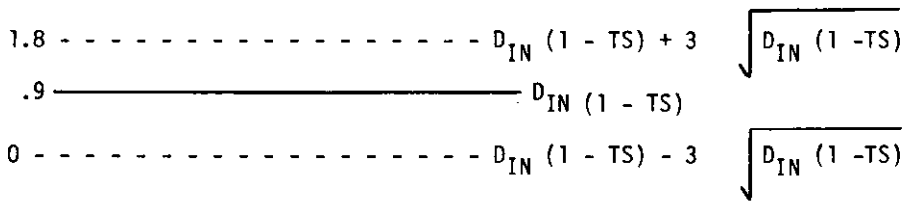


Figure 5.10 Control Chart III, Outgoing Defect Density

Step 8. Plot and compare the observed value of observed defect density for the first and all subsequent batches of screened items as follows:

a. Values of D_o which exceed the upper control limit (e.g. 4.73) on Chart I, clearly indicates that the planning estimates for incoming defect density (D_{IN}) were too low, without having to consider TS. Note that the trial values for the mean and standard deviation, for Chart I, presume perfect screens and tests (i.e., TS = 1). When the condition is evident from data, corrective actions must be taken to reduce D_{IN}, go to steps 5 and 6.

b. Values of the observed defect density which fall above the upper control limit of Chart II indicate the following possible conditions from Table 5.29:

Condition	D_{IN}	TS	
I b	HI	OK	
II d	HI	HI	
III f	OK	HI	
I a	HI	LO	Hi values would be much
III h	LO	HI	higher than expected

Regardless of which of the conditions actually exist, the question of upmost concern is: Is the incoming defect density (D_{IN}) higher than planned or expected? Procedures E2, E3, or E4 should be used to address the question.

c. Values of the observed defect density which fall below the lower control limit of Chart II indicate the following possible conditions from Table 5.29:

Condition	D_{IN}	TS	
I c	OK	LO	
II e	LO	LO	
III g	LO	OK	
I a	HI	LO	LO values would be
III h	LO	HI	much lower than expected

Regardless of the condition which actually might exist the question of upmost concern is: Is the test strength lower than expected? Procedures E2 or E3 should be used to address the question.

d. Values of the observed defect density which fall within the control limits of Chart II indicate the following possible conditions from Table 5.29:

Condition	D_{IN}	TS
IV i	OK	OK
I a	HI	LO
III h	LO	HI

Regardless of the condition which actually might exist the questions of upmost concern are: Is the incoming defect density higher than expected and is the test strength lower than expected? Procedures E2 or E3 should be used to address the question.

Step 9. Evaluate which of the possible conditions which might exist in Step 8 by estimating the parameters of CDE model as outlined in Procedure E2 and E3.

Step 10. Control Chart III represents the outgoing defect density as a function of the planning estimates, D_{IN} and TS, at a given assembly level. Chart III also represents the incoming defect density at the next assembly level of screening, disregarding those defects which are newly introduced into the product at the next assembly level. Steps 1 through 9 are repeated at the next assembly level of screening, but with revised planning estimates of D_{IN} and TS. A repeat of Step 8a of the procedure at the next assembly level will provide some verification that estimates of D_{IN} and TS obtained from previous screening at the previous lower assembly level were correct.

5.6.4 Procedure E2 - Use of CDE model to estimate D_{IN} and TS - Methodology. Obtain estimates of D_{IN} and TS from the screening data and compare them with the results of control chart methods, (Procedure E1). Determine the appropriate corrective action. The corrective actions might include increasing or reducing TS or D_{IN}, depending upon the outcome of the comparison as indicated by Table 5.29 and the results of Procedure E1.

5.6.5 Procedure steps. The results from several batches of screened items will be needed to perform the following:

Step 1. Based upon time-to-failure or cycles to failure data, obtained from the screening fallout over time, estimate the parameters of the Chance Defective Exponential Model. Care should be exercised in using only part or interconnection (workmanship) fallout data for the analyses.

Step 2. Compare the estimates obtained from Step 1 with the planning estimates of D_{IN} and TS and the results of the Control Chart calculations of Procedure E1. Establish which of the conditions of Table 5.29 exist and take the necessary actions to assure that the remaining defect density goals are achieved or to make the screening program more cost effective.

Step 3. When repeated estimates of the model parameters are made for several batches of screened items, and the estimates indicate significant differences from initial planning estimates, a re-evaluation of the screening program should be made.

Step 4. Change the screening regimen, as appropriate, to reflect the new estimates of the screening process variables so as to assure achievement of program objectives.

Step 5. Repeat Steps 1 through 4 interatively, on subsequent batches of screened items, at each level of assembly.

5.6.6 Procedure E3 - Graphical plotting - Methodology. A graphical technique for estimating the parameters D_{IN} and $\bar{\lambda}_D$ of the CDE model can also be used. The technique uses the failure rate function of the CDE model.

$$\lambda_s(t) = \lambda_o + D\bar{\lambda}_D e^{-\bar{\lambda}_D t}$$

At lower assembly levels, the MIL-HDBK-217 predicted failure rates, λ_o for the assembly will be very small because of the relatively small number of parts. In the interest of obtaining rough estimates of D_{IN} and $\bar{\lambda}_D$, λ_o can be assumed to be zero.

$$\lambda_s(t) \simeq D\bar{\lambda}_D e^{-\bar{\lambda}_D t}$$

Taking logarithms we have:

$$\ln \lambda_s(t) \simeq \ln (D \bar{\lambda}_D) - \bar{\lambda}_D t$$

By plotting observed values of $\lambda(t)$ on semi-log graph paper, estimates of D_{IN} and $\bar{\lambda}_D$ can be obtained as illustrated in Figure 5.11.

