Bellcore

GENERIC REQUIREMENTS
GR–1221–CORE
ISSUE 2, JANUARY 1999

Generic Reliability Assurance Requirements for Passive Optical Components

A Module of RQGR, FR-796

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GR–1221–CORE, Issue 1, December 1994.

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

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Reliability Requirements for Passive Optical Components

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Preface

This Preface contains important information about Bellcore's GR process in general, as well as important information about this document.

Bellcore's GR Process

Generic Requirements documents (GRs) provide Bellcore's view of proposed generic criteria for telecommunications equipment, systems, or services, and involve a wide variety of factors, including interoperability, network integrity, funding participant expressed needs, and other input.

Bellcore's GR process implements Telecommunications Act of 1996 directives relative to the development of industry-wide generic requirements relating to telecommunications equipment, including integral software and customer premises equipment. Pursuant to that Act, Bellcore invites members of the industry to fund and participate in the development process for such GRs. Invitations to fund and participate are issued monthly in the *Bellcore Digest of Technical Information*, and posted on Bellcore's web site at *http://www.bellcore.com/DIGEST*.

At the conclusion of the GR development process, Bellcore publishes the GR, which is available by subscription. The subscription price entitles the purchaser to receive that issue of the GR (GR-CORE) along with any Issues List Report (GR-ILR) and revisions, if any are released under that GR project. ILRs contain any technical issues that arise during GR development that Bellcore and the funding participants would like further industry interaction on. The ILR may present issues for discussion, with or without proposed resolutions, and may describe proposed resolutions that lead to changes to the GR. Significant changes or additional material may be released as a revision to the GR-CORE.

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B. GR–1221–CORE Relative Maturity Level, Status, and Plans

GR-1221-CORE was considered mature since it replaced TA-NWT-001221, Issue 2 in December 1994. Currently, Bellcore has no plans to reissue this GR in the near future, but will do so to update its requirements as needed, based on the emergence of new technology and on experience gained from field deployment or additional laboratory experiments. Based on history and recent technology advancements, the next update is expected to be planned in 3 years. An Issue List Report may be released based on the impact and volume of comments received from subscribers.

To Submit Comments

When submitting comments, please include the GR document number, and cite any pertinent section and requirement number. Comments are welcome at any time. They are important because release of Issues List Reports or Revisions may depend on either the extent and complexity of comments submitted and/or Bellcore's planned schedule for such releases.

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1. Introduction

This Generic Requirements document (GR) presents Bellcore's view of proposed generic reliability assurance practices for all kinds of passive optical component, which include fiber optic branching components such as splitters, couplers and wavelength division multiplexers (WDMs), isolators, passive optical filters, etc. As technologies advance and products mature, many discrete devices are developed into higher integrated assembly levels. These discrete and integrated passive optical components play major roles in deployment of a dense wavelength division multiplex (DWDM) network, fiber in the loop (FITL) systems, and a passive distribution network (PDN). Thus, overall performance and reliability of fiber optic equipment and networks depend on these components. The reliability assurance criteria are set forth in this GR. The performance, feature, and function requirements are described in individual component requirement documents, such as the GRs listed in the reference section in the back of this document.

For integrated modules having passive optical devices and some "simple" electronic devices (e.g., with thermoelectric coolers and thermistors), the complete modules shall be tested according to this document but the other electronic parts are covered in TR-NWT-000357, *Generic Requirements for Assuring the Reliability of Components Used in Telecommunications Equipment*, GR-468-CORE, *Generic Reliability Assurance Requirements for Optoelectronic Devices Used in Telecommunications Equipment*, or other applicable documents. The determination of which document takes precedence shall be based on the reliability impact. If the electronics is the main concern, TR-357 shall be used. If active optoelectronic components are the main concern, GR-468 shall be used. If the passive optical components are the main concern, this document shall be used. In some cases, more than one document may be needed.

1.1 Scope and Purpose

The proposed criteria within this document apply to all types of passive optical components, regardless of applications or package styles. The criteria were changed from one single set applicable to controlled environments (e.g., a telephone company central office) and uncontrolled environments (e.g., a FITL system optical network unit) to two sets, one for controlled environments and the other for uncontrolled environments. The reasons are for practicality, cost-effectiveness, and to align with related documents such as GR-468-CORE. Users who do not wish to inventory the same components for different environments should specify that the components meet the criteria for uncontrolled environments so they can be used for controlled environments without reliability concerns.

The criteria here are meant to form a minimum set of reliability assurance practices. This GR is directed toward the design engineering, manufacturing, and reliability/quality organizations of equipment suppliers and optoelectronic device manufacturers, and network planning. It is intended to help ensure the reliable operation of passive optical components in all equipment and network applications of a typical Public Switched

Communications Network. By identifying a set of minimum reliability assurance practices that balance confidence in component reliability with component cost, the manufacturers, services providers, and end users can all benefit.

The criteria here are not meant to define a specific design or to result in a preferred way of accomplishing the design. By taking into account the need to meet these minimum criteria, though, reliability can be *built* into the product design rather than pursued through expensive inspection and testing in manufacture.

1.2 Changes in the Document

Significant changes are identified by change bars ("|") in the margin to attract the reader's attention. Editorial changes, such as wording differences or clarifications, are not explicitly noted.

The important changes made previously were kept in Section 1.2.1 to provide a historic view. The important changes in this reissue are described in Section 1.2.2.

1.2.1 Changes From TA-NWT-001221 Issue 2 to GR-1221-CORE Issue 1

There were various changes made when GR-1221-CORE, Issue 1 was released in December 1994, to maintain consistency with other fiber optic component documents. The following is a list of the important changes:

1. Airborne contaminants test is changed from a requirement to an objective, with a statement added to indicate the test is required in GR-63-CORE for network equipment.
2. The activation energy for the dry heat test and damp heat test was specified as 0.1 eV and 0.25 eV, respectively. There is not enough data to accurately determine these values, although suppliers generally indicate higher values. Therefore, activation energies to 0.3 eV for the dry heat test and 0.8 eV for the damp heat test have been modified for now. This requirement will be reviewed as more data is collected.
3. The durations of the high temperature dry heat storage test and the high temperature damp heat storage test are revised to 2500 hours for qualification, to reflect the changes in activation energies. The duration of 5000 hours is retained and modified as "for information only." The required sample sizes for these two tests in Sections 6.2.4 and 6.2.5 are corrected to LTPD of 10%, as specified in Table 4-2.
4. The testing condition of 85°C/85% RH is added as an acceptable damp heat testing condition.

5. The thermal shock test is removed from Table 4-2, since it only applies to hermetic packages. For hermetic packages, thermal shock is required, but the damp heat test might be reduced to 2000 hours.
6. The adhesive requirements in Section 4.3 have been revised.

1.2.2 Changes From GR-1221-CORE, Issue 1 to Issue 2

This issue involves the participation of manufacturers. For the first time, they have the opportunity to directly decide the criteria to be published. Their input, in addition to input from service providers, generated the changes in this reissue. Some of the changes are major ones that can improve the product reliability with dramatic cost-effectiveness. Some of the major changes are listed here as high-level descriptions.

- The reliability tests in Section 4 are aligned with other Bellcore documents, such as GR-468 and TR-357. For example, MIL-STD methods were added to Sections 4 and 6.
- The flammability test was moved into a new Section 3.1.4 on Environmental, Health, and Safety Considerations.
- Criteria for components used in the CO environment were developed.
- The integrated modules were defined and their reliability criteria were added to Section 4.2.
- Many important changes are incorporated in Section 4.1.2 on component qualification.

1.2.3 Future Additions/Changes

Future additions or changes will be made based on the technology developments and the comments on this document.

It is recognized that as the optical power increases, the high power aging and optical transient tests may become important for passive components. Currently, no hard data are available to be used to develop specific conditions for testing/characterization of optical power aging and transients. A future revision may include criteria with these considerations.

1.3 Related Bellcore Documents

This GR is closely linked to several other GRs. It complements or supplements their criteria on component and system performance or reliability. These include the following:

- GR-326-CORE - Single-mode optical connectors and jumper cable assemblies criteria
- TR-NWT-000357 - Component reliability criteria (for general types of devices, such as transistors, resistors, diodes, integrated circuits, etc.)
- GR-418-CORE - Fiber optic system reliability criteria
- GR-468-CORE - Optoelectronic device reliability criteria
- TR-NWT-000909 - FITL system functional requirements
- GR-1209-CORE - Fiber optic branching component functional criteria.

Other Bellcore TAs, TRs, or GRs provide additional reliability and quality (R&Q) assurance criteria generally applicable to telecommunications products. GR-874-CORE, *An Introduction to the Reliability and Quality Generic Requirements (RQGR)*, details many of those documents. In addition, various other Bellcore documents, plus national and international standards, are referenced by this GR.

1.4 Requirements Terminology

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 Client Company (CC). 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 CC applications*. If a CC identifies a Conditional Requirement as necessary, it shall be treated as a requirement for the application(s). Conditions that may cause the Conditional Requirement to apply include, but are not limited to, certain CC 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 CC. 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*.
- **Conditional Objective** — Feature or function that, in Bellcore’s view, is *desirable in specific CC applications* and may be required by a CC. It represents a goal to be

achieved in the specified Condition(s). If a CC identifies a Conditional Objective as necessary, it shall be treated as a requirement for the application(s). A Conditional Objective is flagged by the letters "**CO**."

- **Condition** — The circumstances that, in Bellcore's view, will cause a Conditional Requirement or Conditional Objective to apply. A Condition is flagged by the letters "**Cn**."

1.5 Requirement Labeling Conventions

As part of Bellcore's new GR Process, proposed requirements and objectives are labeled using conventions that are explained in the following two sections.

1.5.1 Numbering of Requirement and Related Objects

Each Requirement, Objective, Condition, Conditional Requirement, and Conditional Objective object 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.

1.5.2 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.

Tables and Figures within Requirements are identified separately from others within the document text, and do not appear in the Table of Contents. They are numbered sequentially beginning with Table 1 and Figure 1.

1.6 Operating Environments

Passive optical components can be found in various operating environments, which can be generally described as a Central Office (CO) Environment, a Remote Terminal (RT) Environment, and an Uncontrolled (UNC) Environment. These environments have an important impact on the stresses experienced by a device with a resulting consequence on reliability if the device is not sufficiently robust. The reliability assurance criteria are, therefore, to be associated with the particular environment in which the optoelectronic device is expected to operate. In this GR, the reliability assurance criteria are divided into two environment categories - CO and RT&UNC, since the criteria are very similar for RT and UNC environments.

1.6.1 Central Office (CO) Environment

A CO environment, as described in GR-63-CORE, *Network Equipment-Building System (NEBS) Requirements: Physical Protection*, restricts long-term ambient temperatures to a range of 4-38°C. For short periods (up to 72 hours and for a total of not more than 15 days per year), temperatures may go as low as 2°C or as high as 49°C. This same environment can be achieved at remote sites with necessary environmental controls, as in the case of Controlled Environment Vaults (CEVs).

However, increasing numbers of Network Elements (NEs) are being deployed in locations without such environmental controls. The exact operating conditions depend on a number of factors, including type of system enclosure (above-ground cabinet, aerial enclosure, pedestal, etc.), geographic location, and local effects (such as shade from a nearby building or trees). Such non-CO types of conditions are commonly called “uncontrolled environments.” These are sometimes subdivided into two categories.

1.6.2 Remote Terminal (RT) Environment

RT environments are based on the criteria (including temperature extremes) in GR-487-CORE, *Generic Requirements for Electronic Equipment Cabinets*. For example, that document defines a temperature range of -40°C to +46°C for the air temperature outside the enclosure. Inside the enclosure, the air temperature surrounding the equipment can reach +65°C under maximum solar loading and equipment power dissipation.[1] In addition, it is assumed there is sufficient thermal mass inside the enclosure that the time constant for temperature change is on the order of 1 or more hours.

1.6.3 Uncontrolled Environment

As used here, UNC environments exhibit conditions that do not meet the criteria for CO or RT environments described in Sections 1.5.3.1 and 1.5.3.2, respectively. The temperature extremes for a UNC environment are assumed to be similar to that for an RT; however, the thermal time constant at the optoelectronic device level is on the order of minutes (due to the small thermal mass of the electronics in the enclosure and the relatively small size of the enclosure itself). In addition, other conditions such as mechanical shock and vibration, might be more severe than those experienced in a CO or RT environment. An example of a UNC environment would probably be a pedestal (such as the optical network unit of an FITL system).

1.7 Other Terminology

This section explains some of the terminology used in this GR.

1.7.1 Suppliers, Vendors, and Manufacturers

The term "supplier" generally refers to the equipment or system manufacturer. "Vendor" is used to indicate the device manufacturer or distributor. In some cases, the term "manufacturer" is used for better readability - its meaning should be clear from the context of the sentence (and usually applies to the *device* manufacturer).

1.7.2 Quality Levels

The term "quality level" used in this GR and other component reliability documents indicates the scope and depth of a device manufacturer's and/or equipment supplier's component reliability assurance program. It indicates confidence that a device will consistently meet or exceed its predicted reliability performance through the use of different intensities in the device manufacturer's and/or equipment supplier's qualification and lot control practices. Table 1-1 defines three quality levels (Quality Level I is the lowest; Quality Level III is the highest).

Because of the critical nature of optoelectronic devices in telecommunication systems, the practices described here are consistent with the definition of Quality Level III, *unless otherwise noted.* The reliability assurance program for these devices, therefore, would

1. Depending on the location of the optoelectronic device in the system and on the ventilation provided by the system's physical design, the device's ambient operating environment could be 5-20°C higher than the maximum 65°C described for the "system." As with other types of devices, such as integrated circuits, many reliability tests need to go beyond the manufacturer's normal maximum-rated operating conditions in order to accelerate aging or stresses.

include periodic requalification and device screening (which are not generally required for Quality Level II devices). However, it is recognized that the Percent Defective Allowed (PDA), as normally required by Item (h) in Table 1-1, might be difficult or impossible to specify for optoelectronic devices.

Table 1-1. Definition of Quality Levels

QUALITY LEVEL	DESCRIPTION
I	This level shall be assigned to commercial-grade devices that are procured and used *without* thorough device qualification or lot-to-lot controls by the equipment supplier. However, **(a)** steps must be taken to ensure that the devices are compatible with the design application and manufacturing process; and **(b)** an effective feedback and corrective action program must be in place to quickly identify and resolve problems in manufacture and in the field.
II	This level shall be assigned to devices that meet requirements (a) and (b) of Quality Level I, plus the following: **(c)** purchase specifications must explicitly identify important characteristics (optical, electrical, and mechanical) and Acceptable Quality Levels (AQLs) for lot controls; **(d)** devices and vendors must be qualified and identified on approved parts/ vendor lists (device qualification must include appropriate life and endurance tests); **(e)** lot-to-lot controls, either by the equipment supplier or by the device manufacturer, must be in place at adequate AQLs to ensure consistent quality.
III	This level shall be assigned to devices that meet requirements (a) through (e) of Quality Levels I & II, plus the following: **(f)** device families must be requalified periodically; **(g)** lot-to-lot controls must include early life reliability control of 100% screening (e.g., temperature cycling and burn-in) which, *if the results warrant it*, may be reduced to a “reliability audit” (e.g., burn-in on a sample basis) or to an acceptable “reliability monitor” with demonstrated and acceptable cumulative early failure values[a] out to 10,000 hours; **(h)** where screening is used, the percent defective allowed (PDA)[b] shall be specified; and **(i)** an ongoing, continuous reliability improvement program must be implemented by both the equipment supplier and the device manufacturer.

Note a: The number shall be based on the expected constant failure rate since one of the purposes of lot-to-lot controls is to remove infant mortality failures.

Note b: The PDA value should be agreed by the manufacturer and its customers.

2. Reliability Assurance - Overview and Philosophy

Unlike functional or performance generic requirements, reliability assurance criteria are seldom “yes or no” issues. There could be many ways of achieving the same end goal of reliable fiber optic branching components for use in a CC telecommunications network. The following sections first describe the tenets of a comprehensive reliability assurance program, and then discuss the philosophy behind the approach taken in this GR.

[Note: No requirements or objectives appear in Section 2; any wording that suggests criteria is used only for emphasis. Formal criteria related to these discussions are distributed throughout the rest of the document.]

2.1 Overview of Reliability Assurance

The basic reliability of fiber optic equipment and networks can be no better than the reliability of the components used to build them. Moreover, it is generally impossible to thoroughly test the performance and reliability of components once they are installed into the equipment or network. It thus becomes necessary for component manufacturers and equipment suppliers to set up programs to help ensure necessary component reliability.

The major elements of a comprehensive reliability assurance program are as follows:

- Vendor and Device Qualification Programs
- Lot-to-Lot Quality and Reliability Controls
- Feedback and Corrective Action Programs
- Storage and Handling
- Documentation.

