CHAPTER 40

RELIABILITY DEMONSTRATION

CONTENTS

1 INTRODUCTION

1.1 Prior to acceptance into service, a system should be evaluated to check whether the Reliability exhibited under service conditions exceeds the minimum acceptable requirement. The system may be a new design, a modification of an existing system or an Off-The-Shelf product entering service. Similar evaluation may be required if an existing system is required to operate in a new way or in a new environment. In some cases previous field history will provide sufficient confidence for acceptance. In others, one or more Reliability Demonstrations will have to be conducted.

1.2 Reliability Demonstration Tests (RDT) must not be confused with Reliability Growth Testing (RGT), see PtCCh15, and Test, Analyse and Fix (TAF) programmes (PtCCh13) although in many respects these three activities are similar. The primary objective of the latter two is to stimulate Reliability growth by detecting and eliminating ‘systematic’ failure modes and, although Reliability estimates are often made, they generally relate to changing build-standards in development. RDT, however, is mainly concerned with measuring whether or not a specified requirement has been met, in terms which can be contractually binding. It may reveal new failure modes which require corrective action, especially if there have been inadequacies in earlier development tests. There is a relationship between development testing, growth and demonstration and these activities must be planned together.

1.3 This Chapter describes:

a) the purposes of Reliability demonstration;

b) the principles involved;

c) the requirements for demonstration; and

d) the factors to be taken into account when planning and implementing demonstration.

1.4 PtDCh10 describes the mathematical basis of demonstration testing in order to provide an understanding of the criteria which may need to be used when selecting and implementing test plans.

1.5 Demonstration tests are directed at acceptance of a given design standard and are not to be confused with quality tests of production equipment for assurance purposes. Quality tests are not covered in this Manual but Production Reliability Acceptance Testing is addressed in PtCCh44.

1.6 More detailed information appropriate to various aspects of demonstration testing is given in references 1, 2, 3 and 4.

2 PURPOSE OF RELIABILITY DEMONSTRATION

2.1 The primary purpose of a Reliability Demonstration Test (RDT) is to decide whether or not the Reliability of a system is good enough. The result of such a demonstration is therefore a decision to accept the item or reject it. The RDT can also provide a quantitative estimate of the true Reliability but this is not its primary purpose.

2.2 An RDT shows whether the achievement of given Reliability parameter values can be claimed with a given level of confidence. This definition is deliberately couched in terms of ‘claimed’ and ‘confidence’ since statistical parameters are being addressed and the parameters cannot be measured exactly and repeatedly in tests based on small samples. For example if a system is tested for 500 hours and exhibits 5 failures it can be claimed (assuming a constant failure rate) that:

a) the MTBF is at least 50 hours with a confidence of 0.93;

b) the MTBF is at least 100 hours with a confidence of 0.38; and

c) the MTBF is at least 150 hours with a confidence of 0.04.

All of these statements are correct from the results quoted. Note that the higher the claim, the lower the level of confidence.

2.3 Reliability Demonstrations are generally not conducted unless required by contract[*]. Here they form a contractual requirement for design acceptance. This is useful is emphasising the importance of the Reliability requirements. However their effectiveness is often reduced by a lack of clarity in the specification and an unwillingness to incur the timescale and cost penalties of rework following a reject result.

2.4 RDT is commonly based on half the Reliability requirement. This situation has arisen out of the way in which Reliability requirements and RDT requirements have been specified on major projects. The producer’s risk (see PtDCh10 for a definition of terms) is based on the specified Reliability and the consumer’s risk on a fraction, normally half, of that value. This can be regarded is heavily biased in favour of the producer. To address this and remove any bias, the customer should ensure that the specification and contract is clear, simple and harmonised (see PtBCh2).

2.5 RDT is an expensive activity and is not warranted unless it is clear what course of action will be taken in the event of a reject result. RDT may be associated with contract incentives and/or penalties, but great care is needed at the specification stage and in the contract to ensure that any penalties or re-work requirements can be enforced.

2.6 A demonstration test can be any form of test which is agreed between a Contracting Authority and a Contractor to give the necessary assurance that a particular requirement has been met. It is essential, however, that the demonstration requirements are unambiguous and agreed before the demonstration is started.

