ASQ Certfied Reliability Engineer.

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Ch.6 Reliability Testing.

https://www.kekaoxing.com

Industrial Engineering and Management System Research Center.

Reliability Testing Introduction.

[CRE Primer Ⅶ p2]

Reasons for Performing Reliability Testing.

- To include failure modes as well as detect unanticipated failure modes so corrective action can be implemented.
- To determine if items or systems meet reliability requirements that have been previously specified.
- To compare estimated failure rates to actual failure rates.
- To monitor reliability growth over time.
- To determine the safety margin in a design.
- To estimate MTBF or MTTF values.
- To identify weaknesses in the design or parts.

Reliability Testing Introduction.

[CRE Primer Ⅶ p2]

Test Program.

- Statistical testing : to optimize the design of the product and the production process.
- Functional testing : to confirm the design.
- Environmental testing : to ensure that the product can operate under the projected environments.
- Safety testing : to ensure safety of the product, for humans, animals or property.

Reliability Testing Introduction.

[CRE Primer Ⅶ p3]

Some Considerations for Testing.

- How critical is the product ?
- Are safety and reliability a concern ?
- Does the customer need a certain level of reliability ?
- How mature is the design ?
- Are new technologies or process involved ?
- How complex is the product ?
- What are the environmental extremes involved ?
- What is the budget for testing ?
- Are the equipment of facilities able to perform test conditions ?
- How many items are available for testing ?
- What is the existing design reliability ?

Reliability Testing Introduction.

[CRE Primer Ⅶ p4-5]

Requirements for Test Plan.

- A test plan for each item.
  - Characteristics to be tested.
  - Specifications required.
  - Quantity to be tested.
  - Environmental requirements.
  - Document numbers for the plans and procedures.

Reliability Testing Introduction.

[CRE Primer Ⅶ p4-5]

Requirements for Test Plan.

- A parameters spreadsheets and parameters document which guide the testing. Parameter to be tested : Materials, dimensions, color, power levels, resistance, sensitivity, etc. versus the input stresses of vibration, cycling, shock, acceleration, temperature, etc.

- The parameters document contains information about the part or device and attribute items to test for such as vibration, power, temperature, and provides tolerance limits.

- The parameters spreadsheet details the performance requirements charted against the parameters at different levels of production (i.e., nomial, receiving, assembly, production, factor, vendor, etc)

Reliability Testing Introduction.

[CRE Primer Ⅶ p5]

Reliability Test Program Schedule : Example.

	Month							
ITEM	0	1	2	3	4	5	6	7
Develop test plan.	■							
Hazard analysis.		■						
Reliability test procedures.				■				
Design test equipment.			■					
Build test equipment.			■					
Equipment test procedures.				■				
Prototype tests.				■				
Revised tests.				■				
Final tests.					■			
Test report.						■		

Reliability Testing Introduction.

[CRE Primer Ⅶ p7-8]

Types and Application of Reliability Testing.

- **Demonstration Testing.**

  These tests may be run in the prototype or development stage. During testing, estimate of MTTF or MTBF are obtained for comparison to the requirements.

- **Qualification Testing.**

  This is a rigorous test for determining if a design is acceptable for the intended function.

- **Acceptance Testing.**

  Acceptance testing is statistically derived to determine if an item is to be accepted for use.

Reliability Testing Introduction.

[CRE Primer Ⅶ p7-8]

Types and Application of Reliability Testing.

- **Performance Testing.**

  Performance testing is conducted on completed designs and normally manufactured items to verify the reliability predictions and test results in the preproduction phase.

- **Failure Free Testing.**

  When performing an acceptance test on one shot devices, or testing if devices work in a given application, zero failure testing can provide the information on reliability levels at a given level of confidence.

Reliability Testing Introduction.

[CRE Primer Ⅶ p7-8]

Types and Application of Reliability Testing.

- **Screening.**

  Screening tests are 100% tests performed with the intent of eliminating the infant mortality period.

- **Development Testing.**

  Testing of the new product design is usually performed at various periods to verify progress. The testing is an essential part of the research and design process.

Reliability Testing Introduction.

[CRE Primer Ⅶ p10]

Test Procedures.

1. Calibration.

- Calibration of individual instruments.
- Calibration of systems of complex test or environmental equipments.
- Calibration of standards.

