Bellcore

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Comments Requested
(See Preface)

Reliability Prediction Procedure for Electronic Equipment

(A Module of RQGR, FR-796)

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For ordering information, see the References section of this document.

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Volume	Volume Description	Module
1 1997 Edition RQGR Introduction and Reliability Prediction Concepts, Modeling, and Testing	RQGR Introduction	An Introduction to Bellcore's Reliability and Quality Generic Requirements (RQGR), GR-874-CORE
	Reliability Prediction Concepts, Modeling, and Testing	Reliability Prediction Procedure for Electronic Equipment, TR-332
		Bell Communications Research Reliability Manual, SR-TSY-000385
		Reliability and System Architecture Testing, SR-TSY-001130
		Methods and Procedures for System Reliability Analysis, SR-TSY-001171
2 1997 Edition R&Q Physical Design and Component Requirements	R&Q Physical Design Requirements	Generic Requirements for the Physical Design and Manufacture of Telecommunications Products and Equipment, GR-78-CORE
	Component Requirements	Component Reliability Assurance Requirements for Telecommunications Systems, TR-NWT-000357
		Generic Requirements for the Design and Manufacture of Short-Life, Information-Handling Products and Equipment, GR-2969-CORE
		Reliability Assurance Practices for Optoelectronic Devices in Interoffice Applications, TR-NWT-000468
		Electrostatic Discharge Control in the Manufacture of Telecommunications Equipment, TR-NWT-000870
		Generic Requirements for Hybrid Microcircuits Used in Telecommunications Equipment, TR-NWT-000930
		Introduction to Reliability of Laser Diodes and Modules, SR-TSY-001369,

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3 1997 Edition Program, Software, and Product Specific Requirements	R&Q Program Requirements	Statistical Process Control Program Generic Requirements, TR-NWT-001037
		Quality System Generic Requirements for Hardware, GR-1252-CORE
	R&Q Software Requirements	Quality System Generic Requirements for Software, TR-NWT-000179
		Generic Requirements for Software Reliability Prediction, GR-2813-CORE
		Software Reliability and Quality Acceptance Criteria (SRQAC), GR-282-CORE
		Software Architecture Review Checklists, SR-NWT-002419
	R&Q Product Specific Requirements	Reliability and Quality Switching Systems Generic Requirements (RQSSGR), TR-NWT-000284
		Generic Reliability Assurance Requirements for Fiber Optic Transport Systems, TR-NWT-000418
4 1997 Edition R&Q Surveillance and Field Reliability Monitoring Procedures	R&Q Surveillance	BELLCORE-STD-100 and BELLCORE-STD-200 Inspection Resource Allocation Plans, TR-TSY-000016
		Supplier Data Program Analysis, TR-TSY-000389
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		Network Switching Element Outage Performance Monitoring Procedures, SR-TSY-000963
		Analysis and Use of Software Reliability and Quality Data, SR-TSY-001547

NOTE

This document is a module of FR-796, *Reliability and Quality Generic Requirements (RQGR)*.

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Reliability Prediction Procedure for Electronic Equipment

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1. Introduction

This section contains the purpose and scope of the reliability prediction procedure and indicates changes from the previous issue.

1.1 Purpose and Scope

A prediction of reliability is an important element in the process of selecting equipment for use by the Bellcore Client Companies (BCCs) and other buyers of electronic equipment. As used here, reliability is a measure of the frequency of equipment failures as a function of time. Reliability has a major impact on the maintenance and repair costs and on the continuity of service.

The purpose of this procedure is to document the recommended methods for predicting device[1] and unit [2] hardware [3] reliability. This procedure also documents the recommended method for predicting serial system [4] hardware reliability. [5] It contains instructions for suppliers to follow when providing predictions of their device, unit, or serial system reliability (hereinafter called “product” reliability). It also can be used directly by the BCCs for product reliability evaluation.

Device and unit failure rate predictions generated using this procedure are applicable for commercial electronic products whose physical design, manufacture, installation, and reliability assurance practices meet the appropriate Bellcore (or equivalent) generic and product-specific requirements.

This procedure cannot be used directly to predict the reliability of a non-serial system. However, the unit reliability predictions resulting from application of this procedure can be input into system reliability models for prediction of system level hardware reliability parameters.

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[1] “Device” refers to a basic component (or part) listed in Table 11-1 (formerly Table A) of this document.

[2] “Unit” is used herein to describe any customer replaceable assembly of devices. This may include, but is not limited to, circuit packs, modules, plug-in units, racks, power supplies, and ancillary equipment. Unless otherwise dictated by maintenance considerations, a unit will usually be the lowest level of replaceable assemblies/devices.

[3] The procedure is directed toward unit level failures caused by device hardware failures. Failures due to programming errors on firmware devices are not considered. However, the hardware failure rates of firmware devices are considered.

[4] “Serial system” refers to any system for which the failure of any single unit will cause a failure of the system.

[5] Troubles caused by transient faults, software problems, procedural errors, or unexpected operating environments can have a significant impact on system level reliability. Therefore, system hardware failures represent only a portion of the total system trouble rate.

Currently, this procedure also includes some discussion of system level operating and configuration information that may affect overall system reliability. The procedure directs the requesting organization to compile this information in cases where the unit level reliability predictions are computed for input to a specific system reliability model. This system level information is not directly necessary for computation of the unit level reliability predictions, but these information requirements are not currently addressed in any other Bellcore requirements document and are therefore included in this TR.

1.2 Changes

This issue of the Reliability Prediction Procedure (RPP) includes the following changes:

- The revision of device failure rates in Table 11-1 (formerly Table A[6])
- The addition of new devices in Table 11-1
- The addition of failure rates of commercial off-the-shelf computer equipment. Table 11-10 gives the typical observed failure rates of computer-related systems or subsystems
- The revision of quality factors in Table 11-4
- The revision of environmental factors in Table 11-8
- The adjustment of worked examples to be consistent with Table 11-1 revisions
- Text changes to improve clarity.

1.3 Requirements Terminology

Criteria are those standards that a typical BCC may use to determine suitability for its application. As used in this TR, criteria include *requirements*, *conditional requirements, and objectives*.

The following requirements terminology is used throughout this document:

- **Requirement** — Feature or function that, in Bellcore's view, is *necessary* to satisfy the needs of a typical BCC. Failure to meet a requirement may cause application restrictions, result in improper functioning of the product, or hinder operations. A Requirement contains the words *shall* or *must* and is flagged by the letter "**R**."
- **Conditional Requirement** — Feature or function that, in Bellcore's view, is *necessary in specific BCC applications*. If a BCC identifies a Conditional Requirement as necessary, it shall be treated as a requirement for the application(s). Conditions that

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[6] Tables A through K have been renumbered as Tables 11-1 through 11-12 (a new Table 11-10 has also been added).

may cause the Conditional Requirement to apply include, but are not limited to, certain BCC application environments, elements, or other requirements, etc. A Conditional Requirement is flagged by the letters “**CR**.”

- **Objective** — Feature or function that, in Bellcore's view, is *desirable* and may be required by a BCC. An Objective represents a goal to be achieved. An Objective may be reclassified as a Requirement at a specified date. An objective is flagged by the letter “**O**” and includes the words *it is desirable* or *it is an objective*.

1.3.1 Requirement Labeling Conventions

Proposed requirements and objectives are labeled using conventions that are explained in the following two sections.

1.3.1.1 Numbering of Requirement and Related Objects

Each Requirement, Objective, and Conditional Requirement is identified by both a local and an absolute number. The local number consists of the object's document section number and its sequence number in the section (e.g., **R3-1** is the first Requirement in Section 3). The local number appears in the margin to the left of the Requirement. A Requirement object's local number may change in subsequent issues of a document if other Requirements are added to the section or deleted.

The absolute number is a permanently assigned number that will remain for the life of the Requirement; it will not change with new issues of the document. The absolute number is presented in brackets (e.g., **[2]**) at the beginning of the requirement text.

Neither the local nor the absolute number of a Conditional Requirement or Conditional Objective depends on the number of the related Condition(s). If there is any ambiguity about which Conditions apply, the specific Condition(s) will be referred to by number in the text of the Conditional Requirement or Conditional Objective.

References to Requirements, Objectives, or Conditions published in other Generic Requirements documents will include both the document number and the Requirement object’s absolute number. For example, **R2345-12** refers to Requirement **[12]** in GR–2345.

1.3.1.2 Requirement, Conditional Requirement, and Objective Object Identification

A Requirement object may have numerous elements (paragraphs, lists, tables, equations, etc.). To aid the reader in identifying each part of the requirement, an ellipsis character (...) appears in the margin to the left of all elements of the Requirement.

2. Purposes of Reliability Predictions

Unit-level reliability predictions derived in accordance with this procedure serve the following purposes:

- Assess the effect of product reliability on the maintenance activity and on the quantity of spare units required for acceptable field performance of any particular system. For example, predictions of the frequency of unit level maintenance actions can be obtained. Reliability parameters of interest include the following:
  - Steady-state[1] unit failure rate.[2]
  - First-Year Multiplier. The average failure rate during the first year of operation (8760 hours) can be expressed as a multiple of the steady-state failure rate, called the *first-year multiplier*. The steady-state failure rate provides the information needed for long-term product performance. The first-year multiplier, together with the steady-state failure rate, provides a measure of the number of failures expected in the first year of operation.
- Provide necessary input to system-level reliability models.[3]
- Provide necessary input to unit and system-level Life Cycle Cost Analyses.
- Assist in deciding which product to purchase from a list of competing products. As a result, it is essential that reliability predictions be based on a common procedure.
- Set standards for factory reliability tests.
- Set standards for field performance.

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[1] "Steady-state" is that phase of the product's operating life during which the failure rate is constant. Herein the steady-state phase is assumed preceded by an infant mortality phase characterized by a decreasing failure rate.

[2] Unless stated otherwise, all failure rates herein are expressed as *failures per* 10^9 *operating hours,* denoted as FITs.

[3] System-level reliability models can subsequently be used to predict, for example, frequency of system outages in steady-state, frequency of system outages during early life, expected downtime per year, and system availability.

3. Guidelines for Requesting Reliability Predictions

This section contains guidelines for requesting reliability predictions from suppliers of electronic equipment. It covers choosing among the three prediction procedures, operating conditions, and system-level information.

3.1 Required Parameters

The requesting organization should determine the uses and purposes of the reliability predictions. Based on these purposes, the requesting organization can specify the desired reliability parameters. In most situations, the supplier will be asked to provide both the steady-state failure rates and the first-year multipliers.

3.2 Choice of Method

R3-1 **[1]** This procedure includes three general methods, called Methods I, II, and III, for predicting product reliability. (See Sections 5 through 9 for a description of the methods.) The supplier must provide Method I predictions for all devices or units unless the requesting organization allows otherwise in accordance with Section 4.1.

In addition to the Method I predictions, the supplier may submit predictions calculated using Methods II or III. However, in cases where two or more predictions are submitted for the same device or unit, the requesting organization will determine which prediction is to be used.

3.3 Operating Conditions and Environment

Device failure rates vary as a function of operating conditions and environment. The requesting organization should describe the typical operating conditions and physical environment(s) in which the products will operate. This description should include

- The ambient temperature: In cases where the ambient temperature varies significantly over time, the requesting organization should determine, according to its own needs, the temperature value(s) to provide.
- The environmental condition, as described in Table11-8: If the product will be exposed to more than one environment condition, each should be specified. The environmental multiplying factor for each condition should be entered on the “Request for Reliability Prediction” form (Form 1, Figure 10-1).

3.4 System-Level Information

If the reliability predictions are used to determine reliability parameters for a particular system, then the requesting organization:

- May request predictions for specific system-level service-affecting parameters (e.g., frequency of system outage) concurrently with the unit or device reliability predictions. These should be specified on the “Request for Reliability Prediction” form (Form 1, Figure 10-1).
- Should clearly specify the definition of a failure. This is a crucial element in predicting system reliability parameters. For non-complex equipment, the definition of a failure is usually clear. Faults in complex equipment may distinguish between those affecting maintenance or repair and those affecting service. For example, it is often desirable for multichannel systems to define the maximum number of channels that can be out before the system is considered failed, i.e., no longer providing acceptable service.

In addition to overall system reliability objectives, some complex, multi-function systems may have reliability objectives for individual functions or for various states of reduced service capability. For such systems, it may be necessary to develop reliability models to address these additional objectives. Guidelines for developing these models are outside the scope of this document.

The requesting organization should describe any other system-level operating conditions and requirements that may influence reliability. These are to be presented in sufficient detail to preclude significant variations in assumptions on the part of different suppliers. These conditions are likely to be unique for each equipment type. For example, some of the operating conditions affecting reliability predictions for subscriber loop carrier equipment are

- Temperature and humidity variations
- Single or redundant T1 line facilities
- Distance between terminals
- Duration of commercial power outages
- Lightning induction.

3.5 Procedure Verification

On receipt of a completed reliability prediction package, the requesting organization should verify the computations and correct use of the procedure. Any device procurement specifications, circuit design information, field tracking information, test/inspection information, and required worksheets provided in the package should be reviewed for completeness and accuracy.

If the requesting organization requires documentation or information beyond that specified in this procedure, the documentation or information should be requested on the “Request for Reliability Prediction” form (Form 1, Figure 10-1) or in subsequent correspondence.

This procedure allows a supplier to present additional reliability data, such as operational field data, details concerning maintenance features, design features, burn-in[1] procedures, reliability-oriented design controls and standards, and any other factors important in assessing reliability. This information must be carefully considered by the requesting organization to ensure a meaningful analysis of the supplier's product.

It is the responsibility of the requesting organization to provide the supplier with all relevant details of proposed product use. This will enable the supplier to provide only such additional information as is appropriate to the specific case.

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[1] “Burn-in” is defined as any powered operation that fully simulates (with or without acceleration) normal use conditions.

4. Guidelines for the Reliability Prediction Methods

This section contains guidelines for the use of the three reliability prediction methods. For some background on reliability prediction, refer to a tutorial on *Reliability Prediction* at the 1996 Annual Reliability and Maintainability Symposium. The reader may also refer to tutorials on *Basic Reliability* and *Probabilistic Models and Statistical Methods in Reliability* at the same symposium.

4.1 Preferred Methods

This procedure permits use of the best technically supportable evidence of product reliability based on field data, laboratory tests, MIL-HDBK-217F, *Reliability Prediction of Electronic Equipment*, device manufacturer's data, unit supplier's data, or engineering analysis. The methods for predicting reliability are the following:

Method I: Predictions are based solely on the “Parts Count” procedure[1] in Sections 5 and 6. This method can be applied to individual devices or units. Unit level parts count predictions can be calculated using Method I, II, or III device level predictions.

Method II: Unit or device level statistical predictions are based on combining Method I predictions with data from a laboratory test performed in accordance with the criteria given in Section 7.

Method III: Statistical predictions of in-service reliability are based on field tracking data collected in accordance with the criteria given in Section 8.

Although the three methods specified here are preferred, they do not preclude additional predictions that use other technically sound sources of data and/or technically sound engineering techniques. Other sources or techniques could include device manufacturer's data, unit supplier's data, reliability physics considerations, extrapolation models, and engineering analysis. This approach may be particularly useful in adjusting Method I estimates for new technology devices where no substantial field data exists. A supplier must fully explain and document the technical basis for any such predictions. In such cases, the requesting organization will then determine whether the RPP or alternate prediction is used.

Subject to prior approval from the requesting organization, the supplier may submit Parts Count predictions for a specified subset, rather than for the entire set of devices or units.

Sections 5 and 6 discuss Method I; Section 7 discusses Method II; and Section 8 discusses Method III.

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[1] The “Parts Count” procedure used in this method is based on MIL-HDBK-217F.

4.2 Inquiries

Questions regarding the interpretation or use of these methods should be addressed in writing to the organization that requested the reliability prediction. The Network Integrity Planning Center in Bellcore can also provide assistance.

5. Overview of Method I: Parts Count Method

This section provides an overview of Method I, which is used to predict reliability including guidelines for the selection among the three cases for temperature and electrical stress conditions.

5.1 General Description

The prediction technique described in this section is commonly known as the "Parts Count" method in which the unit failure rate is assumed to be equal to the sum of the device failure rates. Modifiers are included to account for variations in equipment operating environment, device quality requirements, and device application conditions, e.g., temperature and electrical stress. For application of this method, the possible combinations of burn-in treatment and device application conditions are separated into three cases, which are described below. Unless the requesting organization requires Case 3, the case to be used is at the supplier's discretion.

Case 1: Black Box option with unit/system burn-in ≤ 1 hour and no device burn-in. Devices are assumed to be operating at 40°C and 50-percent rated electrical stress.

Case 2: Black Box option with unit/system burn-in > 1 hour, but no device burn-in. Devices are assumed to be operating at 40°C and 50-percent rated electrical stress.

Case 3: General Case - all other situations. This case would be used when the supplier wants to take advantage of device burn-in. It would also apply when the supplier wants to use, or the requesting organization requires, reliability predictions that account for operating temperatures or electrical stresses at other than 40°C and 50 percent, respectively. These predictions will henceforth be referred to as "limited stress" predictions.

5.2 Case Selection

This method is designed so that computation of the first year multipliers and steady-state reliability predictions is simplest when there is no burn-in and when the temperature and electrical stress levels are assumed to be 40°C and 50 percent, respectively. Thus, the cases are listed above in order of complexity Case 1 being the simplest. The reason the supplier may opt to use Case 2 is that Case 2 allows for system or unit burn-in time to reduce the failure rate attributed in the infant mortality period. Case 3 (the General Case) allows the use of all types of burn-in to reduce the failure rate attributed in the infant mortality period. The limited stress option, which can only be handled under Case 3, should produce more accurate predictions when the operating temperature and electrical stress do not equal 40°C and 50 percent, respectively.

Some suppliers have questioned the value of burn-in for mature product designs. Bellcore investigated the relevance of burn-in for mature product designs through a study that included three types of burn-in as well as no burn-in. This study examined the trade off of time saved in the manufacturing cycle vs. the cost of any additional failure if burn-in is eliminated. This study concluded that for mature product designs it is not necessary to do a burn-in, and the savings of time and material without burn-in would reduce the cost of the mature product.

Since it is considerably more time-consuming to perform and verify limited stress predictions, it is recommended that Case 3 be used as the sole prediction method only when ten or fewer unit designs are involved or when a more precise reliability prediction is necessary.

The requesting organization has the option to require the supplier to perform a (sampled) limited stress prediction. In cases where a large number of unit level predictions are to be computed, the following approach may be specified if agreement can be reached with the product supplier:

1. The requesting organization selects a sample of ten unit designs that are representative of the system. The following criteria are to be used in the sample selection process:
    a. If any devices are burned-in, select ten unit designs that, on the whole, contain a proportion of these devices consistent with the proportion of burned-in devices in the system.
    b. Do not select unit designs for units that are subjected to unit level burn-in. Predictions for these designs should be computed using the limited stress option. Usually there will be few unit designs in this category.
    c. Include unit designs that are used in large quantities in the system.
    d. Include unit designs that perform different functions, for example, power supplies and digital, analog, and memory units.
2. The product supplier performs a limited stress reliability prediction and calculates the first year multiplier (π_{FY}) for each selected unit design.
3. The product supplier performs a steady-state black box reliability prediction on *all* units (excluding those in item 1b above).
4. The average π_{FY} value determined from the sample in item 2 is applied to all non-sampled unit designs (excluding those in item 1b above).
5. The average ratio between the steady-state black box prediction and steady-state limited stress prediction of the sampled unit designs is applied to all non-sampled designs (excluding those in item 1b above).