3 PRINCIPLES OF DEMONSTRATION

3.1 General

3.1.1 The basic principle of demonstration is that a ‘sample’ of items is tested under conditions which are considered to be representative of their operational use. Based on the

[*] RDT should be considered by contractors as a pre-delivery activity when the contract includes severe penalties for poor reliability performance. Here RDT can act as a project risk assessment tool.

results of such a test, a decision is taken on the acceptability of the ‘population’ of items which the sample represents, that is, future production items.

3.1.2 In any sampling test, there are risks to both the producer and the consumer that a wrong decision can be reached. The degree of risk will vary according to such factors as the sample size and test duration and must therefore be agreed and specified when planning demonstration tests (see PtDCh10).

3.1.3 Demonstration testing may be carried out under laboratory conditions or as field tests but, to be effective, it must:

a) use items which are declared and accepted to be representative of production items (and so be of fixed build standard through out the test);

b) represent typical operational use of the test item as closely as practicable; and

c) provide sufficient test observations to produce results which are statistically significant or can be assessed in some other way.

If any of these conditions cannot be fulfilled, then demonstration is unlikely to warrant the costs involved.

3.2 Statistical Test Plans

3.2.1 Demonstrations of statistical Reliability characteristics are based on statistical considerations. By assuming a particular distribution for the Reliability characteristic of interest, a statistical test plan can be formulated. This enables the accept/reject criteria for agreed values of decision risks to be pre-determined, and stated precisely before testing starts. The standard test plans are based on a negative exponential distribution of times to failure (constant failure rate). Where this assumption cannot be supported, advice must be sought from a statistician.

3.2.2 There are two main types of statistical test plan which may be used for demonstration purposes:

a) fixed time[†]/failure terminated test plans in which testing is continued until a pre-determined test time has been exceeded (accept) or a pre-determined number of failures has occurred (reject); and

b) sequential test plans, often truncated sequential test plans, in which both test time and failures are compared with established criteria to decide whether to accept, reject or continue testing the item.

Each type of test has certain advantages and disadvantages and these are summarised in Table 1. The mathematical bases of the tests are given in PtDCh10.

3.2.3 It is worth noting that the mathematics for one shot devices is different to that for constant hazard situations. This is addressed in PtDCh10.

[†] ‘time’ is the most common variant but ‘distance’ or ‘number of trials’ (for discrete mission trials with success/failure outcomes, e.g. missile firings) may be substituted where appropriate.

Test type	Advantages	Disadvantages
Fixed time / failure terminated	Either maximum test time or maximum number of failures are fixed prior to testing. Therefore, in the former case, the maximum requirements for test equipment and manpower are fixed before testing begins; in the latter case, the maximum number of test items can be determined. The maximum accumulated test time is shorter than for a truncated sequential test based on the same parameters. A better absolute measure of the Reliability characteristic is obtained in most cases.	On average the number of failures and the accumulated test time will exceed those of a similar truncated sequential test. Very good equipment or very bad equipment still has to undergo the maximum accumulated test time or number of failures to reach the agreed point for making a decision
Sequential	The average number of failures to reach a decision is a minimum.	The test has no maximum accumulated test time or number of failures and could, in theory, continue forever. The number of failures - and therefore the test item costs - will vary in a broader range than for a similar time / failure terminated test. This causes administrative problems in scheduling test items, test equipment and manpower. To decide whether to continue testing, it is necessary to know, as you go along, the actual number of valid failures which has occurred. This may not be easy if the failure definition is hard to interpret or there is a lack of evidence on why a failure happened.
Truncated sequential	The average number of failures to reach a decision is a minimum. The test has fixed limits of test time and number of failures.	The number of failures - and therefore the test item costs - will vary in a broader range than for a similar time / failure terminated test. This causes administrative problems in scheduling test items, test equipment and manpower. The maximum accumulated test time and number of failures exceeds those for the equivalent time/failure terminated test. Strictly only applies to Exponential or Poisson failure processes. To decide whether to continue testing, it is necessary to know, as you go along, the actual number of valid failures which has occurred. This may not be easy if the failure definition is hard to interpret or there is a lack of evidence on why a failure happened.

Table 1: Standard Test Plans - Advantages and Disadvantages

3.3 Dormant Storage

3.3.1 Certain items of equipment (torpedoes, missiles, shell fuses, etc), may experience long periods of dormant storage as part of their in-service life history. It may not be possible during development to demonstrate that such items satisfy (or even have the potential to satisfy) the specified requirements before production an acceptance into service. Such items must be put on test as early as practicable and in sufficient quantity to allow engineering assessments to be made of any degradation. However the form of test is more likely to be an accelerated stress test rather than a demonstration.