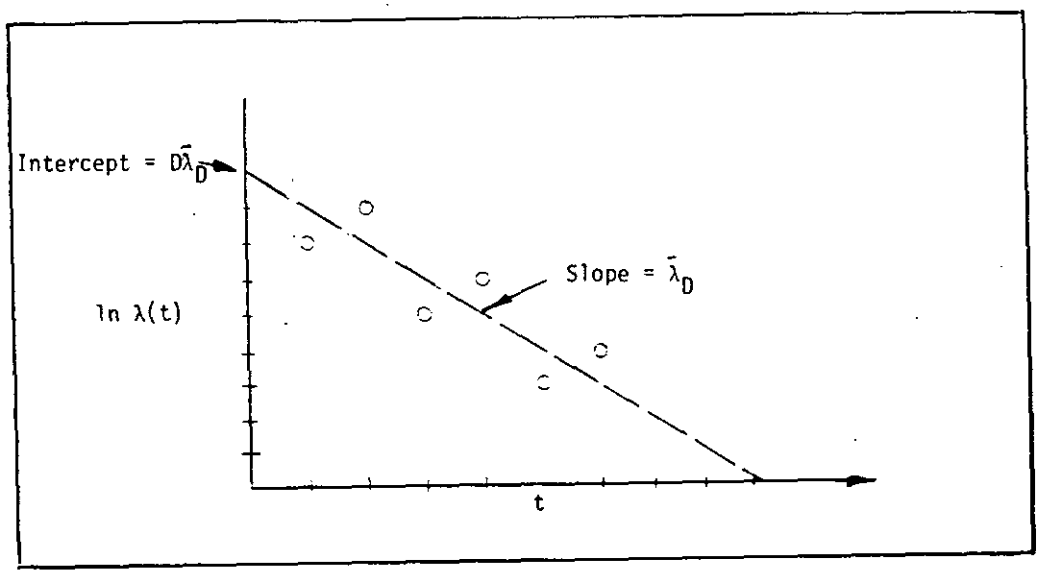


Figure 5.11 Failure Rate vs Time

5.6.7 Procedure steps. Screening results for a batch of screened items and the time-to-failure for each defect must be available to perform the following:

Step 1. Group the fallout data into discrete intervals of time $(0, t_1)$, (t_1, t_2). For temperature cycling screens a convenient grouping would be by each temperature cycle. Groupings for vibration screens might be in two minute time intervals.

Step 2. Estimate the instantaneous failure rate for each time interval using:

$$\hat{\lambda}_j = \frac{F_j}{M_j(t_{j+1} - t_j)}$$

Where: F_j = fallout during the j^{th} interval

$\hat{\lambda}_j$ = estimate of the instantaneous failure rate during j^{th} interval.

M_j = number of items which survived the (j-1) interval.

Step 3. Plot the estimates of $\hat{\lambda}_j$ versus time on a log-linear scale and fit a straight line to the data points.

Step 4. Determine the slope of the fitted line. The slope of this line provides an estimate of $\bar{\lambda}_D$.

Step 5. Determine the y intercept point for the fitted line. The y intercept provides and estimate of $D\bar{\lambda}_D$.

Step 6. Divide the y intercept $D\bar{\lambda}_D$ by the slope $\bar{\lambda}_D$ to obtain an estimate of D_{IN}.

Step 7. Step 6 provides a conservative estimate of D_{IN}. The estimate should be divided by the detection efficiency of the test which was used in conjunction with the screen to obtain D_{IN}.

Step 8. Calculate the screening strength of the screen by substituting the estimated $\bar{\lambda}_D$ and the total time duration of the screen T into $SS(T) = 1 - e^{-\bar{\lambda}_D T}$. Note that screening strength and $\bar{\lambda}_D$ are independent of the test detection efficiency.

Step 9. Multiply the screening strength by the test detection efficiency to determine the test strength.

Step 10. Compare the results obtained against the planned values to determine which condition of Table 5.29 exists and the required corrective action.

5.6.8 Procedure E4 - 90% control intervals on expected fallout. The objective of this procedure is to determine if the expected number of defects in a batch of screened items, based upon planning estimates of D_{IN}, are consistent with the actual fallout.

5.6.9 Methodology. This method should be applied when the user, either through prior experience or by use of experiments, has a high degree of confidence that test strength (TS) values are correct. The 90% control limits are based upon the Binomial distribution. The model assumes that the defects fallout from the screen with the same probability (i.e. test strength) and are independent of one another. Under these assumptions, the defect fallout from the screen has a Binomial distribution:

$$P(\text{defect fallout} = k) = \binom{M}{k} TS^k \quad (1-TS)^{M-k}$$

Where M = postulated or expected number of defects entering the screen

TS = test strength

k = 0, 1, 2, ..., M.

The upper 90% control interval limit (denoted by UL) and the lower 90% control interval limit (denoted by LL) are obtained by solving the following equations for UL and LL.

UL is the smallest integer such that:

$$\sum_{k=UL+1}^{M} \binom{M}{k} TS^k \ (1-TS)^{M-K} < .05$$

LL is the largest integer such that:

$$\sum_{k=0}^{LL-1} \binom{M}{k} TS^k \ (1-TS)^{M-k} < .05$$

5.6.10 Procedure Steps. Screening results for a batch of screened items must be available to perform the following:

Step 1. Multiply the planning estimate for defect density for the item by the number of screened items in the batch to obtain the expected number of the defects.

Step 2. Determine the test strength for the screen/test which was used for the batch of items.

Step 3. Find the value of test strength in the upper row and the expected number of defects (from Step 1) in the left most column of Table 5.30. Find the 90% control limits in the Table corresponding to the two values.

Step 4. If the actual number of defects observed for the batch of screened items falls within the 90% control limits, then the planning estimate of incoming defect density is accepted as being reasonably correct.