6. If the sample adequately represents the total system, this approach will provide a more precise measure of first year and steady-state unit failure rates than is available by the black box option; yet, it will not be as complicated and time-consuming as a limited stress prediction done on every unit design.
7. Care must be used to avoid bias in the sample selection. This is particularly important when system level parameters computed in a system reliability model are to be compared with the system level parameters for a competing system.

When unit level reliability predictions are to be input into system reliability models, whichever case is used must normally be used for all units in the system. Currently, the only exceptions are when

- The requesting organization specifically requests a deviation.
- Limited stress predictions are required, but detailed device application information is not available for purchased sub-assemblies because of proprietary designs. In such instances, a black box prediction (Case 1 or 2) may be applied to these units.
- A sampled limited stress prediction is required.

5.3 Additional Information

Information such as block diagrams, parts lists, procurement specifications, and test requirements may be requested to verify that results presented by the supplier are correct. Some items of this nature are specifically requested in this procedure; additional items may be requested in other documents or letters. If the supplier does not provide the requested information, the worst case assumptions must be used (e.g., if procurement specifications or test/inspection procedures are not provided, the worst quality level will be assumed).

Information required to perform the reliability predictions can be found as follows:

- Section 6 describes the detailed steps used in predicting unit reliability.
- Tables 11-1 through 11-12 contain the information necessary to determine device and unit failure rates and modifying factors.
- Forms 2 through 12 contain worksheets to be used in reliability prediction.

5.4 Operating Temperature Definition

The following definitions apply for selecting temperature factors from Table 11-7 to perform Method I predictions.

- The *unit operating temperature* is determined by placing a temperature probe in the air ½ inch above (or between) the unit(s) while it is operating under normal conditions.[1]
- The *device operating temperature* is the unit operating temperature of the unit in which the device resides.

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[1] "Normal conditions" refer to the operating conditions for which the reliability prediction is to apply. If the reliability predictions are used as input in a system level reliability model, this will be the operating conditions for the product in that particular system.

6. Method I: Parts Count

This section contains the complete formulae for the three cases of Method I reliability prediction.

6.1 Available Options

As described in Section 5.1, there are three cases for the Parts Count Method:

- Case 1 - black box option (assumed operating temperature and electrical stress of 40°C and 50 percent) with unit/system burn-in ≤ 1 hour, no device burn-in
- Case 2 - black box option (assumed operating temperature and electrical stress of 40°C and 50 percent) with unit/system burn-in > 1 hour, no device burn-in
- Case 3 - General Case.

The formulae for the steady-state failure rate and the first-year multiplier are given in Sections 6.2 and 6.3, respectively.

6.2 Steady-State Failure Rate

R6-1 **[2]** The reliability predictions for the Parts Count Method must be based on the correct application of the formulas (1), (2), and (3) contained in this section (either by using an appropriate software or by using the forms contained in Section 10). Similarly, the first-year multipliers must be obtained by correct application of formulas contained in Section 6.3.

6.2.1 Device Steady-State Failure Rate

For the general case (Case 3) the *device* steady-state failure rate, λ_{SS_i} , is given by:

$$\lambda_{SS_i} = \lambda_{G_i}\pi_{Q_i}\pi_{S_i}\pi_{T_i} \tag{6-1}$$

where

λ_{G_i} = generic steady-state failure rate for the i^{th} device (Table 11-1)

π_{Q_i} = quality factor for the i^{th} device (Table 11-4)

π_{S_i} = stress factor for the i^{th} device (Tables 11-5 and 11-6)

π_{T_i} = temperature factor for the i^{th} device (Table 11-7) due to normal operating temperature during the steady state.

The generic steady-state failure rates given in Table 11-1 are based on data supplied by several companies. Most of these failure rates are lower than the corresponding values given in Issue 4 of this document. The failure rates given in Table 11-1 are rounded to two significant digits.

For Cases 1 and 2, since the temperature and electrical stress factors (Tables 11-6 and 11-7) are $\pi_T = \pi_S = 1.0$ at 40°C and 50-percent electrical stress for all device types, the formula can be simplified to:

$$\lambda_{SS_i} = \lambda_{G_i}\pi_{Q_i} \quad \textbf{(6-2)}$$

6.2.2 Unit Steady-State Failure Rate

The unit steady-state failure rate prediction, λ_{SS}, is computed as the sum of the device failure rate predictions for all devices in the unit, multiplied by the unit environmental factor:

$$\lambda_{SS} = \pi_E \sum_{i=1}^{n} N_i \lambda_{SS_i} \quad \textbf{(6-3)}$$

where

n = number of different device types in the unit

N_i = quantity of i^{th} device type

π_E = unit environmental factor (Table 11-8).

6.3 First-Year Multipliers

The computation of the first-year multipliers is preceded by the computation of the equivalent operating times due to screening such as burn-in.

As part of the data request sent out to electronic equipment manufacturers for preparing this issue of TR-332, Bellcore asked for data on quantification of the benefit of other forms of screening such as temperature cycling, voltage stressing, and vibration. Since Bellcore did not receive sufficient data to incorporate the quantification of other forms of screening, Section 6.3 continues to quantify the benefit of burn-in on the first-year multiplier (i.e., early life).

6.3.1 Device Effective Burn-in Time

To compute the first-year multiplier for the i^{th} device type, it is necessary to compute a quantity called the equivalent operating time for the burn-in t_{e_i}.

Case 3: The device burn-in is taken into account to compute the equivalent operating time as follows:

$$t_{e_i} = \frac{A_{b,d}t_{b,d} + A_{b,u}t_{b,u} + A_{b,s}t_{b,s}}{A_{op}\pi_{s_i}}$$

where

$A_{b,d}$ = Arrhenius acceleration factor (Table 11-7, Curve 7) corresponding to the device burn-in temperature

$t_{b,d}$ = device burn-in time (hours)

$A_{b,u}$ = Arrhenius acceleration factor (Table 11-7, Curve 7) corresponding to the unit burn-in temperature

$t_{b,u}$ = unit burn-in time (hours)

$A_{b,s}$ = Arrhenius acceleration factor (Table 11-7, Curve 7) corresponding to the system burn-in temperature

$t_{b,s}$ = system burn-in time (hours)

A_{op} = temperature acceleration factor (Table 11-7, Curve 7) corresponding to normal operating temperature

π_{s_i} = electrical stress factor (Tables 11-5 and 11-6) corresponding to normal operating conditions.

Case 2: Since there is no device level burn-in and the normal operating temperature and electrical stress are assumed to be 40°C and 50 percent, $t_{b,d} = 0.0$, $A_{op} = \pi_{s_i} = 1.0$, and the formula for equivalent operating time for the burn-in reduces to:

$$t_e = A_{b,u}t_{b,u} + A_{b,s}t_{b,s}$$

Case 1: Since unit/system burn-in ≤ 1 hour and there is no device burn-in:

$$t_{e_i} = 1.0$$

6.3.2 Device First-Year Multipliers π_{FY_i}

Case 3:

When device/unit/system burn-in > 1 hour,

- If $t_{e_i} \geq \frac{10,000}{\pi_{T_i}\pi_{S_i}}$, then $\pi_{FY_i} = 1$.

- If $\frac{10,000}{\pi_{T_i}\pi_{S_i}} - 8760 < t_{e_i} < \frac{10,000}{\pi_{T_i}\pi_{S_i}}$, then

$$\pi_{FY_i} = \frac{1.14}{\pi_{T_i}\pi_{S_i}}\left[\frac{t_{e_i}\pi_{T_i}\pi_{S_i}}{10,000} - 4\left[\frac{t_{e_i}\pi_{T_i}\pi_{S_i}}{10,000}\right]^{0.25} + 3\right] + 1.$$

- If $t_{e_i} \le \frac{10,000}{\pi_{T_i}\pi_{S_i}} - 8760$, then

$$\pi_{FY_i} = \frac{0.46}{(\pi_{T_i}\pi_{S_i})^{0.75}}\left[(t_{e_i} + 8760)^{0.25} - t_{e_i}^{0.25}\right]$$

When device/unit/system Burn-in ≤ 1 hour,

- If 10,000 ≥ 8760 $\pi_{T_i}\pi_{S_i}$, then

$$\pi_{FY_i} = 4/(\pi_{T_i}\pi_{S_i})^{0.75} .$$

- Otherwise,

$$\pi_{FY_i} = 1 + 3/(\pi_{T_i}\pi_{S_i}) .$$

Case 2:

Since $\pi_{T_i} = \pi_{S_i} = 1.0$ for Case 2, use the following:

- If $0 < t_{e_i} < 10,000$, then use the π_{FY} value from Table 11-9.

- If $t_{e_i} > 10,000$, then $\pi_{FY} = 1$.

Case 1:

$$\pi_{FY_i} = 4.0$$

6.3.3 Unit First-Year Multiplier (π_{FY})

To obtain the unit first-year multiplier, use the following weighted average of the device first-year multipliers:

$$\pi_{FY} = \sum_{i=1}^{n} (N_i \lambda_{SS_i} \pi_{FY_i}) / \sum_{i=1}^{n} (N_i \lambda_{SS_i})$$

6.4 Worksheets

- Forms 2 and 3 are worksheets for calculating device and unit failure rates for Case 1.
- Forms 2 and 4 are worksheets for calculating device and unit failure rates for Case 2.
- Forms 5 and 6 are worksheets for calculating device and unit failure rates for Case 3.

Completed samples of these forms accompany the examples in the following section.

6.5 Examples

This section contains an example for each of the three cases.

6.5.1 Example 1: Case 1 (Forms 2 and 3)

Assume the unit called EXAMPLE has the following devices:

Device Type	Quantity
IC, Digital, Bipolar, Non-hermetic, 30 gates	17
IC, Digital, NMOS, Non-hermetic, 200 gates	14
Transistor, Si, PNP, Plastic, ≤ 0.6 W	5
Capacitor, Discrete, Fixed, Ceramic	5
Single Display LED, Non-hermetic	1

Device Quality Level I is assumed for the capacitors and the LED, and Device Quality Level II is assumed for all other devices on the unit. The requesting organization has specified the environmental factor $\pi_E = 2.0$ (from Table 11-8) on the “Request For Reliability Prediction” form (Form 1, Figure 10-1).

Assume that the requesting organization does not require a limited stress prediction (Case 3) for the unit EXAMPLE; that is, it is permissible to assume operating conditions of 40°C temperature and 50 percent electrical stress. Furthermore, there is no device, unit, or system burn-in (or there is burn-in but the manufacturer is not claiming credit for it). Under these conditions, reliability predictions for the unit EXAMPLE are calculated using Forms 2 and 3. Figures 6-1 and 6-2 illustrate the completed forms for this example and are shown on the following pages.

6.5.2 Example 2: Case 2 (Forms 2 and 4)

Consider the unit EXAMPLE, from Example 1 (see Section 6.5.1). As in Example 1, assume the requesting organization did not require a limited stress (Case 3) reliability prediction for the unit. However, there is unit burn-in of 72 hours at 70°C, for which the manufacturer would like to receive credit. Reliability predictions for the unit EXAMPLE should then be calculated using Form 2, as in Example 1, and Form 4. Figures 6-1 and 6-3 illustrate completed forms for this example and are shown on the following pages.

Device Reliability Prediction Worksheet

Case 1 Or 2 - Black Box Estimates (50% Stress, Temperature = 40° C,
No Device Burn-in)

π_E = 2.0.

Date 8/1/96
Page 1 **of** 1
Unit EXAMPLE
Manufacturer XYZ, Inc.

Device Type*	**Part Number**	**Circuit Ref. Symbol**	**Qty** (N_j)	**Failure** Rate** (λ_{G_j})	**Quality Factor** (π_{Q_j})	**Total Device Failure Rate** $(N_j \lambda_{Gj}, \pi_{Q_j})$ (f)
IC, Digital, Bipolar Non-herm, 30 gates	A65BC	U1-17	17	22	1.0	374
IC, Digital, NMOS Non-herm, 200 gates	A73X4	U18-31	14	39	1.0	546
Transistor, SI PNP Plastic, ≤ 0.6W	T16AB	Q1-5	5	4	1.0	20
Capacitor, Discrete Fixed, Ceramic	C25BV	C1-5	5	1	3.0	15
Single Display LED, Non-herm	L25X6	CR1	1	3	3.0	9
SUBTOTAL						964

TOTAL = $(\lambda_{SS}) = \pi_E \Sigma N_j \lambda_G \pi_Q$ = (2.0) (964) = 1,928

* Similar parts having the same failure rate, base part number, and quality factor may be combined and entered on one line. Part descriptions should be sufficient to verify that correct failure rate assignment has been made.

** Failure rates come from Table 11-1. If Method II is applied to devices, instead use failure rate (j) from Form 9 (λ^*_{Gj}).

Figure 6-1. Example 1 and 2, Case 1 (Worked Form 2)

Unit Reliability Prediction Worksheet

Case 1 - Black Box Estimates (50% Stress, Temperature = 40° C,
Unit/System Burn-in ≤ 1 Hour, No Device Burn-in)

Date 8/1/96		**Page** 1 **of** 1
Product APPARATUS	**Rev** 1	**Manufacturer** XYZ, Inc.

Unit Name	Unit Number	Repair Category			Steady State Failure Rate (From Form 2) (FITs) λ_{SS}	If Method II is applied to units, (From Form 10) λ^*_{SS}	First Year Multiplier π_{FY}
		Factory Repairable	Field Repairable	Other			
EXAMPLE 1	11-24	X			1,928		4.0

Figure 6-2. Example 1, Case 1 (Worked Form 3)

Unit Reliability Prediction Worksheet

Case 2 - Black Box Estimates (50% Stress, Temperature = 40° C,
No Device Burn-in, Unit/System Burn-in > 1 Hour)

Date 8/1/96

Page 1 **of** 1

Product APPARATUS

Rev 1

Manufacturer XYZ, Inc.

Unit Name	Example 2				
Unit Number	11-24				
Repair category					
Factory repairable	X				
Field repairable					
Other					
Unit burn-in					
Temperature $T_{b,u}$	70°				
Acceleration factor† $A_{b,u}$	3.7				
Time $t_{b,u}$	72				
System burn-in					
Temperature $T_{b,s}$	NA				
Acceleration factor $A_{b,s}$	NA				
Time $t_{b,s}$	NA				
Effective burn-time t_e $t_e = A_{b,u}t_{b,u} + A_{b,s}t_{b,s}$	266				
First year Multiplier (Table 11-9) π_{FY}	2.6				
λ_{SS} (from Form 2) λ_{SS}	1.928				
From Form 12 when Method II is applied to units λ^{*}_{SS}	NA				

Comments:

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† Obtain From Table 11-7, Curve 7

Figure 6-3. Example 2, Case 2 (Worked Form 4)

6.5.3 Example 3: Case 3, General Case (Forms 5 and 6)

Consider again the unit EXAMPLE, from Example 1. Assume that reliability predictions for the unit EXAMPLE must be calculated using the “Limited Stress” option. The unit operating temperature is 45°C. All the transistors are operated at 40-percent electrical stress, and all the capacitors are operated at 50-percent electrical stress. There is both device burn-in and unit burn-in, for which the manufacturer would like to receive credit. The unit burn-in consists of 72 hours at 70°C. In addition, all the bipolar and MOS integrated circuits are burned in for 168 hours at 150°C. Under these conditions, reliability predictions for the unit EXAMPLE must be calculated using Forms 5 and 6. Figures 6-4 and 6-5 illustrate completed forms for this example. The computations shown on Form 5 are normally made by a software package such as the Automated Reliability Prediction Procedure (ARPP). Form 5 illustrates the nature of the computations.

6.6 Instructions for Device Types/Technologies Not in Table 11-1

Surface Mount Technology: RPP base failure rate predictions for surface mount devices are equal to the RPP predictions for the corresponding conventional versions.[1]

New or Application Specific Device Types: There may be cases where failure rate predictions are needed for new or application-specific device types that are not included in Table 11-1. In such cases, the supplier may use either of the following, subject to approval from the requesting organization:

- The RPP failure rate prediction for the Table 11-1 device type that is most similar
- A prediction from another source.

The requesting organization may require the supplier to provide full supporting information, and has the option to accept or reject the proposed failure rate prediction.

6.7 Items Excluded From Unit Failure Rate Calculations

This section discusses the exclusion of devices whose failure will not affect service.

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1. At this time, Bellcore has received no evidence indicating a significant difference in failure rates between conventional and surface mount devices, even though several manufacturers have indicated that surface mount devices appear to be more reliable. Separate failure rate predictions for surface mount devices may be included in future RPP issues if equipment suppliers or users contribute valid field reliability data or other evidence that indicates a significant difference.

Device Reliability Prediction Worksheet

(GENERAL CASE 3 - Including Limited Stress)

Date 8/1/96

Page 1 **of** 1

Unit EXAMPLE

Manufacturer XYZ, Inc.

Device Type			IC, bip	IC, NIMOS	TRANS, Si	Capaci	LED	
Part Number			A65BC	A73X4	T16AB	C25BV	L25X6	
Circuit ref. symbol			U1-17	U18-31	01-5	C1-5	CR1	
Quantity	N_j	(a)	17	14	5	5	1	Cumulative sum of (f)
Generic failure rate*	λ_{Gj}	(b)	22	39	4	1	3	
Quality factor	π_{Qj}	(c)	1.0	1.0	1.0	3.0	3.0	
Stress factor	π_{Sj}	(d)	1.0	1.0	0.64**	1.0	1.0	
Temperature factor	π_{Tj}	(e)	1.2	1.3	1.1	1.0	1.5	
Device quantity x device failure rate $(f) = (a)\times(b)\times(c)\times(d)\times(e)$		(f)	449	710	14	15	14	1,202
Device burn-in Temperature	$T_{b,d}$		150°	150°	NA	NA	NA	Cumulative sum of (u)
Acceleration factor‡	$A_{b,d}$	(g)	48	48	NA	NA	NA	
Time	$t_{b,d}$	(h)	168	168	NA	NA	NA	
Unit burn-in Temperature	$T_{b,u}$		70°	70°	70°	70°	70°	
Acceleration factor‡	$A_{b,u}$	(i)	3.7	3.7	3.7	3.7	3.7	
Time	$t_{b,u}$	(j)	72	72	72	72	72	
System burn-in Temperature	$T_{b,s}$							
Acceleration factor‡	$A_{b,s}$	(k)						
Time	$t_{b,s}$	(m)						
Early Life Temp.Factor‡	A_{op}	(n)	1.3	1.3	1.3	1.3	1.3	
$(o) = 1000/[(d)\times(e)]$		(o)	8,333	7,692	11,363	10,000	6,667	
$(p) = (g)\times(h)+(i)\times(j)+(k)\times(m)$		(p)	8,330	8,330	266	266	266	
Eff. burn-in time: $(p)/[(d)\times(n)]$		(q)	6,408	6,408	256	205	205	
(1) If $(q)\geq(o)$	$(r) = 1$	(r)						
(2) If $(q)\leq(o)-8760$ Look up (q) in Table 11-9		(s)			2.6	2.7		
$(r) = (s)/[(d)\times(e)]^{0.75}$		(r)			2.6	2.7		
(3) Otherwise Look up (p) in Table 11-9		(t)	1.0	1.0			2.6	
$(r) = [(t)-1]/[(d)\times(e)]+1$		(r)	1.0	1.0			2.1	
$(u) = (r)\times(f)$		(u)	449	710	36	41	29	1,265

* Failure rates come from Table 11-1. If Method II is applied to devices, use (p) from Form 11.