3.4 High Reliability Items

3.4.1 The demonstration of high Reliability devices and systems to meaningful levels of classical statistical significance is not always practicable. Many hundreds or thousands of trials may be required which may be costly, time-consuming or impractical. System Reliability requirements of 10^5 hours between failures are not uncommon and would require several hundred thousand hours to demonstrate using the classical approach.

3.4.2 For simple devices with high reliability it is possible to put a large number on test. For example 5000 items on test for 1000 hours provides 5 million hours worth of data, provided that the combination of data from multiple items is valid (that is, the failure rate is constant). However this is only practical with mass production such as is found in the automotive, electronics or telecommunications industries.

3.4.3 Where high system Reliability is achieved through redundancy, the confidence required can often be achieved by addressing the requirement in parts. The lack of confidence is normally associated with the basic Reliability and Maintainability‡ of the parts rather than the logic of fault combination. Take a simple dual redundant system as shown in Figure 1. An overall system MTBF requirement of 10^5 hours might be satisfied by:

a) $MTBF_{path\ 1\ or\ 2}$ = 475h, repair $time_{path\ 1\ or\ 2}$ = 1h, $MTBF_{selector}$ = 1Mh;

b) $MTBF_{path\ 1\ or\ 2}$ = 667h, repair $time_{path\ 1\ or\ 2}$ = 2h, $MTBF_{selector}$ = 1Mh; or

c) any similar combination.

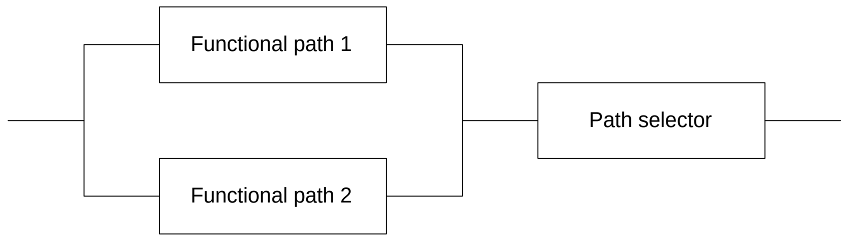

Figure 1: Reliability block diagram for a simple dual redundant system

The relevant target figures for the Functional Paths (450 to 700 hours) are much more readily demonstrated. In contrast the target MTBF for the Path Selector is significantly higher than the original 10^5 hours. However careful consideration of the mechanism of operation reveals that the Path Selector Reliability is related to the number of change-overs and an accelerated test can be undertaken by artificially increasing the rate of change-over. With the first set of MTBF and repair time values above, the MTBF of the Path Selector (10^6 hours) can be expressed as 2100 cycles. Thus a set of two practical Demonstrations can be substituted for one impractical one.

3.4.4 Where statistical tests are not possible, the assurance of a high Reliability device should be undertaken initially by ensuring that a high standard of Reliability engineering procedures is applied during design, development and production. In particular, there should be a high margin between the design intent and the required value. This should be checked by development testing to more stringent environmental levels than would be encountered in the normal operational use of the item. Such engineering procedures will provide increased engineering confidence in the design which may then be substantiated by a limited number of tests for demonstration purposes.

3.5 Use of Prior Data

3.5.1 Bayesian techniques (see PtDCh2) may be used if sufficient data are available to establish a 'prior distribution'. However, particular care must be used when applying these

‡ Maintainability is a factor in system reliability since, for a dual redundant system, a system failure only occurs if a failure occurs in the second functional path while the first is awaiting or being repaired.

techniques and the 'prior distribution' which is to be assumed must be agreed by both the procurement authority and contractor before the tests commence.

3.6 In-Service Demonstration

3.6.1 If a significant level of usage is anticipated in-service this might be made a part of a demonstration process, given the co-operation of the user. For example, it might be specified that 'during the first n years of service, the system is to exhibit an overall Reliability of x'. As with any other formal Demonstrations, all the relevant criteria must be established unambiguously in advance so that no disagreement arises with the decision reached at the end of the demonstration period. It is particularly important that the data collection, classification and analysis procedures are clearly defined and agreed because there is much less control of test conditions in-service and it is generally more difficult to identify those failures which are relevant to Reliability assessments. It is also important that the action to be taken in the event of a reject result is clearly understood and enforceable.