Step 5. If the actual number of defects observed for the batch of screened items falls above the upper control limits, then corrective actions to reduce D_{IN} and/or to increase the test strength should be determined.

Step 6. If the actual number of defects observed for the batch of screened items falls below the lower control limit, then corrective actions to reduce the screening regimen should be determined.

The 90% control interval is given by $\lceil LL, UL \rceil$. Values of $\lceil LL, UL \rceil$ are provided in Table 5.30 as a function of the test strength (TS) and the expected number of defects (M). The expected number of defects entering the screen is accepted as long as the fallout lies between LL and UL.

TABLE 5.30 90 PERCENT CONTROL PROBABILITY INTERVALS

Expected No. of Defects	Test Strength									
	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
5	4 1	5 1	5 1	5 1	5 2	5 2	5 2	5 3	5 3	5 4
6	5 1	5 1	5 2	6 2	6 2	6 3	6 3	6 4	6 4	6 5
7	6 1	6 2	6 2	6 2	7 3	7 3	7 4	7 4	7 5	7 6
8	6 2	7 2	7 3	7 3	8 3	8 4	8 4	8 5	8 6	8 6
9	7 2	7 3	8 3	8 3	8 4	9 5	9 5	9 6	9 6	9 7
10	8 2	8 3	8 3	9 4	9 5	10 5	10 6	10 7	10 7	10 8
11	8 3	9 3	9 4	10 4	10 5	10 6	11 6	11 7	11 8	11 9
12	9 3	9 4	10 4	10 5	11 6	11 6	12 7	12 8	12 9	12 10
13	9 4	10 4	11 5	11 6	12 6	12 7	13 8	13 9	13 10	13 11
14	10 4	11 5	11 5	12 6	12 7	13 8	13 9	14 10	14 11	14 12
15	11 4	11 5	12 6	13 7	13 7	14 8	14 9	15 10	15 11	15 13
16	11 5	12 6	13 6	13 7	14 8	15 9	15 10	16 11	16 12	16 14
17	12 5	13 6	13 7	14 8	15 9	16 10	16 11	17 12	17 13	17 14
18	12 6	13 6	14 7	15 8	16 9	16 10	17 11	18 13	18 14	18 15
19	13 6	14 7	15 8	16 9	16 10	17 11	18 12	18 13	19 15	19 16
20	14 6	15 7	16 8	16 9	17 11	18 12	19 13	19 14	20 16	20 17

Custodian:
Air Force - 17

Preparing Activity:
Air Force - 17

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Review Activities:
Air Force 11, 13, 14, 15, 18, 19, 70, 71, 80, 82, 84, 95, 99

Appendix A
Stress Screening Mathematical Models

10. General. The fundamental objective of a stress screening program is to reduce the number of latent defects in a production lot of equipment to an acceptable level by use of cost effective screening regimens. As basic principles, one would like to be able to use strong screens and efficient tests, within prescribed cost constraints, which have a high probability of precipitating and detecting defects so as to achieve stated objectives. In order to transform these principles into quantitative procedures, it is necessary to define various measures and their relationships to the screening process. Mathematical models for predicting important screening process variables and for relating them to field reliability goals are also needed. This Appendix discusses the mathematical definitions and relationships between quantities such as defect density, screening strength and test detection efficiency.

20. Reference documents (See Section 2)

30. Definitions and acronyms (see Section 3)

40. General mathematical relations

40.1 Defect density. Under reasonable assumptions that the number of latent defects in a product are independently and identically distributed, the number of defectives in an equipment can be described by the Binomial Probability distribution, with parameters N and $\bar{P}$.

Where N = total number of parts in the equipment
$\bar{P}$ = average part fraction defective over all part types

A part, as defined herein, is any identifiable item within the product which can be removed or repaired, (e.g., discrete semiconductor, resistor, integrated circuit, solder joint, connector). For large N and small $\bar{P}$ the Binomial can be approximated by the Poisson distribution with the parameter $D = N\bar{P}$

Where D = Defect Density (average number of latent defects per item)

The defect density $D = N\bar{P}$ can also be represented as:

$$D = N\bar{P} = \sum_{i=1}^{k} n_i p_i \qquad (A\text{-}1)$$

where: n_i = quantity of each part type i
p_i = fraction defective for each part type i
k = number of different part types

The procedures contained in Procedure A of Section 5, for obtaining planning estimates of defect density, are based upon the mathematical relations just described.

40.2 Defect density and yield. Given prior estimates of p_i, equation A-1 can be used to estimate D_{IN}, the incoming latent defect density before assembly screening, since N and n_i are known for the assemblies and equipment to be screened. The remaining defect density D_R can be described in a similar manner, except that the p_i, of equation 1, would be interpreted as the remaining part fraction defective. In terms of a production lot of equipment D_{IN} and D_R can also be expressed as:

$$D_{IN} = \frac{\text{total \# of latent defects introduced}}{\text{total \# of equipments in the Lot}}$$

$$D_R = \frac{\text{total \# of latent defects remaining}}{\text{total \# of equipments in the Lot}}$$

Without an ESS program, a production lot of equipments will contain defects which are introduced into the equipments as escapes from previous part level screens and by poor workmanship or manufacturing processes. The defects introduced is expressed quantitatively as the average number of defects per equipment D_{IN} or defect density. Using the Poisson probability distribution, the probability that an equipment is defective P(D) (i.e., contains one or more defects) is given by:

$$P(D) = 1 - e^{-D_{IN}} \qquad \text{(A-2)}$$

The objective of an ESS program is to reduce D_{IN} to an acceptable level, say D_R, where D_R is defined as the average number of defects remaining per equipment at delivery to the customer. Reducing D_{IN} to D_R also reduces P(D) so that:

$$P(D) = 1 - e^{-D_R} \qquad \text{(A-3)}$$

The probability that an equipment is free of screenable latent defects when offered for acceptance is called Yield and using A-3.

$$\text{Yield} = 1 - P(D) = e^{-D_R} \qquad \text{(A-4)}$$

If the Yield is specified as a goal, then D_R can be determined by:

$$D_R = -\ln (\text{Yield}) \qquad \text{(A-5)}$$

and used as an objective for which an ESS program can be planned, implemented and subsequently monitored and controlled. Both D_R and Yield are used in the handbook Procedures B and E, as the quantitative goal of the ESS program.