2. Proofing the test equipment.

To demonstrate that the test equipment can perform its intended function.

3. The test procedure.

A description in detail of the tools, parts, adjustments, hook ups, data sheet, tools, and materials required for the test.

Reliability Testing Introduction.

[CRE Primer Ⅶ p11]

Human Factors During Reliability Testing.

- **Sight capabilities.**

  Critical functions and indicators should be located within 15° of the line of sight. Color perception and color blindness may be of concern also.

- **Touch capabilities.**

  The placement of "on/off" controls in an instrument panel should be consistent from one panel to the next. Consistency in use of similar size knobs or controls of the "on" function is necessary. Similar shaped control knobs are import.

Reliability Testing Introduction.

[CRE Primer Ⅶ p11]

Human Factors During Reliability Testing.

- **Audio capabilities.**

  The audio information should be simple. If the information is critical, redundant or additional confirmation might be desirable.

- **Human thermal tolerance capabilities.**

  Heating : a temperature of 20°C (68°F) would be desirable for the human.

  Ventilation : a minimum of 0.85m^3 (30ft^3) of air per minute.

  Air conditioning : below 29.5°C (85°F)

  Humidity : about 45% relative humidity at 21°C (70°F)

- **Human vibration capabilities.**

Reliability Testing Introduction.

[CRE Primer Ⅶ p13]

Test Environmental Conditions.

- For testing, the environmental conditions will be at least as normal or typical field conditions. High and low values should be used in the testing arrangement.

- A vibration environment is always used when practical, since it is one of the most economical and quality tool for testing.

- Shock, temperature, and humidity extremes are the other common environments to use.

Reliability Testing Introduction.

[CRE Primer Ⅶ p13]

Combined Environments for Reliability Testing.

- A variety of variables can be used to act on the product : time, vibration, shock, humidity, power, dirt, people, electromagnetic, voltage, electrostatic discharge, radiation, atmosphere, pulses, light, noise, etc.

- Most tests are conducted as single environmental tests, not combined. When different environments are combined into a single test structure, the testing is known as combined environmental reliability testing (CERT)

Development Testing.

[CRE Primer Ⅶ p16-20]

Development Testing : Accelerated Life Tests.

- Accelerated life testing (ALT) is used to obtain performance data on devices or components at a quicker rate through higher stresses than normal. The resulting failure data provides information that is extrapolated to obtain the desired estimate at a future time.

Development Testing.

[CRE Primer Ⅶ p16-20]

Development Testing : Accelerated Life Tests.

- **Benefits of ALT.**
  - To save time and money.
  - To quantify the relationship between stress and performance.
  - To identify design and manufacturing deficiencies.

- **Some problems using ALT.**
  - The stress data may not match up with normal operating conditions.
  - The devices are damaged by high stress testing.
  - Test failures are not related to field failure (new failure mode)

Development Testing.

[CRE Primer Ⅶ p16-20]

Development Testing : Accelerated Life Tests.

- **Necessary Assumption about ALT.**
  - The failure modes uncovered at higher stress must be the same failure modes as at the normal operating levels.
  - The stress used will accelerate the action of the failure mode that is dominant at the normal operating condition.
  - The same statistical model of failure will be true for use at the normal and accelerated conditions.
  - Test units must be identical to the final product.
  - One accelerating stress factor is applied at a time.
  - Stress levels cause failure modes identical to those found under normal operating conditions.

Development Testing.

[CRE Primer Ⅶ p16-20]

Development Testing : Accelerated Life Tests.