** When two stress curves are applied to a device, use the product of the two stress factors: π_S = 0.8 x 0.8 = 0.64

‡ Obtain from Table 11-7, Curve 7.

Figure 6-4. Example 3, Case 3 (Worked Form 5)

Unit Reliability Prediction Worksheet

(GENERAL CASE - Including Limited Stress)

Date 8/1/96

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Product APPARATUS

Rev 1

Manufacturer XYZ, Inc.

Unit Name		EXAMPLE 3				
Unit Number		11-24				
Repair category Factory repairable		X				
Field repairable						
Other						
From Form 5: Sum of (u)	(u)	1,276				
From Form 5: Sum of (f)	(f)	1,206				
Environmental Factor	π_E	2.0				
$\pi_E \times (f)$	λ_{SS}	2,412				
First year multiplier $= (u)/(f)$	π_{FY}	1.1				
If Method II is applied to units, from Form 12:	λ^*_{SS}	NA				
Comments:						

Figure 6-5. Example 3, Case 3 (Worked Form 6)

6.7.1 Default Exclusions

When unit failure rates are being predicted, wire, cable, solder connections, wire wrap connections, and printed wiring boards (but not attached devices and connector fingers) may be excluded.

6.7.2 Approved Exclusions

The supplier must provide unit failure rate predictions that include all devices within the unit. However, when unit failure rate predictions are to be used as input into system reliability models, the supplier may propose that the requesting organization approve exclusion of devices whose failure will not cause an immediate loss of service, necessitate an immediate maintenance visit, or result in additional service disruption during later system maintenance activities. For example, failure of a particular device may not immediately affect service, but may affect the system recovery time given a subsequent outage. This may include devices provided for monitoring, alarm, or maintenance purposes (e.g., channel busy lamps or failure indicator lamps).

To propose exclusions, the supplier must use Form 7, entitled “Items Excluded From Unit Failure Rate Calculations,” for each unit affected. The form should list all items that are proposed for exclusion in the unit failure rate calculation. The bottom portion of Form 7 contains a set of equations that describe the total unit failure rate and first year multiplier in terms of the contribution by “service affecting” and “non-service affecting” values. When exclusions are approved by the requesting organization, the supplier should use the “service affecting” values when completing Form 8.

6.7.3 Example 4

Consider the unit EXAMPLE, introduced in Example 1, Section 6.5.1. Assume that the LED is non-service affecting since it only indicates whether the unit is functioning. In this case Form 7 must be completed. Figure 6-6 illustrates a completed form for this example.

Items Excluded From Unit Failure Rate Calculations

Date	8/1/96	**Unit**	EXAMPLE 1
Manufacturer	XYZ, Inc.		

Device		Reason	From Form 2 or 5	
Type	Number		(f)	(u)*
Single, Display LED, Non-herm	L25X6	LED used for status indication only	9	36
			TOTALS	

After completing this form, calculate the following failure rate data:

Non-service Affecting

$\pi_E \times \Sigma(f) = \lambda_{SS_{na}} =$ 2.0 x 9 = 18

$\frac{\Sigma(u)}{\Sigma(f)} = \pi_{FY_{na}} =$ 36/9 = 4.0

Where:

π_E = environmental factor (from Form 1).

Service Affecting

$\lambda_{SS} - \lambda_{SS_{na}} = \lambda_{SS_a} =$ 1,928 - 18 = 1,910

$\frac{\pi_{FY}\lambda_{SS} - \pi_{FY_{na}}\lambda_{SS_{na}}}{\lambda_{SS_a}} = \pi_{FY_a} =$ 4.0

Where:

λ_{SS} = total unit steady-state failure rate (from Form 3, 4, 6, 10, or 12).

π_{FY} = total unit First-Year Multiplier (from Form 4 or 6).

π_{FY} = 4.0, when λ_{SS} comes from Form 3 or 10.

*When the value of (f) is obtained from Form 2, $(u) = \pi_{FY}$ x (f). Obtain the value of π_{FY} from Form 3, 4, or 6, whichever is applicable.

Comments:

For the above computations, note that in Example 1, π_{FY} = 4.0.

Figure 6-6. Example 4 (Worked Form 7)

7. Method II: Combining Laboratory Data With Parts Count Data

This section contains the formulae for the four general cases of Method II reliability prediction.

7.1 Introduction

Method II is a procedure for predicting unit or device reliability using laboratory data. The purpose of this procedure is to provide a mechanism for suppliers to perform realistic and informative laboratory tests. Suppliers who submit reliability predictions based on laboratory data must obtain prior approval from the requesting organization.

Decisions to implement lab tests need to be made on a case-by-case basis and must be carefully considered. The cost of a lab test must be weighed against the impact of Method I device failure rates on unit failure rates and/or system reliability parameter estimates (relative to reliability objectives). Life cycle costs should also be considered. The Method II base failure rate is calculated as a weighted average of the measured laboratory failure rate and the Parts Count generic failure rate, with the weights determined by the laboratory data.

For devices, the value for the generic failure rate is obtained from Table 11-1; for units, the value is $\lambda_{SS} / (\pi_E \pi_T)$. (These terms will be defined later.) When laboratory tests are very informative, the Method II base failure rate is determined primarily from the laboratory data. When laboratory tests are less informative, the Method II base failure rate will be heavily influenced by the Parts Count generic failure rate.

Using Method II yields device or unit base failure rates to take the place of Parts Count generic failure rates. These base failure rates can then be used to compute Method II steady-state failure rates. Method II device base failure rates can also be substituted for the Table 11-1 generic failure rates in the unit level Parts Count calculations.

When unit level failure rates are to be input into system level reliability models, Method II unit steady-state failure rates should be substituted for the Parts Count failure rates wherever they appear in the system reliability model.

7.2 Method II Criteria

Method II criteria are as follows:

R7-1 **[3]** The supplier must provide all supporting information and Parts Count (Method I) predictions.

Method II may be applied only to *devices* procured or manufactured per Quality Levels II and III, unless there is no generic failure rate prediction for the device listed in Table 11-1. For a quality level I device not listed in Table 11-1, the requesting organization has the option to use a failure rate prediction from another source.

Method II may be applied only to *units* that contain devices procured or manufactured per Quality Levels II and III, unless no generic failure rate predictions are listed in Table 11-1 for some of the devices in the unit. In such a case, the requesting organization has the option to use a failure rate prediction from another source.

R7-2 **[4]** The quality levels of devices tested in the laboratory must be representative of the quality levels of the devices for which the prediction is to be used.

R7-3 **[5]** This section provides information on how many devices or units must be tested, how long the devices or units should be tested, how the devices should be tested, etc. In the criteria below, actual time is elapsed clock time, but effective time is actual time multiplied by an appropriate temperature acceleration factor. Criteria are as follows:

a. Test devices or units for an actual time of at least 500 hours. This ensures that each item is observed for a reasonable period of time - even for highly accelerated tests.

b. Test devices or units for an effective time of at least 3000 hours.

c. Select the number of devices or units placed on test so that at least two failures can be expected. Refer to Section 7.10 for details. Also, at least 500 devices or 50 units are required.

d. Test devices to simulate typical field operations, e.g., humidity and stress.

e. Include product from a representative sample of lots to ensure representativeness of the test.

The supplier may be asked to provide additional information to demonstrate the consistency of failure rates over time.

Statistical predictions for devices based on Method II may be generalized to other devices that have the following:

- The same type/technology
- The same packaging (e.g., hermetic)
- The same or lower levels of complexity
- A construction and design similar in material and technology.

The supplier may also be asked to provide additional data supporting the assertion that the products have similar reliabilities.

A supplier who wishes to use Method II predictions for other products must explain and justify those generalizations.

7.3 Cases for Method II Predictions

There are four general cases where laboratory data can be used for computing Method II predictions. The four cases and the worksheets (forms) provided for the calculations are

- Case L1 - Devices are laboratory tested (devices have had no previous burn-in), Form 9
- Case L2 - Units are laboratory tested (units/devices have had no previous burn-in), Form 10
- Case L3 - Devices are laboratory tested (devices have had previous burn-in), Form 11
- Case L4 - Units are laboratory tested (units/devices have had previous burn-in), Form 12.

R7-4 **[6]** Method II formulae and equations for each case are presented in the following paragraphs. The supplier must use the equations and formulas for the case that corresponds to the collected laboratory data.

7.4 Case L1 - Devices Laboratory Tested (Devices Have Had No Previous Burn-in)

To calculate the Method II *base failure rate* ($\lambda^*_{G_1}$) use the following two equations based on “A Bayes Procedure for Combining Black Box Estimates and Laboratory Tests”:

- If $T_1 \leq 10{,}000$, then

$$\lambda^*_{G_i} = [2 + n] / \left[\left(2/\lambda_{G_i}\right) + (4 \times 10^{-6}) N_0 (T_1)^{0.25} \pi_Q\right] \tag{7-1}$$

- If $T_1 > 10{,}000$, then

$$\lambda^*_{G_i} = [2 + n] / [(2/\lambda_G) + ((3 \times 10^{-5}) + (T_1 \times 10^{-9})) N_0 \pi_Q] \tag{7-2}$$

where

n = the number of failures in the laboratory test.

λ_{G_i} = the device Table 11-1 generic failure rate in FITs. If no generic failure rate is listed in Table 11-1, then a failure rate from another source may be used, subject to the approval of the requesting organization.

N_0 = number of devices on test.

T_1 = effective time on test in hours. The effective time on test is the product of the actual time on test (T_a) and the laboratory test temperature acceleration factor (A_L) from Table 11-7, Curve 7. Form 9 is a worksheet used to calculate device base failure rates for this case.

π_Q = device quality factor from Table 11-4.

When devices are laboratory tested, calculate the Method II unit steady-state failure rate from the device steady-state failure rates by replacing λ_{G_i} by $\lambda^*_{G_1}$ in the appropriate Section 6 equation [Equation (6-1) or (6-2)]. These calculations are made explicit in Forms 2 and 5.

7.5 Case L2 - Units Laboratory Tested (No Previous Unit/Device Burn-In)

When units are tested in the laboratory, the following formulae describes the calculation of the Method II *base failure rate* (λ^*_G):

- If $T_1 \leq 10{,}000$, then

$$\lambda^*_G = [2+n] / \left[(2/\lambda_G) + (4 \times 10^{-6}) N_0 (T_1)^{0.25}\right] \qquad \textbf{(7-3)}$$

- If $T_1 > 10{,}000$, then

$$\lambda^*_G = [2+n] / [(2/\lambda_G) + ((3 \times 10^{-5}) + (T_1 \times 10^{-9})) N_0] \qquad \textbf{(7-4)}$$

where

n = the number of failures in the laboratory test.

λ_G = the unit generic failure rate in FITs. It equals $\lambda_{SS} / (\pi_E \pi_T)$, where λ_{SS} is the Method I unit steady-state failure rate computed in Section 6.2.2, π_T is the unit temperature acceleration factor due to normal operating temperature (Table 11-7, Curve 7), and π_E is the environmental factor used in the computation of λ_{SS}. If no Method I prediction can be computed for a unit, then a failure rate prediction from another source may be used, subject to the approval of the requesting organization.

N_0 = number of devices on test.

T_1 = effective time on test in hours. The effective time on test is the product of the actual time on test (T_a) and the laboratory test temperature acceleration factor (A_L) from Table 11-7, Curve 7.

When units are tested in the laboratory, the Method II unit steady-state failure rate is $\lambda_G^* \ \pi_E \pi_T$. Form 10 is a worksheet used to calculate unit steady-state failure rates for this case.

7.6 Example 5

Consider the unit EXAMPLE from Example 1 (Section 6.5.1). Assume 500 units are tested at 65°C for 1000 hours, resulting in 3 failures. Assume also that the unit will be normally operated at 40°C. The Parts Count prediction was 1928 FITs.

For this example, the effective time on test is:

$$T_1 = T_a \times A_L = 1000 \times 3 = 3000 \text{ hours,}$$

where the acceleration factor (A_L)comes from Table 11-7, Curve 7. $(T_1)^{0.25}$ can be calculated by taking the square root of T_1 twice:

$$(3000)^{0.25} = \sqrt{\sqrt{3000}} = \sqrt{55} = 7.4.$$

Since $N_0 = 500$,

$$0.000004 \times N_0(T_1)^{0.25} = 0.000004 \times 500 \times 7.4 = 0.0148$$

And since $\lambda_{SS} = 1928$, $\pi_T = 1.0$, and $\pi_E = 2.0$, it follows that $\lambda_G = 964$. So, $2/\lambda_G = 2/964 = 0.0021$.

Therefore, the denominator of Equation (7-3) is 0.0169. Since $n = 3$, the numerator of Equation (7-3) is 2+3 or 5. So the laboratory method base failure rate is:

$$\lambda_G^* = 5/0.0164 = 296 \text{ FITs.}$$

The unit steady-state failure rate is $296 \times 2.0 = 592$ FITs.

7.7 Case L3 - Devices Laboratory Tested (Devices Have Had Previous Burn-In)

When there is burn-in, calculation of the Method II estimators is more complicated. Define the total effective burn-in time for Method II for *devices* to be:

$$T_e = A_{b,d}\, t_{b,d}$$

where

$A_{b,d}$ = temperature acceleration factor (from Table11-7, Curve 7) due to device burn-in

$t_{b,d}$ = device burn-in time (hours).

The Method II base failure rate ($\lambda^*_{G_i}$) is:

$$\lambda^*_{G_i} = [2 + n]/[(2/\lambda_{G_i}) + (4 \times 10^{-6})\, N_0 W \pi_Q]$$

where n, λ_{G_i}, and N_0 are defined in Section 7.4, and W is calculated as follows:

- If $T_1 + T_e \leq 10{,}000$, then

$$W = (T_1 + T_e)^{0.25} - T_e^{0.25}$$

- If $T_1 + T_e > 10{,}000 \geq T_e$, then

$$W = ((T_1 + T_e)/4000) + 7.5 - T_e^{0.25}$$

- If $T_e > 10{,}000$, then

$$W = T_1 / 4000$$

where T_1 is the effective time on test.

Form 11 is a worksheet that can be used to calculate device base failure rates in this case.

When devices are laboratory tested, calculate the Method II unit steady-state failure rate from the device steady-state failure rates by simply replacing λ_{G_i} by $\lambda^*_{G_i}$ in the appropriate Section 6 equation [Equation (6-1) or (6-2)].

These calculations are made explicit in Form 11.

7.8 Case L4 - Units Laboratory Tested (Units/Devices Have Had Previous Burn-In)

For *units* tested in the laboratory, the total effective burn-in time for Method II is:

$$T_e = T^*_{b,d} + A_{b,u}\, t_{b,u}$$

where

$T^*_{b,d}$ = average device effective burn-in time.

$A_{b,d}$ = temperature acceleration factor (from Table 11-7, Curve 7) corresponding to the unit burn-in temperature.

$t_{b,d}$ = unit burn-in time (hours).

The following formula describes how to calculate the Method II base failure rate (λ^*_G) is:

$$\lambda^*_G = [2 + n]/[(2/\lambda_G) + (4 \times 10^{-6})\, N_0 W]$$

where n, λ_G, and N_0 are defined in Section 7.5 and W is calculated as follows:

- If $T_1 + T_e \leq 10{,}000$, then

$$W = (T_1 + T_e)^{0.25} - T_e^{0.25}$$

- If $T_1 + T_e > 10{,}000 \geq T_e$, then

$$W = ((T_1 + T_e)/4000) + 7.5 - T_e^{0.25}$$

- If $T_e > 10{,}000$, then

$$W = T_1 / 4000$$

where T_1 is the effective time on test.

Form 12 is a worksheet that can be used to calculate unit base failure rates in this case.

When *units* are tested in the laboratory, the Method II unit steady-state failure rate is $\lambda^*_G \pi_E \pi_T$.

7.9 Example 6

Consider the unit EXAMPLE from Example 1 (Section 6.5). Assume that there are 1000 hours of unit burn-in at 70°C, and that the unit will be operated at 40°C. Under these conditions, reliability predictions are calculated as shown below.

As in Example 5, $n = 3$, $\lambda_G = 964$, and $N_0 = 500$. Only W must be calculated. To calculate W, first calculate T_e.

$$T_e = T^*_{b,d} + A_{b,u}\, t_{b,u} = 0 + (3.7) \times (1000) = 3700$$

The factor 3.7 comes from Column 7 of Table 11-7. W is given by

$$W = (3000 + 3700)^{0.25} - (3700)^{0.25} = 1.25$$

Therefore,

$$\lambda^*_G = 5/(0.0021 + 0.0025) = 1087 \text{ FITs}$$

The unit steady-state failure rate is (1087) × (2.0) = 2174 FITs.

7.10 Calculation of the Number of Units or Devices on Test

The following formula gives the number (N_0) of units or devices to be placed on test so that at least two failures can be expected:

$$N_0 = (0.5 \times 10^6) / [R((T_1 + T_e)^{0.25} - \mathrm{T}_\mathrm{e}^{0.25})],$$

where

R = Method I prediction, if one can be computed. If no Method I prediction can be computed, then a prediction from an alternate source may be used, subject to approval from the requesting organization.

T_1 = Effective time on test in hours (see Section 7.4 for devices and Section 7.5 for units).

T_e = Effective burn-in time, if any, in hours (see Section 7.7 for devices and Section 7.8 for units).

8. Method III: Predictions From Field Tracking

This section gives the applicability criteria and the reliability prediction procedure for Method III.

8.1 Introduction

Field tracking data and supporting information must meet the criteria listed later in this section. The field tracking process, system, and data must be available for review by the requesting organization to ensure that these criteria have been satisfied.

Field tracking data may be used for direct computation of field failure rates at the unit or device level, depending on the supporting information provided. The unit or device level field failure rates are then used to determine the Method III unit or device level steady-state[1] failure rate predictions, which can then be applied in a system level reliability model for the supplier's system.

The Method III failure rate prediction is a weighted average of the observed field failure rate and the Parts Count prediction, with the weights determined by the field data. When there are a large number of total operating hours for a device or unit during a field tracking study, the Method III failure rate prediction is heavily influenced by the field data. When there are a small number of total operating hours, the Method III failure rate prediction is more heavily influenced by the parts count prediction.

8.2 Applicability

The Method III procedure and computations are intended for application to field data collected from a population of devices or units that are all in the steady-state phase of operation, but the procedure may be applied to field data collected from a population of devices or units that does not meet this condition. However, no infant mortality adjustment to the Method III prediction is permitted. Method III criteria and procedure are given in Section 8.4.

8.3 Definitions and Symbols

This section contains the definitions and symbols needed to describe the Method III prediction procedure.

---

[1] Method III does not include procedures for predicting failure rates or other measures of reliability during the infant mortality phase of operation.

8.3.1 Definitions

Subject system refers to the system for which failure rate predictions are needed.

Subject unit refers to a unit-type that belongs to the subject system.