The critical nature of many fiber optic branching components, plus the rapid evolution of designs and manufacturing practices, make such a program particularly important. The components used in a telecommunications system should be initially qualified and purchased only from approved vendors. The reliability and quality of each lot should be tested and analyzed. Any problem detected in the manufacturing processes or reported from field applications should be examined and corrected. This information should be fed back as inputs for vendor and device qualification. Components should also be stored properly, avoiding excessive heat and humidity. Manufacturers and suppliers should carefully adhere to electrostatic discharge (ESD) precautions they have tailored for their particular situations. The reliability assurance program should be fully documented to ensure consistency and continuity.

Figure 2-1 depicts the elements of a comprehensive reliability assurance.

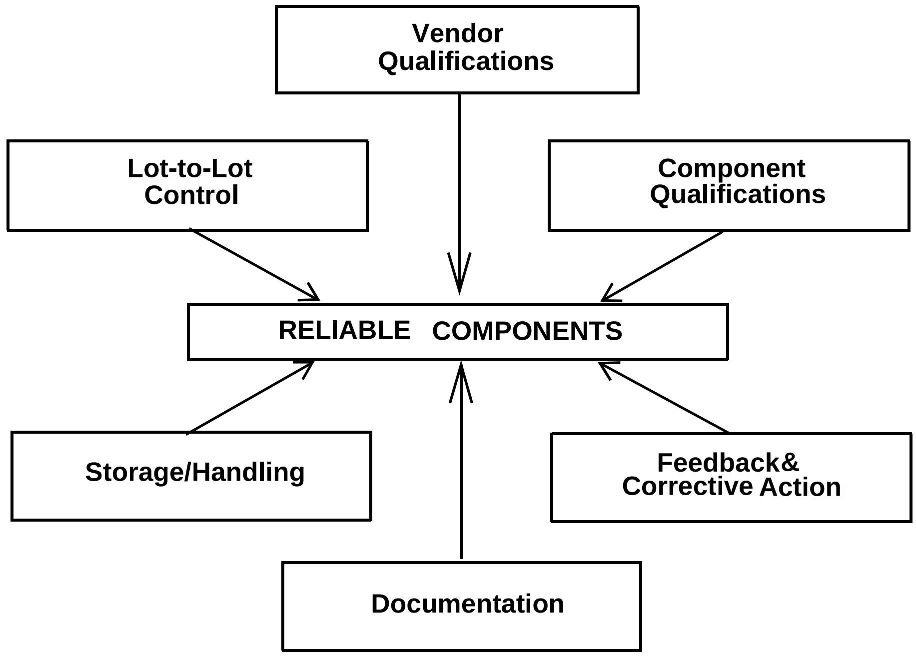

Figure 2-1. Elements of a Comprehensive Reliability Assurance Program

2.2 Generic Requirements Philosophy

Many of the criteria in this GR deal with necessary elements of a comprehensive reliability assurance program; as such, they are clearly satisfied or not by the component manufacturer's and/or equipment supplier's practices. However, many other criteria deal with demonstration of component reliability or with levels of confidence. The *intent* of these latter requirements and objectives can sometimes be accomplished in alternative ways. While the various tests and procedures in this GR have been developed to establish an appropriate baseline for a comprehensive reliability assurance program, other techniques could prove to be more cost-effective.

The difficulty of such alternative approaches involves the demonstration by the manufacturer or supplier of their equivalency or effectiveness. Although certain general guidelines can be described, specific steps to demonstrate this cannot be determined in advance for every situation. Nevertheless, manufacturers and suppliers are encouraged to investigate "improved" test methods and practices.

This does not suggest that the Bellcore criteria contained here can be satisfied by any arbitrary approach. To avoid problems and possible disagreement later, Bellcore can be contacted to resolve most questions prior to significant expenditures in special equipment or testing by the manufacturer or supplier.

3. Basic Reliability Assurance Program Requirements

This section deals with the basic elements of a reliability assurance program, including vendor and device qualification, lot-to-lot controls, feedback and corrective action programs, device storage and handling, documentation and test data, and other considerations.

3.1 Vendor and Device Qualification

Qualification deals with the capability of a prospective vendor and its specific device(s) to meet the needs of the equipment supplier or network operator. It involves assessment of the vendor's quality and reliability assurance program, measurement of the device's characteristics, and investigation of all aspects of long-term reliability.

R3-1 **[1]** Suppliers of telecommunication equipment shall document and establish formal vendor and device qualification programs. These programs shall include procedures for both adding and removing vendors and devices from an "approved vendors list" and/or "approved parts list" [also see **R3-5**].

O3-2 **[2]** As part of vendor qualification, equipment suppliers should visit the vendors manufacturing locations, and examine both the facilities and implemented test practices. Suppliers should pay particular attention to the Quality Assurance/Quality Control (QA/QC) programs that the vendors have in place, and at the quality and reliability data that the vendors have accumulated on their products. Only those fiber optic component vendors who have demonstrate that they are committed to producing reliable devices should be considered as acceptable sources.

R3-3 **[3]** To help ensure that their reliability needs are met, equipment suppliers shall obtain the results of environmental and reliability life tests on the fiber optic components they plan to use.

Suppliers without the capability of performing such tests themselves may have the tests run for them by independent test laboratories or may use vendor-supplied data (if a formal audit/monitor program of the vendor is run in conjunction).

G*ood supplier-vendor interfaces and thorough qualification testing are of little value if the purchasing organization ignores the collected information and continues to buy their devices from any available source.*

3.1.1 Specification and Control

The equipment supplier is responsible for specifying and controlling the devices that it allows in manufacturing its products. The two primary means of doing this are purchase specifications and approved vendor/parts lists.

R3-4 **[4]** All fiber optic components used in system manufacture shall be identified on a purchase specification or some equivalent form of control document.

… Such documents shall identify all relevant performance, quality and reliability requirements, allowable operating conditions (minimum- and maximum-rated operating temperatures, supply voltage, minimum output power, etc.), and lot-to-lot controls. Functional parameters shall include most, if not all, of the measurements used to characterize the devices during initial qualification.

R3-5 **[5]** Approved Vendor Lists (AVLs) and Approved Parts Lists (APLs) shall be carefully maintained for routine use by manufacturing, QA, and the purchasing organization. AVLs and APLs shall be treated as a "controlled" document (e.g., dated, signed by appropriate management, and removed from use when superseded by newer versions).

… The AVL and APL shall be provided as inputs to the purchase specification process. Only vendors and part types that have completed qualification successfully shall be referenced on purchase specifications and included in AVLs/APLs.

As a common current industry practice, a computer database with restricted access and change controls can serve as an AVL/APL with quick updating capabilities.

3.1.2 Vendor Approval

Prior to (or concurrent with) device qualification, the device manufacturer needs to undergo its own "vendor qualification process." This effort, known as vendor approval, is a formal, documented procedure that typically includes a review or inspection of the vendor's facilities.

R3-6 **[6]** The criteria for determining acceptance shall include the vendor's QA/QC procedures (as documented and implemented), Statistical Quality Control (SQC) data, and availability of reliability data. Vendors shall be specifically asked to provide typical reliability test data (i.e., qualification test data and the results of screening). These data shall be examined for evidence that their designs are sound and that their processing has been consistent over time.

R3-7 **[7]** The equipment supplier shall clearly document the results of vendor acceptance activities (including vendor surveys, if performed) [per **O3-2**].

As indicated by **O3-2**, the equipment supplier should still attempt to visit the vendor's facility and complete a survey in person even if the device processing, assembly, or testing is performed in a different country. If the equipment supplier deems this impossible, review of reliability test data and statistical quality control data is crucial to confirm that the vendor's operations are under adequate control.

O3-8 **[8]** Vendor acceptance reports should be retained for a minimum of 5 years.

O3-9 **[9]** Approved vendors should be revisited every 2 years or more often. [This is in addition to more frequent, regular communication with the vendor to review any problems (or to confirm the lack of such problems).]

ISO 9000 standards establish a part of the foundation for building a vendor approval program.

Note: On-site appraisal of vendors might not be necessary if they have been formally certified by ISO-accredited inspectors as meeting the relevant standards in ISO 9000; this would be determined by the equipment supplier or component manufacturer who is considering the particular vendor, based on other available information. Because ISO 9000 standards are written for any type of product, the reliability needs for telecommunications systems and components lead to certain additional criteria (including those given here, as well as other considerations that the procuring company might feel necessary).

3.1.3 General Criteria for Device Qualification

Device qualification has two primary purposes. First, it confirms the ability of the device to meet the equipment supplier's performance requirements (as detailed in purchase specifications). Equally important, qualification testing verifies the long-term performance of the device.

Thus, equipment suppliers need to complete characterization tests and perform environmental/reliability life tests on the fiber optic components that they plan to use in their products. Environmental/reliability life tests determine if the basic device design and the fabrication materials and processes are sound and can be expected to provide adequate long-term reliability.

The following sections address issues that are common to all passive optical components.

3.1.3.1 Qualification Tests

Appropriate test programs, sequences, and sample sizes for qualification testing of individual device codes are provided in Section 4.1. Other proposed, or currently used, qualification programs may also be acceptable in part or in whole, if they can be shown to be technically comparable. [At this time, it is felt that specific procedures for demonstrating this are not possible to delineate in advance.]

R3-10 **[10]** Substitution of tests or changes in test limits shall be supported by reliability consideration and technical justification that shall be available for review on request.

R3-11 **[11]** Actual practices and procedures used for device qualification shall be documented.

R3-12 **[12]** Qualification test results shall be clearly recorded and saved for a minimum of 5 years.

O3-13 **[13]** Qualification test results should be saved for a minimum of 10 years.

3.1.3.2 Device Codes that Fail Qualification

Device types that fail any aspect of the qualification sequence are defined as failing the device's qualification evaluation.

O3-14 **[14]** Appropriate failure analysis and corrective action should occur before any retest is attempted.

R3-15 **[15]** When the corrective action requires a significant change in the device materials, processing, assembly, or screening, the entire qualification sequence (not just the failed test) shall be repeated. [Bellcore may be contacted to resolve any questions on this matter.]

3.1.3.3 Qualification of Devices by Similarity

Because small differences in device fabrication, assembly, or screening can have a significant impact on reliability, fiber optic components are not as amenable as general electrical components to qualification by similarity. One possible example would be a "product family" of splitters of different numbers of ports. It is permissible to base qualification on only the largest port-count devices if

- Large port-count devices assembled by concatenation of smaller port-count devices in two or more stages; or
- Devices for which the fiber/substrate interface connection is identical for both large and small port-count devices. Moreover, the qualification must be on the largest port-count devices for the product family to be covered.

Additionally, if a new device is developed based on existing products, it may not be necessary to repeat the entire qualification sequence. An example is a new filter tuned to a different wavelength but based on the same technology, or even from the same manufacturing line. An adequate understanding of failure and degradation mechanisms may be used to identify which qualification tests need to be performed. The qualification data of existing similar products can be used if the same technology platform exists, made by the same manufacturer, fabricated using the same process flow and controls at a designated manufacturing location, and are of similar complexity and packaging.

3.1.3.4 Use of Nonconforming Devices for Qualification

For the purpose of certain qualification tests, devices that do not meet the supplier's or vendor's performance specifications for minor reasons may be used, thus reducing the cost of qualification efforts. For example, a device that is slightly outside the specification for optical loss would normally be adequate for mechanical and thermal shock tests. [Bellcore may be contacted regarding a manufacturer's plans to use non-conforming devices.]

3.1.3.5 Provisional Use of Devices

Due to marketing strategies and competitive issues, manufacturers often want to use new products before completion of all qualification tests. This is a sensitive issue with respect to the lengthy tests required to demonstrate reliability. Based on experience by many manufacturers, as well as Bellcore's own reliability testing, it appears that serious reliability problems often become apparent before the end of the tests.

Therefore, **provisional use** (sometimes referred to as preliminary qualification or provisional qualification) of devices undergoing initial qualification does meet the intent of this GR if the following conditions are satisfied:

R3-16 **[16]** The device code must have successfully passed other qualification requirements outlined in this GR. The minimum number of test cycles/hours is no less than the number given in Table 1, which is based on the total duration of the full test (in progress toward timely completion). Provisional use of the device shall not exceed the periods in Table 1.

… Table 1. Requirements for Provisional Use of Devices in Qualification

Total Length of Full Test	Provisional Use Allowed After...	Maximum Period for Provisional Use
500 cycles	100 cycles	3 months
1000 cycles	250 cycles	6 months
2000 hours	1000 hours	3 months
5000 hours	2500 hours	6 months
10000 hours	5000 hours	12 months

O3-17 **[17]** The equipment supplier and/or device manufacturer should have procedures in place to notify customers of the equipment/device within 5 business days of finding and confirming any reliability problem in the remainder of the test. This notification deadline may be extended to 7 business days for the purpose of obtaining preliminary failure analysis.

… The equipment supplier and device manufacturer should have documented procedures for other appropriate actions (beyond notifying its customers, as applicable) to take in response to the problem.

For example, assume an equipment supplier approves a device for provisional use. If the reliability test is being performed by the device manufacturer, the manufacturer would notify the supplier within 5 business days of finding and confirming the reliability problem. Furthermore, if the device is being used in the assembly of a fiber optic system, then the supplier would notify its customer of the equipment (e.g., an RBOC) within the next 2 business days. Depending on the nature of the problem, the equipment supplier would also take further actions consistent with its documented internal procedures, likely ranging from special testing of the devices or circuit packs to suspension of system assembly pending detailed failure analysis results.

3.1.3.6 Low Volume Parts

Even though they might be used in small quantities, the passive optical components covered by this document are considered critical by Bellcore. As such, they generally do *not* qualify for any exemptions from the full qualification program - any specific exceptions to this policy are noted in the detailed criteria in later sections.

R3-18 **[18]** Exceptions to a full qualification program due to usage in small quantities (or for other reasons) must be evaluated case by case, and clearly documented.

3.1.3.7 Hermeticity

Hermetic packaging may be required for certain critical applications, principally where serious reliability problems would be encountered due to the presence of severe environmental conditions. Testing hermeticity is not trivial for these components. The traditional hermeticity definition used for integrated circuits (ICs) as passing the fine leak test may not apply, because the fiber coating of the pigtails can absorb and release helium which result in a faulty leakage indication. The moisture content measurement after the damp/heat stress test is a practical and useful test. RGA measurements after aging, temperature cycling, and thermal shock tests are recommended.

R3-19 **[19]** The moisture content shall be measured after the damp/heat stress test is completed.

Non-hermetic components may be appropriate in other situations if sufficient technical data, as described in this document, can be provided to demonstrate component reliability in the presence of temperature and humidity.

3.1.3.8 Solder Flux

Although there are no electrical contacts in most passive optical components, it is not advisable to use corrosive solder fluxes inside the component package. Such fluxes could attack the integrity of the mechanical structure and hermetic seals. TR-357 and GR-78 contain detailed criteria.

3.1.3.9 Use of Vendor-Supplied Data

In many cases, device vendors themselves will be running qualification tests similar to those described in this document. Where appropriate tests are conducted, it may be possible for equipment suppliers to use vendor-supplied data to satisfy the requirements of certain portions of the equipment supplier's overall qualification program.

R3-20 **[20]** Equipment suppliers who make significant use of vendor-supplied data shall establish a program to verify the accuracy and validity of this information. The audit/monitor program shall be continued as long as vendor-supplied qualification data are used.

O3-21 **[21]** Such programs should include repeating certain tests (by the equipment supplier or an independent test laboratory), and/or reviewing the component vendor's test methods, facilities, data collection, and analysis practices in detail.

R3-22 **[22]** The results of any verification tests shall be documented.

O3-23 **[23]** Verification test reports should be saved for a minimum of 5 years.

3.1.3.10 Treatment of Internally Manufactured Devices

R3-24 **[24]** Devices manufactured internally by the equipment supplier itself, or by another division of the same parent company, shall meet the same qualification and requalification requirements as specified herein for purchased parts.

R3-25 **[25]** The equipment supplier's manufacturing location(s) must have continuous access to device test data and shall periodically review the information. In addition, the supplier must be readily capable of providing such data if questions arise.

3.1.4 Environment, Health, and Safety Considerations

3.1.4.1 Environment Considerations

R3-26 **[26]** All materials in the components shall be tested for their toxicities. The results shall comply with the environmental regulations. If toxic materials are used, relevant information shall be provided.

3.1.4.2 Health Considerations

Personnel are strongly cautioned never to look directly into the laser or other optoelectronic components at anytime. The components and materials covered in this document may emit non-visible light that may be potentially hazardous. Although most of the optical output power levels are generally not very high, there are exceptions such as pump lasers. Virtually all the power is concentrated into a narrow frequency band, which implies that the energy can be focused into a very intense spot on the retina by the lens within the viewer's eyes.

R3-27 **[27]** The light emitting components and materials must be labeled according to appropriate standards and regulations.