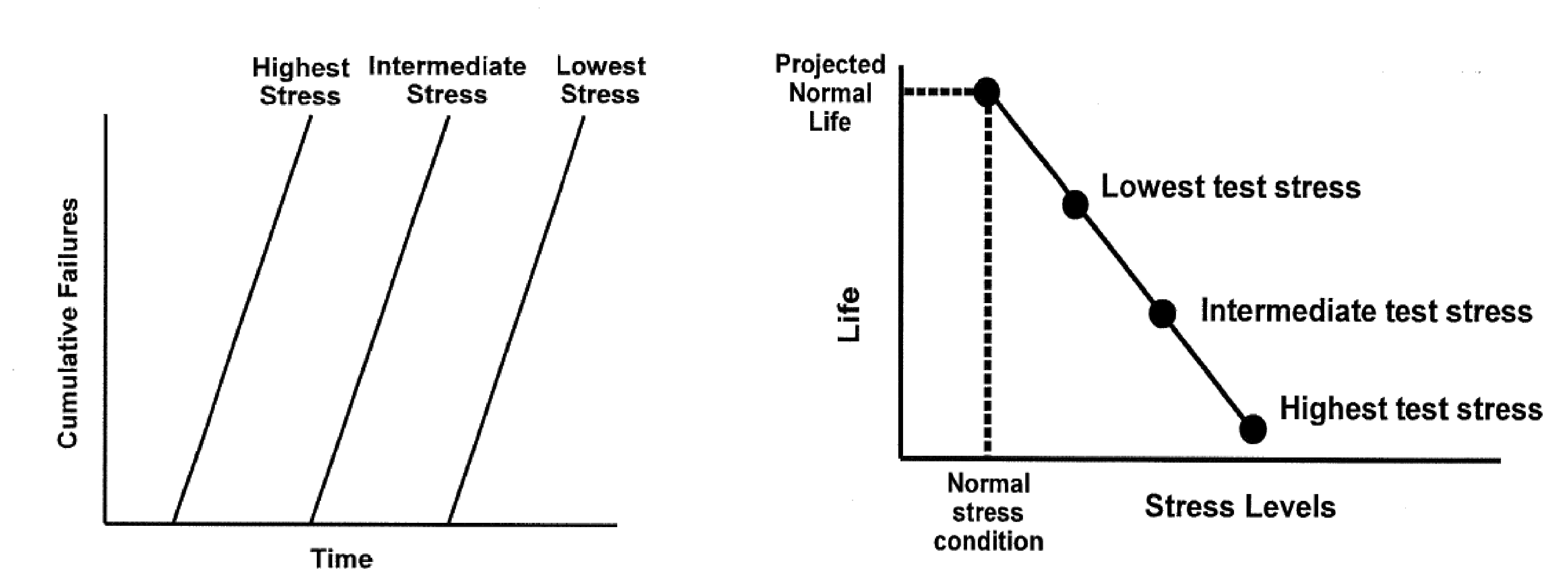
- **Necessary Assumption about ALT.**
  - Accelerating stress levels do not exceed maximum component design.
  - Establish as the high stress the most extreme condition where the model can still hold true.
  - Conduct tests at 2 or more stress levels, where at least 20% of the test units will fail.
  - Conduct tests at the lowest level (as close to the normal operating conditions as possible), but which will still yield some failure (at least 5 failures).

Development Testing.

[CRE Primer Ⅶ p16-20]

Development Testing : Accelerated Life Tests.

- Necessary Assumption about ALT.



Development Testing.

[CRE Primer Ⅶ p16-20]

Development Testing : Accelerated Life Tests.

1. Statistics-based models (parametric and nonparametric)

Parametric models : Exponential, Weibull, Rayleigh, Lognormal.

Nonparametric models : Linear, multiple regression model,
Proportional-hazards (hazard rates are proportional at different stresses).

2. Physics-statistics models.

Arrhenius model, Eyring model, Inverse power run model, Combination model (Arrhenius and inverse power rule)

3. Physics-experimental based models.

Electromigration model, Humidity dependence failure, Fatigue failures.

Development Testing.

[CRE Primer Ⅶ p21]

Development Testing : Step-Stress Testing.

- Step-stress testing places the units at normal level and gradually increases the stress until failure. The stresses are applied in stepwise sequence. The testing continues until all the units have failed.

- The step-stress failure plot has a much higher slop than ordinary life data. It also has additional variables compounded into the test, making statistical analysis less meaningful.

- The design should provide for a failure free stress life greater than the design life. Thus the test can be used to confirm that the design is correct.

Development Testing.

[CRE Primer Ⅶ p23]

Development Testing : Highly Accelerated Life Test (HALT).

- HALT is a development tool that can increase the robustness and reliability of a system. It should be performed early in the development cycle and repeated with the final product revision.

- The process of HALT testing exposes product to stresses of temperature, rapid thermal cycle, vibration, and operational conditions which far exceed those encountered in the filed.

Development Testing.

[CRE Primer Ⅶ p23]

Development Testing : Highly Accelerated Life Test (HALT).

- The objective of HALT is to continue the test until the unit fails. The testing provides indications of design weaknesses in a mush shorter time than is required for normal use conditions. Failures are used to modify the design, prior to production.