4 REQUIREMENTS FOR RELIABILITY DEMONSTRATION

4.1 Requirements for Reliability demonstration must be established by the MOD(PE) Project Manager during the early stages of a project and must be included in the contract. When deciding at this early stage whether or not a demonstration is justified, the Project Manager must assess the probable cost-effectiveness. Factors to be examined should include:

a) the overall consequences of not achieving the specified Reliability requirement (e.g. increased spares provisioning);

b) the actions to be taken if the test reaches a reject result;

c) the political pressures that will exist, following a reject result, for, on one hand, taking corrective action and, on the other, ignoring the result;

d) the relationship with any Reliability growth programme (see para 5.2);

e) the Availability of hardware, test facilities and resources for effective demonstration (see para 3.1.3);

f) the ability to express the decision criteria in meaningful and acceptable contractual terms;

g) the contractual consequences of the decision criteria (e.g. contract penalties or incentive payments);

h) the total cost of implementing the Reliability demonstration; and

i) other methods for achieving the necessary assurance of acceptable Reliability.

4.2 When a Reliability demonstration is required, the contract/specification must include:

a) the project milestone by which demonstration is to be completed (since further project funding may depend on the outcome);

b) the build-standard and quantity of items to be demonstrated;

c) the operational scenario, environmental conditions and maintenance policy to be assumed for demonstration purposes;

d) the specified minimum value of Reliability which the item is required to achieve and the required value of consumer's confidence to be demonstrated;

e) no items that confuse or contradict the values required[§];

f) a definition of what constitutes a defect or a failure and what circumstances allow either to be discounted in the Reliability assessments (e.g. misuse);

g) how the faults, defects and anomalies which occur during the trial will be judged (or "sentenced") as reluctant or not relevant to the Demonstration.

h) the consequences of meeting the decision criteria.

i) the consequences of failing to meet the decision criteria;

4.3 The requirements for Reliability demonstration and the detailed means by which the requirements are to be met must be stated in the project plan addressing Reliability activities (PtCCh49). Typical factors to be taken into account in planning and implementing Demonstrations are described in Section 5.

5 PLANNING AND IMPLEMENTING DEMONSTRATION

5.1 General

5.1.1 Demonstrations must be planned, at least in outline, during the Project Definition stages, along with the Reliability Development Testing and Growth Programmes, so that:

a) the total Reliability test programme is fully integrated and properly funded in the Development Cost Plan;

b) the use of resources is optimised; and

c) details are included in the project plan for Reliability achievement (PtCCh49).

5.1.2 The main factors to be considered when planning and implementing Reliability Demonstrations are listed below and amplified in subsequent paragraphs:

a) relationship with the development testing programme;

b) timing and duration;

c) test items and type of tests;

d) resource requirements (including access to equipment, sites and support services);

e) test conditions;

f) criteria for assessing achievement;

g) test plan documentation and test conduct;

h) analysis of results and reports;

[§] It is recommended that neither the producer's confidence and value of the parameter to which it refers nor the discrimination ratio be specified. The discrimination between the consumer's requirement and the producer's design aim and the level of project risk to be taken are for the producer to decide. What can additionally be specified are constraints on the overall timescale and project risk that are acceptable.

5.2 Relationship with Development Testing

5.2.1 Generally, Reliability development testing and demonstration testing will require common test facilities and resources and this may impose a constraint on the total test time available within the overall project timescale. It is necessary to decide the best balance between growth testing and demonstration. More growth testing should lead to a higher Reliability achievement (Option 1 in Figure 2) but is accompanied by a lower demonstration confidence due to the reduced demonstration time. Likewise a higher demonstration confidence can be achieved with a longer RDT but this reduces the time for RGT and hence the achieved Reliability(Option 2 in Figure 2).