Tracked systems refers to the particular sample of in-service systems from which field tracking data is collected. The tracked systems may be of a different type than the subject system [see Section 8.4, Methods III(b) and III(c)].

Tracked unit refers to a unit in the tracked systems for which reliability data is being collected. A tracked unit may be of a different type than the corresponding subject unit for which the reliability is being predicted [see Section 8.4, Method III(c)]. However, the tracked system is similar to the subject system. Both systems are similar in design and construction, and the differences are due to environmental and operating conditions.

8.3.2 Symbols

t - Total Operating Hours of the device or unit in the tracked systems

f - number of failures observed in the tracked systems in time t (field failure count)

N_i - quantity of i^{th} device

λ_{SS1} - For a subject unit: the Method I steady-state failure rate prediction λ_{SS}. For a subject device: the Method I steady-state failure rate prediction λ_{SSi}, multiplied by the environmental factor, π_E, for the subject system. That is:

$$\lambda_{SS1} = \lambda_{SS}, \text{ for a subject unit, and}$$

$$\lambda_{SS1} = \lambda_{\mathrm{SSi}}\ \pi_E, \text{ for a subject device.}$$

λ_{SS} and λ_{SSi} are the Method I predictions, as specified in Section 8.6.

λ_{SS2} - For a tracked unit (when different from the subject unit): the Method I, Case 3 steady-state failure rate prediction. That is:

$$\lambda_{SS2} = \lambda_{SS},$$

where λ_{SS} is the Method I, Case 3 steady-state failure rate prediction for a tracked unit.

Θ_{SSi} - the Method III failure rate prediction for the i^{th} device

Θ_{SS} - the Method III unit failure rate prediction

Θ_{SS3} - general symbol used for a Method III unit or device level failure rate prediction.

π_{T1},π_{T2} - the temperature factors from Table 11-7 for the device or unit operating under normal temperatures in the subject (1) and tracked (2) system. For devices, use the temperature stress curve indicated in Table 11-1. For units, use temperature stress Curve 7.

8.4 Method III Criteria

This section describes three general categories of field data and the criteria for Method III applicability.

8.4.1 Source Data

When unit level reliability predictions are to be used as input to a system reliability model for evaluation of a supplier's system, three general categories of field data may be used to compute Method III predictions. Methods III(a), III(b), and III(c) are specified based on the source category of the field data.

Method III(a)

Statistical predictions of the failure rates of device types, unit types, or subsystems based on their in-service performance as part of the subject system.

Method III(b)

Statistical predictions of the failure rates of device types, unit types, or subsystems of the subject system based on their in-service performance as part of another system. Proper adjustments of those estimates, which take into account all differences between the operating conditions/environment of the equipment items in the two systems, are required in all cases.

Method III(c)

Statistical predictions of the failure rates of unit types or subsystems (excluding device types) of the subject system based on the in-service performance of similar equipment items from the same manufacturer that have a construction and design similar in material and technology and that are used in similar applications and environments. This does not imply that reliability parameters estimated for similar items can be directly applied to the unit types or subsystems of the subject system. Proper adjustments of those estimates, which take into account all design and operating condition differences between the tracked equipment items and those in the subject system for which the failure rates are being estimated, are required in all cases. A supplier who uses Method III(c) must explain and justify those adjustments.

8.4.2 Study Length and Total Operating Hours

R8-1 **[7]** This section specifies the length of the field tracking study and the total operating hours required when using Method III. The criteria are

… 1. The field tracking study must cover an elapsed clock time of at least 3000 hours.

… 2. The total operating hours t must satisfy the following:

… *For Methods IIIa and IIIb:*

$$t \geq \frac{2 \times 10^{9}}{\lambda_{SS1}}$$

… *For Method IIIc:* $t \geq \frac{2 \times 10^{9}}{\lambda_{SS2}}$

8.4.3 Subject Unit or Device Selection

Use of Method III failure rate predictions in system reliability models is permitted as follows:

- When Method III predictions are submitted for all unit or device types that make up the subject system
- When Method III predictions are submitted for a set of subject unit or device types that have been selected by the requesting organization
- When Method III predictions are submitted for a set of subject unit or device types that meet some criteria designated by the requesting organization for example, unit types whose failure rates account for more than some designated percentage of the total individual line downtime.

8.4.4 Quality and Environmental Level

R8-2 **[8]** Method III failure rate predictions are permitted for devices of any quality level and for units containing devices of any quality level, subject to the following:

…
- The quality levels (see Table 11-3) of devices used in the subject system must be equal to or better than the quality levels of the devices in the tracked systems.

…
- For a Quality Level I device type, the requesting organization has the option to use the Method III prediction, the Method I prediction or, if no generic failure rate is included in Table 11-1, a failure rate prediction from another source.

…
- For a unit type that contains Quality Level I devices, the requesting organization has the option to use the Method III prediction, the Method I prediction or, if the unit contains devices for which no generic failure rate is included in Table 11-1, a failure rate prediction from another source.

Method III failure rate predictions are permitted for devices or units deployed in a ground fixed or ground mobile environment (see Table 11-8), subject to the following:

- The environmental level of the subject system must be the same or less severe than the environmental level of the tracked systems.

8.5 Field Data and Information

R8-3 **[9]**The supplier must provide the following field data and supporting information:

…
- The definition of "failure" for each unit type being tracked and for each device type for which Method III predictions are to be computed.

…
- A general description of how a No Trouble Found (NTF) is determined for a returned unit, and a complete description of any failure mode that is not counted as a failure in the field tracking study (e.g., handling damage).

…
- Unit types and quantities (in-service and spare) for each tracked system. If field data is to be used for device-level reliability predictions, then the device types and quantities must also be provided for each unit type tracked during the field tracking study.

…
- The total operating hours during the field tracking study for each unit type being tracked, and for each device type for which Method III predictions are to be computed. The general formula used to compute the total operating hours must also be provided. If the field tracking study does not provide an accurate count of the actual operating hours in the field, a reasonable estimate of the operating hours may be obtained by taking into account the shipping dates and average times for shipment, delivery, and installation.

…
- The total number of failures for each unit type tracked during the study. If the data is to be used for device-level reliability predictions, then the total number of failures for each device type must also be included.

R8-4 **[10]**The supplier must maintain the following historical and accounting information and provide any part of it upon request:

…
1. For any unit (in-service or spare) deployed in the tracked systems during the study period

…
    - A unique identification number, serial number, or bar code - the number or bar code must be on the unit and clearly visible

…
    - Shipment date

…
    - Destination (site or system)

…
    - Date the unit was available for deployment

…
    - Date returned to repair facility due to possible failure

…
    - Results of test (failure or NTF)

… • The identity of devices that had failed and were replaced in the failed unit (for device level reliability predictions only)

… • Date repaired unit was available for re-deployment.

… 2. The results of weekly (or more frequent) repair/shipping activity audits that confirm all units are accounted for and all maintenance actions are properly recorded. The audits must cover all processing, testing, repair, and data entry activity for units returned or shipped out during the auditing period (for all company and external repair activities). Repair activities conducted at field locations (if any) must also be covered.

8.6 Method III Procedure

R8-5 **[11]**The Method III reliability predictions must be based on the correct application of the steps outlined below.

Step 1: Determine the number of field failures, *f*, and the total operating hours, *t*, for the unit or device in the tracked systems.

Step 2: If using Methods IIIb or IIIc, determine the operating temperature factors π_{T1} and π_{T2} as defined in Section 8.3.

Step 3: If Table 11-1 includes the generic failure rates necessary to compute a Method I prediction for the subject device or unit, then compute the value of λ_{SS1}, as defined in Section 8.3 and in accordance with the following:

- For Methods IIIa and IIIb: compute λ_{SS1} using either the Method I, Case 1, or Case 3 failure rate prediction, unless the choice is specified by the requesting organization.
- For Method IIIc: compute λ_{SS1} using the Method I, Case 3 prediction.

Step 4: When the tracked unit is different than the subject unit (i.e., when using Method IIIc) and Table 11-1 includes the generic failure rates necessary to compute a Method I prediction for the tracked unit, then compute λ_{SS2}, as defined in Section 8.3.

Step 5: Compute the adjustment value, *V*, as follows:

V =	1.0	For Method IIIa
	$\frac{\pi_{T2}}{\pi_{T1}}$	For Method IIIb
	$\frac{\lambda_{SS2}}{\lambda_{SS1}}$	For Method IIIc

Method IIIc may not be used in cases where Table 11-1 does not include the necessary generic failure rates to compute both λ_{SS1} and λ_{SS2} as defined in Section 8.3 and in accordance with Step 3 above.

Step 6: Calculate the Method III failure rate prediction, Θ_{SS3}, as follows:

$$\Theta_{SS3} = \frac{2 + f}{\frac{2}{\lambda_{SS1}} + (V \times t \times 10^{-9})}$$

where V is computed in Step 5 above.

The Method III failure rate is obtained as a weighted average of the generic steady-state failure rate and the field failure rate. Bellcore assumes that the generic steady-state failure rate is based on the data that includes two failures.

If λ_{SS1} is not available: the Method IIIa and Method IIIb failure rate prediction, Θ_{SS3}, is computed as follows:

$$\Theta_{SS3} = \frac{10^9 \times U}{t \times V}$$

where V is computed in Step 5 above, and U is the upper 95 percent confidence limit for the mean of a Poisson variable given that f field failures were observed. The values of U are provided in Table 11-12 for f ranging from 0 to 160.

8.7 Examples

This section gives two examples of reliability predictions at the unit level.

8.7.1 Example 7; Unit Level, Method III(a)

A supplier has field tracking data on a remote switching terminal that meets all Method III criteria. The total operating hours for circuit pack #xyz during the study period is 10^8 hours, with field failure count $f = 70$ and an operating temperature of 50°C. For circuit pack #xyz (ground fixed environment) $\lambda_{SS1} = 600$ FITs, and is computed using the Method I, Case 1 prediction.

From Step 5, $V = 1.0$, and from Step 6:

$$\Theta_{SS} = \frac{2 + 70}{\frac{2}{600} + (1.0 \times 10^8 \times 10^{-9})} = 697 \text{ FITs.}$$

8.7.2 Example 8; Unit Level, Method III(b)

A supplier has unit level field tracking data for circuit pack #xyz from the operation of System 2 remote switching terminals and wants to use that data to predict the failure rate of circuit pack #xyz operating in System 1 remote switching terminals. Both systems operate in a ground fixed environment. The field failure count for the pack in System 2 is $f = 70$ with total operating time $t = 10^8$ hours. The operating temperature of the pack is 55°C in System 1 and 50°C in System 2. $\lambda_{SS1} = 600$ FITs, and is computed using the Method I, Case 1 prediction.

From Table 11-7, Curve 7, $\pi_{T1} = 2.0$ and $\pi_{T2} = 1.6$; from Step 5,

$$V = \frac{\pi_{T2}}{\pi_{T1}} = \frac{1.6}{2.0} = 0.8.$$

Then from Step 6:

$$\Theta_{SS} = \frac{2 + 70}{\frac{2}{600} + (0.8 \times 10^{8} \times 10^{-9})} = 864 \text{ FITs.}$$

9. Serial System Reliability (Service Affecting Reliability Data)

This section describes the computation of reliability predictions for serial systems.

9.1 Steady-State Failure Rate

If the specified reliability parameters, failure criteria, equipment configuration, and operating conditions indicate that a serial reliability model is appropriate, the total system failure rate, λ_{SYS}, will be the sum of all the unit steady-state failure rates, λ_{SS}. That is,

$$\lambda_{SYS} = \sum_{j=1}^{M} \lambda_{SS(j)}$$

where $\lambda_{SS(j)}$ is the unit steady-state failure rate for unit j and M is the number of units. The discussion in early subsections of Section 6 omitted the subscript j for simplicity because there was only one unit. Note that the unit steady-state failure rates are assumed to reflect only service affecting failures. The unit failure rates come from Form 3, 4, or 6, depending on whether Case 1, 2, or 3, respectively, was used (see Sections 6.2 and 6.4). It is assumed that these unit failure rates have been modified to remove non-service affecting failures (see Form 7 and Section 6.6). However, before doing so, the service impact of repairing faults in non-service affecting components should be considered.

9.2 First-Year Multiplier

The system first-year multiplier π_{FYSYS} for a serial system is given by the following:

$$\pi_{FYSYS} = \frac{\sum_{j=1}^{M} \lambda_{SS(j)}\pi_{FY(j)}}{\lambda_{SYS}}$$

where $\pi_{FY(j)}$ is the unit first-year multiplier for the j^{th} unit.

9.3 Applicability

Many communications systems do not conform to a serial reliability model. If the requesting organization concludes that the serial model is inappropriate, a suitable reliability model must be developed. Complex systems will require the application of techniques described in various reliability engineering references (for example, *Probabilistic Reliability: An Engineering Approach*, “Practical Markov Modeling for Reliability Analysis,” “Modeling IC Failure Rates,” and SR-TSY-001171, *Methods and Procedures for System Reliability Analysis*). Specification of reliability modeling techniques for complex systems is beyond the scope of this procedure. The supplier must submit drawings, diagrams, or specifications necessary to substantiate the reliability model.

9.4 Assumptions and Supporting Information

In developing repair rates or expected times to restore service, it may be assumed that all necessary test equipment and replacement units are present and operational. The supplier must state assumptions concerning the numbers of maintenance craftspersons, particularly for the case of multiple failures. Supporting information for the estimated repair rates or expected times to restore service must also be provided. Evidence should include descriptions of alarms or other failure detection and reporting capabilities, as well as travel time assumptions, and manual or automatic diagnostic aids.

9.5 Reporting

Enter the reliability determinations on Form 8, the “System Reliability Report” (Figure 10-8).

The supplier should present any additional reliability information or factors that enhance or detract from the equipment reliability by completing Form 13, the “Additional Reliability Data Report” (Figure 10-13). Quantitative effects on equipment reliability must be described.

The supplier must provide nonproprietary design information, such as functional block diagrams, parts lists, procurement specifications, and test requirements, as requested in preceding paragraphs or required by the requesting organization. Each submitted document should be included on Form 14, the “List of Supporting Documents” (Figure 10-14).

10. Form/Worksheet Exhibits and Preparation Instructions

The following pages include form/worksheet exhibits and associated preparation instructions for the reliability prediction procedure. These worksheets and instructions may be copied and used as needed.

REQUEST FOR RELIABILITY PREDICTION

Product ___________________________________ Request Date ________________________________

Manufacturer ______________________________ Estimate Due ________________________________

LIFE CYCLE COST DATA REQUESTED:

☐ Steady-state failure rate for each unit (λ_{SS})

☐ Time averaged first year failure rate multiplier (π_{FY})

SERVICE AFFECTING SYSTEM RELIABILITY PARAMETERS REQUESTED:

DEFINITION OF A SYSTEM FAILURE:

OPTIONS PER PARTS COUNT METHOD:

☐ Supplier May Use Any Case

☐ Limited Stress only - Supplier Must Use Case 3

☐ Sampled Limited Stress - Supplier Must Use Case 3 on a Sample of Units

RELIABILITY PREDICTION METHOD:

☐ Method I: Parts Count

☐ Other ______________________________

☐ Method II: Combination of Laboratory Data & Parts Count

☐ Method III: Field Tracking Data - Also include Parts Count Method

OPERATING CONDITIONS:

ENVIRONMENT(S): π_E =

STEADY-STATE RELIABILITY OBJECTIVES:

ADDITIONAL INFORMATION REQUESTED FROMN SUPPLIER:

SEND RESPONSE TO: ____

Figure 10-1. Request for Reliability Prediction (Form 1)

Instructions for Form 1: Request for Reliability Prediction

1. Provide the items of information on the top portion of the form.
2. Mark the life cycle cost data requested.
3. Specify the system level service-affecting parameters (e.g., frequency of system outage).
4. Define the system failures that affect service (not maintenance). For complex systems, it would be desirable to specify the acceptable level of service.
5. Describe the operating conditions, including the ambient temperature.
6. Specify the environmental condition and the corresponding π_E from Table 11-8.
7. Specify the steady-state reliability objectives for the overall system. For multi-function systems, there may be reliability objectives for individual functions.
8. Provide any additional reliability information requested from the supplier such as burn-in procedures and reliability-oriented design controls.

Device Reliability Prediction Worksheet

Case 1 Or 2 - Black Box Estimates (50% Stress, Temperature = 40° C,
No Device Burn-in)

π_E = ____________ .

Date	**Page ______of ______**
Unit	**Manufacturer**

Device Type*	**Part Number**	**Circuit Ref. Symbol**	**Qty** (N_j)	**Failure** Rate** $\left(\lambda_{G_j}\right)$	**Quality Factor** $\left(\pi_{Q_j}\right)$	**Total Device Failure Rate** $\left(N_j\lambda_{Gj}, \pi_{Q_j}\right)$ (f)
SUBTOTAL						

TOTAL = $(\lambda_{SS}) = \pi_E \Sigma N_j \lambda_G \pi_Q$ = (   ) (   ) =

* Similar parts having the same failure rate, base part number, and quality factor may be combined and entered on one line. Part descriptions should be sufficient to verify that correct failure rate assignment has been made.

** Failure rates come from Table 11-1. If Method II is applied to devices, instead use failure rate (j) from Form 9 (λ^*_{Gj}).

Figure 10-2. Device Reliability Prediction, Case 1 or 2 (Form 2)

Instructions for Form 2: Worksheet for Device Reliability Prediction

Case 1 or 2: Black Box Estimates (50% Stress, Temperature = 40°C, No Device Burn-In)

1. Provide the items of information requested on the top portion of the form.
2. Fill in one row of the form for each device used in the unit. If more than one device will have the same value in each of the columns, the devices may be combined on one row.
3. Enter the device type. The description should be sufficient to verify that the correct failure rate was selected.
4. Enter the device part number. If multiple devices are listed in a row, the base part number is sufficient.
5. Enter the circuit reference symbol(s).
6. Record the quantity (N_i) of devices covered in the row.
7. Record the base failure rate (λ_{G_i}).

   For Method I, this value may be obtained from Table 11-1. If a device is not listed in Table 11-1, select a failure rate for a device that is most like the unlisted device. If no reasonable match can be made, use available field data, test data, or the device manufacturer's reliability estimate. Document and submit the rationale used in determining the failure rate. When using failure rates calculated according to Method II, enter $\lambda^*_{G_i}$ from Form 9 or 11.
8. Record the quality factor (π_{Q_i}).

   Use the guidelines in Table 11-3to evaluate the device procurement and test requirements and to determine the appropriate quality level for the device. Submit representative examples of procurement specifications and quality/test requirements to justify use of quality levels other than Level I. Select a Quality Factor (π_{Q_i}) in Table 11-4 that corresponds to the quality level that was determined for each device.
9. Determine the total device failure rate by performing the calculation indicated in the last column.
10. When all devices in a unit have been accounted for, sum the last column.
11. Use the equation on the bottom of Form 2 to calculate the unit λ_{SS}. Be sure to include the π_E term obtained from Form 1.