- In summary, HALT is a development tool that can increase the robustness and reliability of a system.

Development Testing.

[CRE Primer Ⅶ p24-25]

Development Testing : Reliability Growth Testing.

- The test, analyze, and fix method (TAAF) is used to measure improvements in reliability. Deficiencies are found and fixed.

- The TAAF program is the basis for a Reliability Growth Test (RGT) program. RGT/TAAF can be used to help prevent nonconforming products from leaving the plant.

Development Testing.

[CRE Primer Ⅶ p24-31]

Development Testing : Reliability Growth Testing.

- **Some consideration for TAAF programs.**
  1. Analyze all failure and take action in design or manufacture. All failures must be tracked to their root causes.
  2. Take corrective actions as quickly as possible. This will cause drawing revisions or delays, but the effectiveness of the corrective action will be increased.

Development Testing.

[CRE Primer Ⅶ p24-31]

Development Testing : Reliability Growth Testing.

- **The Duane Model.**

$$\theta_c = \theta_o \left(\frac{T}{T_0} \right)^{\alpha}, \qquad \theta_i = \frac{\theta_c}{1-\alpha}$$

where

θ_c = The cumulative MTBF at the desired time.

θ_o = The cumulative MTBF at the beginning of the test period.

θ_i = The instantaneous MTBF.

α = The slope of the rate of MTBF growth.

T = The desired test time or test time since the beginning of the test.

T_o = The beginning test time.

Development Testing.

[CRE Primer Ⅶ p24-31]

Development Testing : Reliability Growth Testing.

- **The AMSAA Model.**

  The AMSAA model means the Army Materials Systems Analysis Activity model. It is a Weibull process used to model reliability growth. This model assumes that system failures during the development testing phase follow the nonhomogeneous Poisson process.

$$\theta_i(t) = \frac{\alpha}{\beta}\left(\frac{t}{\alpha}\right)^{1-\beta}$$

where : β is the shape parameter.

α is the scale parameter.

t is the time.

Software Testing.

[CRE Primer Ⅶ p32-37]

Software Development Testing

- **White Box Software Testing.**

  White box software testing is a test case design method that uses knowledge of the program's procedural design control structure to derive test cases.

  - Guarantee that all independent paths within a module have been exercised at least once.
  - Exercise all logical conditions on their true and false sides.
  - Excercise all loops in their boundaries and within their operational bounds.
  - Excercise internal data structure to ensure their validity.

- **Simulation.**

  A simulation is a model that behaves or operates like a given system when provided a set of controlled inputs.

  Simulation tools can provide the ability to test the behavior of some software before the software is built.

Software Testing.

[CRE Primer Ⅶ p32-37]

Software Development Testing

- **Fault Injection.**

  Fault injection or fault insertion involves the seeding a known number of errors int a program, testing the program for a while, and then counting the number of seeded versus original errors detected. The total number of original errors in the program can then be estimated.

- **Software Test Levels.**

  Unit Testing : A unit is usually the work of one programmer, and unit testing is the testing done to show that the unit does or does not satisfy its functional specification.

  Component Testing : A component is an integrated aggregate of one or more units. Component testing is the testing done to show that the component does not satisfy its functional specification.

Software Testing.

[CRE Primer Ⅶ p32-37]

Software Development Testing

- **Software Test Levels.**

Integration Testing : Integration is a process by which hardware and software components are aggregated to create larger components. Integrated testing is testing done to show that the combination of components are incorrect and inconsistent.

System Testing : A system is a big component. System testing is aimed at revealing bugs that cannot be attributed to components, as such, but to the inconsistencies between components, or to the planned interactions of components, and other objects.

Product Testing.

[CRE Primer Ⅶ p38]

Topic Areas of Product Testing.

- Qualification Testing.
- Product Reliability Acceptance Testing (PRAT)
- Stress Screening.
- Attribute Testing.
- Degradation Testing.
- Software Testing.

Qualification/Demonstration Testing.

[CRE Primer Ⅶ p38-55]

Reliability Ration Sequential Testing (PRST).