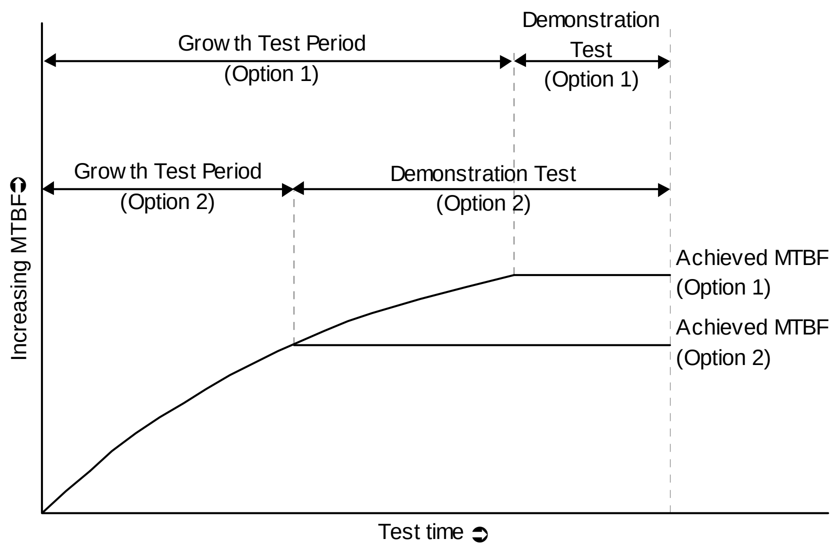

Figure 2: RGT and RDT options when the total test period is constrained

5.3 Timing and Duration

5.3.1 Demonstration should not normally begin before modifications resulting from Reliability development testing have been embodied in the test items.

5.3.2 Ideally, demonstration should be completed in sufficient time for the results to be taken into account for the release of the design for general production. This would minimise the level of re-work on attaining a reject result. However this cannot always be achieved.

5.3.3 The test duration will depend upon the nature of the test item, the type of demonstration, the Availability of test resources and logistic support, etc. The calendar time necessary to accommodate the required test time must be realistically estimated to ensure that the RDT meets the overall programme requirements.

5.4 Test Items and Type of Tests

5.4.1 Demonstration should always be carried out on the highest level of assembly which is practicable, since this increases the realism of the test conditions by testing the largest possible number of system interfaces. It also reduces the expected logistical Reliability[**] and hence the time to reach the required levels of confidence.

5.4.2 When parts of a complete system are to be demonstrated individually, factors to be considered include:

a) which items are most critical within the total system?

b) can the Reliability requirement for a particular item be expressed in terms which can be measured under test?

c) can the operational scenario and associated environments for a particular item be closely represented?

d) are the individual demonstration results to be compared independently with the apportioned value?

e) what mathematical method will be used to combine results if the individual results are to be combined for comparison with the system Reliability requirement?

f) how will the reliability effects of untested system interfaces be accounted if individual results are to be combined?

5.4.3 Statistically designed standard test plans (based on a constant failure rate assumption) which are suitable for use in demonstration testing are given in References 1, 2, 3 and 4. The mathematical basis for these plans and their characteristics are described in PtDCh10. If no standard test plan meets the project requirements, a plan must be derived as described in PtDCh10

5.4.4 In addition to any general factors such as those described at para 5.4.2, the selection of a particular test plan will depend upon the quantitative criteria of the plan. These include the producer's and consumer's risks, their associated Reliability levels, and the expected duration (see PtDCh10).

5.4.5 If planning storage demonstration tests (see para 3.3), the number of test items and the test requirements will depend upon the nature of the item, the degree to which it can be tested non-destructively, the probable modes of degradation and the specified requirements. From consideration of these various factors, a suitable surveillance programme must be planned to monitor any degradation in the test item (e.g. physical, chemical, performance, etc.) throughout the test period.

5.5 Resource Requirements

5.5.1 Demonstration testing is resource intensive. The necessary resources should be identified at an early stage. These may include access to equipment and sites, supporting

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[**] Increasing the amount of equipment under test increases the rate at which equipment failures will be experienced (assuming reliability is being tested and not life). This is accompanied by an increase in the acceptable failure rate for the same specification. This faster acquisition of data produces a shorter test for a given levels of risk.

It may be that increasing the amount of equipment under test introduces redundancy such that the system failure rate is reduced. This is immaterial, since the smaller test was considering non-redundant elements.

activities (ships at sea, airborne targets, security, etc) and services (power supplies, cooling, etc). Failure to ensure that the overall programme provides the necessary facilities for the demonstration will result in elongation of the programme or cancellation of the demonstration.

5.6 Test Conditions

5.6.1 The demonstration test cycle must represent as closely as practicable the prescribed operational scenario and environmental conditions anticipated in-service. This will require test facilities which can provide combinations of environmental conditions.