40.3 Screening strength. The screening strength (SS) of a screen is expressed as the probability that the screen will precipitate a defect to a detectable state given that a defect susceptible to the screen is present. Expressed as a function of time, the screening strength is:

$$SS(t) = 1 - e^{-\bar{\lambda}_D t} \qquad \text{(A-6)}$$

where: $SS(t)$ = Screening strength associated with a given screen type for stress duration of time t

$\bar{\lambda}_D$ = average failure rate of a defect under a given set of stress conditions. Note that under the exponential assumption $\bar{\lambda}_D$ is constant. However, $\bar{\lambda}_D$ corresponds to a specific set of stress conditions, i.e., larger stresses correlate to larger but constant $\bar{\lambda}_D$'s.

Screening strength and defect failure rates for various screen types are given in Tables 5.14 through 5.18.

40.4 Screening strength and yield. Using the relationships described previously, D_{IN} the incoming defect density is acted upon by the screening strength SS(t) to precipitate latent defects to failure. Assuming that tests will always detect a failure, the fallout from the screen is given by:

$$D_{IN} \bullet SS(t) = F \text{ (fallout)} \qquad \text{(A-7)}$$

The remaining defect density after the last screen is applied is D_R and is given by:

$$D_R = D_{IN} \left(1 - SS(t)\right) \qquad \text{(A-8)}$$

Substituting equation A-8 into equation A-4 gives the following expression for yield:

$$\text{Yield} = \exp\left[-D_{IN}\,(1 - SS(t))\right] = e^{-D_R} \qquad \text{(A-9)}$$

or $$\text{Yield} = \exp\left[-D_{IN}\, e^{-\bar{\lambda}_D t}\right] = e^{-D_R}$$

Equation A-9 provides one of the relations for determining failure-free acceptance test requirements which is discussed futher in Appendix C.

40.5 Test detection efficiency. The test detection efficiency is a measure of test thoroughness or coverage which is expressed as the fraction of defects detectable by a defined procedure to the total possible number of patent defects which can be present. Detection efficiency is characterized as the probability of detection. Test detection efficiency is a measure used in Procedure B. Guidance for determining test detection efficiency is provided in paragraph 4.10.3.4.

40.6 Test strength. The Test Strength (TS) is defined as the joint probability that a screen will precipitate a defect to a detectable state and that a test will detect the defect and is given by:

$$TS = SS \bullet DE$$

40.7 Relationships between D_R and D_{IN}. Fig A-1 provides a model of the production screening process flow which incorporates the previously defined quantities (D_{IN}, SS, DE, TS and D_R). Average rework costs to repair or replace defectives at each assembly level are also shown in the figure.

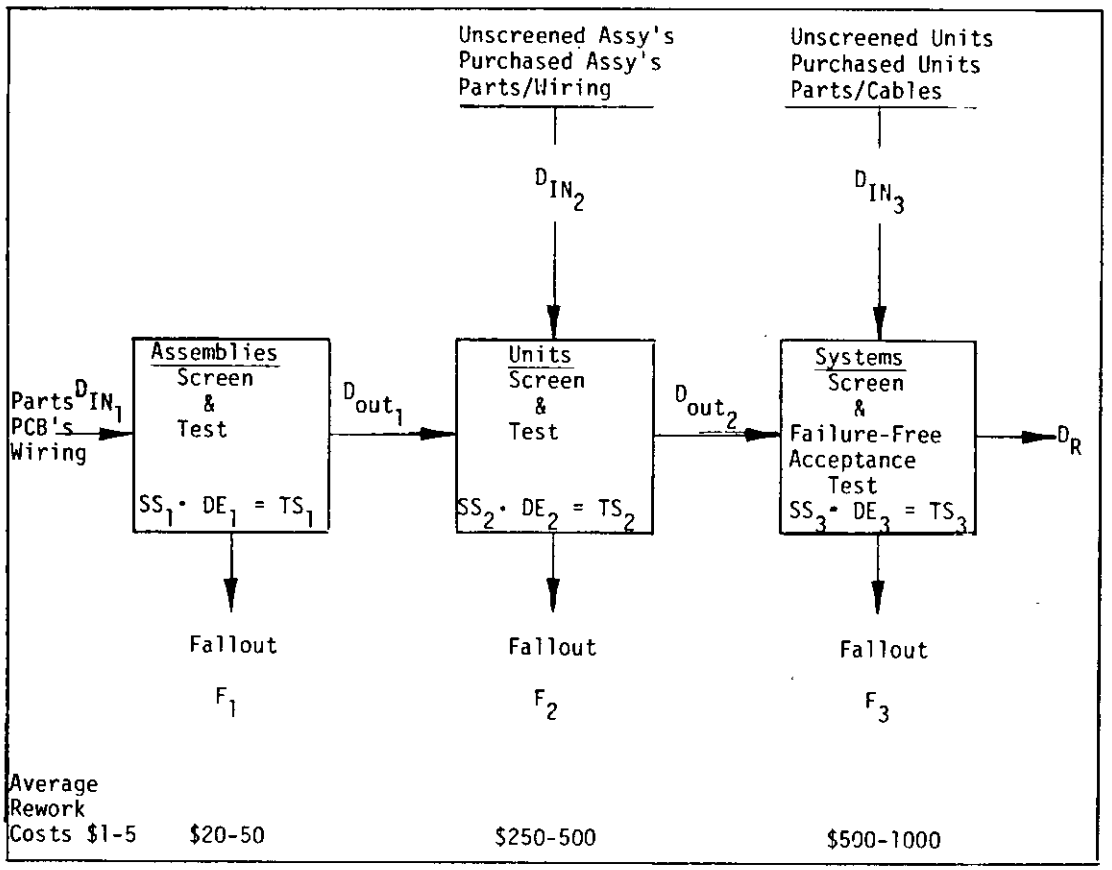

Figure A-1 Production Screening Process Flow Model

For a single screen i D_{out_i} is related to D_{IN_i} by:

$$D_{out_i} = D_{IN_i} \ (1-TS_i)$$

and the fallout F is given by:

$$F_i = D_{IN_i} \ (TS)_i$$

For multiple screens at different assembly levels and assuming that screening is applied on a 100% basis at these assembly levels, D_R is related to D_{IN} by:

$$D_R = D_{IN_1} \prod_{i=1}^{3} (1-TS_i) + D_{IN_2} \prod_{i=2}^{3} (1-TS_i) + D_{IN_3} (1-TS_3) \quad (A-10)$$

$$D_{IN} = \sum_{i=1}^{3} D_{IN_i} \qquad i = \text{assembly stages}$$

In planning an ESS program and depending upon screen placement and the candidate screening sequences selected, variations of equation (A-10) are used to allocate Test Strengths to the various assembly levels, in an interative fashion, so as to achieve the required D_R. Procedure B in Section 5, "Screen Selection and Placement", is based upon use of the models and relationships just described. Screening and rework costs at each level of assembly must be taken into account as part of screen selection and placement process. Procedure D of Section 5, "Cost Effective Analysis" uses these costs in conjunction with the use of Procedure B.

40.8 Cost effectiveness of ESS programs. Without an ESS program, D_{IN} defects will remain in the equipment at delivery and eventually will fail early in field use due to the stresses naturally imposed by the operating environment. As the defects are weeded-out and assuming that no new defects are introduced during repair, and that no design problems exist, the reliability of the equipment can approach and perhaps exceed predicted (specified) values. The cost benefits to the government of finding and eliminating the defects in the factory versus the field depends in part, upon the cost per field repair. For example, if the average cost per field repair is $5000 and the average cost to remove the defect in the factory is $10,000 the screening program is clearly not cost effective. In planning an ESS program, a cost threshold C_T is compared against the cost of per defect removed in the factory C_D so that:

$$C_D \leq C_T$$

where:

$$C_D = \frac{\text{Total Manufacturer's Screening Program Costs}}{\text{Number of Defects Eliminated}}$$

And: C_T = Average cost of a field repair ($1000 is used)

The contractor can structure the ESS regimen using the cost analysis of Procedure D, to reduce C_D by removing defects early in the manufacturing process when rework costs are lower or by using less costly screens. For critical missions, where reliability is of overriding concern and cost is secondary, the cost threshold C_T is used as a baseline against which the cost of the screening program can be evaluated. The procuring activity must decide on how much the cost threshold should be exceeded in order to achieve high reliability requirements.

40.9 Chance Defective Exponential Model (CDE). The CDE model is based upon the assumption that the population of parts within a lot of like equipments is comprised of two subpopulations, i.e., a main subpopulation of "good" parts and a much smaller subpopulation of defectives. The defectives contain major flaws which degrade with stress and time and are manifested as early-life failures. The failure rate of a defective part is several orders of magnitude greater than the failure rate of a "good" part. Therefore, relatively few defectives can dominate the reliability of the equipment during early product life.

Additional assumptions, terms and definitions which are used in the CDE model are:

(a) The number of defectives in an equipment is independent and identically distributed and the distribution is Binomial with parameters N and $\bar{P}$.

where: N = total number of parts in an equipment
$\bar{P}$ = average part fraction defective

For large N and small $\bar{P}$ the Binomial can be approximated by the Poisson distribution so that $D = N\bar{P}$ is the average number of defects per item (defect density).

$$D = N\bar{P} = \sum_{i-1}^{k} n_i p_i$$

where: n_i = quantity of part type i
p_i = fraction defective part type i

The defect density D is one of three parameters of the CDE model.

(b) The failure distribution of the "good" or main subpopulation of parts in an equipment is exponential with parameter λ_o and the reliability function is given by, $R_o(t) = e^{-\lambda_o t}$. λ_o is another parameter of the CDE model. The parameter λ_o can also be expressed as $\lambda_o \simeq (N-D)\,\bar{\lambda}_G$, where $\bar{\lambda}_G$ is the average failure rate of a "good" part.

(c) The failure distribution of a defective part is exponential with parameter $\bar{\lambda}_D$ and the reliability function is given by $R_D = e^{-\bar{\lambda}_D t}$. The parameter $\bar{\lambda}_D$ is defined as the average failure rate of a defective part under a particular stress environment. Note that when the CDE model is applied to a screen, $(1-R_D) = 1 - e^{-\bar{\lambda}_D t} = SS(t)$, the screening strength. Note that the average failure rate of a defective part is much greater than the average failure rate of a "good" part. I.E. $\bar{\lambda}_D >> \bar{\lambda}_G$ and with large defect densities the failure rate of the defective population can be greater than the population of "goods". I.E. $D\bar{\lambda}_D > (N-D)\,\bar{\lambda}_G$.