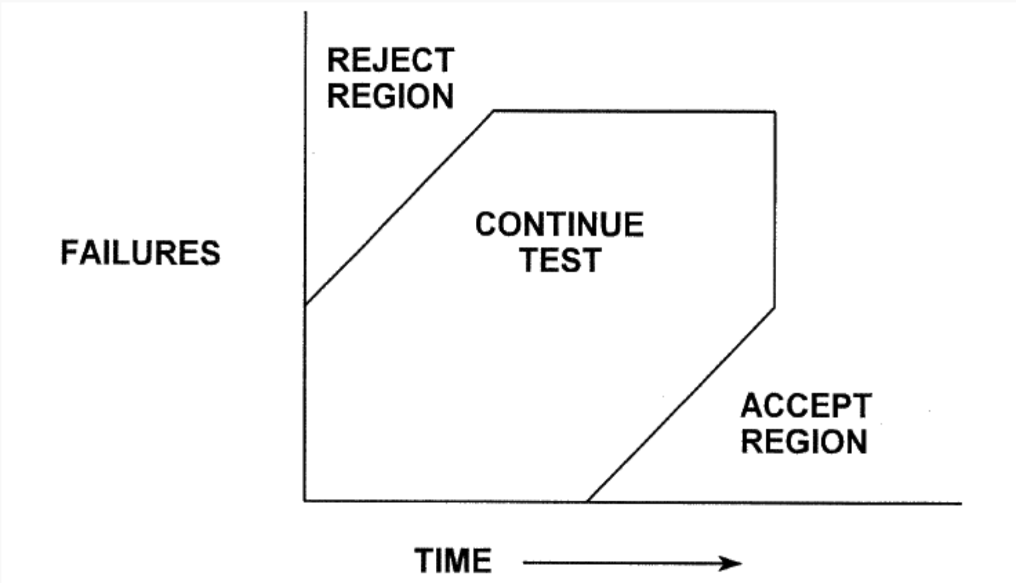
- Sequential testing for products designed to operate for some period of time is outlined in MIL-HDBK-781.
- Items are placed on test, and failures that occur are plotted against test time. A decision is made based on the plotted point. The decision is one of three, accept the items as meeting the required MTBF, reject the items as not meeting the acceptable MTBF or continue testing.

Qualification/Demonstration Testing.

[CRE Primer Ⅶ p38-55]

Probability Ratio Sequential Testing (PRST).

- Sequential testing plans provide for the least amount of time to make a decision when product is either very good or very bad as compared to the reliability requirement.



Qualification/Demonstration Testing.

[CRE Primer Ⅶ p38-55]

Designing Probability Ratio Sequential Testing (PRST).

- Inputs of PRST.

1. Upper test MTBF : θ_0 .
2. Lower test MTBF : θ_1 .
3. Discrimination ratio : $d = \theta_0/\theta_1$.
4. Producer's risk : α .
5. Consumer's risk : β .

Qualification/Demonstration Testing.

[CRE Primer Ⅶ p38-55]

Designing Probability Ratio Sequential Testing (PRST).

- The decision criteria.

1. Stop the test and accept if $r \leq a + bt$
2. Stop the test and reject if $r \geq c + bt$
3. Continue the test if $a + bt < r < c + bt$

where $a = \dfrac{\ln\left(\dfrac{\beta}{1-\alpha}\right)}{\ln d}$, $b = \dfrac{\dfrac{1}{\theta_1} - \dfrac{1}{\theta_0}}{\ln d}$, $c = \dfrac{\ln\left(\dfrac{(d+1)(1-\beta)}{2d\alpha}\right)}{\ln d}$

Qualification/Demonstration Testing.

[CRE Primer Ⅶ p38-55]

Designing Probability Ratio Sequential Testing (PRST).

- Truncation Point for Failures and Time.

1. Truncation Point for Failure.

$$\frac{\chi^2((1-\alpha),\ 2r)}{\chi^2(\beta,\ 2r)} \geq \frac{\theta_1}{\theta_0}$$