Some of the related documents and organizations are provided below for reference (but not limited to):

- IEC 60825-1 Safety of Laser Products - Part 1: Equipment classification, requirements and user's guide (http://www.iec.ch/cgi-bin/procgi.pl/www/iecwww.p?wwwlang=E&wwwprog=cat-det.p&wartnum=017336
- FDA Title 21, Part 1040.10 Performance Standards for Light Emitting Products (http://www.verity.fda.gov/search97cgi/s97_cgi.exe?action=View&VdkVgwKey=http%3A%2F%2Fwww%2Efda%2Egov%2Fcdrh%2Fdevadvice%2Fpart1040%2Ehtml&DocOffset=7&DocsFound=12&QueryZip=light%2Demitting+products&Collection=C4&SearchUrl=http%3A%2F%2Fwww%2Everity%2Efda%2Egov%2Fsearch97cgi%2Fs97%5Fcgi%2Eexe%3Faction%3DSearch%26QueryZip%3Dlight%252Demitting%2Bproducts%26ResultTemplate%3Dstndrslp%252Ehts%26QueryText%3Dlight%252Demitting%2Bproducts%26Collection%3DC4%26ResultStart%3D1%26ResultCount%3D10&hlnavigate=ALL)
- OSHA Pub8-1.7- Guidelines for LAser Safety and Hazard Assessment (http://www.osha-slc.gov:80/OshDoc/Directive_data/PUB_8-1_7.html).

3.1.4.3 Safety Considerations

It is known that many fiber pigtails used in optoelectronic components are flammable and even allow fire propagation. Fortunately, these materials are usually used in limited amounts and used in confined areas inside of the frame. However, they need to be tested and the results communicated to the ultimate users.

R3-28 **[28]** All pigtails and materials shall be tested according to Section 4.2 of GR-63-CORE. Failure results shall be provided to customers.

Although most of today's products are hermetic metal packages, the trend for low cost, nonhermetic packages is driving the designs of the components used in the loop.

R3-29 **[29]** All component packages shall be tested according to Section 4.4.2.5 in TR-NWT-000357.

3.1.5 Other General Information for Qualification

Several acronyms are used in the detailed tables for device qualification. "LTPD" refers to Lot Tolerance Percent Defective as described in Appendix B of Military Specification MIL-M-38510F or in Appendix C of MIL-S-19500G.[1] "SS" refers to a suggested sample size appropriate for the specified LTPD. "C" indicates the maximum number of failures allowed for that sample size. An abbreviated table for LTPD sampling is given in Appendix A.

1. The same information also may be found in Appendix A of IEC Pub. 747-10.

With regard to endurance tests, different time and temperature combinations may be chosen by the supplier if the alternate test conditions are shown to be at least as effective as those in this document. This often involves the use of models for calculating an acceleration factor. Intrinsic failure mechanisms are defined as the type modeled by the Arrhenius relationship (such as chemical reactions or processes involving diffusion). Extrinsic failure mechanisms are characterized by threshold-type failures, such as those resulting from mechanical impact, bending, or applied tension - in such cases, it is not appropriate to use the Arrhenius relationship. Any questions on this need to be resolved prior to any extensive reliability testing [see **R3-10**].

R3-30 **[30]** Equivalent time and temperature requirements shall be calculated using the Arrhenius relationship. Technical justification of the activation energy used for different conditions in temperature-dependent life tests is required.

… Acceleration models (for failure mechanisms affected by other stresses, such as optical power or humidity) shall be demonstrated theoretically (if possible) and empirically. Associated acceleration/deceleration factors must be clearly identified.

Temperature and humidity acceleration factors are described in Section 6.3. A default value for the temperature activation energy is given in Section 4.1.2.

R3-31 **[31]** Unless otherwise specified, all failures observed in qualification testing must normally be counted and must be reported, regardless of the failure mode. Omission of any failures from test results must be clearly justified and documented.

Although reliability tests are usually designed to detect one type of failure mechanism, other unexpected failure mechanisms often occur and should not be excluded from the test results. Exceptions are accidental damage or extraordinary circumstances, such as a fiber pigtail that is broken due to mishandling.

O3-32 **[32]** To simplify review (by customers or their representatives) of failure rate predictions, the format in Table 3-1 is recommended for use by device manufacturers and/or equipment suppliers.

R3-33 **[33]** The testing data and supporting evidence for Table 3-1 shall be documented and available for review on request.

Table 3-1 is most useful if there is only one dominant failure mechanism, which might not be valid for all component designs and technologies. In addition, the failure rate might vary over time according to the failure distribution, for which there is limited data and currently no consensus candidate.

Table 3-1. Sample Format for Reporting Failure Rate Predictions

Item	Value
Median Life (ML) @ 40°C	years
Standard Deviation (σ)	
Wear-Out Failure Rate (λ_{WO}) @ 40°C	FITs*
Wear-Out Activation Energy (E_a)	eV
Basis of Predictions (field data, life test, theory)	
Random Failure Rate (λ_R) @ 40°C	FITs*
Random Failure Activation Energy (E_a)	eV

* A FIT is a failure unit equivalent to the number of failures per billion operating hours.

O3-34 **[34]** The format for reporting the status of all reliability tests should follow the format in Table 3-2.

Table 3-2. Sample Report Format for Reliability Test Status

Test*	Date Completed	Sample Size	Number of Failures	Test Passed?
Mechanical Shock				
Vibration				
Thermal Shock				
High Temp. Storage (Dry)				
High Temp. Storage (Damp)				
Low Temp. Storage				
Temp. Cycle Endurance				
Temp./Humidity Cycling				

* See Section 4.1.2 and Table 4-2 for the minimum list of required reliability tests.

Completing this summary table does not relieve the manufacturer or supplier of satisfying the respective requirements for each test nor of reporting the detailed results in a comprehensive report, as described elsewhere in this GR.

R3-35 **[35]** The testing data and supporting evidence for Table 3-2 shall be documented and available for review at the request.

3.1.6 Requalification

R3-36 **[36]** Periodic requalification shall be performed by the equipment supplier and/or device manufacturer if significant changes in design, materials, processing, assembly, or screening are made in the product for any reason (enhanced performance, cost reduction, quality or reliability problem in manufacturing or field use, etc.). The supplier's on-going reliability monitoring program may be substituted for periodic requalification applied to devices if the on-going reliability program addresses failure mechanisms that were addressed during product qualification. This reliability monitoring program shall include qualification by family, using different codes on a rotational basis. This program must be tied to failure mode engineering analysis and qualification results shall include critical process control information.

The nature of "significant" design and manufacturing changes need to be clearly defined by the equipment supplier. As a minimum, they should include any changes that could impact reliability (e.g., a change in the method used to attach the fiber pigtail, a reduction in screening time, production start-up at another facility, new or different suppliers of materials or component parts).

R3-37 **[37]** The equipment supplier and/or device manufacturer shall document the conditions that require all or part of the qualification test sequence to be repeated.

O3-38 **[38]** The equipment supplier's contract or purchase agreement should require that vendors notify the supplier in advance of any changes in the performance, quality, reliability, or safety of their products.

O3-39 **[39]** In the absence of significant changes in the product, each device family should be requalified every 2 years or more often. The requalification should be initiated within 2 years after the completion of the previous (re)qualification.

This periodic requalification, which is also called "qualification maintenance" or a "reliability monitor" by some manufacturers, is meant to catch unexpected problems resulting from an accumulation of minor changes that invariably occur in the product design and manufacturing process over time. Different approaches can be used to avoid problems with staffing levels (for reliability engineers and test equipment operators) and environmental chamber capacity. The common industry practices described below are generally considered acceptable alternatives for **O3-39**.

- A revolving sequence of reliability tests that cover all the qualification criteria in this document within a 2-year period (as opposed to performing all the tests in parallel in a short time interval) is one way to minimize the cost impact of the requalification objective.

- Another possible way to reduce costs is use of sample sizes smaller than the minimum numbers given in the qualification criteria of this document **-** it would be acceptable for the purposes of periodic requalification if the test(s) are repeated for the same product such that the total number of devices subjected to the test(s) within the 2-year period satisfies the required sample sizes.

In the second approach, however, a single device failure might or might not result in "failure" of the requalification effort, depending on the total number of devices still to be tested. For example, if a test requiring an LTPD of 20% was split into two sequential groups of nine devices each (with one failure allowed in total), the test is not automatically a "failure" when one device fails in the first group; the test would be a "failure" if one or more devices failed in each group, though.

A device manufacturer's "reliability monitor" program can be an effective alternative for periodic requalification in some cases.

R3-40 **[40]** A reliability monitor program must meet the following conditions for it to be used to satisfy the periodic requalification objective [**O3-39**] of this document:

… • Results are not reported on a device family basis unless the definition of "family" is based on demonstrated technology similarity.

… • No reliability problems have been identified from field returns.

… • The range of tests and conditions used in the monitor program meet or exceed the criteria given for periodic requalification.

Note: The qualification/requalification of optical connectors, if supplied on passive optical components, is covered separately by GR-326-CORE. However, this does not exempt connectors from assembly on these components where specifically required by the test procedures in Section 6.2.

3.2 Lot-To-Lot Quality and Reliability Controls

Qualification testing is intended to help ensure that passive optical components meet specifications (of the equipment supplier and/or network operator) and that they have adequate long-term reliability and durability. Comprehensive controls deal with the quality and reliability of individual lots. As part of this, important performance requirements need to be clearly detailed in device specifications. Quality- and reliability-oriented lot acceptance criteria should also be clearly established for each device or product family. Test results for product from each vendor need to be summarized periodically, and the quality performance of the respective vendors analyzed. Documented procedures should clearly specify actions to be taken to correct problems or to disqualify vendors that show substandard quality.

A lot's overall reliability can sometimes be enhanced through the use of screens (e.g., burn-in) that remove "weak" devices. For fiber optic components, screening might include temperature cycling and/or temperature aging. If the passive component contains a heater element etc. a stabilization burn-in might be required.

3.2.1 General Criteria for Lot Controls

It is usually not possible to adequately test the performance or reliability of passive optical components once they are assembled onto circuit boards or installed in a network. Traditionally, conformance to performance requirements is assessed by individual device testing either at the vendor's location (source inspection) or at the using plant (incoming inspection).

The following sections address general lot-to-lot control issues that are common to all passive optical components.

3.2.1.1 Definition of a Lot

O3-41 **[41]** From an equipment supplier's perspective, a lot should be considered as a unit made up of devices with the same device code and packaging (manufactured by the same supplier), and with a range of less than 6 weeks in package date codes.

… Maximum lot sizes should not exceed 1000 parts, unless the equipment supplier has implemented sampling practices that positively ensure the random selection of components for inspection and test. Otherwise, shipments larger than this should be split into smaller groups that meet the above definition; each of these groups (or lots) should then be separately subjected to the full set of lot acceptance tests identified in the equipment supplier's detailed device specification.

While this definition makes sense for general components made in a series of discrete batches, such as the usual case for integrated circuits (ICs) or transistors, it sometimes has less meaning for fiber optic components. In some cases, components might be made in a continuous, "seamless" process for which individual batches cannot be discerned.

Although the term "lot" is be used universally in this document, the associated criteria are intended to reflect the reliability practices in process controls appropriate for both equipment suppliers and device manufacturers; where necessary, separate criteria are identified for different situations.

O3-42 **[42]** If passive optical components are manufactured in a continuous process analogous to general components, the definition of a lot given above [**O3-36**] applies.

… If passive optical components are manufactured in batches spaced significantly apart in time, the definition of a lot given above [**O3-41**] is still used. The same criteria for lot controls would also apply unless special exceptions are noted.

… If passive optical components are manufactured in a continuous manner *without clearly defined batches*, then the associated criteria for lot controls should be applied based on practically sized “groups” made sequentially in time.

… The equipment supplier or device manufacturer should demonstrate if other definitions are used for a lot.

In the last case above, for example, the size of the group or lot might be 100, 500, or 1000 devices, depending on the situation.

R3-43 **[43]** The manufacturer’s definition of a “lot” shall be clearly documented.

3.2.1.2 Purchase Specifications

R3-44 **[44]** Lot-to-lot controls shall be documented and shall be referenced in purchase specifications (see Section 3.2.1.4).

O3-45 **[45]** If devices are purchased pre-screened, the PDA or LTPD should be specified in the purchase specifications.

3.2.1.3 Source Inspection/Incoming Inspection

R3-46 **[46]** Conformance to purchase specifications must normally be assessed by individual device tests at the device manufacturer’s location (source inspection on outgoing product) or at the equipment supplier’s location (incoming inspection).

Under certain circumstances, ship-to-stock practices may be substituted for electrical and optical testing at incoming inspection (see Section 3.2.1.4). Any other exceptions to traditional incoming inspection will be identified in the detailed requirements.

R3-47 **[47]** When incoming inspection is used to confirm conformance to purchase specifications, a comprehensive testing plan shall be established.

The program shall include test conditions, pass/fail criteria, data collection, and effective use of the data.

… Test results shall be made available in a timely manner for review by the organizations receiving and using the components.

It is crucial that the user organizations have quick access to both quality and reliability data in order to implement special procedures when unusual results are noted.

3.2.1.4 Ship-to-Stock Programs

Ship-to-stock or other alternative inventory programs that bypass "normal" incoming inspection (or source inspection) may be used if the following conditions are satisfied:

R3-48 **[48]** Use of ship-to-stock practices for passive optical components by an equipment manufacturer must be clearly identified.

R3-49 **[49]** Conditions for a *possible* ship-to-stock program must include the following (to be fully documented by the equipment supplier):

… • Devices shall be approved by the equipment supplier for ship-to-stock only on the basis of individual device codes. If ship-to-stock is approved for a family code, technology similarities to justify the approval shall be demonstrated.

… • The equipment supplier shall be able to demonstrate from incoming inspection records and field data (or substantiate via other means) a history of satisfactory quality and reliability performance for the specific device from this vendor. [A history based on a product family, as described in Section 3.1.3.3, is acceptable for a new device.]

… • Final test measurements on all parameters specified by the equipment supplier shall be provided by the manufacturer for each device and included as routine information with the shipped lot - *OR* - the manufacturer's lot controls must have been previously assessed as meeting the intent of this document (i.e., there are no serious differences from the criteria given here for lot controls, feedback and corrective action, and other related issues).

… • Periodically, on an interval of 6 months or less, a lot shall be randomly selected by the equipment supplier and subjected to the full set of lot acceptance tests required by the supplier (in accordance with the relevant criteria here). All devices in the lot shall be tested.

… • The equipment supplier shall document specific criteria for approving and removing device codes from its ship-to-stock list.

R3-50 **[50]** A single rejection of a lot based on (a) failure to pass the annual audit [**R**3-44d] or (b) unresolved problems found in system manufacturing or from field returns shall result in the device code being removed from ship-to-stock status.

3.2.1.5 Test Plan

The test plan for incoming lots needs to be documented in detail.

R3-51 **[51]** Individual device specifications shall either include the actual lot control practices or reference the appropriate document(s) in which the practices are described.

R3-52 **[52]** Lot control practices shall include the tests to be performed, the test method (or its reference), sampling levels, and accept/reject criteria.

O3-53 **[53]** Lot control procedures should be subject to a document control program (e.g., dated, signed by appropriate management, and removed from use when superseded by newer versions).

3.2.1.6 Test Equipment

R3-54 **[54]** The equipment supplier shall have access to the test equipment necessary to perform lot inspection and screening.

… This test equipment shall be maintained and calibrated on a regular basis (at least as often as recommended by the test equipment manufacturer).

CO3-55 **[55]** Test equipment should be subject to the maintenance, calibration, and other controls that meet the relevant criteria in ISO 9001.

3.2.1.7 Data Recording and Retention

R3-56 **[56]** All information relevant to lot inspection and screening shall be recorded and retained for later review and summary. As a minimum, collected information shall include the following:

… • The device code, supplier, lot size, date code, and/or serial number

… • The number of devices tested and number of defectives found for each series of tests performed

…

- The disposition of defectives, any follow-up required, and any other special notes (e.g., rejection of entire lot).

3.2.1.8 Treatment of Defective Devices and Lots

R3-57 **[57]** Procedures that describe the handling and disposition of defective devices and rejected lots shall be documented.

O3-58 **[58]** The device vendor should be required to provide *timely* feedback on the nature of serious or recurring problems and the corrective actions it has taken.

3.2.1.9 Summary of Vendor History Data

R3-59 **[59]** Results from lot incoming inspection and screening shall be summarized periodically for each device vendor.

O3-60 **[60]** Vendors with poor histories should be required to show corrective action, or else be removed (disqualified) from the approved vendor list (AVL), if practical.

O3-61 **[61]** Reports detailing these data summaries and correspondence with component vendors (regarding their corrective action efforts) should be retained for at least 5 years as evidence that an effective feedback program is in place and working.