Given that a system contains n defective parts, the conditional reliability of the system R_s (t/n) is:

$$R_s\ (t/n) = R_o\ (t) \bullet R_D\ (t)^n \qquad n = 0,1,2..$$

Using the Binomial the joint probability of survival and n defects present is:

$$R_s\ (t/n) \bullet P(n) = R_o\ (t) \left[R_D\ (t)\right]^n \binom{N}{n} \bar{P}^n\ q^{N-n}$$

For large N and small $\bar{P}$ the Binomial can be approximated by the Poisson with parameter $D = N\bar{P}$ so that the unconditional survival probability for any number of defects m is given by:

$$R_s(t) = R_o(t) \sum_{m=0}^{\infty} R_D(t)^m \frac{(D)^m e^{-D}}{m!} \qquad \text{For all real values of m} \qquad (A\text{-}11)$$

Performing the summation in A-11 gives the reliability function:

$$R_s(t) = R_o(t)\ e^{-D\left[1-R_D(t)\right]} \qquad (A\text{-}12)$$

Using assumptions (b) $R_o(t) = e^{-\lambda_o t}$ and assumption (c) $R_D(t) = e^{-\bar{\lambda}_D t}$ above; equation A-12 becomes:

$$R_s(t) = \exp\left[-\lambda_o\ t - D\ (1-e^{-\bar{\lambda}_D t})\right] \qquad (A\text{-}13)$$

The failure rate for the system $\lambda_s(t)$ is given by:

$$\lambda_s(t) = -\frac{d}{dt} \ln\ R_s(t)$$

resulting in: $\lambda_s(t) = \lambda_o + D\,\bar{\lambda}_D\ e^{-\bar{\lambda}_D t}$ (A-14)

The probability density function for the system is given by:

$$f_s(t) = \lambda_s(t) \bullet R_s(t)$$

so that: $f_s(t) = \left[\lambda_o + D\,\bar{\lambda}_D e^{\bar{\lambda}_D t}\right] \exp\left[-\lambda_o t - D(1-e^{\bar{\lambda}_D t})\right]$ (A-15)

The expected number of failures for the system in time t is given by:

$$E_s(T) = \int_0^T t \; f_s(t)\, dt$$

which gives: $E_s(T) = \lambda_o T + D(1-e^{-\bar{\lambda}_D T})$ (A-16)

40.10 Relating D_R to field reliability and failure rate. Using the CDE model the reliability and failure rate of a system which has not had ESS exposure during manufacture is given by equations (A-13) and (A-14) as:

$$R_s(t) = \exp\left[-\lambda_o t - D_{IN}\,(1-e^{-\bar{\lambda}_D t})\right]$$

$$\lambda_s(t) = \lambda_o + D_{IN}\,\bar{\lambda}_D e^{-\bar{\lambda}_D t}$$

$\bar{\lambda}_D$ is viewed as the failure rate of a defective under the field stress conditions to which the system will be exposed and λ_o is the MIL-HDBK-217 predicted or specified failure rate for the system.

Given the same system which has been exposed to ESS during manufacture, then D_{IN} is reduced D_R and the other model paramters λ_o and $\bar{\lambda}_D$ have the same interpretation as before. The failure rate function (equation A-14) both with and without an ESS program is illustrated in Fig A-2.

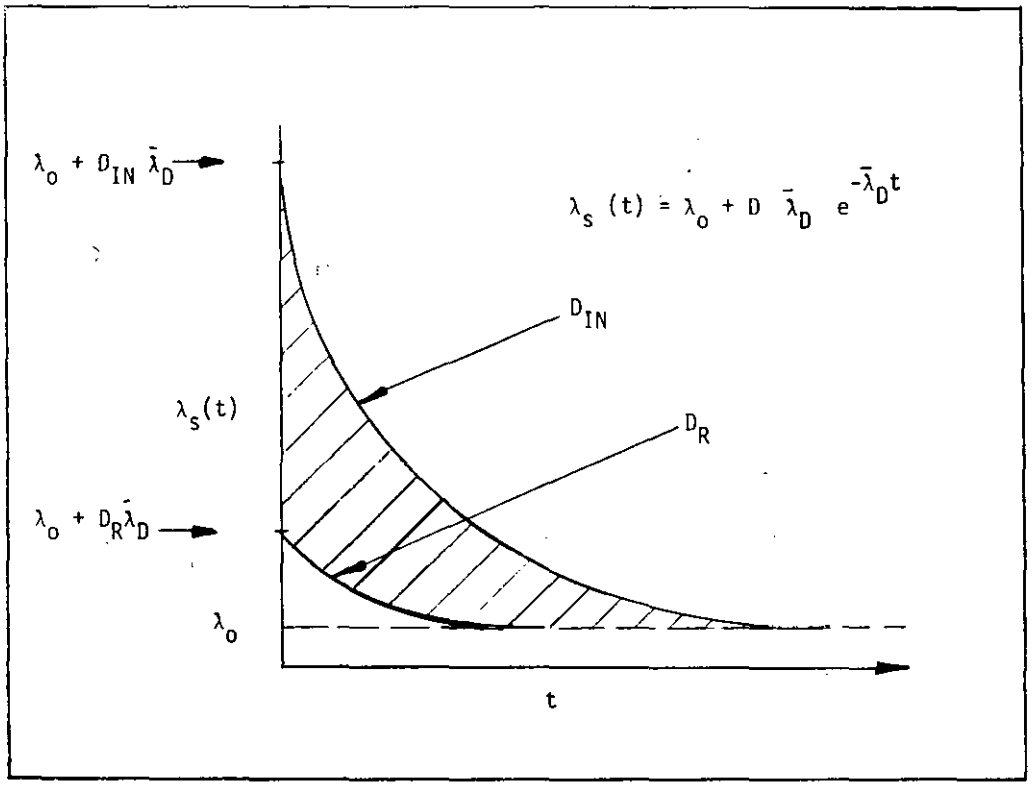

Figure A-2 Field Failure Rate vs Defect Density

The shaded area represents the defects removed from the product as a result of the ESS program conducted during manufacture.