2. Truncation Point for Time.

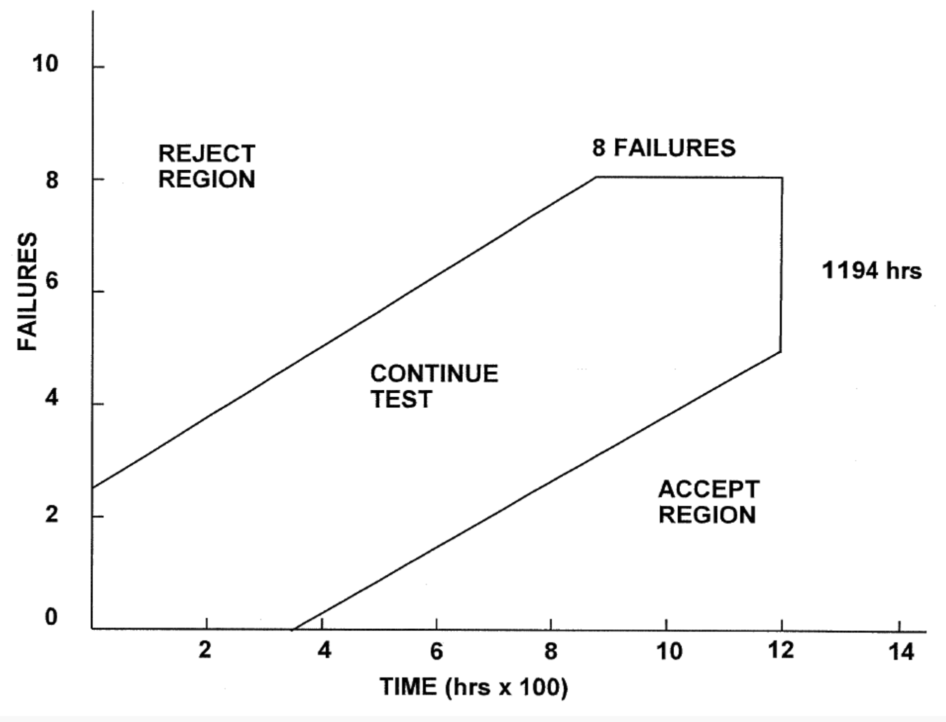
$$T = \frac{\theta_0\ \chi^2((1-\alpha),\ 2r)}{2}$$

Qualification/Demonstration Testing.

[CRE Primer Ⅶ p38-55]

Example of PRST.

- θ_0 = 300 hrs, θ_1 = 100 hrs, α = 0.05, β = 0.10



- a = -2.049
- b = 0.006068
- c = 2.26186
- r = 8
- T = 1194.3

Qualification/Demonstration Testing.

[CRE Primer Ⅶ p38-55]

Time and Failure Terminated Tests.

- Time Terminated Tests with Replacement : r and n.

$$\frac{\chi^2((1-\alpha),\ 2r)}{\chi^2(\beta,\ 2r)} \geq \frac{\theta_1}{\theta_0}$$

$$n = \frac{\theta_0\ \chi^2((1-\alpha),\ 2r)}{2T}$$

- Time Terminated Tests without Replacement : MIL-HDBK-108

- Failure Terminated Tests with Replacement : MIL-HDBK-108

Qualification/Demonstration Testing.

[CRE Primer Ⅶ p38-55]

Sample Size Calculation.

- A requirement for an item may state that reliability must be at least 95% at a confidence level of 90%. What this states is that the user wants to be 90% confident that the reliability is a least 95%.

- The reliability engineer must determine a sample size that (with zero failures allowed in the test) will give evidence that the requirement is met. To calculate the sample size we determine *n* by the following.

$$\mathbf{n = \frac{ln\ (1 - confidence\ level)}{ln\ reliability}}$$

Product Reliability Acceptance Testing.

[CRE Primer Ⅶ p56-57]

Product Reliability Acceptance Testing (PRAT).

- Product reliability acceptance testing (PRAT) takes place during the manufacturing state of the device or system. It is used to detect decreases in reliability from the original design.

- The PRAT can be periodic or continuous during production, and can be performed on all of the devices or on a sample. PRAT usage will provide the necessary data and reaction for corrective and preventive data.

Product Reliability Acceptance Testing.

[CRE Primer Ⅶ p56-57]

Product Reliability Acceptance Testing (PRAT).

- There are at least 5 methods of acceptance testing in the production mode.
    1. Sequential testing (Probability Ratio Sequential Tests)
    2. All-equipment production reliability acceptance test.
    3. Bayesian reliability testing.
    4. Minimum MTBF assurance tests.
    5. Statistical process control.

Environmental Stress Screening.

[CRE Primer Ⅶ p58-61]

Introduction.

- ESS is used to remove hidden design and manufacturing process defects. ESS detection test designed to find problems.