3.2.1.10 Low Volume Parts

Since the passive optical devices covered by this document are considered critical by Bellcore, they are generally not exempted from any of the lot testing.

R3-62 **[62]** When lot sizes are small and cannot justify or support the sampling plans needed for lot acceptance testing, the entire lot (100 percent) shall be subjected to the quality and reliability audit tests. For these small lots, any tests considered destructive may be excluded.

R3-63 **[63]** The tracking of ‘low volume’ device codes shall be included in the data collection and analysis procedures.

3.2.1.11 Use of Vendor-Supplied Data

Data provided by the device manufacturer may also be used by the equipment supplier in lieu of incoming inspection tests and screening if an agreement is arranged between the device and equipment manufacturers and the following criteria are met.

R3-64 **[64]** In cases where vendor-supplied data is used for lot-to-lot controls, verifiable test results shall be provided (with the shipment of devices or within a time specified by the equipment supplier) for the supplier's records on lot quality.

R3-65 **[65]** The equipment supplier shall periodically audit the results through a documented verification program that it has developed.

3.2.1.12 Treatment of Internally Manufactured Devices

R3-66 **[66]** Devices manufactured internally by the equipment supplier itself, or by another division of the same parent company, shall meet the same lot testing and screening requirements as specified herein for purchased devices.

If appropriate lot quality and reliability testing is performed at device manufacturing locations, this testing does not need to be repeated at other locations of the equipment supplier.

R3-67 **[67]** In cases where equipment assembly locations do not perform incoming inspections of passive optical components made by another division of the company, the assembly locations must have continuous access to the test results or follow the criteria for ship-to-stock devices. The supplier must also be readily capable of demonstrating that the correct tests are being run and that lot dispositions are being made properly (normally involving routine review of the test results, plus regular technical meetings with the other divisions).

3.2.2 Other General Information for Lot-To-Lot Controls

Although screens are usually designed to detect one type of failure mechanism, other unexpected failure mechanisms can occur as well, and should not be excluded from the test results.[2]

2. Pigtail breakage or pull-out may indicate a need for a more robust fiber attachment or improved handling procedures, for example.

R3-68 **[68]** Unless otherwise specified, all failures observed in lot testing must be counted, regardless of the failure mode.

The test conditions identified in later tables are only minimum requirements; equipment suppliers, at their discretion, may specify greater stresses.

3.3 Standardized Test Procedures

To help ensure consistent results in correlating data between manufacturers and customers, it is important for the same procedures to be employed in tests and measurements. This need is a fundamental purpose of national and international standards efforts.

O3-69 **[69]** Procedures used in the performance of tests and the measurement of parameters required by this document should be performed in accordance with available national or international standards.

At the time that this GR was issued, the following TIA standards were available or under development:

- FOTP-2 - Impact test measurements
- FOTP-3 - Temperature cycling
- FOTP-4 - Temperature life
- FOTP-5 - Humidity test procedures
- FOTP-11 - Vibration
- FOTP-71 - Temperature shock.

O3-70 **[70]** If conflicts occur between national and international standards, United States national standards should take precedence if the product is manufactured and marketed in the United States.

In the efforts to align the criteria in this document with other related documents (e.g., GR-468 and GR-1209), the MIL-STD testing procedures and methods are added and may be considered as the preferred methods.

3.4 Feedback and Corrective Action

The requirements in this section apply to equipment manufacturers since this data collection cannot be performed by component vendors. Similar feedback and corrective action program should be considered by device manufacturers to control and improve their practices and products, and work closely with the equipment manufacturers as their customers.

R3-71 **[71]** Equipment suppliers shall collect data relating to device drop-out levels at each stage of equipment manufacture (first circuit pack test, system level testing, etc.). The data shall also be analyzed to identify any devices that are failing at a higher than expected rate.

O3-72 **[72]** Device replacement data associated with the repair of field returns represent additional valuable information that should be made available to the engineering organization responsible for the company's or division's reliability effort.

Without such feedback, device engineering and the QA/QC organization can have little confidence that their in-place programs are effective.

Analysis of the device replacement data help identify devices that are exhibiting high failure rates. Quite often, however, this information will have limited utility without additional detail on the actual (electrical and physical) causes of the device failures. Detailed findings of device failure analysis are essential for determining a sensible corrective action plan.

R3-73 **[73]** The causes for device failures shall be determined for all common failure modes and summarized in order to help direct the corrective action effort [see Section 3.3.8]. Equipment suppliers shall either have their own internal failure analysis laboratories to perform detailed device failure analysis, or have arrangements with an independent test lab or with the device manufacturer.

The backbone of an effective feedback and corrective action program is the *timely* collection and analysis of data.

R3-74 **[74]** In addition to any vendor-supplied data that are received, an equipment supplier shall collect device-level data from the following:

… • Incoming inspection and screening (unless the devices are approved for ship-to-stock or the equipment manufacturer has demonstrated the direct access to its suppliers' testing data)

… • Circuit pack test

… • Circuit pack burn-in

… • System-level test

… • System-level burn-in

… • System installation

… • Repair of field returns.

3.4.1 Incoming Inspection and Screening

Data collected from incoming inspection and screening would most directly indicate which device vendors are consistently in control, and which vendors need to take corrective action.

R3-75 **[75]** When problems are found, the device vendor shall be formally notified of the problem. The vendor shall also be required to respond with its assessment and any corrective actions that it has implemented.

Problems in correlating results (between testing by the vendor and testing by the equipment supplier) may show up at this point, but must be expeditiously resolved.

3.4.2 System-Level Testing

As fiber optic components are assembled into a system, the components must work properly with one another throughout the operating temperature range. Details on component drop-out rates can help point out subtle component problems (including specification inadequacies) or marginal system designs.

System-level testing throughout the operating temperature range can identify weak components (infant mortality) and also might highlight marginal designs. Sometimes, for example, intermittent behavior can only be identified as components are heated and cooled. Extreme temperatures can also exaggerate marginal parametric conditions to the point that they cause failures, which can then be identified and corrected.

3.4.3 Repair of Field Returns

Based on the number of units shipped, equipment suppliers should be able to estimate the number of field failures that are expected for each component type. The confidence in this estimate depends on the number of devices in the field and their aggregate service time, with confidence improving as more device-hours are accumulated. Component types failing at a higher than expected rate should receive appropriate attention. However, expected failure rates based on a relatively few samples of a new design might be difficult to predict with the level of confidence desired; therefore, failure analysis might be required to resolve any question.

O3-76 **[76]** From predicted device failure rates, equipment suppliers should have some estimate of the number of failures that would be expected in field use, over any given period of time, for each device code. Devices that are being removed (during the repair of field returns) at rates higher than expected should be examined to determine why the additional failures are occurring, and to ensure that a major problem is not developing.

3.4.4 Data Collection and Analysis

R3-77 **[77]** The data collection system shall be implemented in such a manner that information can be compiled and analyzed for rapid feedback to all responsible groups (e.g., device engineering, quality assurance, quality control, manufacturing supervisors, etc.).

R3-78 **[78]** Reports summarizing device drop-out rates and circuit pack yields at various stages of assembly and test shall be issued on a periodic basis (no less frequently than every 3 months) for upper level management review. The report shall include number of units received for repair, number of units that are “no trouble founds” (NTFs) or “no fault founds” (NFFs), number of units modified, and number of units repaired.

O3-79 **[79]** The reports should track the length of time that identified problems persist and the efforts to resolve them. Follow-up reports should note specific actions to confirm that a problem was corrected.

3.4.5 Unconfirmed Failures

Components returned from the field that cannot be confirmed as failures by the equipment supplier are known as NTFs or similar terms. NTFs can indicate inadequate test procedures, marginal designs, unexpected compatibility problems between components obtained from different manufacturers, or other reasons for concern.

O3-80 **[80]** NTFs should be tracked as part of the data collection on field returns. When they exceed thresholds set by the supplier, the causes should be investigated and corrected. The supplier also should be prepared to explain and justify the NTF thresholds that it has set.

3.4.6 Device Failure Analysis

O3-81 **[81]** Because of their critical nature, *all* passive optical components failing in the field with less than 1 year of operation (i.e., early failures or infant mortality) should be submitted for failure analysis.

R3-82 **[82]** The equipment supplier shall document the conditions that mandate failure analysis of a representative sample of “bad” devices with similar failure modes.

R3-83 **[83]** The equipment supplier shall either maintain its own facilities or make arrangements (prior to actual need) with an independent laboratory or device manufacturer to perform any necessary failure analysis.[3]

3.5 Device Storage and Handling

R3-84 **[84]** The normal flow of fiber optic components from when they are received until they have been successfully tested in the system shall be clearly described in flow charts or other documentation. Differences from the practices for general electrical or electronic components shall be noted.

3.5.1 Nonconforming Material

R3-85 **[85]** Devices and lots that do not conform to purchase specifications must be segregated from good devices, from parts awaiting test and from field returns.

3.5.2 Material Review System

R3-86 **[86]** Equipment suppliers and device manufacturers shall establish and document practices for handling all nonconforming materials.

O3-87 **[87]** If nonconforming product is to be used “as is” or, if some form of additional testing or screening is required, appropriate component engineering and quality assurance engineers should be involved in the decisions (through formal sign-offs on the authorization).

R3-88 **[88]** Detailed records on the disposition of all nonconforming material shall be maintained for at least 1 year. Summary records shall be retained for at least 5 years. Results shall be reviewed periodically to ensure that the same problems are not being encountered repeatedly.

R3-89 **[89]** Problems discovered in the quality system shall be resolved within a specified time limit using the corrective action or quality improvement process. The timeliness and effectiveness of corrective actions shall be monitored and documented.

3. Complete failure analysis involves identifying the failure mode (e.g., no optical output), the failure mechanism (i.e., the physical, chemical, thermal, or other process that caused the failure), *and* the most likely immediate cause of the failure.

3.5.3 Stockroom Inventory Practices

3.5.3.1 FIFO Inventory Policy

R3-90 **[90]** Stockroom practices must ensure that no items are in storage in excess of their shelf life.

R3-91 **[91]** Inventory practices and shelf stock shall be audited periodically to check the effectiveness of the stockroom practices.

O3-92 **[92]** A first-in/first-out (FIFO) policy should be implemented for all shelf-life items.

3.5.3.2 Reworked Parts

R3-93 **[93]** All devices that are reworked must pass incoming inspection before they are returned to the stockroom.

3.5.4 ESD

For manufacturers of passive optical components, ESD precautions are clearly not necessary. If there are any active components integrated with these passive optical components, ESD precautions would be important. Detailed criteria on ESD testing and prevention in TR-NWT-000870, *Electrostatic Discharge Control in the Manufacture of Telecommunications Equipment*, would apply.

It is also important to note that even though passive optical components are immune to ESD damage, the charges carried in these components can cause ESD damages on active components when they are assembled together. Therefore, for manufacturers of products that include active devices, appropriate handling procedures must be observed to prevent damaging ESD events during equipment assembly and in the field.

3.6 Documentation and Test Data

As noted in many places throughout this document, all aspects, procedures, practices, and test methods related to reliability assurance need to be properly documented.

R3-94 **[94]** All reliability assurance procedures, practices and test methods shall be documented. Such documents have to be officially recognized and shall be formally controlled.[4]

O3-95 **[95]** The supplier's quality and reliability manual should identify any special reliability assurance requirements (e.g., testing, screening, handling) that are unique to fiber optic components.

3.6.1 Availability of Documentation

To understand the reliability program of the equipment supplier or device manufacturer, background information is necessary. Similar information might also be needed in the resolution of field problems or other reliability issues.

R3-96 **[96]** Equipment suppliers and/or device manufacturers shall provide the following information on request:

… • component description

… • the process flow chart highlighting inspection and testing

… • assembly procedures (including baking and/or curing steps)

… • re-work, etc.

… The supplier/manufacturer shall provide written explanation giving the extraordinary reasons for any information that it cannot provide (e.g., involving sensitive proprietary information).

R3-97 **[97]** The equipment supplier and/or device manufacturer shall make available all documents relevant to its reliability assurance program for fiber optic components. These include

… • vendor qualification practices

… • device qualification procedures and requalification practices

… • individual device specifications

4. In contrast, reports by engineers or managers on current practices and procedures usually do not have the same stature. Such reports sometimes give the appearance that changes could be made without formal review or that they reflect the views of only certain individuals.

… • procedures for adding vendors and devices to the AVL and APL

… • procedures for removing vendors and devices from the AVL and APL

… • incoming inspection procedures

… • screening practices

… • storage and handling practices

… • ESD control programs

… • data collection and analysis procedures

… • procedures describing the handling, repair, failure analysis, and corrective action associated with field returns

… • internal auditing procedures to ensure all the above procedures are being observed.

3.6.2 Availability of Other Information

Reviewers also need access to summary reports and test data to have confidence that the documented practices are actually followed. Where sensitive and/or proprietary information is involved, equipment suppliers may be allowed to "mask off" sensitive items, or to ask reviewers to sign nondisclosure agreements.

R3-98 **[98]** The following information must be provided for review on request:

… • long-term environmental life test results on specific devices

… • recent incoming inspection and screening data on specific devices

… • drop-out rates or failure levels of specific devices at first circuit pack test, at system test, in system burn-in, and from the repair of field returns

… • failure analysis results for specific devices

… • corrective action assignment and follow-up.

3.7 Availability of Devices

In some cases, equipment purchasers (or their representatives) might wish to obtain a small number of fiber optic components (less than 20) of a particular type for independent reliability tests or other analyses.

R3-99 **[99]** Equipment suppliers shall formally respond to requests for sample devices (plus accompanying functional specifications or performance sheets) in a timely fashion, and shall refuse such requests only if there are extraordinary reasons that would make such availability unacceptable.

When such requests are made, the organization making the request would be expected to reimburse the equipment supplier for the normal costs of the components.

4. Specific Reliability and Quality Criteria

The equipment manufacturer has the final responsibility for ensuring that the components meet the appropriate quality level. The component manufacturer has the responsibility for having the reliability tests performed and documented. If the equipment manufacturer relies on the component manufacturer to supply reliability data, the equipment manufacturer needs to verify the accuracy of the data by periodic audits.

The qualification and lot-to-lot (process) controls are developed for simple devices and more complicated integrated modules, as outlined in Section 4.1. An example of a passive optical device is described as a simple splitter with two or more ports without connectors or splices within the package, and no parts can be easily replaced or repaired without costly efforts.

An integrated passive optical module is defined as an assembly of unpackaged discrete optical and other components in a primary package, such that there is no optical to electrical or electrical to optical conversion between the signal input port(s) and the signal output port(s) of the device to achieve its designated function. The qualification guidelines are covered in Section 4.2.

4.1 Qualification of Passive Optical Devices

R4-1 **[100]** The equipment supplier shall perform or obtain verifiable data for the qualification of fiber optic components, including characterization and reliability tests.

4.1.1 Characterization

R4-2 **[101]** Fiber optic components shall be fully characterized for optical performance as part of device qualification. A sample size of at least 11 devices (LTPD of 20%) is required.

O4-3 **[102]** Table 4-1 lists a typical set of parameters that should be included for characterization of branching components. The necessary characterization and associated parametric limits that should be included for other devices may be provided in manufacturer's detailed specifications or Bellcore device-specific GRs.

Table 4-1. Typical Characterization Tests for Branching Components

Test or Measurement	Test Temperature
Optical Bandpass	min., room, max.
Insertion Loss	min., room, max.
Uniformity*	min., room, max.
Wavelength Isolation*	min., room, max.
Wavelength Stability	min., room, max.
Directivity	min., room, max.
Reflectance	min., room, max.
Polarization Dependent Loss	min., room, max.

* if applicable

If the equipment supplier is purchasing passive optical components, it shall identify the required limits and describe the necessary attributes in the purchase specification for the devices.

Test procedures are in the applicable documents (e.g., GR-1209-CORE for branching components, GR-2854-CORE for dispersion compensators, GR-2882-CORE for isolators and circulators, and GR-2883-CORE for filters). A failure is defined as any component that does not meet all the specified parametric limits at any time during the reliability test sequence and/or the specified allowed changes.

O4-4 **[103]** Fiber optic component data also should be obtained from the vendor (in-house or external) on a much larger population (~ 50-200 units representing a minimum of three different date codes). Distributions of measured parameters should be compared to specification limits and design requirements to assure that adequate margins exist.

4.1.2 Reliability Tests

R4-5 **[104]** Reliability tests for fiber optic components shall include mechanical/physical tests as well as endurance tests. Table 4-2 lists a minimum set of tests that must be performed. The manufacturer must provide testing data and analysis results, including failure analysis, on request.

R4-6 **[105]** Optical performance tests shall be completed before and after each of the reliability tests. Pass/fail criteria shall be consistent with the performance criteria in the applicable documents (e.g., Section 4.2 of GR-1209-CORE for branching components, Section 4.1 of GR-2854-CORE for dispersion compensators, Section 4.1 of GR-2882-CORE for isolators and circulators, and Section 4.1 of GR-2883-CORE for filters).