Appendix B
Establishing Goals for Remaining Defect Density (Yield)

10. General. In establishing goals for remaining defect density, it is necessary to relate measures which normally fall within the realm of statistical quality control (a manufacturing function) to measures which fall within the realm of reliability (a design function). The primary distinction between statistical quality control and reliability measures is that in the former, the measures are related to static populations and their sample statistics, whereas in the latter the measures are dynamically related to product performance over time in the field mission environment. For example, latent defect density is a static measure and the failure rate or MTBF is a reliability measure. These two measures are used to arrive at values for remaining defect density. Two methods are described below, one makes use of the failure rate function of the CDE model and the other uses a lower bound on the part fraction defective of 50 PPM. Both methods relate defect density and failure rates and lead to reasonably consistent estimates for remaining defect density.

20. Reference documents (see Section 2)

30. Definitions and acronyms (see Section 3)

40. General mathematical relations

40.1 Failure rate function - CDE model. Using the failure rate function for the CDE model and assuming a remaining defect density of D_R the system failure rate in the field environment as a function of time is given by:

$$\lambda_s(t) = \lambda_o + D_R \bar{\lambda}_D e^{-\bar{\lambda}_D t} \qquad \text{(B-1)}$$

Where:

$\lambda_s(t)$ - failure rate of the system at time t

λ_o - specified failure rate for the system (non-screenable defects)

D_R - average number of latent defects remaining per system at delivery

$\bar{\lambda}_D$ - average failure rate of a latent defect in the field environment

For t=0, at the start of equipment life in the field environment equation (B-1) becomes:

$$\lambda_s(0) = \lambda_o + D\bar{\lambda}_D \qquad \text{(B-2)}$$

The system failure rate at t=0 is thus seen to be the sum of λ_o, the contractually specified or predicted failure rate and $D_R\bar{\lambda}_D$, the product of the field failure rate of a defect and the remaining defect density. When the defect density D_R =0, the failure rate of the system at the start of equipment life is equal to λ_o, the specified failure rate.

The definition of a latent defect is not precise, i.e. a latent defect is an inherent or induced weakness which results in premature or early failure of the product in its intended use environment. What is an early or premature failure? To be slightly more precise one might say that latent defects represent a subpopulation in the equipment, whose average failure rate differs significantly from the main population of "good" parts? The average failure rate of a "good" part is in the range of approximately 1 failure per 10^6 - 10^7 operating hours (MIL-HDBK-217). It would therefore be reasonable to assume that the average failure rate of defective in the field must be greater than one failure per thousand hours in order to be considered a prematurely failing latent defective. Failure rates for defects which are in the range of 10^{-4} to 10^{-5}, are indeed possible, but they would be indistinguishable from the main population as early failures. To summarize then, and in order to provide a slighly more precise, but sill arbitrary definition: a latent defect can be defined as an inherent or induced weakness which has a failure rate in the field environment which is greater than 10^{-3} failures per hour.

Stress screening is designed to accelerate failure mechanisms of latent defects so that the defects can be precipitated to failure earlier than they would have failed in the intended use environment. Stated another way, stress screens are used to accelerate the failure rate of defectives.

Returning to the CDE failure rate equation (B-1) and dividing both sides of the equation by λ_o we have:

$$\frac{\lambda_s(o)}{\lambda_o} = 1 + \frac{D_R\,\bar{\lambda}_D}{\lambda_o} \qquad \text{(B-3)}$$

In equation (B-3), Letting:

$$\frac{\lambda_s(o)}{\lambda_o} = \frac{\text{Failure Rate of the system at t = o}}{\text{Specified failure rate of the system}} = R_1$$

and:

$$\frac{\bar{\lambda}_D}{\lambda_o} = \frac{\text{Failure rate of a defect}}{\text{Specified failure rate of the system}} = R_2$$

Equation (B-3) then becomes:

$$R_1 = 1 + D_R R_2$$

and solving for D_R we have

$$D_R = \frac{R_1 - 1}{R_2} \qquad \text{(B-4)}$$

Given that a failure rate for the system, which is 10% larger than the specified failure rate at the start of product life is considered acceptable, then $R_1 = 1.1$. In addition, as was previously discussed, a reasonable range for the failure rate of a latent defect in the field environment is $> 10^{-3}$ failures per hour. Selecting the upper value of 10^{-3} then the ratio R_2 can be calculated as a function of the specified failure rate, i.e., $R_2 = \frac{10^{-3}}{\lambda_o}$ Solving equation (B-4) for D_R, using $R_1 = 1.1$ and $R_2 = 10^{-3}/\lambda_o$, results in the following table for remaining defect density as a function of the specified failure rate λ_o.

Table B-1 Remaining Defect Density D_R vs Failure Rate (CDE Model)

$R_1 = 1.1 \qquad \bar{\lambda}_D = 10^{-3}$

Failure Rate λ_o	MTBF	D_R
.1	10	10
.01	100	1
.005	200	.5
.002	500	.2
.001	1000	.1
.0005	2000	.05
.0002	5000	.02
.0001	10000	.01
.00001	100000	.001

A simple relation for determining remaining defect density as a function of λ_o, can be noted from the data in Table B-1 as:

$$100\ \lambda_o = D_R \qquad (B\text{-}5)$$

Table B-2 provides values for remaining defect density for values of $\bar{\lambda}_D$ which range from 10^{-1} to 10^{-4}. As will be shown in the next section, $\bar{\lambda}_D = 10^{-3}$, provides values of D_R which are consistent with goals on part fraction defective of 50 PPM.