- ESS can be performed on incoming devices or products received from a subcontractor. The tests would prevent weak parts, design flaws, etc., from being used in the final assembly.

- ESS should be designed to remove defects at a lower level of testing instead of the more expensive higher levels. The test conditions simulate failures typical of early field failure, not of the full life profile. In comparison with PRAT, ESS will employ less expensive test facilities and is recommended for 100% sampling.

Environmental Stress Screening.

[CRE Primer Ⅶ p58-61]

Environmental Stress Screening (ESS).

- The most common stresses to use.
  - Temperature : thermal cycling.
  - Humidity.
  - Vibration : random.
  - Moisture.
  - Electrical.
  - Duty cycle.
  - Pressure.
  - Higher impact loads.
  - Overloads.
  - Time.

Environmental Stress Screening.

[CRE Primer Ⅶ p58-61]

Three Methods for Making Time Determination.

- **MIL-HDBK-781A (1996).**

  This method will provides an ESS time that will ensure that a certain percentage of defectives have been uncovered.

- **MIL-HDBK-2164A (1996).**

  This test requires a defect-free test period under stress conditions before the test is concluded. Recommendations are provided for thermal and vibration stress, duration of the pre-defects fee test and the defects free test.

- **Graphical Method.**

  A plot of the observed failure rate versus time under stress is made.

Burn-in Testing.

[CRE Primer Ⅶ p61-66]

Introduction.

- The initial stage of a product's life usually exhibits a high failure rate due to weak or substandard components, manufacturing problems, design constraints, handling, bending, cutting of components, and installation lapses.

- A "burn-in" test performed at stressed conditions (accelerated conditions under time) will eliminate those poor items. The test must not significantly overstress the remaining good parts.

Burn-in Testing.

[CRE Primer Ⅶ p61-66]

Classifications of Burn-in costs.

1. Burn-in constant cost (BICC) : Costs associated per device for "burn-in constant costs", handling of devices for testing, packing and shipping, etc.

2. Burn-in failure costs (BIFC) : Costs associated with the devices for failure during burn-in. The cost of removing, handling, delays, etc.

3. Burn-in time dependent costs (BITC) : Costs associated with the burn-in chamber, production delays from testing, and test costs.

4. Customer repair costs (CRC) and loss of goodwill (LG) : Costs associated with failure in the field by a customer.

Burn-in Testing.

[CRE Primer Ⅶ p61-66]

Calling of Total Cost.

- The total costs associated with burn-in.

$$TCBI = BICC + FDBI(BIFC) + DAYS(BITC) + FABI(CRC+LG)$$

where, FDBI = The number of failures during burn-in.
FABI = The number of failures after burn-in.
FWBI = Number of failures with the customer, failures without burn-in.
DAYS = Number of days on burn-in.
Assumption : the weak components follow an exponential distribution.

- The total costs, if burn-in is omitted.

$$TC = FWBI\ (CRC + LG)$$

Burn-in Testing.

[CRE Primer Ⅶ p61-66]

Three Testing Methods for Burn-in.

1. Performed at ambient conditions with either on power conditions or running the device through a range of motions/cycles.

2. Performed with vibration to accelerate mechanical failures. The typical amount of vibration would be at 75% of expected levels. This would be useful for finding mechanical problems involving workmanship, poor solder joints, week structural components, etc.

3. Performed with temperature cycling on various electronic components.

Burn-in Testing.

[CRE Primer Ⅶ p61-66]

Burn-in Strategy to seek the early failure.

1. Identify the critical parts.
2. Use a realistic burn-in environment.
3. Find the time to failure parameters (what is the curve ?)
4. For all other components in the design, use a constant hazard rate.
5. Compute the cumulative distribution function.
6. Use a Weibull distribution to determine weak parts percentages, characteristics life and shape parameters.

Highly Accelerated Stress Screening (HASS).

[CRE Primer Ⅶ p67]

Introduction.

- Highly accelerated stress screening (HASS) is a production test performed on various components or a complete system. The product is assumed to be free of engineering issues and ready for production. HASS limits are determined by HALT results.

- HASS testing is used to stress test the system or components during production and helps detect and separate all units with manufacturing defects. This is a combination test that varies temperature, vibration, and operating conditions.

- HASS is a production test that will help reduce manufacturing defects and, thus, increase the reliability of the product.