Different groups of sample devices may be used for each test or the same sample may be used for several tests, but the manufacturer must be aware of the cumulative degradation carried over from one test to the next.

The object of the dry and damp heat tests is to assess the effects of temperature and humidity on the expected operating life of the component. In addition to the thermal activation energy, the presence of water vapor at an elevated temperature produces an accelerated aging effect.

One of the primary failure mechanisms is the epoxy failure. Several parameters have been used to measure the degradation of epoxy in several temperature and humidity conditions. However, the data so far cannot accurately determine the value for activation energy. One definite conclusion is that the stress due to moisture is more critical than that from temperature. Suppliers generally indicate higher values for activation energies. With these inputs, the activation energy requirement is modified accordingly. However, Bellcore will review this requirement as more data become available.

As noted in Section 3.1.5, acceleration factors must be calculated using the Arrhenius relationship if technical justification of an alternative model is not available.

R4-7 **[106]** If technical data are not available in support of other values, an activation energy of 0.3 eV shall be assumed for the dry heat test and an effective activation energy of 0.8 eV shall be assumed for the damp heat test. In the latter case, the higher activation energy accounts for the difference between the test’s high humidity and “average” operating conditions, such that a separate term for humidity would not be included in the calculation of the acceleration factor.

R4-8 **[107]** Manufacturers may use a different activation energy from those in **R4–7** for the Arrhenius model, or a different model for calculating acceleration, if its use can be supported by empirical data. The empirical data must be based on reliability testing or field returns, and shall be available for review upon request.

Table 4-2. Required Reliability Tests

HEADING	TEST	REFERENCE	CONDITIONS	SAMPLING[a]			ENV'T	
				LTPD	SS	C	CO	UNC[b]
Mechanical Integrity	Mechanical Shock	Sec. 6.2.1	5 times/direction, 6 directions, 500 G, 1 ms	20	11	0	R	R
	Vibration	Sec. 6.2.2	20G, 20-2,000 Hz min/cy, 4 min/cy, 4 cy/axis	20	11	0	R	R
	Thermal Shock[c]	Sec. 6.2.3	ΔT = 100°C (0°C to 100°C)	20	11	0	R	R
	Solderability (if applicable)	MIL-STD-883 Method 2003	(steam aging not required)	20	11	0	R	R
	Fiber Integrity[d]	—	—	20	11	0	R	R
Endurance	High Temp. Storage (dry)	Sec. 6.2.4	85°C or max. storage T 2,000 hrs.	20	11	0	R	R
	High Temp. Storage (damp) or Damp Heat (Hermetic)	Sec. 6.2.5[e]	75°C/90%RH or 85°C/85%RH					
			100 hrs	20	11	0	R	—
			500 hrs for info	—	11	0	R	—
			75°C/90%RH or 85°C/85%RH					
			500 hrs	20	11	0	—	R
			1,000 hrs for info	—	11	0	—	R
	High Temp. Storage (damp) or Damp Heat (Non-Hermetic)	Sec. 6.2.5[e]	75°C/90%RH or 85°C/85%RH					
			500 hrs	20	11	0	R	—
			2,000 hrs for info	—	11	0	R	—
			75°C/90%RH or 85°C/85%RH					
			2,000 hrs	20	11	0	—	R
			5,000 hrs for info	—	11	0	—	R
	Low Temp. Storage	Sec. 6.2.6	-40°C or min. storage T 2,000 hrs.	20	11	0	O	R
	Temperature Cycling	Sec. 6.2.7	-40°C to +70°C					
			100 pass/fail	20	11	0	R	—
			500 for info.	—	11	—	R	—
			-40°C to +85°C					
			500 pass/fail	20	11	0	—	R
			1,000 for info.	—	11	—	—	R
	Cyc. Moist. Resis.	Sec. 6.2.8	—	20	11	0	—	R
Special Test	Internal Moisture[b]	MIL-STD-883 Method 1018	*max.* 5,000 ppm water vapor	20	11	0	R	R
	ESD	Section 6.2.9		—	6	—	R	R

Notes:

a LTPD (in %); min. acceptable sample size (SS) and corresponding number of allowed failures (C).

b The RT applications are included in this category.

c This is only required for hermetic packages.

d The component shall be tested to the criteria in the appropriate fiber integrity sections of the applicable documents (e.g., GR-468 for optoelectronic components, GR-1209-CORE for branching components, GR-2854-CORE for dispersion compensators, GR-2882-CORE for isolators and circulators, and GR-2883-CORE for filters).

e The test at 85°C/85%RH according to the procedures specified in IEC Pub. 68-2-3 or MIL-STD-202 Method 103 is acceptable.

Some passive optical components may possess degradation mechanisms that are sensitive to temperature (and humidity, in the case of non-hermetic modules), and other stimuli such as electrical and or optical power. An example might be the change in performance of thermo-optical switches and attenuators. In these cases, it is the responsibility of the component manufacturer to conduct an Accelerated Aging test as part of the qualification test program, to determine the reliability parameters associated with these mechanisms.

If the modules are cooled through the use of a thermoelectric cooler (TEC), then both Accelerated Aging and High Temperature Storage testing shall be performed. If the modules do not contain a TEC, and the Accelerated Aging test is performed under the same conditions and duration, the High Temperature Storage test(s) are not required.

R4-9 **[108]** If the modules are cooled through the use of a thermoelectric cooler (TEC), the component shall be tested

… • At 70°C and 2000 hours for pass/fail and 5000 hours for information for CO applications; or

… • At 85°C and 2000 hours for pass/fail and 5000 hours for information for RT/UNC applications.

Damp heat testing may be waived provided all of the following criteria are met:

1. The device is to be used in a CO environment.
2. The package is truly hermetic (e.g., sealed using a brazed/soldered or welded process).
3. No epoxy is used in a non-hermetic portion of the component.
4. The hermetic sealing process control is monitored by performing periodic Residual Gas Analysis (RGA, in Section 6.2.9) tests to demonstrate the routine achievement of <5000 ppm internal moisture.
5. RGA tests are performed at the completion of the Aging, Thermal Shock, and temperature cycling qualification tests.

On request, data in support of waiving the damp heat test shall be made available by the manufacturer.

To demonstrate different acceleration models or activation energies, a matrix of multiple temperatures and humidities would provide the most thorough understanding (see Table 4–3). However, as a minimum, or as the first tests performed, three specific sets of conditions are required.

Table 4-3. Test Matrix for Demonstrating Acceleration Factors

[Relative Humidity as a Function of Temperature and Absolute Humidity

Absolute Humidity [gm/m^3]	**Temperature [°C]**							
	25	**40**	**45**	**55**	**65**	**75**	**85**	**95**
19.2	85	38	30	19	12	8	6	4
42.5	sat	85	67	42	27	18	12	9
54.0		sat	85	53	34	23	16	11
86.0			sat	85	55	37	25	18
134.0				sat	85	57	39	27
200.0					sat	85	58	41
211.0						90	61	43
293.0						sat	85	60
419.0							sat	85

O4-10 **[109]** In order of priority, the following life tests should be performed as part of any effort to validate alternative acceleration models or activation energies:

… 1. High temperature damp heat = 75°C, 90% RH (or 85°C, 85% RH)

… 2. High temperature dry heat = 85°C, ~16%RH

… 3. Moderate temperature damp heat = 45°C, 85% RH.

… Minimum sample size is 22 devices for each life test. Results should include estimates of median life or mean-time-to-failure (MTTF), and a “spread” parameter (e.g., standard deviation).

O4-11 **[110]** The reliability database should be supplemented by additional accelerated aging data obtained from the vendor and with field data as they become available.

The purpose of the temperature cycling life test is to demonstrate the long-term mechanical stability of the package.

R4-12 **[111]** A temperature cycle life test shall be performed in accordance with the procedures of Section 6.2.7. The minimum and maximum temperatures shall be at least -40°C and +70°C for CO environments and -40°C and +85°C for RT/UNC environments. The minimum sample size is 11 devices (LTPD of 20%). Results after 500 cycles shall be used for “passing” or “failing” the test. Failures between 500 and 1000 cycles shall be investigated and corrective actions shall be implemented. The failure criteria shall be consistent with Section 4.1 of this document.

The airborne contaminants test, specified as an objective in Issue 1 of GR-1221, was removed from this issue. However, it is worth noting that all network equipment that may use passive optical components is expected to meet the airborne contaminants test as specified in **R-113, O-114**, and **R-115** of GR-63-CORE.

4.2 Qualification of Integrated Passive Optical Module

The integrated module may contain additional components to increase its functionality. For example, these might include photodiode(s) to provide an electrical monitor output(s), and electrical passive and active devices (including ICs) to compare these monitor outputs against a pre-set reference and to generate a feedback signal to internal or external components (e.g., a TEC current or laser diode bias). The products are very diverse and some are still in development stages. At this time, there are no commonly accepted definitions in the industry; therefore, no specific criteria can be developed. Bellcore and the industry (participating funders) are actively working on this area. Manufacturers should follow the guidelines below until the specific criteria can be developed in a future version of this document.

As a guideline, the integrated module shall be qualified for the components used and for the complete module.

- Optoelectronic Qualification: Optoelectronic devices shall be qualified to the applicable requirements of GR-468-CORE. For example, a photodiode shall be qualified in accordance with Section 8.1 and a TEC shall be qualified in accordance with Section 4.7.2 of GR-468.
- Conventional Passive Component Qualification: Conventional simple passive optical devices (e.g., splitters, filters, WDM devices, and isolators) shall be qualified in accordance with Section 4.1 of this document or other applicable documents (e.g., GR-326 for jumper cables and single mode optical connectors).
- Electronics Qualification: All electronic components shall be qualified according to TR-NWT-000357. If the electronics are contained in a hybrid assembly, the hybrid shall be qualified to TR-NWT-000930.
- Module Qualification: The fully assembled module shall be qualified by characterization and reliability tests. The manufacturer shall identify the parameters

for characterization based on the actual design and specification of the integrated module. The manufacturer shall determine (with justification) the weakest link (the least reliable component) and develop the appropriate qualifications accordingly.

4.3 Quality Assurance and Lot Controls

As noted in Section 1.1, functional criteria for passive optical devices are contained in device-specific GRs. These same parametric criteria apply to quality assurance (i.e., incoming inspection). Every device does not have to be tested against all of these parameters, as described below.

4.3.1 Visual Inspection

R4-13 **[112]** Incoming lots of fiber optic components shall be visually inspected on at least a sample basis (to be determined in accordance with a statistical sampling plan established by the equipment supplier).

O4-14 **[113]** Visual inspection (or another step in lot acceptance procedures) should check at least for the following:

… • Package condition

… • Required documentation

… • Product appearance/condition

… • Product identification/marking

… • Inspection of connectors or adaptors.

These inspection criteria are consistent with the items that would be addressed in a quality technology review, as described in Section 3.4.2 of GR-1209-CORE.

4.3.2 Optical Testing

The full set of optical characteristics need not be measured on each device, but may be extrapolated from a representative subset of data (the manufacturer must be able to justify the subset chosen). The test procedures and parametric limits are found in GR-1209-CORE. Criteria for ship-to-stock practices are given in Section 3.2.1.4.

R4-15 **[114]** If 100% testing is not performed, adequate data shall be collected and a statistically justified sampling plan must be established. The technical data to support the sampling test program shall be available on request.

O4-16 **[115]** Table 4-4 lists a typical set of parameters that should be included for lot-to-lot controls of branching components. The polarization Dependent Loss is recommended to be measured on a sample basis. The necessary characterization that should be included for other devices may be provided in manufacturer's detailed specifications or Bellcore device-specific GRs.

Table 4-4. Typical Optical Parameters s for Branching Components

Test or Measurement	Test Temperature
Optical Bandpass	room
Insertion Loss	room
Wavelength Isolation[a]	room
Uniformity[a]	room
Directivity[b]	room
Reflectance[b]	room
Channel Width[c]	room

Notes:
a. If applicable.
b. See text below.
c. To replace Optical Bandpass for DWDM applications.

100% measurement of directivity and reflectance (by the device manufacturer and/or system supplier) would not be required if it were known that the transport systems/ services only involved digital applications. For video applications, directivity and reflectance measurements would be critical and could not be reduced to a sample. Since the future use of a local access network (or other application of passive optical devices) cannot be anticipated with certainty, 100% reflectance measurements are normally necessary. The only exceptions to this would be [1] the direct use of passive optical devices as part of the integral hardware of a digital fiber optic transport system; or [2] the manufacturer specifies that the device is only intended for digital applications.

4.3.3 Stress Screening

A temperature cycle screen helps eliminate components that have any instability in the optical alignment of the components or have built-in mechanical stresses due to improper assembly operations.

O4-17 **[116]** All fiber optic components should be subjected to a temperature cycle screen. The recommended screening consists of 10 cycles between temperature limits of at least -40°C and +70°C for CO applications and -40°C and +85°C for RT/UNC applications; if these are outside the component's specifications, the minimum- and maximum-specified storage temperatures should be used. Sampling screening, other testing conditions, or number of cycles may be allowed if the equivalent effectiveness can be demonstrated.

Quality Level definitions in Table 1-1 should be referenced here. For Quality level III devices, lot-to-lot controls must include early life reliability control of 100% screening that may be reduced to a "reliability audit" (e.g., burn-in on a sample basis) or to an acceptable "reliability monitor" if an ongoing, continuous reliability improvement program is implemented by both the equipment supplier and the device manufacturer.

Pass/fail criteria are given in the applicable documents (e.g., Section 4.2 of GR-1209-CORE for branching components, Section 4.1 of GR-2854-CORE for dispersion compensators, Section 4.1 of GR-2882-CORE for isolators and circulators, and Section 4.1 of GR-2883-CORE for filters). *The number of temperature cycles may be reduced if the manufacturer can technically justify the proposal.*

O4-18 **[117]** The demonstration of the effectiveness of alternate temperature cycle conditions for screening should include first characterizing devices after the proposed number of temperature cycles and again after 10 cycles, presumably showing that no significant degradation nor additional failures occurred. The demonstration should be proved on adequate samples over multiple lots.

R4-19 **[118]** Optical criteria shall be measured before and after screening. Any "major" changes (as defined and documented by the equipment supplier, in addition to pass/fail criteria) shall result in rejection of a device.

O4-20 **[119]** The pass/fail criteria should be no more than 20% changes on the specified parameters.

O4-21 **[120]** The manufacturer should record the optical criteria before and after screening on a sample of components as a production audit.

4.3.4 Optical Adhesives

Quality assurance and incoming inspection of optical adhesives are covered in Section 4.4.

4.3.5 Optical Fiber

Fiber leads on the components must be compatible with fiber used in a typical public switched network (Section 5.3). Examples of criteria are given in Section 3.3.1 of GR-1209-CORE, *Generic Requirements for Fiber Optic Branching Components.*

4.4 Reliability and Quality of Optical Adhesives

Optical adhesives are commonly used in packaging passive optical components. Their uses include structures, adhesion, index matching, and the combination of these. It is important to point out that many of these components are not in the hermetically sealed packages, as it is well known that adhesives are sensitive to moisture. Therefore, the reliability of optical adhesion is often the determining factor of the component reliability.

The extent to which the manufacturing and assembly of passive optical devices relies on UV-curable and epoxy-based adhesives is unprecedented in the telecommunications industry. The use of these materials introduces reliability concerns that must be addressed. The most important of these is the ability of the devices to function satisfactorily for long periods under adverse environmental conditions. The failure modes and the failure rates depend on the use of the adhesives. Appropriate reliability programs have to be developed and implemented accordingly to address the following concerns:

- Adhesives are often used to attach optical fibers in different applications. As an example, in coupler packages the adhesive provides the critical support to the fiber and limits tensile stresses because the small-diameter fused segment is much weaker than regular fiber. Loss of adhesion sometimes allows the fiber to move or piston. This may cause sharp bending or buckling and eventual fiber breakage. If the reduced adhesion allows the fused segment to move, the refractive index can change even if there is no buckling-induced birefringence. Additionally, any loose fiber is susceptible to breakage under mechanical shock or vibration. If epoxy flows and interacts with the fused segment, the coupling ratio may change. If the temperature is raised to be close to the epoxy glass transition temperature, epoxy may creep, increasing the chances of the above problems.
- Even though the package may not be hermetic, outgassing may still be a problem for the continual curing of the adhesive after the device has been sealed. The epoxy curing may result in outgassing of solvents, extenders, or reaction by-products and their subsequent deposition on optical surfaces causing signal transmission degradation.

- Another concern is the use of adhesives with a glass transition temperature (Tg) within the operating temperature range. The Tg may be thought of as separating two regimes of material behavior. At temperatures below Tg, the material behaves more or less as a rigid solid and can be used as a structural element; above Tg the material is much softer and will deform plastically under an applied load. In addition, the thermal coefficient of expansion increases by a factor of two or three above the Tg. The materials that compose the package might have different Tgs, might expand and contract at different rates, and might deform over different temperature ranges. This deformation can be locked-in by temperature cycling through the Tg.