Unit Reliability Prediction Worksheet

Case 1 - Black Box Estimates (50% Stress, Temperature = 40° C,
Unit/System Burn-in ≤ 1 Hour, No Device Burn-in)

Date		**Page _______of _______**
Product	**Rev**	**Manufacturer**

Unit Name	**Unit Number**	**Repair Category**			**Steady State Failure Rate (From Form 2) (FITs)** λ_{SS}	**If Method II is applied to units, (From Form 10)** λ^*_{SS}	**First Year Multiplier** π_{FY}
		Factory Repairable	**Field Repairable**	**Other**			
							4.0
							4.0
							4.0
							4.0
							4.0
							4.0
							4.0
							4.0
							4.0
							4.0
							4.0
							4.0
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							4.0
							4.0
							4.0
							4.0
							4.0
							4.0
							4.0
							4.0
							4.0

Figure 10-3. Unit Reliability Prediction, Case 1 (Form 3)

Instructions for Form 3: Worksheet for Unit Reliability Prediction

Case 1: Black Box Estimates (50% Stress, Temperature = 40°C, Unit/System Burn-In $\leq$ 1 Hour, No Device Burn-In)

1. Provide the items of information requested on the top portion of the form.
2. Fill in one row of the form for each unit-type comprising the product.
3. Indicate the repair category by placing an (X) in the appropriate column.
4. Enter the unit steady-state failure rate (λ_{SS}) obtained from the bottom of Form 2.
5. If units are lab tested and Method II is being applied, enter λ^*_{SS} from Form 10.
6. $\pi_{FY} = 4$ has already been entered on the form.

Unit Reliability Prediction Worksheet

Case 2 - Black Box Estimates (50% Stress, Temperature = 40° C,
No Device Burn-in, Unit/System Burn-in > 1 Hour)

Date		**Page ______of ______**
Product	**Rev**	**Manufacturer**

Unit Name					
Unit Number					
Repair category Factory repairable					
Field repairable					
Other					
Unit burn-in Temperature $T_{b,u}$					
Acceleration factor† $A_{b,u}$					
Time $t_{b,u}$					
System burn-in Temperature $T_{b,s}$					
Acceleration factor‡ $A_{b,s}$					
Time $t_{b,s}$					
Effective burn-time t_e $t_e = A_{b,u}t_{b,u} + A_{b,s}t_{b,s}$					
First year Multiplier (Table 11-9 π_{FY}					
λ_{SS} (from Form 2) λ_{SS}					
From Form 12 when Method II is applied to units λ^*_{SS}					

Comments:

---

†Obtain From Table 11-7, Curve 7

Figure 10-4. Unit Reliability Prediction, Case 2 (Form 4)

Instructions for Form 4: Worksheet for Unit Reliability Prediction

Case 2: Black Box Estimates (50% Stress, Temperature = 40°C, No Device Burn-In, Unit/System Burn-In ≥ 1 Hour)

1. Provide the items of information requested on the top portion of the form.
2. Fill in one column of the form for each unit comprising the product.
3. Indicate the repair category by placing an (X) in the appropriate row.
4. If more than one hour of equivalent operating time at 40°C is accumulated on the unit before final acceptance of the product, provide the operating data as follows:

$T_{b,u}$ = Unit burn-in temperature (°C)

$A_{b,u}$ = Arrhenius acceleration factor (Table 11-7, Curve 7) corresponding to the unit burn-in temperature

$t_{b,u}$ = Unit burn-in time (hours)

$T_{b,s}$ = System burn-in temperature (°C)

$A_{b,s}$ = Arrhenius acceleration factor (Table 11-7, Curve 7) corresponding to the system burn-in temperature

$t_{b,s}$ = System burn-in time (hours). If more than one burn-in temperature is involved in unit or system burn-in, record the additional T_b, A_b, and t_b values in the appropriate row. The same column may be used to record multiple sets of T_b, A_b, and t_b data.

5. Determine the effective burn-in time (t_e) accumulated as a result of unit and system burn-in. Be sure to include all T_b, A_b, and t_b values.
6. Take the unit first year failure rate multiplier (π_{FY}) from Table 11-9.
7. Record the unit steady-state failure rate λ_{SS} (obtained from the bottom of Form 2, or, when using results from Method II, use λ_{SS}^* from the bottom of Form 12).
8. When Method II is applied to units, enter λ_{SS}^* from the bottom of Form 12.

Unit Reliability Prediction Worksheet

(GENERAL CASE 3 - Including Limited Stress)

Date **Page _____of_____**

Unit **Manufacturer**

Device Type								Cumulative sum of (f)
Part Number								
Circuit ref. symbol								
Quantity	N_j	(a)						
Generic failure rate[†]	λ_{Gj}	(b)						
Quality factor	π_{Qj}	(c)						
Stress factor	π_{Sj}	(d)						
Temperature factor	π_{Tj}	(e)						
Device quantity x device failure rate $(f) = (a) \times (b) \times (c) \times (d) \times (e)$		(f)						
Device burn-in Temperature	$T_{b,d}$							Cumulative sum of (u)
Acceleration factor[‡]	$A_{b,d}$	(g)						
Time	$t_{b,d}$	(h)						
Unit Burn- in Temperature	$T_{b,u}$							
Acceleration factor[‡]	$A_{b,u}$	(i)						
Time	$t_{b,u}$	(j)						
System burn-in Temperature	$T_{b,s}$							
Acceleration factor[‡]	$A_{b,s}$	(k)						
Time	$t_{b,s}$	(m)						
Early Life Temp. Factor[‡]	A_{op}	(n)						
$(o) = 1000/[(d) \times (e)]$		(o)						
$(p) = (g) \times (h) + (i) \times (j) + (k) \times (m)$		(p)						
Eff. burn-in time: $(p)/[(d) \times (n)]$		(q)						
$(1) \mathrm{If} (q) \geq (o)$	$(r) = 1$	(r)						
$(2) \mathrm{If} (q) \leq (o) - 8760$ Look up (q) in Table 11-9		(s)						
$(r) = (s)/[(d) \times (e)]^{0.75}$		(r)						
(3) Otherwise Look up (p) in Table 11-9		(t)						
$(r) = [(t) - 1]/[(d) \times (e)] + 1$		(r)						
$(u) = (r) \times (f)$		(u)						

[†] Failure rates come from Table 11-9. If Method II is applied devices, use (p) from Form 11.

[‡] Obtain From Table G, Curve 7

Figure 10-5. Device Reliability Prediction, General Case (Form 5)

Instructions for Form 5: Worksheet for Device Reliability Prediction, General Case

1. Provide the items of information requested at the top of the form.
2. Fill in one column of the form for each device in the unit. If more than one device will have the same value in *each* of the rows, they may be combined.
3. Enter the device type. The description should be sufficient to verify that the correct failure rate was selected.
4. Enter the device part number. If multiple devices are listed in a column, the base part number is sufficient.
5. Enter the circuit reference symbol(s).
6. Record the quantity (N_i) of devices covered in the column.
7. Record the base failure rate (λ_{G_i}). For Method I, this value is obtained from Table 11-1. If a device is not listed in Table 11-1, select the failure rate for the device most like the unlisted device. If no reasonable match can be made, use field data, test data, or the device manufacturer's reliability estimate. Document and submit the rationale used to determine the failure rate. When using failure rates calculated according to Method II, enter $\lambda^*_{G_i}$, from Form 9 or 11.
8. Record the quality factor (π_{Q_i}). Use the guidelines in Table 11-3 to evaluate the device procurement and test requirements and to determine the appropriate quality level for the device. Submit representative examples of procurement specifications and quality/test requirements to justify use of quality levels other than Level I. Select a quality factor (π_{Q_i}) in Table 11-4 that corresponds to the quality level that was determined for each device.
9. Use Table 11-1 to find the applicable temperature stress curve for the device. Record the stress factor (π_{S_i}). If no curve number is listed, use $\pi_S = 1.0$. If a curve number is listed, evaluate the application of the device and determine the average ratio of actual to rated stress using the guidelines of Table 11-5. Use Table 11-6 to find π_S based on the appropriate stress ratio and stress curve. Round off the percent stress to the nearest 10 percent before entering from Table 11-6.
10. Use Table 11-7 to determine the device steady-state temperature factor (π_T).
11. Determine the product of the device quantity and the device steady-state failure rate by (f) = (a)×(b)×(c)×(d)×(e).

12. Record the following burn-in data:

$T_{b,d}$ = device burn-in temperature (°C)

$A_{b,d}$ = Arrhenius acceleration factor (Table 11-7, Curve 7) corresponding to the device burn-in temperature.

$t_{b,d}$ = device burn-in time (hours)

$T_{b,u}$ = unit burn-in temperature (°C)

$A_{b,u}$ = Arrhenius acceleration factor (Table 11-7, Curve 7) corresponding to the unit burn-in temperature

$t_{b,u}$ = unit burn-in time (hours)

$T_{b,s}$ = system burn-in temperature (°C)

$A_{b,s}$ = Arrhenius acceleration factor (Table 11-7, Curve 7) corresponding to the system burn-in temperature

$t_{b,s}$ = system burn-in time (hours). If more than one burn-in temperature is involved in unit or system burn-in, record the additional T_b, A_b, and t_b values in the appropriate row. The same column may be used to record multiple sets of T_b, A_b, and t_b data.

13. Calculate device first year multiplier by completing operations shown in remaining rows. To calculate (n), use the operating temperature and look up the answer in Table 11-7, Curve 7.

14. Add the columns to find the cumulative sum of row (f) and the cumulative sum of row (u), respectively. Transcribe totals onto Form 6.

Unit Reliability Prediction Worksheet

(GENERAL CASE - Including Limited Stress)

Date			**Page ______of ______**
Product		**Rev**	**Manufacturer**

Unit Name						
Unit Number						
Repair category Factory repairable						
Field repairable						
Other						
From Form 5: Sum of (u)	(u)					
From Form 5: Sum of (f)	(f)					
Environmental Factor	π_E					
$\pi_E \times (f)$	λ_{SS}					
First year multiplier $= (u)/(f)$	π_{FY}					
If Method II is applied to units, from Form 12:	λ^*_{SS}					
Comments:						

Figure 10-6. Unit Reliability Prediction, General Case (Form 6)

Instructions for Form 6: Worksheet for Unit Reliability Prediction, General Case

1. Provide the items of information requested on the top portion of the form.
2. Fill in one column of the form for each unit comprising the product.
3. Indicate the repair category by placing an (X) in the appropriate row.
4. Complete Form 5 for the devices in each unit.
5. After completing Form 5, sum rows (f) and (u) and transcribe the total onto Form 6.
6. Record the environmental factor π_E (from Form 1).
7. Calculate the unit steady-state failure rate (λ_{SS}) by multiplying π_E and (f).
8. Calculate and record the first year multiplier (π_{FY}).
9. If Method II is applied to this unit, record the Method II steady-state failure rate taken from the bottom of Form 12.

Items Excluded From Unit Failure Rate Calculations

Date	**Unit**
Manufacturer	

Device		Reason	From Form 2 or 5	
Type	Number		(f)	(u)*
			TOTALS	

After completing this form, calculate the following failure rate data:

Non-service Affecting

$\pi_E \times \Sigma(f) = \lambda_{SS_{na}} =$ ☐

$\frac{\Sigma(u)}{\Sigma(f)} = \pi_{FY_{na}} =$ ☐

Where:

π_E = environmental factor (from Form 1).

Service Affecting

$\lambda_{SS} - \lambda_{SS_{na}} = \lambda_{SS_a} =$ ☐

$\frac{\pi_{FY}\lambda_{SS} - \pi_{FY_{na}}\lambda_{SS_{na}}}{\lambda_{SS_a}} = \pi_{FY_a} =$ ☐

Where:

λ_{SS} = total unit steady-state failure rate (from Form 3, 4, 6, 10, or 12).

π_{FY} = total unit First-Year Multiplier (from Form 4 or 6).

π_{FY} = 4.0, when λ_{SS} comes from Form 3 or 10.

*When the value of (f) is obtained from Form 2, $(u) = \pi_{FY} \times (f)$. Obtain the value of π_{FY} from Form 3, 4, or 6, whichever is applicable.

Comments:

Figure 10-7. Items Excluded from Unit Failure Rate Calculations (Form 7)

SYSTEM RELIABILITY REPORT
(Service Affecting Reliability Data)

System ____ **Date** ______

Manufacturer ____

A. Does the serial reliability model give usable results?

YES _________ (Complete A only)

NO __________(Complete B, C, and D)

If the answer is "YES", the estimated steady-state system reliability is:

____

B. The serial model for system reliability is inappropriate because: (Give specific reasons. List unit failure rates to be excluded or modified.)

C. The following reliability model is needed to give usable results. (Add additional pages if required.)

D. If a reliability model is included in Step (C), use it to combine the unit failure rates and repair rates or mean time to repair to obtain the appropriate reliability measure(s) of system reliability. Please show details of all calculations.

The estimated steady-state system reliability measures are:

____

____

Figure 10-8. System Reliability Report (Form 8)

Device Reliability Prediction Laboratory Data Worksheet

Case L-1 Devices Laboratory Tested (No Previous Burn-in)

Date

Page _____of_____

Unit

Manufacturer

Device Type								
Part Number								
Circuit ref. symbol								
Time on Test	T_a	(a)						
Laboratory test Temperature								
Acceleration factor†	A_L	(b)						
Effective time on test (c) = (a) x (b)	T_1	(c)						
Number of devices on test	N_0	(d)						
Number of lab failures	n	(e)						
Failure rate‡	λ_{Gj}	(f)						
Quality Factor	π_Q	(g)						
(1) If $(c) \le 10,000$ $(h) = 4 \times 10^{-6} \times (c)^{0.25}$ (2) If $(c) > 10,000$ $(h) = 3 \times 10^{-5} + (c) \times 10^{-9}$		(h)						
$i = [2/(f)] + (d) \times (g) \times (h)$		(i)						
Base failure rate $(j) = [2 + (e)]/(i)$	λ^*_G	(j)						

Comments:

†Obtain From Table 11-7, Curve 7

‡Obtain From Table 11-1

Figure 10-9. Device Reliability Prediction, Case L-1 (Form 9)

Instructions for Form 9: Worksheet for Device Reliability Prediction, Laboratory Data

Case L-1: Devices Laboratory Tested, No Burn-In

1. Provide the information requested on the top portion of the form.
2. Fill in one column of the form for each device used in the unit.
3. Enter the device type. The description should be sufficient to verify that the correct base failure rate was selected.
4. Enter the device part number.
5. Enter the circuit reference symbol(s).
6. Record the actual time spent on test (T_a) in hours.
7. Record the laboratory test temperature.
8. Determine the laboratory test temperature acceleration factor (A_L) from Table 11-7.
9. Calculate the effective time on test (T_1) by (c) = (a)×(b).
10. Record the number of devices on test (N_o).
11. Enter the total number of laboratory failures, *n*.
12. Record the device generic failure rate (λ_{G_i}). This value may be obtained from Table 11-1. If a device is not listed in Table 11-1, select a failure rate for a device that is most like the unlisted device. If no reasonable match can be made, use available field data, test data, or the device manufacturer’s reliability estimate. Document and submit the rationale used in determining the failure rate.
13. Record the device quality factor π_Q from Table 11-4.
14. Calculate the device base failure rate ($\lambda^*_{G_i}$) by performing the operations shown in the remaining rows.
15. To calculate the unit steady-state failure rate from these failure rates, transcribe the device base failure rate ($\lambda^*_{G_i}$) onto Form 2 or 5.

Unit Reliability Prediction Laboratory Data Worksheet

Case L-2 Units Laboratory Tested, No Previous Unit/Devices Burn-in

Date		**Page _____of_____**	
Product	Rev	Manufacturer	

Unit Name							
Unit Number							
Repair category Factory repairable							
Field repairable							
Other							
Time on test	T_a	(a)					
Laboratory test Temperature							
Acceleration factor†		(b)					
Operation Temperature							
Acceleration factor†		(c)					
Effective time on test (e) = (a) x (b)	T_1	(e)					
Number of lab failures	n	(f)					
Steady-state failure rate‡	λ_{SS}	(g)					
Environmental factor	π_E	(h)					
Failure rate $(i) = (g)/[(h)(c)]$	λ_G	(i)					
Number of units on test	N_0	(j)					
(1) If $(e) < 10,000$ $(k) = 4 \times (10)^{-6} \times (e)^{0.25}$ (2) If $(e) > 10,000$ $(k) = 3 \times 10^{-5} + (e) \times 10^{-9}$		(k)					
$(m) = [2/(i)] + (j) \times (k)$		(m)					
Base failure rate $(p) = [2 + (f)]/(m)$	λ^*_G	(n)					
Method II steady-state failure rate $(p) = (h) \times (n) \times (c)$	λ^*_{SS}	(p)					

Comments:

†Obtain from Table 11-7, Curve 7.

‡Obtain from Form 2.

Figure 10-10. Unit Reliability Prediction, Case L-2 (Form 10)

Instructions for Form 10: Worksheet for Unit Reliability Prediction, Laboratory Data

Case L-2: Units Laboratory Tested, No Burn-In

1. Provide the items of information requested on the top portion of the form.
2. Fill in one column of the form for each unit comprising the product.
3. Indicate the repair category by placing an (X) in the appropriate row.
4. Record the actual time spent on test (T_a) in hours.
5. Record the laboratory test temperature.
6. Determine the laboratory test temperature acceleration factor from Table 11-7.
7. Record the unit operating temperature.
8. Determine the operating temperature acceleration factor from Table 11-7.
9. Calculate the effective time on test (T_1) by (e) = (a)×(b).
10. Record the number of laboratory failures, n.
11. Transcribe the unit steady-state failure rate (λ_{SS}) from Form 2.
12. Enter the unit environmental factor π_E from Form 1.
13. Determine the failure rate (λ_G) by (i) = (g) / {(h)×(c)}.
14. Record the number of units on test (N_o).
15. Determine the unit base failure rate (λ_G^*) and Method II steady-state failure rate (λ_{SS}^*) by performing the operations shown in the remaining rows.

Device Reliability Prediction
Laboratory Data Worksheet

Case L-3 Devices Laboratory Tested (Devices Have Had Burn-in)

Date

Page _____of_____

Unit

Manufacturer

Device Name								
Part Number								
Circuit ref. symbol								
Failure rate[†]	λ_{Gj}	(a)						
Quality factor	π_Q	(b)						
Device burn-in Temperature	$T_{b,d}$							
Acceleration factor[‡]	$A_{b,d}$	(c)						
Time	$t_{b,d}$	(d)						
Effective burn-in time (c)x(d)	t_e	(e)						
Laboratory test Laboratory test temperature								
Test acceleration factor[‡]		(f)						
Time on test		(g)						
Operation Temperature								
Acceleration factor		(g)						
Number of devices on test	N_0	(h)						
Number of lab failures	n	(i)						
Effective time on test (j) = (f) x (g)	T_1	(j)						
(k) = (e) + (j)		(k)						
Weighing factor (1) If $(k) \le 10,000$ $(m) = (k)^{0.25} - (e)^{0.25}$ (2) If $(k) > 10,000$ and $(e) \le 10,000$ $(m) = (k)/4000 + 7.5 - (e)^{0.25}$ (3) If $(e) > 10,000$ $(m) = (j)/4$	W	(m)						
$(n) = [(2/(a)] + 4 \times 10^{-6} \times (b) \times (h) \times (m)$		(n)						
Method II steady-state failure rate $(p) = [2 + (i)]/(n)$	λ^*_{Gj}	(p)						

Comments:

[†] Obtain from Table 11-1.

[‡] Obtain from Table 11-7.