5.6.2 The test cycle should be determined in a similar manner to the Reliability development test cycle through analysis of the expected environmental and operating conditions. The environmental conditions to be assumed for demonstration testing must be specified or agreed by MOD(PE) Project Manager.

5.6.3 If a part of the system is being tested alone then the conditions of the test must represent the conditions experienced by the item within its system context. This internal environment may be quite different from the actual environment for the system as a whole.

5.6.4 The hardware to be tested must be to an agreed production standard as defined by frozen drawings and specifications before the demonstration is started. During the demonstration, any scheduled maintenance and repair found necessary must be carried out as detailed in the in-service procedures.

5.6.5 Normally, design modification of demonstration test items will not be permitted during the test. However, all defects and failures must be investigated, reported and repaired as necessary.

5.7 Criteria and Means for Assessing Achievement

5.7.1 The functional parameters to be monitored during the demonstration and the criteria for test item failure must be defined. The requirements for test and monitoring equipment must be established.

5.7.2 The types of failure to be considered non-accountable for the purposes of the demonstration must be defined and agreed in advance of any demonstration. The Responsible Authority to be consulted in any cases of doubt must be specified.

5.7.3 The periods of test time to be considered non-accountable for the purposes of the demonstration must be defined and agreed in advance of any demonstration. The Responsible Authority to be consulted in any cases of doubt must be specified.

5.7.4 The assessment of achievement is central to the whole demonstration activity. All criteria which have any bearing on this assessment must be defined in unambiguous terms and agreed.

5.7.5 The test plan must also specify how the incidents, defects, faults and anomalies will be classified as relevant failures or not. Often there is an Assessment Team or Incident Sentencing Committee with representation from both the producer and consumer, and they are responsible for interpreting the failure definition(s) and classifying arising.

5.8 Test Plan Documentation and Test Conduct

5.8.1 The documentation and test conduct for demonstration testing will be similar to that for Reliability development testing. Test specifications, test instructions and test logs as appropriate to demonstration testing should be prepared.

5.8.2 The items and Reliability characteristics to be demonstrated, and the assumptions for planning purposes must be defined. The actual Reliability levels to be demonstrated must be stated and their relationship with the total system requirement shown. Any items which normally form part of the total system but which are excluded from demonstration must be listed separately. Their predicted reliability and the means of ensuring that these will be achieved must be recorded.

5.9 Analysis of Results and Reports

5.9.1 The precise way in which the test results are analysed will depend upon the form of test which has been carried out. The principle results will, however, be a recommendation to the Project Manager to either ‘accept’ or ‘reject’ the system.

5.9.2 Estimates of Reliability values and the associated confidence limits may also be made whether the main result is for acceptance or rejection. Such estimation makes use of the data that will have been accumulated during the test. These secondary results should be expressed in the same terms as the relevant Reliability requirements so that a direct and unambiguous comparison can be made.

5.9.3 Reliability Demonstration must be formally reported to enable the Project Manager and other interested parties to assess the appropriate course of action and for the reasons behind that choice to be recorded. The report should include:

a) the objectives of the demonstration;
b) the test or trials conditions and facilities and their relationship to the operational scenario and duty cycle;
c) any constraints on the demonstration;
d) identification and configuration of the equipment under test;
e) the test/trials plan, procedures and methods (or appropriate references);
f) the criteria for assessing achievement;
g) full details of the test/trials results, including the follow-up action taken on any failures;
h) details of other relevant test results and data;
i) the methods used to analyse the results and determine confidence limits;
j) the achieved Reliability compared whit the specified requirement; and
k) any residual problem areas and recommendations for proposed corrective action.

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REFERENCES

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2. US Department of Defense: *Handbook for Reliability Test Methods, Plans, and Environments for Engineering Development Qualification and Production.* MIL-HDBK-781A. 1 April 1996

3. IEC Publication 605-1. *Equipment Reliability Testing Part 1: General Requirements.* International Electrotechnical Commission. 1978 (Also apprears in BS5760 as Part 10.1)

4. IEC Publication 605-7. *Equipment Reliability Testing Part 7: Compliance Test Plans for Failure Rate and Mean Time Between Failures Assuming Constant Failure Rate.* International Electrotechnical Commission (IEC Standard). 1978 (Also apprears in BS5760 as Part 10.7)

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