A complete reliability characterization program begins with the selection of a suitable adhesive and appropriate curing conditions, and continues with control of the storage for the limited shelf-life adhesive, training of the assembly operators according to established procedures, and is verified by periodic monitoring.

Bellcore and the industry have studied adhesive reliability for several years. Most of the failure modes that occurred in early years have been studied and controlled. However, direct links between adhesive reliability and component reliability are still lacking. As much as the community would like to qualify adhesives for optical components to cut down the development cycle and the cost, the ultimate qualification of adhesives still depends on the qualification of the components using the adhesive.

4.4.1 Qualification and Requalification

R4-22 **[121]** A detailed specification shall be generated and used by the component manufacturer for the purchase of epoxies and adhesives.

R4-23 **[122]** The adhesion used in the component or its packages shall be separately qualified and periodically requalified. The program shall include testing data and criteria for the curing cycle, glass transition temperature (Tg), viscosity, and air bubbles.

It is prudent to specify (in the detailed specification) that a shipment of adhesive contain only one batch or lot number to avoid multiple verification tests, since in many cases the appropriate curing cycle may be different for each delivered lot.

The reliability of an adhesive not only depends on the materials but also heavily depends on the curing process. Adhesives are polymeric materials with large amounts of long hydrocarbon chains and functional groups. The curing process forms cross-linked covalent bonds as the adhesive reacts chemically with a cross-linker, such as polyamide. UV light or heat is used to enhance the curing process. When the adhesive is fully cured, the hydrocarbon chains are mostly entangled, resulting in increased tensile strength. Adhesives shrink during the curing process. As such, the adhesive and the cure cycle together are considered as a critical component in the assembly operation. The optimization of the cure cycle (time-temperature test condition matrix) must be repeated each time a new adhesive is considered for use in the package.

The air bubbles, particularly large air bubbles or bubbles of uneven sizes, often cause a loss of structural support or adhesion.

R4-24 **[123]** Adhesives used as structural elements in the device shall have a glass transition temperature (Tg) equal to or greater than 95°C as measured by the following differential scanning calorimetry (DSC) test procedure: Samples of (uncured) adhesive mixture (5-10 mg) are placed in a standard DSC sample pan and cured under the same conditions as the production adhesive. Each test sample is placed in a calibrated DSC and cooled to 0°C and allowed to reach thermal equilibrium. A thermal scan is recorded as the temperature is raised from 0°C to +200°C at a rate of 10°C per minute. The Tg is the temperature of the midpoint of the transition deflection.

R4-25 **[124]** The passive fiber optic component manufacturer shall verify the cure cycle by ascertaining that the glass transition temperature (Tg) of the cured adhesive for each lot measured with DSC is not more than 10°C from the Tg of a reference standard. The adhesive tested shall be the production samples. If the above method is not used, one of the methods listed below (or a suitable equivalent) must be used to verify [for each incoming lot] that the adhesive is completely cured.

… a. The passive fiber optic component manufacturer shall verify the cure cycle by heating a sample of cured adhesive in a mass spectrometer and monitoring the evolved gases. The sample shall be heated to 350°C at a constant rate. The mass spectrometer shall be scanned from 10 to 600 AMU once per second. The presence of reaction by-products, solvents, vehicles, etc. at temperatures below the decomposition of the adhesive indicates an incomplete or ineffective curing cycle.

… b. The passive fiber optic component manufacturer shall perform residual gas analysis (RGA) on sealed hermetic packages that have completed an extended life test at maximum temperature. The presence of reaction by-products, solvents, vehicles, etc. indicates that a reliability hazard exists due to an incomplete or ineffective curing cycle. The presence of these gases will cause degradation in the uncontrolled environment, where temperature cycling could lead to condensation on optically active surfaces.

… c. The passive fiber optic component manufacturer shall verify the cure cycle by performing thermal gravimetric analysis (TGA) on a sample of cured adhesive. This is performed by placing a sample of the cured adhesive in the TGA, purging with dry nitrogen for approximately 15 to 30 minutes, and monitoring the weight of the sample as the temperature is increased. As the unreacted components volatilize, the weight decreases and indicates the extent of the curing process. The test consists of scanning the temperature 50°C to 150°C at a rate of approximately 5°C per minute and monitoring the weight loss: a 0.1 wt % or less weight loss is considered evidence of a properly cured adhesive in which two or more components are mixed. A 0.25 wt % or less weight loss is considered evidence of a properly uv-cured adhesive.

… d. The passive fiber optic component manufacturer shall verify the cure cycle by subjecting a sample of cured adhesive to gas chromatographic analysis. This is performed by placing a sample of the cured adhesive into a sealed vial, heating for a specified time (15 minutes to 1 hour) at a temperature above the operating temperature and below the curing temperature. The presence of reaction by-products, solvents, vehicles, etc. indicate incomplete or ineffective curing.

R4-26 **[125]** The passive fiber optic component manufacturer shall have documentation for storage, shelf-life, assembly operator training, pot life, cure cycle, manufacturing audit, and requalification in accordance with Section 3.6.

4.4.2 Raw Material Storage

The raw adhesives materials have a relatively sensitive shelf-life.

R4-27 **[126]** Rigorous first-in/ first-out (FIFO) must be developed and implemented for raw adhesive materials. The inventory dates must be clearly marked.

R4-28 **[127]** The adhesive shall be properly stored and used during its useful shelf-life; any adhesive not used shall be discarded when its shelf-life has expired.

4.4.3 Lot-To-Lot Controls

R4-29 **[128]** Incoming inspection procedures shall be documented and followed by the component manufacturer.

R4-30 **[129]** The cure cycle must be verified each time a new lot of adhesive is received (as part of incoming inspection) by performing the cure cycle and verifying the stability of the adhesive.

R4-31 **[130]** Work instructions, posted at the work station, shall control the application of the adhesive in the device package, the allowable pot life (after mixing), and the steps in the curing cycle.

5. Performance Criteria

5.1 Optical Requirements and Objectives

Optical test requirements consist of optical bandpass, insertion loss, uniformity, wavelength isolation, reflectance, and polarization stability. The optical functional and performance requirements given in Section 4.1 of GR-1209-CORE serve as the pre- and post-test measurements for the reliability verification procedures specified in Section 6. Interim measurements may be abbreviated to simply identify failures (rather than to collect variables data). Continuous monitoring of devices while on test is not required.

5.2 Optical Test Procedures

For performing the optical measurements required in this document and in GR-1209-CORE, the preferred test methods are given in Section 5.1 of GR-1209-CORE.

5.3 Optical Fiber and Optical Connectors

Optical fiber pigtails on fiber optic branching components must be compatible with the fiber used in a public switched network. Fiber optic components may be supplied with “coated” (also known as “standard”), “buffered” (1-mm jacketed), or “ruggedized” (3-mm cable) single-mode fiber pigtails. The pigtails may be connectorized by the component manufacturer, or may be supplied without connectors.

Detailed criteria applicable to fiber pigtails are given in GR-409-CORE and GR-20-CORE.

Detailed criteria applicable to fiber optic connectors are given in GR-326-CORE, *Generic Requirements for Optical Fiber Connectors.*

6. Reliability Test Procedures

In parallel with programs to develop processes capable of fabricating passive fiber optic components, programs to assess the reliability of these components must be undertaken. The reliability program must provide timely feedback to the design and manufacturing engineering groups, establish a baseline against which process variations can be compared, and provide a reliability baseline for customer applications.

The reliability program is undertaken to characterize the performance of the overall manufacturing process, including infant-mortality and wear-out mechanisms. The test samples are to be produced by the normal fabrication techniques, i.e., they are not to be subjected to any special handling or screening associated with "high-reliability" product. Each test sample is to be composed of components from lots processed several weeks apart in order to obtain a valid prediction of the failure rate of the process rather than that of an individual lot.

Device analysis performed on the "out-of-spec" components at interim downtimes (measuring points during the test sequence) and on the functioning components at termination of the accelerated stress tests is used to assess the effectiveness of the visual inspections and screens. In this way, the infant-mortality mechanisms and wear-out mechanisms (there may be more than one) can be separated and identified. This permits construction of a complete picture of the process reliability and provides feedback to the design and manufacturing engineering groups.

R6-1 **[131]** The manufacturer shall have a documented reliability assessment program in place that meets the requirements in Section 3.

R6-2 **[132]** The test sample components shall be selected from several non-sequentially produced lots.

R6-3 **[133]** Device analysis shall be performed on all components that are observed to be "out-of-spec" during the accelerated stress tests and on a representative sample of functioning ("in-spec") components upon termination of the accelerated stress test.

O6-4 **[134]** A power change of 10% or 0.5 db (e.g., insertion loss increased from 0.3 dB to 0.8 dB) is recommended as the failure criterion.

6.1 Reliability Test Pass/Fail Criteria

The accelerated stress tests are intended to determine the ability of the passive fiber optic components to perform their functions as designed over an extended period of time. The pass/fail criteria for the components under test are the parametric limits specified in Section 5.1.

R6-5 **[135]** Components under test are required to meet all parametric limits specified in Section 5.1 at the conclusion of each reliability test procedure of Section 6.2.

R6-6 **[136]** Components that test "out-of-spec" for any parameter shall be considered a failed unit, regardless of whether it tests "in-spec" after subsequent stress testing.

R6-7 **[137]** The "Time-on-Test" credited to a component that fails during an interim downtime test shall be from the start of the test to the last interim downtime test at which the device tested "in-spec" for all parameters.

6.2 Reliability Test Procedures

The test procedures adopted for use in the performance of the reliability assessment program are industry standard procedures with the test conditions, test duration and sample sizes specified to suit telecommunication applications.

6.2.1 Mechanical Shock (Impact Test)

The mechanical shock (or impact) test is based on MIL-STD-883, Method 2002, with the following conditions:

Number of Shocks:	5 times per direction for 6 directions (on 3 axes)
Shock Level:	500 G
Duration:	1 ms

OR

the procedures stated in EIA/TIA-455-2A for light service applications, with the following conditions:

Drop Height:	1.8 meters (6 feet)
Number of drops per three mutually perpendicular axes:	8
Number of repetitions of impact test cycle:	5

R6-8 **[138]** The component shall be mounted rigidly so that the shock is transmitted to the internal components and not absorbed or cushioned by the fiber pigtails or leads.

A suggested method of performing this test to EIA/TIA-455-2A procedures is to mount the fiber optic component inside a container filled with a rigid packing medium (such as sand or small glass beads) so that the package does not shift or bounce around when the container is dropped. In this way, the impact shock is not absorbed by an elastic packing material or by the component fiber pigtails or leads, but is fully transmitted to the internal components.

6.2.2 Variable Frequency Vibration Test

The variable frequency vibration test is based on MIL-STD-883, Method 2007, with the following conditions:

Condition:	Condition A
Acceleration:	20 G maximum acceleration
Frequency:	20-2,000 Hz
Duration:	4 min per cycle and 4 cycles per axis

OR

the procedures stated in EIA/TIA-455-11A, test condition IV, with the following conditions:

Vibration Type:	Sinusoidal
Frequency:	10 to 2,000 Hz
Accel. (or Amplitude):	20 G (or 1.52 mm or 0.060 in double amplitude), whichever is less.
Sweep Time:	10 to 2000 Hz and returned to 10 Hz in 20 minutes.
Duration:	Sweep cycle performed 12 times in each of three mutually perpendicular directions (total of 36 times).

6.2.3 Thermal Shock Test

The thermal shock test is based on MIL-STD-883 Method 1011 with the following conditions:

Temperature Range:	$\Delta T = 100°C$ (0°C to 100°C), liquid-to-liquid
Dwell Times:	$\geq$ 5 minutes at temperature extremes
Transfer Time:	$\leq$ 10 seconds
Number of Cycles:	15

OR

the procedures stated in EIA/TIA-455-71, with the following conditions:

Temperature Range:	ΔT = 100°C (within the operating temperature range of the device under test), liquid-to-liquid
Dwell Times:	≥ 30 minutes at temperature extremes
Transfer Time:	≤2 minutes
Number of Cycles:	20

6.2.4 High Temperature Storage Test (Dry Heat)

The high temperature storage (dry heat) test is based on the procedures stated in EIA/TIA-455-4A, with the following conditions:

Temperature:	85°C (±2°C) or the maximum storage temperature
Humidity:	<40% RH
Test Duration:	2,000 hrs for qualification and 5,000 hrs for information

R6-9 **[139]** Functionality of the components under test shall be verified during the test by interim downtime measurements either at test temperature or at room temperature. Data shall be taken initially, and then at 168-, 500-, 1000-, 2000-, and 5000-hour intervals.

Additional interim measurements may be taken at the discretion of the manufacturer.

O6-10 **[140]** Insertion loss should be monitored in-situ for all ports.

R6-11 **[141]** Devices that are supplied with connectors shall have the entire assembly (device package, leads and connectors) subjected to the test conditions.

6.2.5 High Temperature Storage Test (Damp Heat)

The high temperature storage (damp heat) test is based on the procedures stated in MIL-STD-883 Method 103 or EIA/TIA-455-5A, test type 1, with the following conditions:

Temperature:	75°C (±2°C)
Humidity:	90% (±5%) RH

OR

Temperature:	85°C (±2°C)
Humidity:	85% (±5%) RH
Test Duration:	As specified by the packages (hermetic or not) and the operational environments (CO or RT/UNC) in Section 4 Table 3.

Note: The test at 85°C/85%RH according to the procedures specified in IEC Pub. 68-2-3 or MIL-STD-202 Method 103 is acceptable. The test shall meet the durations specified in Table 2 in Section 4, which may be different from those in the IEC or MIL-STD documents.

R6-12 **[142]**The functionality of the components under test shall be verified during the test by interim downtime measurements either at test temperature or at room temperature. Data shall be taken initially and at the end, as well as interim measurements, such as at 100, 168, 500, 1000, 2000, and 5000 hour intervals.

O6-13 **[143]**Insertion loss should be monitored in-situ for all ports.

R6-14 **[144]**Devices that are supplied with connectors shall have the entire assembly (device package, leads and connectors) subjected to the test conditions.

6.2.6 Low Temperature Storage Test

The low temperature storage test is based on the procedures stated in EIA/TIA-455-4A, with the following conditions:

Temperature:	-40°C (±5°C)
Humidity:	Uncontrolled
Test Duration:	2,000 hrs for qualification and ≥5000 hrs for information

R6-15 **[145]**Functionality of the components under test shall be verified during the test by interim downtime measurements either at test temperature or at room temperature. Data shall be taken initially, and then at 168-, 500-, 1000-, 2000-, and 5000-hour intervals as a minimum. The strength of the epoxy joint shall be tested after 2000 and 5000 hours.

Additional interim measurements may be taken at the discretion of the manufacturer.

6.2.7 Temperature Cycling Test

The temperature cycling test is based on the procedures stated in MIL-STD-883, Method 1010, with the following conditions or EIA/TIA-455-3A, with the following conditions:

Temperature:	-40°C to 70°C (±2°C) for CO 40°C to 85°C (±2°C) for RT/UNC
Dwell Time at Extremes:	≥15 minutes
Number of Cycles:	100 pass/fail, 500 for information for CO 500 pass/fail, 1000 for information for RT/UNC

A pause at room temperature (approximately 20-25°C) during the transition between extremes is optional.

6.2.8 Cyclic Moisture Resistance Test

The cyclic moisture resistance (temperature-humidity cycling) test is based on the procedures stated in MIL-STD-883, Method 1004, with reduced ramping time to the subzero temperature or IEC 68-2-38, with the following conditions:

Temperature Profile:	Refer to Figure 6.1
Relative Humidity:	85-95% at 75°C; uncontrolled at 25°C & -40°C
Dwell Time at Extremes:	3 to 16 Hours
Number of Cycles:	5 complete cycles (each complete cycle has 5 sub-cycles)

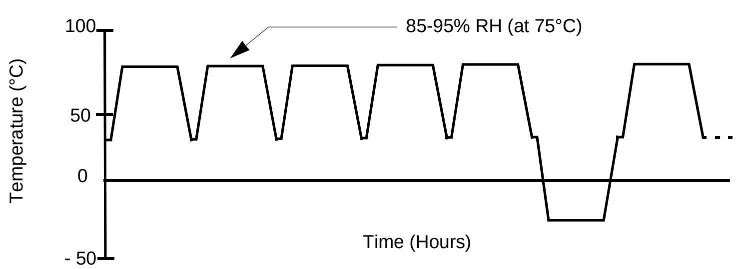

Figure 6-1. Thermal Profile of Cyclic Moisture Resistance Test

This climatic sequence is designed to stress components under conditions of condensation and freezing during the temperature cycling in an RT or UNC environment.