Figure 10-11. Device Reliability Prediction, Case L-3 (Form 11)

Instructions for Form 11: Worksheet for Device Reliability Prediction

Case L-3: Devices Laboratory Tested with Burn-In

1. Provide the items of information requested on the top portion of the form.
2. Fill in one column of the form for each device used in the unit.
3. Enter the device type. The description should be sufficient to verify that the correct base failure rate was selected.
4. Enter the device part number.
5. Enter the circuit reference symbol(s).
6. Record the device generic failure rate (λ_{G_i}) from Table 11-1. If a device is not listed in Table 11-1, select a failure rate for a device that is most like the unlisted device. If no reasonable match can be made, use available field data, test data, or the device manufacturer’s reliability estimate. Document and submit the rationale used in determining the failure rate.
7. Record the device quality factor π_Q from Table 11-4.
8. Record the following device burn-in data:

   $T_{b,d}$ = device burn-in temperature (°C)
   $A_{b,d}$ = Arrhenius acceleration factor (Table 11-7, Curve 7) corresponding to the device burn-in temperature.
   $t_{b,d}$ = device burn-in time (hours)

9. Calculate the effective burn-in time by (e) = (c)×(d).
10. Record the following laboratory test data:
    1. Laboratory test temperature (°C)
    2. Arrhenius acceleration factor (Table 11-7, Curve 7) corresponding to the laboratory test temperature
    3. Actual time on test (hours).
11. Record the number of devices on test (N_o).
12. Enter the total number of laboratory failures, *n*.
13. Calculate the effective time on test, in hours, by (j) = (f)×(g).
14. Calculate the Method II device base failure rate ($\lambda^*_{G_i}$) by performing the operations shown in the remaining rows.

To calculate unit steady-state failure rates from these failure rates, transcribe the device base failure rate ($\lambda^*_{G_i}$) onto Form 2 or 5.

Device Reliability Prediction Laboratory Data Worksheet

Case L-4Devices Laboratory Tested (Devices Have Had Burn-in)

Date

Page _____of_____

Product **Rev** **Manufacturer**

Unit Name							
Unit Number							
Repair category Factory repairable							
Field repairable							
Other							
Unit burn-in Temperature	$T_{b,u}$						
Acceleration factor†	$A_{b,u}$						
Time	$t_{b,u}$						
Device burn-in	$T^*_{b,d}$						
Effective burn-in time $(a) = A_{b,u}t_{b,u} + T^*_{b,u}$	t_e	(a)					
Laboratory test Temperature							
Acceleration factor†	A_L	(b)					
Time on test	T_a	(c)					
Effective time on test (d) = (b) x (c)	T_1	(d)					
Number of lab failures	n	(e)					
Steady-state failure rate	λ_{SS}	(f)					
Temperature factor†		(g)					
Environmental factor	π_E	(h)					
Failure rate $(i) = (f)/[(g) \times (h)]$	λ_G	(i)					
Number of units on test	N_0	(j)					
Enter 4 x 10^{-6}		(k)					
(i) = (a) + (d)		(l)					
(1) If $(i) < 10,000$ $(m) = (i)^{0.25} - (a)^{0.25}$ (2) If $(i) > 10,000$ and $(a) \le 10,000$ $(m) = (i)/4000 + 7.5 - (a)^{0.25}$ (3) If $(a) > 10,000$ $(m) = (d)/4$	w	(m)					
$(n) = 2/(i) + (j) \times (k) \times (m)$		(n)					
Base failure rate $(p) = [2 + (e)]/(a)$	λ^*_G	(o)					
Method II steady-state failure rate $(q) = (h) \times (p) \times (g)$	λ^*_{SS}	(p)					

Comments:

†Obtain from Table 11-7, Curve 7.

Figure 10-12. Unit Reliability Prediction, Case L-4 (Form 12)

Instructions for Form 12: Worksheet for Unit Reliability Prediction

Case L-4: Units Laboratory Tested with Burn-In (Unit/Device Burn-in)

1. Provide the items of information requested on the top portion of the form.
2. Fill in one column of the form for each unit comprising the product.
3. Indicate the repair category by placing an (X) in the appropriate row.
4. Record the following device burn-in data:

   $T_{b,u}$ = unit burn-in temperature (°C)

   $A_{b,u}$ = Arrhenius acceleration factor (Table 11-7, Curve 7) corresponding to the unit burn-in temperature

   $t_{b,u}$ = unit burn-in time (hours). If more than one burn-in temperature is involved in unit burn-in, record the additional T_b, A_b, and t_b values in the appropriate row. The same column may be used to record multiple sets of T_b, A_b, and t_b data.

5. Calculate $T_{b,d}^{*}$, the average accelerated burn-in time of the devices in the unit, or give a close approximation as follows:

$$T_{b,d}^{*} = \left[\sum_{i=1}^{N^*} A_{b,i} t_{b,i} N_i \lambda_{G_i}\right] \Big/ \left[\sum_{i=1}^{N^*} N_i \lambda_{G_i}\right]$$

   where

   $A_{b,i}$ = temperature acceleration factor (Table 11-7, Curve 7) for the i^{th} device

   $t_{b,i}$ = burn-in time for the i^{th} device (in hours)

   N_i = number of devices of this type in the unit

   N^* = number of device types in the unit

   Document and submit calculations used to determine $T_{b,d}^{*}$.

6. Calculate the effective burn-in time $T_e = A_{b,u}t_{b,u} + T_{b,d}^{*}$.

7. Record the following laboratory test data:
   - Laboratory test temperature (°C)
   - Arrhenius acceleration factor A_L (Table 11-7, Curve 7) corresponding to the laboratory test temperature
   - Actual time on test T_a (hours).
8. Calculate the effective time on test (T_1), by (d) = (b)×(c).
9. Record the number of laboratory failures, *n*.
10. Transcribe the steady-state failure rate (λ_{SS}) from Form 4 or 6.
11. Determine the temperature acceleration factor at normal operating temperature from Table 11-7.
12. Enter the environmental factor π_E from Form 1.
13. Determine the failure rate λ_G by (i) = (f) / {(g)×(h)}.
14. Record the number of units on test (N_o).
15. Perform the calculations indicated in the remaining rows to determine the Method II steady-state failure rate (λ_{SS}). To calculate Method II predictions on unit failure rates, substitute λ_{SS} onto Form 3, 4, or 6, whichever is applicable.

ADDITIONAL RELIABILITY DATA REPORT

System ____ **Date** ______

Manufacturer ____

A. Describe design controls and standards imposed on this system that enhance its reliability.

B. Present results of operational reliability studies, describe burn-in procedures, etc.

C. Describe maintenance aspects of system design as they relate to reliability.

Figure 10-13. Additional Reliability Data Report (Form 13)

LIST OF SUPPORTING DOCUMENTS

System ____ **Date** ______

Manufacturer ____

List below the supporting documents that contain nonproprietary design information:

Figure 10-14. List of Supporting Documents (Form 14)

11. Tables

The following pages include tables that contain the information required to derive the reliability predictions for a variety of electronic equipment. These tables may be copied and used as needed.

Table 11-1 gives the 90% Upper Confidence Level (UCL) point estimates of generic steady-state failure rates in FITS for a variety of devices. These failure rates are based on data provided by several suppliers. For alphanumeric displays, we did not receive any data to revise the generic steady-state failure rates given in Issue 5 of TR-332. For some other types of devices (such as resistors, diodes, and capacitors), some failure rates were revised based on the recent data. The remaining failure rates were left unchanged either because the recent data supported them or because no new data is available. The new or changed values are in **boldface**. The failure rates in Table 11-1 are rounded to two significant digits.

Table 11-1 does not include any failure rates for solder joints or bare circuit packs. Bellcore expects the board assembly manufacturers to control their manufacturing processes (including soldering) in accordance with TR-NWT-000357, Issue 2. Properly controlled soldering processes will result in negligible contribution to the board failure rate due to solder joint defects.

Table 11-2 describes the procedure for computing the failure rates for hybrid microcircuits. Tables 11-3[1] and 11-4 define the quality levels and quality factors, respectively. Tables 11-5 and 11-6 give the stress factors. Table 11-7 gives the temperature factors.

Table 11-8 defines the environmental conditions and gives stress factors. Table 11-9 gives the first year multipliers. Table 11-10 gives the typical failure rates of computer related systems or subsystems. Table 11-11 gives the reliability conversion factors. Finally, Table 11-12 gives the upper 95% confidence limit for the mean of a Poisson distribution.

---

[1] The Quality Level to be used for estimating the reliability of a given system shall be determined by an analysis of the equipment manufacturer’s component engineering program against the criteria contained in TR-NWT-000357 and on its implementation throughout all stages of the product realization process.

Table 11-1. Device Failure Rates (Sheet 1 of 16)

Classes of Microprocessors and Their Relative Complexities						
Microprocessor		**Internal Bus Width**			**Complexity**	
Class A	(4004)		4-Bit		2,300	Transistors
Class B	(8085)					
Class C	(8086)				29,000	Transistors
Class D	(8088)		16-Bit		29,000	Transistors
Class 1	(80186)					
Class 2	(80286)		16-Bit		134,000	Transistors
Class 3	(80386)		32-Bit		275,000	Transistors
Class 4	(80486)		32-Bit		1.2 Million	Transistors
Class 5	(Pentium)		32-Bit		3.1 Million	Transistors
Class 6						
Class 7						

Table 11-1. Device Failure Rates[a] (Sheet 2 of 16)

DEVICE TYPE		BIPOLAR		NMOS		CMOS	
		FAILURE RATE[b]	TEMP STRESS (Tbl 11-7)	FAILURE RATE[b]	TEMP STRESS (Tbl 11-7)	FAILURE RATE[b]	TEMP STRESS (Tbl 11-7)
INTEGRATED CIRCUIT DIGITAL							
Range	**Nominal**						
1-20 GATES [c]	15	21	6	27	8	15	8
21-50	40	22	6	29	8	15	8
51-100	80	23	6	30	8	15	8
101-500	400	29	6	39	8	17	8
501-1000	800	33	6	45	8	18	8
1001-2000	1600	39	6	52	8	19	8
2001-3000	2500	42	6	58	8	20	8
3001-5000	4000	47	6	65	8	21	8
5001-7500	6500	52	6	73	8	22	8
7501-10000	9000	56	6	79	8	23	8
10001-15000	13000	61	6	86	8	24	8
15001-20000	18000	65	6	93	8	25	8
20001-30000	25000	70	6	100	8	26	8
30001-50000	40000	77	6	110	8	27	8
MICROPROCESSORS[d]							
Range	**Nominal**						
1-20 GATES[c]	15	10	6	**31**	8	15	8
21-50	40	11	6	**33**	8	15	8
51-100	80	11	6	**35**	8	15	8
101-500	400	14	6	**50**	8	17	8
501-1000	800	16	6	**60**	8	18	8
1001-2000	1600	19	6	**75**	8	19	8
2001-3000	2500	21	6	**86**	8	20	8
3001-5000	4000	24	6	**100**	8	21	8
5001-7500	6500	26	6	**117**	8	22	8
7501-10000	9000	28	6	**130**	8	23	8
10001-15000	13000	31	6	**147**	8	24	8
15001-20000	18000	33	6	**164**	8	25	8
20001-30000	25000	36	6	**183**	8	26	8
30001-50000	40000	40	6	**213**	8	27	8

a. Table values that are changed for this issue are in **boldface**. Note that all Integrated Circuit failure rates in Table 11-1 are reported at Quality Level II and separate Quality Factors are to be applied to distinguish hermetic and non-hermetic (see Table 11-4). The base failure rates given in Table 11-1 apply to both conventional (through-hole) and surface mount technology (see Section 6.6).

b. Failures in 10^9 hours.

c. The number of gates is equal to the number of logical gates on the device schematic.

d. It includes associated peripheral circuits.

Table 11-1. Device Failure Rates[a] (Sheet 3 of 16)

DEVICE TYPE		**FAILURE RATE[b] (Tbl 11-7)**	
INTEGRATED CIRCUITS ANALOG			
Range	**Nominal**		
1-32 Transistors	20 Transistors	19	9
33-90	70	33	9
91-170	150	46	9
171-260	200	52	9
261-360	300	62	9
361-470	450	74	9
471-590	550	81	9
591-720	700	90	9
721-860	800	95	9
HYBRID MICROCIRCUIT		See Table 11-2	

a. Table values that are changed for this issue are in **boldface**. Note that all Integrated Circuit failure rates in Table 11-1 are reported at Quality Level II (see Table 11-4). The base failure rates given in Table 11-1 apply to both conventional (through-hole) and surface mount technology (see Section 6.6).

b. Failures in 10^9 hours.

Table 11-1. Device Failure Rates[a] (Sheet 4 of 16)

DEVICE TYPE		BIPOLAR		NMOS		CMOS	
		FAILURE RATE[b]	TEMP STRESS (Tbl 11-7)	FAILURE RATE[b]	TEMP STRESS (Tbl 11-7)	FAILURE RATE[b]	TEMP STRESS (Tbl 11-7)
RANDOM ACCESS MEMORY		**STATIC**		**STATIC**		**STATIC**	
Range	**Nominal**						
1-320 BITS	256 BITS	19	7	15	9	**13**	9
321-576	512 BITS	22	7	17	9	15	9
577-1120	1K[c]	27	7	20	9	17	9
1121-2240	2K	34	7	24	9	20	9
2241-5000	4K	43	6	30	9	24	9
5001-11000	8K	**55**	6	37	9	29	9
11001-17000	16K	**71**	6	45	9	35	9
17001-38000	32K	**92**	6	57	9	42	9
38001-74000	64K	**119**	6	71	8	50	8
74001-150,000	128K	**155**	6	88	8	61	8
150,001-300,000	256K	**201**	6	110	8	73	8
300,001-600,000	512K	**261**	6	**138**	8	88	8
600,001-1,200,000	1024K	**339**	6	**172**	8	**106**	8
1,200,001-2,400,000	2048K	**441**	6	**215**	8	**128**	8
2,400,001-4,800,000	4096K	**573**	6	**268**	8	**155**	8
Range	**Nominal**			**DYNAMIC**		**DYNAMIC**	
1-320 BITS	256 BITS			14	9	14	9
321-576	512 BITS			14	9	14	9
577-1120	1K			15	9	15	9
1121-2240	2K			16	9	16	9
2241-5000	4K			17	9	17	9
5001-11000	8K			19	9	19	9
1101-17000	16K			20	9	20	9
17001-38000	32K			22	9	22	9
38001-74000	64K			23	8	23	8
74001-150,000	128K			25	8	25	8
150,001-300,000	256K			27	8	27	8
300,001-600,000	512K			30	8	30	8
600,001-1,200,000	1024K			32	8	32	8
1,200,001-2,400,000	2048K			34	8	34	8
2,400,001-4,800,000	4096K			37	8	37	8
4,800,001-9,600,000	8192K			40	8	40	8
9,600,001-19,200,000	16383K			43	8	43	8
19,200,001-38,400,000	32768K			47	8	47	8

a. Table values that are changed for this issue are in **boldface**. Note that all Integrated Circuit failure rates in Table 11-1 are reported at Quality Level II and separate Quality Factors are to be applied to distinguish hermetic and non-hermetic (see Table 11-4).

b. Failures in 10^9 hours.

c. K equals 1024 BITS.

Table 11-1. Device Failure Rates (Sheet 5 of 16)

GATE ARRAYS, PROGRAM ARRAY LOGIC (PAL)
1. Determine the number of gates being used for the digital portion of the circuit. 2. Determine the number of transistors being used for the analog portion of the circuit (if any). 3. Look up the base failure rates for a digital IC and linear device using the number of gates and transistors determined in Steps 1 and 2. 4. Sum the failure rates determined in Step 3. Temperature stress curve: the curve listed for a digital IC with the number of gates determined in Step 1.

Table 11-1. Device Failure Rates[a] (Sheet 6 of 16)

DEVICE TYPE		BIPOLAR		NMOS		CMOS	
		FAILURE RATE[b]	TEMP STRESS (Tbl 11-7)	FAILURE RATE[b]	TEMP STRESS (Tbl 11-7)	FAILURE RATE[b]	TEMP STRESS (Tbl 11-7)
ROMS, PROMS, EPROMS[c]							
Range	**Nominal**						
1-320 BITS	256 BITS	5	6	10	9	12	9
321-576	512 BITS	6	6	11	9	13	9
577-1120	1K[d]	7	6	12	9	14	9
1121-2240	2K	10	6	14	9	17	9
2241-5000	4K	**15**	6	16	9	19	9
5001-11000	8K	**24**	6	19	9	23	9
11001-17000	16K	**41**	6	23	9	27	9
17001-38000	32K	**69**	6	27	9	31	9
38001-74000	64K	**119**	6	32	10	37	10
74001-150,000	128K	**207**	6	38	10	43	10
150,001-300,000	256K	**360**	6	45	10	51	10
300,001-600,000	512K	**628**	6	53	10	60	10
600,001-1,200,000	1024K	**1096**	6	63	10	71	10
1,200,001-2,400,000	2048K	**1912**	6	75	10	84	10
2,400,001-4,800,000	4096K	**3338**	6	89	10	99	10

a. Table values that are changed for this issue are in **boldface**. Note that all Integrated Circuit failure rates in Table 11-1 are reported at Quality Level II and separate Quality Factors are to be applied to distinguish hermetic and non-hermetic (see Table 11-4).

b. Failures in 10^9 hours.

c. Includes electrically erasable 11-1nd flash versions.

d. K equals 1024 BITS.

Table 11-1. Device Failure Rates (Sheet 7 of 16)

Device Type	Model
Digital IC	
Bipolar	$\lambda = 7.45\ (G + 100)^{0.221}$
NMOS	$\lambda = 8.56\ (G + 100)^{0.243}$
CMOS	$\lambda = 8.96\ (G + 100)^{0.105}$
Microprocessors*	
Bipolar	$\lambda = 3.33\ (G + 100)^{0.235}$
NMOS	$\lambda = \mathbf{6.32}\ (G + 100)^{\mathbf{0.332}}$
CMOS	$\lambda = 8.96\ (G + 100)^{0.105}$
Static RAM	
Bipolar	$\lambda = \mathbf{24.68}\ (B + 0.25)^{\mathbf{0.378}}$
NMOS	$\lambda = 18.58\ (B + 0.25)^{0.321}$
CMOS	$\lambda = 16.27\ (B + 0.25)^{0.271}$
Dynamic RAM	
NMOS	$\lambda = 14.79\ (B + 0.25)^{0.111}$
CMOS	$\lambda = 14.79\ (B + 0.25)^{0.111}$
ROM/PROM/EPROM	
Bipolar	$\lambda = 4.16\ (B + 1)^{\mathbf{0.804}}$
NMOS	$\lambda = 11.35\ (B + 0.25)^{0.248}$
CMOS	$\lambda = 13.75\ (B + 0.25)^{0.237}$
Analog IC	
	$\lambda = 5.03\ (T)^{0.440}$
where	λ = failure rate in FITS G = number of gates B = number of kilobits T = number of transistors
* The failure rate of a microcontroller is estimated by summing up the failure of the microprocessor and the Random Access Memory (RAM) it contends.	