Attribute Testing.

[CRE Primer Ⅶ p68-69]

Attribute Testing.

- For some products, reliability is measured only in terms of how many failed units exist in a sample. Each unit is either functional or failed.

Confidence Intervals for Proportion.

$$p \pm z_{\frac{\alpha}{2}} \sqrt{\frac{p(1-p)}{n}}$$

where p = the population proportion estimate.

n = the sample size.

$z_{\frac{\alpha}{2}}$ = the appropriate confidence level from a z table.

Analysis of ALT.

[CRE Primer Ⅶ p69-78]

Analysis of Accelerated Life Tests.

- The time to failure. $t_0 = A_F \times t_s$
- Probability density function. $f_0(t) = \left(\frac{1}{A_F}\right) f_s\left(\frac{t}{A_F}\right)$
- Reliability function. $R_0(t) = R_s\left(\frac{t}{A_F}\right)$
- Hazard function. $h_0(t) = \left(\frac{1}{A_F}\right) h_s\left(\frac{t}{A_F}\right)$

Degradation Testing.

[CRE Primer Ⅶ p79-82]

Introduction.

- Several nonparametric models can be used to describe degradation testing. The basic concept is that materials can degrade due to exposure to environmental conditions such as heat, light, chemicals, electrical fields, biological agents or other stresses.

- Varieties of degradation testing.
  - The Linear Model.
  - Proportional Hazards Model.
  - The Arrhenius Model.
  - The Eyring Model.
  - Inverse Power Rule Model.
  - Combination Model.

Degradation Testing.

[CRE Primer Ⅶ p79-82]

The Arrhenius Model.

- This model uses the effects of applied stresses on the failure rate of the units under test. Evaluated temperature is the most commonly used environmental stress for ALT of electronic devices.

Degradation Testing.

[CRE Primer Ⅶ p79-82]

The Arrhenius Model.

- The life relationship.

$$L_o = L_s \exp\left(\frac{E_a}{k}\left[\frac{1}{T_o} - \frac{1}{T_s}\right]\right)$$

- The thermal acceleration factor.

$$A_T = \frac{L_o}{L_s} = \exp\left(\frac{E_a}{k}\left[\frac{1}{T_o} - \frac{1}{T_s}\right]\right)$$

where E_a = the activation energy (eV).

k = the Boltzmann Constant (8.623×10^{-5} eV/K)

T = temperature in Kelvin.

Software Testing.

[CRE Primer Ⅶ p83-91]

Software Product Testing.

- **Black Box Testing.**

  Black box testing methods focus on the functional requirements of the software and based on the external characteristics of the program being tested.

  Black box testing enables the software engineer to derive sets of input conditions that will fully exercise all functional requirements for a program.

- **Software Beta Testing.**

  Most software product builders use a process called beta testing to uncover errors that only the end user seems able to find. The beta test is conducted at one or more customer sites by end users of the software.

Software Testing.

[CRE Primer Ⅶ p83-91]

Software Product Testing.

- **Field Testing.**

  Field testing of a system occurs in the customer environment prior to the system being placed in operation. Fie이 testing can include acceptance, qualification or operational testing.

- **Regression Testing.**

  Regression testing involves conducting all or some of the previous tests to ensure that new errors have not been introduced. It involves selective retesting to detect faults introduced during modification of a system or system component, to verify that modifications have not caused unintended adverse effects, or to verify that a modified system or component still meets its specified requirements.

Software Testing.

[CRE Primer Ⅶ p83-91]

Software Product Testing.

- **Equivalence Class Partitioning.**

  Equivalent partitioning is a black box testing method that divides the input domain of a program into classes of data from which test cases can be derived. Equivalent partitioning strives to define a test case that uncovers classes of errors, thereby reducing the total number of test cases that must be developed.

Software Testing.

[CRE Primer Ⅶ p83-91]

Test Cases.

- Test cases are developed using black box methods and then supplementary test cases are developed as necessary using white-box methods.

- Examples of black-box methods include equivalent class partitioning, boundary-value analysis, and cause-effect graphing.

- Some Principles for Test Cases.
  - It has a reasonable probability of catching an error. If a program might fail in a particular way, a test is designed to catch it.
  - It is not redundant. If two tests look for the same error, run only one.
  - It is neither too simple nor too complex.
  - It makes program failure obvious.