R6-16 **[146]** The temperature profile used for the temperature humidity cycle test chamber shall be recorded and be available for review as part of the test documentation package.

R6-17 **[147]** Devices that are supplied with connectors shall have the entire assembly (device package, leads and connectors) subjected to the test conditions.

6.2.9 Residual Gas Analysis

The procedure shall follow MIL-STD-883, Method 1018, Procedure 1. The result including the trace organic contaminations shall be provided.

6.2.10 ESD Threshold

ESD-damage thresholds should be determined at room temperature (25°C) on the completed device. The devices for this test shall be subjected to the normal incoming inspection and screening procedures. To prevent influencing the test results, the following ESD-prevention measures shall be used:

- Devices for this test shall be transported only while inserted in conductive foam.
- All operators shall wear grounding straps when handling the devices.

The detailed test procedure for measuring ESD threshold is given in TR-NWT-000870. At the current time, this procedure is based only on the human body model (HBM). TR-NWT-000870 also provides instructions on verifying the ESD pulse waveform (whether custom-made or commercial test equipment is used).

Appendix A: Lot Tolerance Percentage Defective (LTPD) Table

Table A-1. LTPD Sampling Plan[a]

LTPD [%]	50	30	20	15	10	7	5	3	2	1.5
Acceptance Number (c)	Minimum Sample Sizes									
0	5	8	11	15	22	32	45	76	116	153
1	8	13	18	25	38	55	77	129	195	258
2	11	18	25	34	52	75	105	176	266	354
3	13	22	32	43	65	94	132	221	333	444
4	16	27	38	52	78	113	158	265	398	531
5	19	31	45	60	91	131	184	308	462	617
6	21	35	51	68	104	149	209	349	528	700
7	24	39	57	77	116	166	234	390	589	783
8	26	43	63	85	126	184	258	431	648	864
9	28	47	69	93	140	201	282	471	709	945
10	31	51	75	100	152	218	306	511	770	1025

a. Taken from *General Specification for Microcircuits*, Military Specification MIL-M-38510F (October 1983).

Appendix B: Reliability Calculation

The typical failure rates versus operating time are usually described by a “bathtub curve” that has three distinct zones: infant mortality, constant rate failure, and wear-out zone. The infant mortality failures are usually defined as those occurring in the first year of operation. The infant mortality rate is often negligible if effective screening steps are implemented. The failures of a constant rate are those that occur when devices suddenly degrade. Therefore, they are often referred to as sudden failures. They are also called random failures because they randomly occur independent of the operating time. Unlike constant rate failures, the failures in the wear-out zone are caused by mechanisms that degrade in performance gradually until the device or system does not function any more. The wear-out failure rate is a function of operations (including the operating conditions and operating time). Wear-out and random failure rates are not interchangeable. They usually result from different failure mechanisms and they represent different reliability measures. A device's total failure rate, then, is the sum of these two contributions. The median life indicates when the wear-out mechanism starts to show up and dominates the total failure rate of the component. A complete reliability calculation should include all four parameters discussed here: infant mortality, random failures, wear-out failures, and median life.

To estimate the failure rate of a packaged passive component, one can either take the “parts count” approach or consider the package as a black box. The latter is easier and adopted if the technology and construction information is lacking, but it yields less accurate estimates. This is particularly true if the device under study is based on new technology and/or does not have adequate track records. It is less accurate even if the technology and construction information is provided, because there are usually more than one failure mode and they have different acceleration factors. Therefore, the prediction based on the parts/materials and technologies of these components is preferred. In other words, the failure rate of the packaged component is the sum of the failure rates of the materials and devices that make up the module.

The failure rates provided are considered as the base failure rates for the devices discussed. The failure rates to be used in the system reliability modeling should include the multiplying factors, as described in TR-332. These multiplying factors include the quality factor, the stress factor, the temperature factor, and environmental factor. The assigned values of multiplier factors are given in TR-332.

The device Quality Levels are determined by the reliability programs as how well they are in compliance with those criteria specified in this document.

The (electrical) stress factor does not generally apply to the passive components covered in this document. The temperature factor is already taken into consideration. The environment factor is determined by the harshness of the operating environment.

The following procedures are meant to provide only a minimum approach to the assessment of device reliability by the equipment supplier. There are much more sophisticated techniques available, which are encouraged if they also address the basic issues outlined here.

Median Life

The median life (ML) should be calculated from the distribution of failures (excluding infant mortality and random failures). The ML is the time that 50% of the population has failed (this is different from the mean or average life) obtained from a fit of the data to a lognormal distribution function. The ML is easily found from a plot of the cumulative failures (in percent) versus time (in hours) on lognormal probability paper. As shown for the example plotted in Figure B-1, typical failure data do not always exhibit a perfect lognormal distribution (which would have given a straight line). Rather, a linear best fit to the data must be obtained.[1] In theory, a linear plot would be produced only when all failures are a result of a single failure mechanism.

The ML corresponds to the 50% point of the fitted line. In addition, the standard deviation (σ) of the distribution should be found from the plot. Its value indicates the width of the distribution (i.e., the relative period over which the failures will occur). In most cases, it can be easily calculated using the following equation:

$$\sigma = \frac{\ln(t_{84}) - \ln(t_{16})}{2}$$

where t_{84} and t_{16} are the times to 84% and 16% failures, respectively, as taken from the lognormal plot. On some probability paper, it can be obtained directly from a special scale.

In the case of (accelerated) life tests, the data should be plotted for the actual test temperature. With ML and found for this temperature, results can be calculated for other temperatures, including the normal operating temperature. The Arrhenius relationship should be used for this calculation to describe the temperature effect. As discussed early, the moisture impacts strongly on passive component reliability. The overall effect can be expressed as:

$$\frac{ML(T_2)}{ML(T_1)} = \exp\left(\left[\frac{E_a}{k}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)\right] + \eta \times (RH_1^{\,n} - RH_2^{\,n})\right)$$

where

E_a is the activation energy,
k is Boltzmann's constant,

1. Care must be taken to exclude infant mortality or early life failures from the main population. Failure analysis should be performed on all infant mortality and early life failures, as well as a sample from the main population of failures, to confirm differences in the cause(s) of failures.

T_1 and T_2 are the temperatures in Kelvin,

η is humidity factor (determined by relative humidity experiments)

n is relative humidity factor (determined by relative humidity experiments), and

RH_1 and RH_2 are the relative humidity (%).

It is true that some failure mechanisms may not be best described by the Arrhenius relationship. However, unless the failure mechanism and associated activation energy can be identified, the data generated using the Arrhenius relationship is recognized as a best estimate.

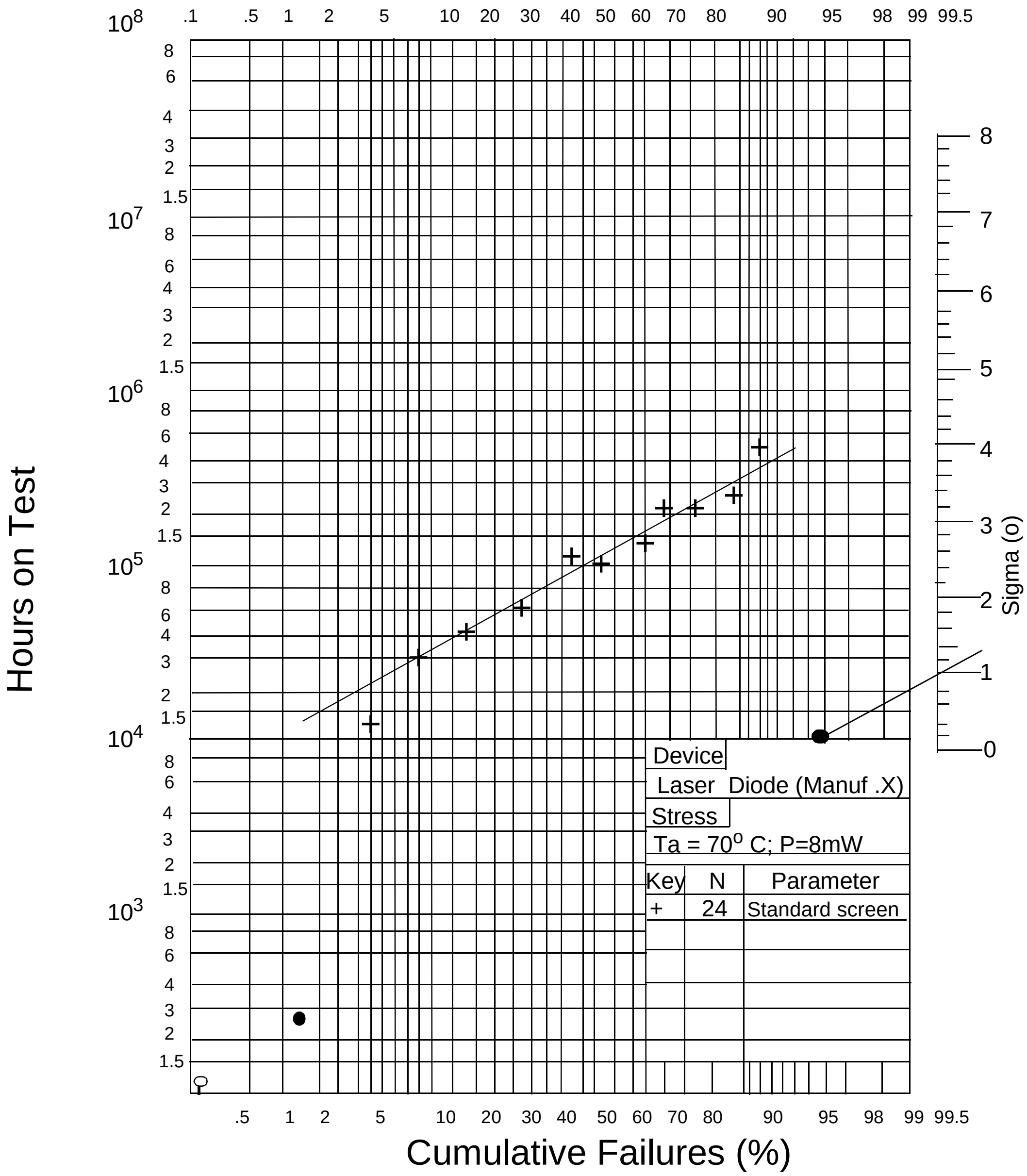

Figure B-1. Example of a Lognormal Probability Plot

Wear-Out Failure Rate

The wear-out failure rate is calculated from the median life and standard deviation (as described above, assuming a lognormal distribution). It depends on how long a device has been operating, and except for narrow distributions (less than ~0.7), it will peak before ML is reached. In some cases, the peak will occur before the design life of the equipment or system is reached.

Consequently, the wear-out failure rate should be taken as the maximum value over the life of the equipment. Calculations for ¼, ½, and the full design life usually will be sufficient (e.g., 5, 10, and 20 years of service for equipment with a design life of 20 years).

An easy way of obtaining these numbers is to use "Goldthwaite" curves.[2] Figure B-2 shows several cases. For example, a laser diode life test might give ML = 1 hours (calculated for a 40°C normal operating temperature), with σ = 1.0. After 20 years (1.75 hours) of operation, the expected failure rate will be ~430 FITs.[3]

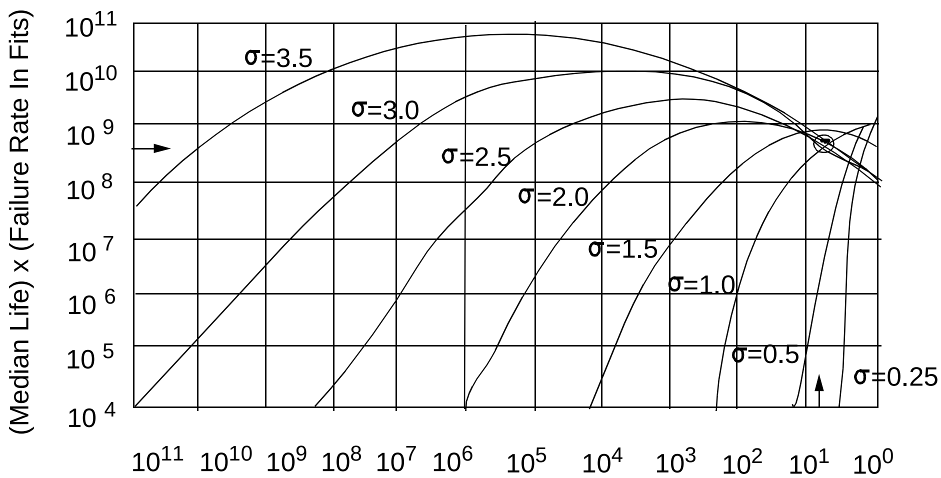

Figure B-2. Goldthwaite Curves

If the same values for service life are used repeatedly, the curves can be customized for those cases.[4] The resulting individual plot for each service life calculation (e.g., 5, 10, and 20 years) gives the failure rate versus median life in direct terms.

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2. See "Failure Rate Study for the Lognormal Lifetime Model" by L.R. Goldthwaite, in *Proceedings of the 7th Symposium on Reliability and Quality Control*, 1961, pp. 208-213; the use of Goldthwaite plots is described in *Accelerated Testing Handbook* by D.S. Peck and O.D. Trapp, Technology Associates (Portola Valley, CA, 1981).

3. A FIT, or **F**ailure Un**it**, corresponds to failures per billion device-hours.

4. See "A Comprehensive Review of the Lognormal Failure Distribution with Application to LED Reliability" by A.S. Jordan, *Microelectron. Reliability*, Vol. 18, pp. 267-279 (1978).

Random Failure Rate

The random failure rate reflects the probability of failures not associated with wear-out mechanisms. Since there should be no infant mortality failures (Section 4.3 calls for normal screening before life testing), any failures that are not considered wear-out must be counted in this random failure category. The random failure rate is assumed to be constant over time; then, if wear-out is negligible, the random and “steady-state” failure rates are equivalent.

An exponential distribution is used to model random failures. The failure rate should be reported for both 60% and 90% one-sided confidence limits. A point estimate (i.e., the calculation of the number of failures divided by time, or the inverse of this) is not sufficient.

Computer programs can be used to find the failure rate for any given confidence limit. However, a simple equation gives a reasonable approximation for applications involving optoelectronic devices.

$$\text{FailureRate} = (10^9 N\gamma)/t_{tot}$$

where

N is the number of random failures,

t_{tot} is the total device hours calculated from the Arrhenius relationship, and

γ is taken from the table below.

N	0	1	2	3	4	5
γ (60% C.L.)	0.92	2.02	1.55	1.39	1.31	1.26
γ (90% C.L.)	2.30	3.89	2.66	2.23	2.00	1.85

The equation of Arrhenius relationship holds for failures less than 10% of the population. [**Note:** If there are no failures (i.e., N=0), use N=1 in the equation and use the value of *gamma* for N=0.]

Approximate values also can be obtained from the nomograph shown in Figure B-3.[5] For example, 1 failure out of 1 device-hours yields upper limits of ~0.004 percent failures per 1,000 hours (= 40 FITs) and ~0.002 percent failures per 1,000 hours (= 20 FITs) for confidence levels of 90% and 60%, respectively.[6] Note that, if the number of device-hours is relatively low, there can be a significant failure rate even when no failures are observed.