Table 11-1. Device Failure Rates[a] (Sheet 8 of 16)

DEVICE TYPE	FAILURE RATE[b]	TEMP STRESS (Tbl 11-7)	NOTES
OPTO-ELECTRONIC DEVICES			
FIBER OPTIC LASER MODULE			
Uncontrolled Environments	**4500**	7	See Note A below
Controlled Environments	**4500**	7	See Note A below
FIBER OPTIC LED MODULE			
Uncontrolled Environments	**1100**	8	See Note A below
Controlled Environments	**240**	8	See Note A below
FIBER OPTIC DETECTOR MODULE			
Uncontrolled Environments	**1400**	10	See Note A below
Controlled Environments	500	10	See Note A below
FIBER OPTIC COUPLER			
Uncontrolled Environments	**1100**	5	See Note A below
Controlled Environments	**180**	5	See Note A below
WDM (Passive)			
Uncontrolled Environments	**1500**	5	See Note A below
Controlled Environments	**550**	5	See Note A below
OPTICAL ISOLATOR	300	10	See Note A below
OPTICAL FILTER	**4500**	5	See Note A below
OTHER OPTICAL DEVICES			
Single LED/LCD Display	3	10	
Phototransistor	**60**	10	
Photodiode	15	10	
SINGLE ISOLATORS			
Photodiode Detector	**10**	10	
Phototransistor Detector	**15**	10	
Light Sensitive Resistor	**20**	10	

Note A: In this document, a module is defined as a small packaged assembly that includes a laser diode/LED/detector and easy means for electrical connections and optical couplings. Only Quality Level III fiber-optic devices should be used for major network products. Only hermetic fiber-optic devices should be used for the laser modules, LED modules, and detector modules in major network products. The impact of Quality Level III is already incorporated in these failure rates. The environmental factor π_E=2.0 should be used for the uncontrolled environments. Non-hermetic or lower quality parts are expected to have much higher failure rates than those predicted by using Table 11-4 device quality factors. If the module contains other electronic devices or hybrids (such as laser drive in the laser module and amplifiers in the detector module), additional failure rates should be added to the failure rates given here. Also, significant differences in failure rates of these devices are expected among different suppliers. Bellcore recommends that field data and/or laboratory data be used to support reliability predictions for these devices, and that additional questions be directed to the Physical Protection and Network Hardware Department in Bellcore.

[a] Table values in **boldface** are new or revised in this issue of the RPP.

[b] Failures in 10^9 hours.

Table 11-1. Device Failure Rates[a] (Sheet 9 of 16)

DEVICE TYPE	FAILURE RATE[b]	TEMP STRESS (Tbl 11-7)	NOTES
DUAL ISOLATORS			
Photodiode Detector	**20**	10	
Phototransistor Detector	**30**	10	
Light Sensitive Resistor	**40**	10	
ALPHA-NUMERIC DISPLAYS			
1 Character	20	10	
1 Character w/Logic Chip	30	10	
2 Character	30	10	
2 Character w/Logic Chip	40	10	
3 Character	40	10	
3 Character w/Logic Chip	50	10	
4 Character	45	10	
5 Character	50	10	
6 Character	50	10	
7 Character	55	10	
8 Character	60	10	
9 Character	65	10	
10 Character	70	10	

a. Table values in **boldface** are new or revised in this issue of the RPP.

b. Failures in 10^9 hours.

Table 11-1. Device Failure Rates[a] (Sheet 10 of 16)

DEVICE TYPE	FAILURE RATE[b]	TEMP STRESS (Tbl 11-7)	ELEC STRESS (Tbl 11-6)	NOTES
TRANSISTORS				
SILICON				
NPN				
≤ 0.6 W	4	4	E,E[c]	
0.6-6.0 W	6	4	E,E[c]	
> 6.0 W	10	4	E,E[c]	
PNP				
≤ 0.6 W	4	4	E,E[c]	
0.6-6.0 W	6	4	E,E[c]	
> 6.0 W	10	4	E,E[c]	
GERMANIUM				
NPN				
≤ 0.6 W	60	4	E,E[c]	
0.6-6.0 W	90	4	E,E[c]	
> 6.0 W	150	4	E,E[c]	
PNP				
≤ 0.6 W	20	4	E	
0.6-6.0 W	30	4	E	
> 6.0 W	55	4	E	
FIELD EFFECT				
Silicon				
Linear	40	4	E	
Switch	20	4	E	
High Frequency	170	4	E	
GaAs				
Low Noise (≤ 100 mW)	100	4	E	
Driver (≤ 100 mW)	**700**	4	E	
UNIJUNCTION	180	4	E	
MICROWAVE				
Pulse Amplifier	**1100**	7	E	
Continuous Wave	**2200**	7	E	

[a] Table values in **boldface** are new or revised in this issue of the RPP.

[b] Failures in 10^9 hours.

[c] First curve is (P operate/P rated). Second curve is (V_{ceo} operate/V_{ceo} rated). When two stress curves apply, take the product of the two stress factors. For example, if a Silicon Transistor (NPN, 0.6 - 6.0W) is operated at P = 40% and V = 60%, the electric stress is 0.8 X 13 = 1.04.

Table 11-1. Device Failure Rates[a] (Sheet 11 of 16)

DEVICE TYPE	FAILURE RATE[b]	TEMP STRESS (Tbl 11-7)	ELEC STRESS (Tbl 11-6)	NOTES
DIODES				
SILICON				
General Purpose				
< 1 AMP	3	4	F,K[c]	
1 - 20 AMP	6	4	F,K[c]	
> 20 AMP	9	4	F,K[c]	
Microwave Detector	100	3	F	
Microwave Mixer	150	3	F	
GERMANIUM				
General Purpose				
< 1 AMP	12	8	F,K[c]	
1 - 20 AMP	30	8	F,K[c]	
> 20 AMP	120	8	F,K[c]	
Microwave Detector	**270**	8	F	
Microwave Mixer	500	8	F	
VOLTAGE REGULATOR				
≤ 0.5 W	3	3	E	
0.6-1.5 W	6	3	E	
> 1.5 W	9	3	E	
THYRISTOR				
≤ 1 AMP	12	4	F	
> 1 AMP	25	4	F	
VARACTOR, STEP RECOVERY, TUNNEL	20	3	H	
VARISTOR, SILICON CARBIDE	10	3	C	
VARISTOR, METAL OXIDE	10	3	C	

a. Table values in **boldface** are new or revised in this issue of the RPP.

b. Failures in 10^9 hours.

c. First curve is (I operate/I rated). Second curve is (V_r operate/V_r rated). When two stress curves apply, take the product of the two stress factors.

Table 11-1. Device Failure Rates[a] (Sheet 12 of 16)

DEVICE TYPE	FAILURE RATE[b]	TEMP STRESS (Tbl 11-7)	ELEC STRESS (Tbl 11-6)	NOTES
THERMISTOR				
Bead	4	7		
Disk	10	7		
Rod	15	7		
Polymetric Positive Temp. Coefficient (PPTC) Device	**10**			
RESISTORS, FIXED (including SMT)				
COMPOSITION				
≤ 1 MEGOHM	1	6	D	
> 1 MEGOHM	4	4	D	
FILM (Carbon, Oxide, Metal)				
≤ 1 MEGOHM	0.5	3	C	
> 1 MEGOHM	3	3	C	
FILM, POWER (> 1W)[c]				
≤ 1 MEGOHM	3	1	A	
> 1 MEGOHM	7	1	A	
WIREWOUND, ACCURATE				
≤ 1 MEGOHM	**16**	2	C	
> 1 MEGOHM	**41**	2	C	
WIREWOUND, POWER, LEAD MOUNTED	10	3	D	
WIREWOUND, POWER, CHASSIS MOUNTED	10	3	D	

a. Table values in **boldface** are new or revised in this issue of the RPP.

b. Failures in 10^9 hours.

c. This includes the failure rates for chip (Surface Mount Technology) that was listed separately in TR-NWT-000332, Issue 3, September 1990.

Table 11-1. Device Failure Rates[a] (Sheet 13 of 16)

DEVICE TYPE	FAILURE RATE[b]	TEMP STRESS (Tbl 11-7)	ELEC STRESS (Tbl 11-6)	NOTES
RESISTORS, VARIABLE				
NON-WIREWOUND				
Film				
≤ 200K OHM	25	3	B	
> 200K OHM	40	3	B	
Low Precision, Carbon				
≤ 200K OHM	35	4	B	
> 200K OHM	50	4	B	
Precision				
≤ 200K OHM	25	4	A	
> 200K OHM	40	4	A	
Trimmer				
≤ 200K OHM	25	2	A	
> 200K OHM	40	2	A	
WIREWOUND				
High Power				
≤ 5K OHM	170	3	B	
> 5K OHM	240	3	B	
Leadscrew	25	3	C	
Precision				
≤ 100K OHM	**200**	3	A	
> 100K OHM	**350**	3	A	
Semi-Precision				
≤ 5K OHM	**85**	4	C	
> 5K OHM	**120**	4	C	
RESISTORS, NETWORKS, DISCRETE ELEMENTS	1	6		Per Resistor
RESISTORS, NETWORKS, THICK OR THIN FILM	0.5	6		Per Resistor

a. Table values in **boldface** are new or revised in this issue of the RPP.

b. Failures in 10^9 hours.

Table 11-1. Device Failure Rates[a] (Sheet 14 of 16)

DEVICE TYPE	FAILURE RATE[b]	TEMP STRESS (Tbl 11-7)	ELEC STRESS (Tbl 11-6)	NOTES
CAPACITORS, DISCRETE				
FIXED				
Paper	10	2	J	
Paper/Plastic	10	2	J	
Plastic	1	3	J	
Mica	1	7	G	
Glass	1	7	G	
Ceramic[c]	1	1	H	
Tantalum, Solid, Hermetic[c]	1	3	G	
Tantalum, Solid, Non-Hermetic	5	3	G	
Tantalum, Nonsolid	7	3	G	
Aluminum, Axial Lead				
< 400 µf	15	7	E	
400 µf-12000 µf	25	7	E	
> 12000 µf	40	7	E	
Aluminum, Chassis Mounted				
< 400 µf	**40**	7	E	
400-12000 µf	**75**	7	E	
> 12000 µf	**105**	7	E	
VARIABLE				
Air, Trimmer	10	5	H	
Ceramic	8	3	J	
Piston, Glass	3	5	H	
Vacuum	25	2	I	
CAPACITOR NETWORK				Sum Individual Capacitor Failure Rate

a. Table values in **boldface** are new or revised in this issue of the RPP.

b. Failures in 10^9 hours.

c. This includes the failure rates for chip (Surface Mount Technology) that was listed separately in TR-NWT-000332, Issue 3, September 1990.

Table 11-1. Device Failure Rates[a] (Sheet 15 of 16)

DEVICE TYPE	FAILURE RATE[b]	TEMP STRESS (Tbl 11-7)	ELEC STRESS (Tbl 11-6)	NOTES
INDUCTIVE DEVICES				
TRANSFORMER				
Pulse Low Level	4	3		
Pulse High Level	19	3		
Audio	7	3		
Power (> 1W)	19	3		
Radio Frequency	30	3		
COIL				
Load Coil	7	3		
Power Filter	19	3		
Radio Frequency, Fixed	0.5	3		
Radio Frequency, Variable	1	3		
CONNECTORS				
General Purpose, Power	5	7		Per Pin
Coaxial, Electric	0.5	7		
Coaxial, Optical	100	7		Per Pin
Multi-Pin	0.2	7		Per Pin
Printed Board, Edge	0.2	7		Per Pin
Ribbon Cable	0.2	7		Per Pin
IC Socket	0.2	7		Per Pin
SWITCHES[c]				
Toggle or Pushbutton	10	7	C	Add 5 per Contact Pair
Rocker or Slide	10	7	C	Add 5 per Contact Pair
Rotary	15	7	C	Add 5 per Contact Pair
RELAYS				
General Purpose	70	3	C	
Contactor	**270**	3	C	
Latching	70	3	C	
Reed	50	3	C	
Thermal, Bimetal	50	3	C	
Mercury	50	3	C	
Solid State	25	3	C	
ROTATING DEVICES[d]				
Blower Assembly	2000			
Blower Motor	500			
Fan Assembly < 6" Diameter	100			
Fan Motor < 1/3 HP	50			

a. Table values in **boldface** are new or revised in this issue of the RPP.

b. Failures in 10^9 hours.

c. The number of contact pairs equals $n \times m$, where n equals the number of poles and m equals the number of throws. For example, a single pole double throw (SPDT) switch has $1 \times 2 = 2$ contact pairs.

d. These are limited life components. The steady-state rates given here apply during the useful life before unacceptable wearout.

Table 11-1. Device Failure Rates[a] (Sheet 16 of 16)

DEVICE TYPE	FAILURE RATE[b]	NOTES
MISCELLANEOUS DEVICES		
GYROSCOPE[c]	50,000	
VIBRATOR		
60 Hertz	15,000	
120 Hertz	20,000	
400 Hertz	40,000	
CERAMIC RESONATOR	25	
QUARTZ CRYSTAL	25	
CRYSTAL OSCILLATOR[d]		
Quartz Controlled	60	
Voltage Controlled	60	
CIRCUIT BREAKER		
Protection-Only Application (per pole)	170	per pole
Power On/Off Application (per pole)	1700	per pole
FUSE		
≤ 30A	**5**	
> 30A	**10**	
LAMP		
Neon	200	
Incandescent		
5V DC	1400	
12V DC	**4200**	
48V DC	4300	
METER	300	
HEATER (Crystal Oven)[c]	1000	
MICROWAVE ELEMENTS		
Coaxial and Waveguide		
Load	15	
Attenuator		
Fixed	10	
Variable	10	
Fixed Elements		
Directional Couplers	10	
Fixed Stubs	10	
Cavities	10	
Variable Elements		
Tuned Stubs	100	
Tuned Cavities	100	
Ferrite Devices (Transmit)	200	
Ferrite Devices (Receive)	100	
THERMO-ELECTRIC COOLER (< 2W)	500	
DELAY LINES	100	
BATTERY		
Nickel Cadmium	100	
Lithium	150	

a. Table values in **boldface** are new or revised in this issue of the RPP.

b. Failures in 10^9 hours.

c. Originally derived from MIL-HDBK-271B, Table 2.13-1, revised September 1976.

d. Crystal oscillators are temperature compensated.

Table 11-2. Hybrid Microcircuit Failure Rate Determination (Sheet 1 of 2)

Hybrid microcircuits are nonstandard and their complexity cannot be determined from their names or functions. To predict failure rates for these devices, use the procedure described in this table.

The Hybrid Failure rate model is

$$\lambda_{HIC} = \left\{\sum(\lambda_G \pi_Q \pi_S \pi_T)\right\} + \{(N_I\lambda_I + N_C\lambda_C + N_R\lambda_R)(\pi_F)\}$$

where:

λ_G = device failure rate for each chip or packaged device used[a]
π_Q = quality factor
π_S = stress factor
π_T = temperature factor
N_I = number of internal interconnects (i.e., crossovers, excluding any device leads or external HIC package leads)[b]
λ_I = 0.8
N_C = number of thin or thick film capacitors
λ_C = 0.5
N_R = number of thin or thick film resistors
λ_R = 0.2
π_F = circuit function factor - 1.0 for digital HICs, 1.25 for linear or linear-digital HICs

[a] Table 11-1 gives the generic steady-state failure rates of semiconductor devices in FITS irrespective of whether the semiconductor devices are packaged (i.e., encapsulated) or are bare chips (i.e., unencapsulated). If the HIC contains bare chip semiconductors, use the hermetic or nonhermetic device quality factor (Table 11-4) depending on the type of encapsulation used for the HIC. If the HIC contains encapsulated semiconductors, ignore the HIC encapsulation and use the hermetic or nonhermetic device quality factor (Table 11-4) according to the packaging of the semiconductor devices used.

[b] If HIC includes any type of connector, the connector should be considered as an attached component.

Table 11-2. Hybrid Microcircuit Failure Rate Determination (Sheet 2 of 2)

When Forms 2 and 3 (or Forms 2 and 4) are used to record reliability data for the unit in which the HIC is located:

1. Calculate the HIC failure rate on a separate sheet of paper. Show all details.
2. On Form 2, record the HIC identifying data and enter the HIC failure rate in column (f).

When Forms 5 and 6 are used to record reliability data for the unit in which the HIC is located:

1. Calculate the HIC failure rate on a separate sheet of paper. Show all details.
2. On Form 5, record the HIC identifying data and enter the quantity of the particular HIC times the HIC failure rate in row (f).
3. To get credit for HIC and/or unit burn-in as it affects Infant Mortality of the HIC, complete the operations as shown in Form 5. The product of $\pi_S \pi_T$ shall be determined by $\lambda_{HIC} / \lambda_{HIC_{BB}}$

where:

$\lambda_{HIC_{BB}}$ = HIC failure rate when π_S and π_T are set equal to 1.0 for all devices in the HIC.

If devices comprising a HIC are burned-in on a device level, the reliability calculations become more complicated. Since this condition is seldom expected to occur, no provision has been made for it in these instructions. For further assistance in this regard, contact the requesting organization.

Table 11-3. Device Quality Level Description (Sheet 1 of 2)

The device failure rates contained in this document reflect the expected field reliability performance of generic device types. The actual reliability of a specific device will vary as a function of the degree of effort and attention paid by an equipment manufacturer to factors such as device selection/application, supplier selection/control, electrical/mechanical design margins, equipment manufacture process control, and quality program requirements. The quality levels described below are not intended to characterize or quantify all of the factors that may influence device reliability. They provide an indication of the total effort an equipment manufacturer considers reasonable to expend to control these factors. These quality levels also reflect the scope and depth of the particular equipment manufacturer's component engineering program.
QUALITY LEVEL 0—This level shall be assigned to commercial-grade, reengineered, remanufactured, reworked, salvaged, or gray-market components that are procured and used without device qualification, lot-to-lot controls, or an effective feedback and corrective action program by the primary equipment manufacturer or its outsourced lower-level design or manufacturing subcontractors. However, steps must have been taken to ensure that the components are compatible with the design application.
QUALITY LEVEL I —This level shall be assigned to commercial-grade components that are procured and used *without* thorough device qualification or lot-to-lot controls by the equipment manufacturer. However, **(a)** steps must have been taken to ensure that the components are compatible with the design application and manufacturing process; and **(b)** an effective feedback and corrective action program must be in place to identify and resolve problems quickly in manufacture and in the field.
QUALITY LEVEL II —This level shall be assigned to components that meet requirements (a) and (b) of Quality Level I, plus the following: **(c)** purchase specifications must explicitly identify important characteristics (electrical, mechanical, thermal, and environmental) and acceptable quality levels (i.e., AQLs, DPMs, etc.) for lot control; **(d)** devices and device manufacturers must be qualified and identified on approved parts/manufacturer's lists (device qualification must include appropriate life and endurance tests); **(e)** lot-to-lot controls, either by the equipment manufacturer or the device manufacturer, must be in place at adequate AQLs/DPMs to ensure consistent quality.

Table 11-3. Device Quality Level Description (Sheet 1 of 2)

QUALITY LEVEL III —This level shall be assigned to components that meet requirements (a) through (e) of Quality Levels I and II, plus the following: **(f)** device families must be requalified periodically; **(g)** lot-to-lot controls must include early life reliability control of 100 percent screening (temperature cycling and burn-in), which, *if the results warrant it*, may be reduced to a “reliability audit” (i.e., a sample basis) or to an acceptable “reliability monitor” with demonstrated and acceptable 11-3umulative early failure values of less than 200 ppm out to 10,000 hours; **(h)** where burn-in screening is used, the percent defective allowed (PDA) shall be specified and shall not exceed 2%; and **(i)** an ongoing, continuous reliability improvement program must be implemented by both the device and equipment manufacturers.