Table B-2 Remaining Defect Density (D_R) vs Failure Rates (CDE Model)

$R_1 = 1.1$ and $\bar{\lambda}_D = 10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}$

Predicted Failure Rate	Remaining Defect Density (D_R)			
λ_o	$\bar{\lambda}_D = 10^{-1}$	$\bar{\lambda}_D = 10^{-2}$	$\bar{\lambda}_D = 10^{-3}$	$\bar{\lambda}_D = 10^{-4}$
.1	.1	1	10	100
.01	.01	.1	1	10
.005	.005	.05	.5	5
.002	.002	.02	.2	2
.001	.001	.01	.1	1
.0005	.0005	.005	.05	.5
.0002	.0002	.002	.02	.2
.0001	.0001	.001	.01	.1
.00001	.00001	.0001	.001	.01

40.2 Remaining part fraction defective goals in PPM. Determining goals on remaining defect density for an equipment can also be approached by using goals on the remaining fraction defective for the parts contained in the equipment. Recall from the discussions on the relationships between part and assembly fraction defective, in Section 4.6 that, if reasonable yields are to be achieved, part fraction defective levels must be < 100 PPM. The method described below uses a goal, for the part fraction defective, of 50 PPM to obtain estimates of remaining defect density. The calculations, shown below, are presented only to illustrate consistency with the results obtained in the previous section. The method should not be used, in practice, to determine remaining defect density goals. The CDE failure rate model of Section 10.1 should be used.

Using a series model, the failure rate of an equipment can be expressed as the sum of the failure rates of the electronic parts (diodes, transistors, etc.) and the interconnections (wire wrap, hand solder, etc.) which comprise the system. Assuming average failure rates for the parts and interconnections in the equipment, the system failure rate (λ_s) is given by:

$$\lambda_s = N_p \bar{\lambda}_p + N_c \bar{\lambda}_c \qquad \text{(B-6)}$$

where: N_p = Number of electronic parts
N_c = Number of interconnections
λ_p = Average failure rate of the parts
λ_c = Average failure rate of the interconnections

Reasonable values for $\bar{\lambda}_p$ and $\bar{\lambda}_c$ are, respectively, $.5 \times 10^{-6}$ and $.0003 \times 10^{-6}$ failures per hour (per MIL-HDBK-217). A review of prediction data for various equipment has shown that the average number of interconnections per part is about 3. Substituting in equation (B-6) we have:

$$\lambda_s = .5N_p + .0003\ (3N_p) \times 10^{-6}$$

$$\lambda_s = N_p\ (.5 + .0009) \times 10\text{-}6$$

$$\lambda_s = .50009\ N_p \times 10^{-6}$$

The contribution to the system failure rate of the interconnections can be seen to be negligible. The calculations in Table B-3, therefore, use $\lambda_s \simeq .5\ N_p \times 10^{-6}$ to estimate the system failure rate as a function of the number of parts used in the system. D_R is estimated using the relation $D_R = N_p$ (50PPM).

Table B-3 Remaining Defect Density vs Failure Rate - PPM Method

N_p	$\lambda_s = N_p(.5 \times 10^{-6})$	MTBF	$D_R = N_p \bullet 50PPM$
20K	.01	100	1
10K	.005	200	.5
5K	.0025	400	.25
2K	.001	1000	.1
1K	.0005	2000	.05
.2K	.0001	10000	.01
.1K	.00005	20000	.005

The remaining defect density D_R calculated by the above method is consistent with the CDE model calculations in the previous Section 10.1 Equation B-5, therefore, provides a reasonable method for establishing goals on remaining defect density.

Appendix C
Failure Free Acceptance Test Derivation

10. General. A failure-free acceptance test applied at the system level provides a means of formally verifying that goals on remaining defect density (Yield) have been achieved. Yield can be verified by conducting a failure-free acceptance test of predetermined length T. The verified yield is defined as the conditional probability of having no screenable latent defects given that the equipment survives a failure-free period of length T without failure.

20. Reference documents (see Section 2)

30. Definitions and acronyms (see Section 3)

40. General mathematical relations

40.1 Derivation. Using equation A-9 of Appendix A, the yield is given by:

$$\text{Yield} = \exp\left[-D \exp\left(-\bar{\lambda}_D t\right)\right] \qquad \text{(C-1)}$$

where D = defect density at the start of failure-free period

$\bar{\lambda}_D$ = average failure rate of a defect under the stress conditions of the failure-free test.

A lower confidence bound on yield, based upon survival of a failure-free period of length T, can be computed by calculating an upper confidence bound on D. Following Brownlee an upper confidence bound D^* is obtained by using the CDE model reliability function, equation A-13 of Appendix A, and solving:

$$\exp\left[-\lambda_o T - D^*\left(1 - \exp\left(-\bar{\lambda}_D T\right)\right)\right] = 1 - \text{CONF} \qquad \text{(C-2)}$$

for D^*. The left side of equation (C-2) is the probability of surviving T according to the CDE model where λ_o is the predicted or specified failure rate for the equipment and the other variables are as previously defined. CONF is the desired confidence level. The value of D^* is thus:

$$D^* = \frac{\ln\left[1/(1 - \text{CONF})\right] - \bar{\lambda}_D T/(\bar{\lambda}_D/\lambda_o)}{1 - \exp\left(-\bar{\lambda}_D t\right)} \qquad \text{(C-3)}$$

The upper confidence bound on D is then:

$$\bar{D} = \text{Max } (0, D^*)$$

and the lower confidence bound on yield is given by:

$$\exp\left[-\bar{D} \exp\left(\bar{\lambda}_D t\right)\right]. \qquad \text{(C-4)}$$

Tables 5.19-5.28, contained in Procedure D of Section 5, provides the x % lower confidence bounds on yield as a function of $\bar{\lambda}_D T$ and $\bar{\lambda}_D/\lambda_o$. The values in the tables were obtained by use of equations (C-3) and (C-4).

Successful application of a failure-free acceptance test is strongly dependent on accurate knowledge of the defect density at the start of the failure-free test and the screening strength of the screen. These values should be obtained from actual screening process results, using the monitoring and control methods outlined in Procedure E.

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