5. The nomograph is taken from MIL-STD-690B and is provided here as a convenience.

6. The conversion factor between %/1,000 hrs and FITs is 10^4.

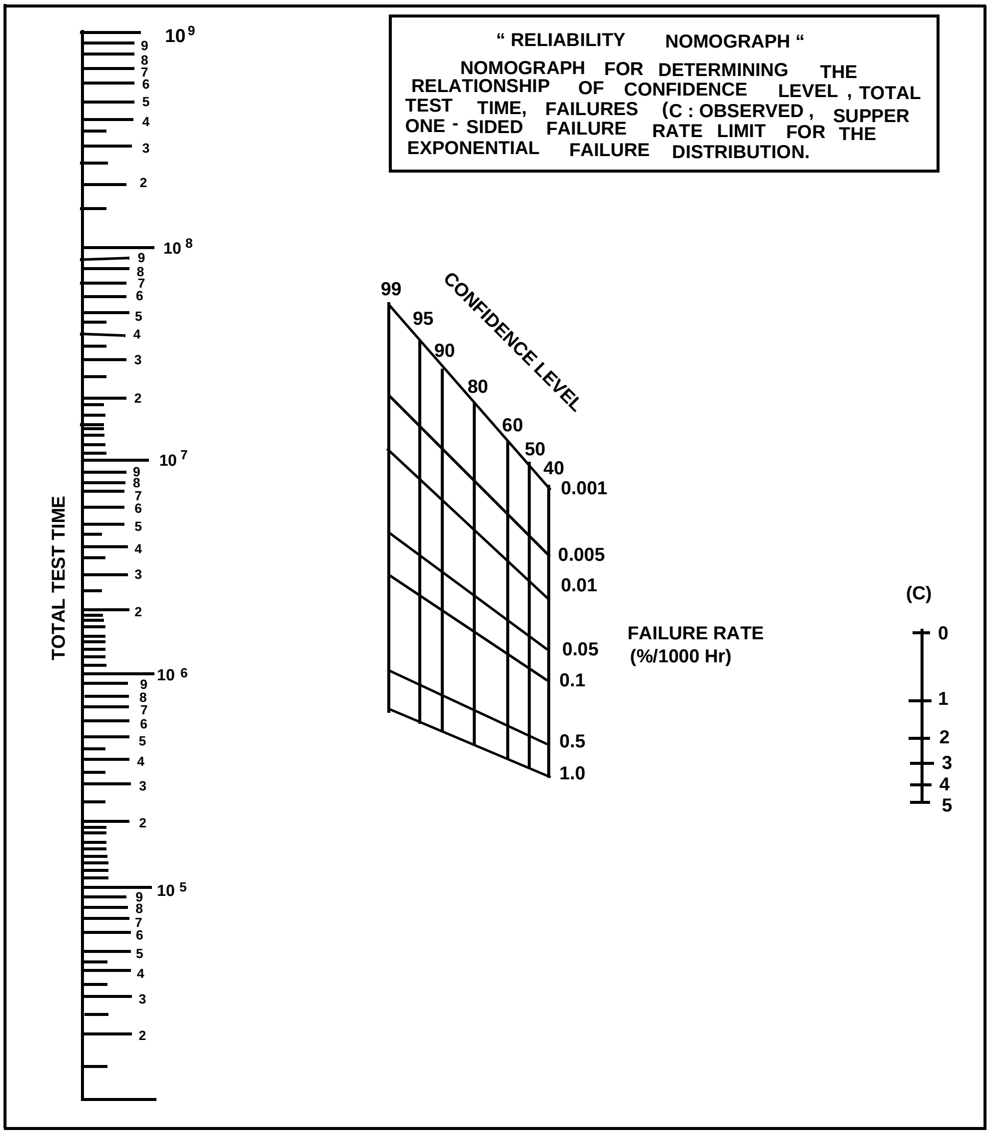

Figure B-3. Nomograph for Calculating Random Failure Rates

Reporting of Results

Failure rates and associated device reliability information should be reported using formats similar to the one shown in Table B-1. Results for modules, which can be more complex, should be documented and reported using the same basic approach, but should provide additional details on the module components.

Table B-1. Sample Format for Reporting Reliability Information

PARAMETER	MEASURED VALUE
Median Life (ML) @ 40°C	years
Standard Deviation (σ)	
Maximum Wear-Out Failure Rate (λ_{max})	FITs
Wear-Out Activation Energy (E_a)	eV
Random Failure Rate (λ_R) @ 40°C	FITs
Random Failure Activation Energy (E_a)	eV

In addition to this basic information, the equipment supplier shall provide (on request) other supplemental information. For a given test, this should include the following:

1. Sample size
2. Test conditions
3. End-of-life criteria
4. Number of failures allowed and number observed
5. Results of failure analysis
6. Number of failures excluded from the results (and the reasons).

References

A number of publications are related to the practices described in this document. These include other Bellcore documents, military specifications and standards, International Electrotechnical Commission (IEC) publications, and Telecommunications Industry Association (TIA) standards. They are listed in the following sections.

Bellcore References

GR-20-CORE *Generic Requirements for Optical Fiber and Fiber Optic Cable,* Issue 2 (Bellcore, July 1998).

GR-63-CORE *Network Equipment-Building System (NEBS) Requirements: Physical Protection,* Issue 1 (Bellcore, October 1995). (A module of LSSGR, FR-64; TSGR, FR-440; and NEBSFR, FR-2063.)

GR-78-CORE *Generic Requirements for the Physical Design and Manufacture of Telecommunications Products and Equipment,* Issue 1 (Bellcore, September 1997). (A module of RQGR, FR-796 and NEBSFR, FR-2063.)

TR-NWT-000284 *Reliability and Quality Switching Systems Generic Requirements (RQSSGR)*, Issue 2 (Bellcore, October 1990).

TR-332 *Reliability Prediction Procedure for Electronic Equipment*, Issue 6 (Bellcore, December 1997). (A module of RQGR, FR-796.)

GR-326-CORE *Generic Requirements for Single-Mode Optical Connectors and Jumper Assemblies*, Issue 2 (Bellcore, December 1996).

TR-NWT-000357 *Generic Requirements for Assuring the Reliability of Components Used in Telecommunications Equipment*, Issue 2 (Bellcore, October 1993).

GR-409-CORE *Generic Requirements for Premises Fiber Optic Cable*, Issue 1 (Bellcore, May 1994).

GR-418-CORE *Generic Reliability Assurance Requirements for Fiber Optic Transport Systems,* Issue 1 (Bellcore, December 1997). (A module of RQGR, FR-796.)

GR-468-CORE *Generic Reliability Assurance Requirements for Optoelectronic Devices Used in Telecommunications Equipment,* Issue 1 (Bellcore, December 1998). (A module of RQGR, FR-796.)

GR-487-CORE *Generic Requirements for Electronic Equipment Cabinets,* Issue 1 (Bellcore, June 1996).

TR-NWT-000870 *Electrostatic Discharge Control in the Manufacture of Telecommunications Equipment*, Issue 1 (Bellcore, February 1991). (A module of RQGR, FR-796.)

GR-874-CORE *An Introduction to the Reliability and Quality Generic Requirements (RQGR),* Issue 3 (Bellcore, April 1994). (A module of RQGR, FR-796.)

TA-NWT-000909 *Generic Requirements and Objectives for Fiber in the Loop Systems,* Issue 2 (Bellcore, December 1993).

TR-NWT-000930 *Generic Requirements for Hybrid Microcircuits Used in Telecommunications Equipment*, Issue 2 (Bellcore, September 1993).

TA-NWT-000983 *Reliability Assurance Practices for Optoelectronic Devices in Loop Applications,* Issue 2 (Bellcore, December 1993).

GR-1209-CORE *Generic Requirements for Fiber Optic Branching Components,* Issue 2 (Bellcore, February 1998).

GR-1217-CORE *Generic Requirements for Separable Electrical Connectors Used in Telecommunications Hardware,* Issue 1 (Bellcore, November 1995). (A module of NEBSFR, FR-2063.)

GR-2853-CORE *Generic Requirements for AM/Digital Video Laser Transmitters, Optical Fiber Amplifiers, and Receivers,* Issue 3 (Bellcore, December 1996).

GR-2854-CORE *Generic Requirements for Fiber Optic Dispersion Compensators,* Issue 2 (Bellcore, December 1997).

GR-2882-CORE *Generic Requirements for Optical Isolators and Circulators,* Issue 1 (Bellcore, December 1995).

GR-2883-CORE *Generic Requirements for Fiber Optic Filters,* Issue 1 (Bellcore, December 1995).

Note:

All Bellcore documents are subject to change, and their citation in this document reflects the most current information available at the time of this printing. Readers are advised to check current status and availability of all documents.

To Contact Bellcore

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  3. Click on ***DOCS - Bellcore Product Catalog***
  4. Enter data in one or more of the fields (e.g., enter a document number in the ***Product Number*** field), then follow the instructions to search the online catalog.

Non-Bellcore References

ASTM B827-92 *Airborne Contaminants Test*

EIA/TIA-455-2A *FOTP-2: Impact Test Measurements*

EIA/TIA-455-3A *FOTP-3: Procedure to Measure Temperature Cycling Effects on Optical Fiber*

EIA/TIA-455-4A *FOTP-4: Fiber Optic Connector/Component Temperature Life*

EIA/TIA-455-5A *FOTP-5: Humidity Test Procedures For Fiber Optic Connecting Devices*

EIA/TIA-455-11A *FOTP-11: Vibration Test Procedure For Fiber Optic Connecting Devices*

EIA/TIA-455-12A *FOTP-12: Fluid Immersion Test For Fiber Optic Components*

EIA/TIA-455-16A *FOTP-16: Salt Spray (Corrosion) Test For Fiber Optic Components*

EIA/TIA-455-71A *FOTP-71: Procedure to Measure Temperature-Shock Effects on Fiber Optic Components, Optical Cable, and Other Passive Fiber Optic Components*

IEC Pub. 68-2-38 *Composite Temperature/Humidity Cycle Test (Test Z/AD)*

IEC Pub. 747-10 *Semiconductor Devices - Part 10: Generic Specification for Discrete Devices and Integrated Circuits*

MIL-S-19500G *General Specification for Semiconductor Devices*

MIL-M-38510F *General Specification for Microcircuits*

Copies of ASTM documents may be ordered from:

American Society for Testing and Materials
1916 Race Street
Philadelphia, PA 19103
(215)299-5400

To obtain EIA/TIA documents, contact:

Global Engineering Documents
1–800–854-7179 (in the U.S. or Canada)
(714)261-1455 (For Foreign Calls)

IEC documents may be ordered through the American National Standards Institute:

ANSI
Customer Service Department
11 West 42nd Street
New York, NY 10036
(212)642-4900

To obtain IEEE documents, contact:

IEEE Service Center
Box 1331
445 Hose Lane
Piscataway, NJ 08855-1331
1–800–678-IEEE

Copies of Military Standards or Specifications may be ordered from:

Naval Publications and Forms Center
Code 3015
5801 Tabor Avenue
Philadelphia, PA 19120
(215)697-3321

Internet References

- IEC 60825-1 Safety of Laser Products - Part 1: Equipment classification, requirements and user’s guide. Type: (http://www.iec.ch/cgi-bin/procgi.pl/www/iecwww.p?wwwlang=E&wwwprog=cat-det.p&wartnum=017336
- FDA Title 21, Part 1040.10 Performance Standards for Light Emitting Products. Type: (http://www.verity.fda.gov/search97cgi/s97_cgi.exe?action=View&VdkVgwKey=http%3A%2F%2Fwww%2Efda%2Egov%2Fcdrh%2Fdevadvice%2Fpart1040%2Ehtml&DocOffset=7&DocsFound=12&QueryZip=light%2Demitting+products&Collection=C4&SearchUrl=http%3A%2F%2Fwww%2Everity%2Efda%2Egov%2Fsearch97cgi%2Fs97%5Fcgi%2Eexe%3Faction%3DSearch%26QueryZip%3Dlight%252Demitting%2Bproducts%26ResultTemplate%3Dstndrslp%252Ehts%26QueryText%3Dlight%252Demitting%2Bproducts%26Collection%3DC4%26ResultStart%3D1%26ResultCount%3D10&hlnavigate=ALL)
- OSHA Pub. 8-1.7- Guidelines for Laser Safety and Hazard Assessment. Type: (http://www.osha-slc.gov:80/OshDoc/Directive_data/PUB_8-1_7.html)

Glossary

Acronyms

ASTM — American Society of Testing and Materials

APL — [Manufacturer’s] Approved Parts List

AQL — Acceptable Quality Level

AVL — [Manufacturer’s] Approved Vendor List

CC — Client Company

CEV — Controlled Environment Vault

CO — Conditional Objective

CO — Central Office

CR — Coupling Ratio

CR — Conditional Requirement

DMA — Dynamic Mechanical Analysis

DSC — Differential Scanning Calorimeter

DUT — Device Under Test

DWDM — Dense Wavelength-Division Multiplexing

EIA — Electronics Industry Association

ESD — Electrostatic Discharge

FA — Framework Technical Advisory

FIFO — First-In/First-Out

FIT — Failure Unit (number of failures per billion operating hours)

FITL — Fiber In The Loop

FOTP — Fiber Optic Test Procedure

HBM — Human Body Model

IC — Integrated Circuit

IEC — International Electrotechnical Commission

IP — Industry Practice

LTPD — Lot Tolerance Percentage Defective

ML — Median Life

MTTF — Mean-Time-To-Failure

NE — Network Element

NFF — No Fault Found

NTF — No Trouble Found

PDA — Percent Defective Allowed

PDN — Passive Distribution Network

QA — Quality Assurance

QC — Quality Control

R&Q — Reliability and Quality

RBOC — Regional Bell Operating Company

RGA — Residual Gas Analysis

RH — Relative Humidity

RT — Remote Terminal

SQC — Statistical Quality Control

SR — Special Report

SS — Sample Size

TA — Technical Advisory

TEC — Thermoelectric Cooler

TGA — Thermal Gravimetric Analysis

TIA — Telecommunications Industry Association

TR — Technical Reference

UNC — Uncontrolled

UV — ultraviolet

WDM — Wavelength-Division Multiplexing

Terms

Bandpass (or Bandwidth) — See Optical Bandpass.

Branching Component — A passive component having more than two ports, that distributes optical power among fibers. **Synonyms**: Branching Device, Coupler.

Channel — See Optical Channel.

Combiner — A branching component that serves to combine optical power.

Coupler — Synonym: Branching Component.

Coupling Ratio (CR or C_{ij}) — The ratio of fractional power transferred from input port to *i* to output port *j*, to the total power transferred from port *i* to all output ports. In terms of the transfer coefficients.

$$Cij = \frac{tij}{\sum_j tij} \times 100$$

The coupling ratio defines the optical power distribution of the input signals among the output ports in %.

Demultiplexing — The process of separating optical channels.

Directivity (D_{ij}) — The fraction t_{ij} of power transferred from input port, *i*, to another input port, *j*.

$$D_{ij} = -10 \log t_{ij} \text{ in dB}$$

Here, t_{ij} is the transfer coefficient from input port i to input port j.

Fused Biconic Taper (FBT) — A coupling of fibers made by pulling and fusing together two or more fibers.

Fused Tapered Coupler — A branching component made using FBT technology.

Insertion Loss (L_{ij}) — The fraction t_{ij} of power transferred from input port, *i*, to output port, *j*, measured over the optical bandpass. In terms of the transfer coefficient,

$$L_{ij} = -10 \log t_{ij} \text{ in dB}$$

Multiplexing — The process of combining channels together.

Near-End Isolation — See Directivity.

Non-uniform Coupler — A branching component in which the distribution of power among the output ports is uneven.

Optical Bandpass — The range of optical wavelengths that can be transmitted through a component.

Optical Channel (λ_i) — An optical wavelength band for WDM optical communication.

Optical Channel Spacing — The difference in wavelength between channel centers.

Optical Channel Width ($\Delta \lambda_i$) — The optical wavelength range of a channel.

Optical Directional Coupler (ODC) — Passive components that combine and separate optical power among fibers. **Synonyms**: Splitter, Coupler.

Optical Spectrum — The distribution of optical power as a function of wavelength.

Pigtail — A short length of optical fiber (usually ~ 1 m), permanently fixed to a component, used to couple power between the component and a transmission fiber.

Polarization — The direction of the electric field in the lightwave. In a fiber, the electric field orientation.

Port — An opening for input or output of light from a component.

Reflectance (R_i) — The fraction t_{ij} of power transferred from input port, *i*, back to the same input port, *j*. In terms of the transfer coefficient,

$$R_i = 10 \log t_{ii} \text{ in dB}$$

Reflective Star Coupler — A branching component in which light launched into any port is distributed to all ports, usually uniformly.

Splice — The point where two fibers are joined together to make a continuous optical path, or the device or means used to align two fibers ends to create a continuous optical path.

Splitter — A branching component that serves to divide optical power.

Star Couple — A branching component that combines signals from several fibers and redistributes the composite signal to several other fibers.

Tap — A branching component that removes and/or inserts a small fraction of optical power onto a fiber.

Tree Coupler — A branching component that distributes a signal from one fiber to several other fibers, or combines signals from several fibers onto one fiber.

Uniform Coupler — A branching component that distributes equal power to all output ports.

Uniformity (ΔL) — The maximum variation of insertion loss between ports in a uniform branching component.

$$\Delta \mathbf{L} = \text{Max} \mid 10 \log (t_{ij}/t_{ik}) \mid \text{ in dB}$$

Here t_{ij} and $t_{\iota\kappa}$ are transfer coefficients, where *i* represents and input port and *j* and *k* represent any two output ports, or vice versa.

Wavelength-Division-Multiplexing (WDM) — The provisioning of two or more optical channels over a common optical waveguide, the channels being differentiated by their wavelengths.

Wavelength-Division Multiplexers (WDMs) — Passive fiber optic branching components that combine or separate optical channels. Power is distributed based on wavelength, permitting multiple wavelength transmission over a single fiber.

Wavelength Isolation (I_{ij}) — The fraction t_{ij} (λ_k) of power in channel λ_k (i = k) blocked from input port *i* to output port *j*, in units of dB.

$$I_{ij} = -10 \log t_{ij} (\lambda_k) \text{ in dB}$$

Wideband Coupler (WBC) — A branching component having equalized insertion loss at both the 1310-nm and the 1550-nm wavelength regions.