Table 11-3. Device Quality Level Description (Sheet 2 of 2)

Note	It is the manufacturer's responsibility to provide justification for all levels **other than Level 0.** For more information on component reliability assurance practices, see TR-NWT-000357 and GR-2969-CORE. TR-NWT-000357 also includes discussion of alternative types of reliability assurance practices such as reliability monitoring programs for qualification and lot-to-lot controls.

Table 11-4. Device Quality Factors (π_Q)[a]

Quality Level[b]	Semiconductor Devices (Discrete and Integrated)		All Other Devices
	Hermetic	Non-Hermetic	
0	6.0	6.0	6.0
I	3.0	3.0	3.0
II	1.0	1.0	1.0
III[c]	0.9	0.9	0.9

a. To be used only in conjunction with failure rates contained in this document.

b. See Table 11-3 for definition of quality levels.

c. Only Quality Level III fiber optic devices should be used for laser modules, LED modules, detector modules, and couplers. The quality factor for these fiber optic devices is 1.0.

Table 11-5. Guidelines for Determination of Stress Levels

Table 11-1 describes the appropriate curve to use for each type of device. If no curve number is shown, the π_S factor may be considered to be 1.0.

The stress percentage is calculated by multiplying the ratio of applied voltage to the rated voltage by 100. A similar computation is made for current and power. The ratios for different types of components are computed as follows:

Capacitor -	Sum of applied dc voltage plus ac peak voltage / rated voltage
Resistor, fixed -	applied power / rated power
Resistor, variable -	V_{in}^2 / total resistance) / rated power
Relay, Switch -	Contact current / rated current (rating appropriate for type of load, e.g., resistive, inductive, lamp)
Diode, general - purpose, Thyristor	average forward current / rated forward current
Diode, zener -	actual zener current or power / rated zener current or power
Varactor, Step - recovery, Tunnel diode	actual dissipated power / rated power
Transistor -	Power dissipated / rated power.

The stress factors shown in Table 11-6 vary as a function of the effect of electrical stress on the various types of devices and on the amount of stress encountered in any particular application. If, during normal operation of the end product in which the device is used, the amount of stress varies, determine the average stress. If two stress factors apply for a device, take the product of the two stress factors.

Note: “Rated” as used here refers to the maximum or minimum value specified by the manufacturer after any derating for temperature, etc.

Table 11-6. Stress Factors (π_S)

	Electrical Stress Curve:										
% STRESS	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**[a]
10	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.2	0.2	0.1	1.0
20	0.8	0.8	0.7	0.6	0.5	0.4	0.3	0.3	0.3	0.2	1.0
30	0.9	0.8	0.8	0.7	0.6	0.6	0.5	0.4	0.4	0.3	1.0
40	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	1.0
50	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
60	1.1	1.1	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.8	1.1
70	1.1	1.2	1.3	1.5	1.6	1.8	2.0	2.3	2.5	3.3	1.1
80	1.2	1.3	1.5	1.8	2.1	2.4	2.9	3.4	4.0	5.9	1.2
90	1.3	1.4	1.7	2.1	2.6	3.2	4.1	5.2	6.3	10.6	1.3

Note: The stress factors π_S are given by the following equation:

$$\pi_S = e^{m(p_1 - p_0)}$$

where

p_1 = applied stress percentage
p_0 = reference stress (50%)
m = fitting parameter

Curve	A	B	C	D	E	F	G	H	I	J	K
m	0.006	0.009	0.013	0.019	0.024	0.029	0.035	0.041	0.046	0.059	0.006

[a] If $p_1 < 50\%$ for Stress Curve K, $\pi_S = 1$.

Table 11-7. Temperature Factors π_T (Sheet 1 of 2)

For long-term failure rates, refer to Table 11-1 to determine the appropriate temperature stress curve.

TEMPERATURE FACTORS (π_T)										
Operating Ambient Temperature[a] °C	**Temperature Stress Curve**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
30	1.0	0.9	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.4
31	1.0	0.9	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5
32	1.0	0.9	0.9	0.8	0.8	0.7	0.6	0.6	0.6	0.5
33	1.0	0.9	0.9	0.9	0.8	0.7	0.7	0.7	0.6	0.6
34	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6
35	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7
36	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7
37	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.8	0.8
38	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.8
39	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9
40	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
41	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1
42	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.2
43	1.0	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.3
44	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.3	1.4
45	1.0	1.0	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.5
46	1.0	1.1	1.1	1.1	1.2	1.3	1.3	1.4	1.5	1.6
47	1.0	1.1	1.1	1.2	1.3	1.3	1.4	1.4	1.6	1.8
48	1.0	1.1	1.1	1.2	1.3	1.4	1.4	1.5	1.7	1.9
49	1.0	1.1	1.1	1.2	1.3	1.4	1.5	1.6	1.8	2.1
50	1.0	1.1	1.1	1.2	1.4	1.5	1.6	1.7	1.9	2.2
51	1.0	1.1	1.2	1.3	1.4	1.6	1.7	1.8	2.0	2.4
52	1.0	1.1	1.2	1.3	1.5	1.6	1.7	1.9	2.2	2.6
53	1.0	1.1	1.2	1.3	1.5	1.7	1.8	1.9	2.3	2.8
54	1.0	1.1	1.2	1.4	1.6	1.7	1.9	2.0	2.4	3.0
55	1.0	1.1	1.2	1.4	1.6	1.8	2.0	2.1	2.6	3.3
56	1.0	1.2	1.2	1.4	1.7	1.9	2.1	2.3	2.8	3.5
57	1.0	1.2	1.3	1.4	1.7	2.0	2.2	2.4	2.9	3.8
58	1.1	1.2 π_T	$=$ 1.3 e	1.5	1.8	2.0	2.2	2.5	3.1	4.1
59	1.1	1.2	1.3	1.5	1.8	2.1	2.3	2.6	3.3	4.4
60	1.1	1.2	1.3	1.5	1.9	2.2	2.4	2.7	3.5	4.8
61	1.1	1.2	1.3	1.6	1.9	2.3	2.5	2.9	3.7	5.1
62	1.1	1.2	1.3	1.6	2.0	2.3	2.7	3.0	3.9	5.5
63	1.1	1.2	1.4	1.6	2.0	2.4	2.8	3.1	4.2	5.9
64	1.1	1.2	1.4	1.7	2.1	2.5	2.9	3.3	4.4	6.4

[a] When the ambient temperature above the devices does not vary more than a few degrees, a single temperature reading is considered adequate. In this case, the ambient temperatures of the devices and the unit containing these devices are taken to be the temperature obtained by placing a probe in the air ½ inch above the unit. If there is a wide variation in ambient temperature above the devices, it would be necessary to use special procedures not contained in this document. In such cases, a reliability analyst should be consulted.

Table 11-7. Temperature Factors π_T (Sheet 2 of 2)

TEMPERATURE FACTORS (π_T)										
Operating Ambient Temperature[a] °C	**Temperature Stress Curve**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
65	1.1	1.2	1.4	1.7	2.2	2.6	3.0	3.4	4.7	6.8
70							3.7			
75							4.5			
80							5.4			
85							6.5			
90							7.7			
95							9.2			
100							11			
105							13			
110							15			
115							18			
120							21			
125							24			
130							28			
135							32			
140							37			
145							42			
150							48			

[a] When the ambient temperature above the devices does not vary more than a few degrees, a single temperature reading is considered adequate. In this case, the ambient temperatures of the devices and the unit containing these devices are taken to be the temperature obtained by placing a probe in the air ½ inch above the unit. If there is a wide variation in ambient temperature above the devices, it would be necessary to use special procedures not contained in this document. In such cases, a reliability analyst should be consulted.

Note: The temperature factors π_T are derived by the following equation:

$$\frac{Ea}{k}\left[\frac{1}{T_0}-\frac{1}{T_1}\right]$$

where

T_0 = reference temperature in °k = 40 + 273
T_1 = operating temperature in °C + 273
Ea = activation energy
k = Boltzman constant = $8.62 \text{ X } 10^{-5}$

Curve	1	2	3	4	5	6	7	8	9	10
Ea	0.05	0.10	0.15	0.22	0.28	0.35	0.40	0.45	0.56	0.70

Table 11-8. Environmental Conditions and Multiplying Factors (π_E)

ENVIRONMENT	E SYMBOL	π_E	NOMINAL ENVIRONMENTAL CONDITIONS
Ground, Fixed, Controlled	G_B	1.0	Nearly zero environmental stress with optimum engineering operation and maintenance. Typical applications are central office, environmentally controlled vaults, environmentally controlled remote shelters, and environmentally controlled customer premise areas.
Ground, Fixed, Uncontrolled	G_F	2.0	Some environmental stress with limited maintenance. Typical applications are manholes, poles, remote terminals, customer premise areas subject to shock, vibration, temperature, or atmospheric variations.
Ground, Mobile (both vehicular mounted and portable)	G_M	6.0	Conditions more severe than G_F, mostly for shock and vibration. More maintenance limited and susceptible to operator abuse. Typical applications are mobile telephone, portable operating equipment, and test equipment.
Airborne, commercial	A_C	10	Conditions more severe than for G_F, mostly for pressure, temperature, shock, and vibration. In addition, the application is more maintenance limited than for G_F. Typical applications are in the passenger compartment of commercial aircraft.
Spacebased, commercial	S_C	15	Low earth orbit. Conditions as for $A_{C,}$ but with no maintenance. Typical applications are commercial communication satellites.

Table 11-9. First Year Multiplier (π_{FY})

Time (hours)	Multiplier	Time (hours)	Multiplier
0-1	4.0	600-799	2.2
2	3.9	800-999	2.1
3-4	3.8	1000-1199	2.0
5-9	3.7	1200-1399	1.9
10-14	3.6	1400-1599	1.8
15-24	3.5	1600-1999	1.7
25-34	3.4	2000-2499	1.6
35-49	3.3	2500-2999	1.5
50-69	3.2	3000-3499	1.4
70-99	3.1	3500-3999	1.3
100-149	3.0	4000-4900	1.2
150-199	2.8	5000-5999	1.2
200-249	2.7	6000-6999	1.1
250-349	2.6	7000-10000	1.0
350-399	2.5		
400-499	2.4		
500-599	2.3		

For Case 2:

Black Box option with unit/system burn-in > 1 hour, no device burn-in

Use line (a) on Form 4 as the **Time** in selecting the first year **multiplier** from Table 11-9.

For Case 3: General Case

When operating temperature and electrical stress are 40°C and 50 percent, respectively, the stress factors are equal to one.

Use line (p), Form 5, as the **Time** in selecting the first year **Multiplier** from Table 11-9.

- If (p) ≤ 2240, then record the **Multiplier** on Form 5, line (s).
- If (p) > 2240, then record the **Multiplier** on Form 5, line (t).

When operating temperature and electrical stress are not 40°C and 50 percent (limited stress option):

> Table 11-9 cannot be used directly for calculation of the first year **Multiplier**. However, the first year **Multiplier** can be calculated from Table 11-9 multiplier values using Form 5, as follows:
>
> - If (q) ≤ (o) - 8760 from Form 5, then select the multiplier value from Table 11-9 that corresponds to the time value in line (q). Record that multiplier value on Form 5, line (s), and compute the first year **Multiplier** using the formula on the following line.
> - If (q) > (o) - 8760 from Form 5, then select the multiplier value from Table 11-9 that corresponds to the time value in line (p). Record that multiplier value on Form 5, line (t), and compute the first year **Multiplier** using the formula on the following line.

Table 11-10. Typical Failure Rates of Computer Related Systems or Subsystems

Equipment	Failure Rate (FITS)*
Clock	5,900
Display	
Color	141,000
Monochrome	81,000
Drives	
CD-ROM	71,000
Floppy Disk	55,000
Hard Disk	71,000
Tape Drive	107,000
Ethernet	24,000
IEEE Bus (Related Hardware)	14,000
Key Board (101 keys)	23,000
Modem	42,000
Mouse	10,000
Personal Computer	450,000
Power Supply	
Airborne	158,000
Ground	45,000
Uninterruptible (UPS)	5,800
Printer	
Dot Matrix, Low Speed	354,000
Graphics Plotter	30,000
Impact, High Speed	170,000
Thermal	71,000
Workstation	316,000

* Number of failures in 10^9 device-hours.

Note: Table 11-10 gives the ballpark number of failure rates for Commercial Out-the-Shelf (COTS) equipment. The design life of computer equipment (typically less than 5 years) is significantly shorter compared to telecommunications equipment (>25 years). The failure rate is the measure of equipment on how frequently an equipment is expected to die during its expected lifetime. The rate of computer equipment is high for Dead on Arrival (DOA) and infant (the first few weeks) mortality. The steady-state failure rate of an equipment may also vary in a wide range based on a different manufacturer.

Table 11-11. Reliability Conversion Factors

From	To	Operation
FITs[a]	Failures/10^6 hrs.	FITs $\times 10^{-3}$
FITs	% Failures/1000 hrs.	FITs $\times 10^{-4}$
FITs	% Failures/yr. or Failures/100 units/yr.	FITs/1142
FITs	% Failures/mo. or Failures/100 units/mo.	FITs/13700
FITs	MTBF[b]	$\frac{10^9 \text{ hours}}{\text{FITs}}$
Failures/10^6	FITs	Failures/10^6 hrs. $\times 10^3$
% Failures/1000 hrs.	FITs	% Failures/1000 hrs. $\times 10^4$
% Failures/yr. or Failures/100 units/yr.	FITs	% Failures/yr. × 1142
% Failures/mo. or Failures/100 units/mo.	FITs	% Failures/mo. × 13,700
MTBF	FITs	$\frac{10^9}{\text{MTBF}}$

a. Failures in 10^9 hours.

b. Mean time (hours) between failures.

Table 11-12. Upper 95% Confidence Limit (*U*) for the Mean of a Poisson Distribution

Failure Count *f*	**Upper Confidence Limit** *U*	**Failure Count** *f*	**Upper Confidence Limit** *U*	**Failure Count** *f*	**Upper Confidence Limit** *U*	**Failure Count** *f*	**Upper Confidence Limit** *U*
0	3.0						
1	4.7	41	53.2	81	97.4	121	140.7
2	6.3	42	54.3	82	98.5	122	141.8
3	7.8	43	55.5	83	99.6	123	142.9
4	9.2	44	56.6	84	100.7	124	143.9
5	10.5	45	57.7	85	101.8	125	145.0
6	11.8	46	58.8	86	102.9	126	146.1
7	13.1	47	59.9	87	104.0	127	147.2
8	14.4	48	61.1	88	105.1	128	148.2
9	15.7	49	62.2	89	106.2	129	149.3
10	17.0	50	63.3	90	107.2	130	150.4
11	18.2	51	64.4	91	108.3	131	151.5
12	19.4	52	65.5	92	109.4	132	152.5
13	20.7	53	66.6	93	110.5	133	153.6
14	21.9	54	67.7	94	111.6	134	154.7
15	23.1	55	68.9	95	112.7	135	155.7
16	24.3	56	70.0	96	113.8	136	156.8
17	25.5	57	71.1	97	114.8	137	157.9
18	26.7	58	72.2	98	115.9	138	158.9
19	27.9	59	73.3	99	117.0	139	160.0
20	29.1	60	74.4	100	118.1	140	161.1
21	30.2	61	75.5	101	119.2	141	162.2
22	31.4	62	76.6	102	120.2	142	163.2
23	32.6	63	77.7	103	121.3	143	164.3
24	33.8	64	78.8	104	122.4	144	165.4
25	34.9	65	79.9	105	123.5	145	166.4
26	36.1	66	81.0	106	124.6	146	167.5
27	37.2	67	82.1	107	125.6	147	168.6
28	38.4	68	83.2	108	126.7	148	169.6
29	39.5	69	84.3	109	127.8	149	170.7
30	40.7	70	85.4	110	128.9	150	171.8
31	41.8	71	86.5	111	130.0	151	172.8
32	43.0	72	87.6	112	131.0	152	173.9
33	44.1	73	88.7	113	132.1	153	175.0
34	45.3	74	89.8	114	133.2	154	176.0
35	46.4	75	90.9	115	134.3	155	177.1
36	47.5	76	92.0	116	135.3	156	178.2
37	48.7	77	93.1	117	136.4	157	179.2
38	49.8	78	94.2	118	137.5	158	180.3
39	50.9	79	95.3	119	138.6	159	181.4
40	52.1	80	96.4	120	139.6	160	182.4

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IEEE Standards 661, 1979; 269, 1983; and 743, 1984.

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Other Document

Herman R. Silbiger, “Human Factors of Telephone Communication in Noisy Environments,” Proceedings of the National Electronic Conference, 1981, pp. 35, 170 174.

Glossary

Definition of Terms

Burn-in	The operation of a device under accelerated temperature or other stress conditions to stabilize its performance.
Circuit Pack	A printed wiring board assembly containing inserted components. Also referred to as “plug-in.”
Component	Any electrical part (e.g., integrated circuit, diode, resistor) with distinct electrical characteristics.
Device	Any electrical part (e.g., integrated circuit, diode, resistor) with distinct electrical characteristics.
Failure Rate	Failures in 10^9 operating hours (FITS).
First-year multiplier	Ratio of the first-year failure rate to the steady-state failure rate.
Hermetic	Gas-tight enclosure that is completely sealed by fusion or other comparable means to ensure a low rate of gas leakage over a long period of time (e.g., glass metal seal with a leak rate $<10^{-7}$ cc/atm/sec. and life time of 25 years).
Method I	Reliability predictions using the parts count procedure.
Method II	Reliability predictions based on combining laboratory data with parts count data.
Method III	Reliability predictions based on field tracking data.
Non-hermetic	Not airtight, e.g., a plastic encapsulated integrated circuit.
Optical Module	A small packaged assembly that includes a laser diode/LED/detector and easy means for electrical connections and optical couplings.
Steady-State Failure Rate	The constant failure rate after one year of operation.
System	A complete assembly that performs an operational function.
Unit	An assembly of devices (e.g., circuit pack, module, plug-in, racks, and power supplies).

Acronyms

AQL	Acceptable Quality Level
ARPP	Automated Reliability Prediction Procedure
CMOS	Complementary Metal-Oxide Semiconductor
DC	Direct Current
DPM	Defects Per Million
EEPROM	Electrically Erasable Programmable Read-Only Memory
EPROM	Erasable Programmable Read-Only Memory
FITS	Failure per billion device hours
HIC	Hybrid Integrated Circuit
IC	Integrated Circuit
LED	Light Emitting Diode
MEGOHM	10^6 Ohm
MOD	Metal-Oxide Semiconductor
MTBF	Mean Time Between Failures
µf	Microfarad (10^{-6} farad)
mW	10^{-3} Watts
NMOS	N-type Metal-Oxide Semiconductor
NTF	No Trouble Found
PAL	Programmable Array Logic
PDA	Percent Defective Allowed
PROM	Programmable Read-Only Memory
RAM	Random Access Memory
ROM	Read-Only Memory
RPP	Reliability Prediction Procedure
WDM	Wavelength Division Multiplexer