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PRACTICAL RELIABILITY

Volume V - Parts

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This volume is Vol. 5 - Parts. The material discussed supplements that in the other volumes which is concerned with parts. For a complete consideration of the practical reliability of parts all five volumes must be used. B. M. Berry is the principal author of this report.

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FOREWORD

The typical few-of-a kind nature of NASA systems has made reliability a premium even on the initial items delivered in a program. Reliability defined and treated on the basis of percentage of items operating successfully has much less meaning than when larger sample sizes are available as in military and commercial products. Reliability thus becomes based more on engineering confidence that the item will work as intended. The key to reliability is thus good engineering--designing reliability into the system and engineering to prevent degradation of the designed-in reliability from fabrication, testing and operation.

The PRACTICAL RELIABILITY series of reports is addressed to the typical engineer to aid his comprehension of practical problems in engineering for reliability. In these reports the intent is to present fundamental concepts on a particular subject in an interesting, mainly narrative form and make the reader aware of practical problems in applying them. There is little emphasis on describing procedures and how to implement them. Thus there is liberal use of references for both background theory and cookbook procedures. The present coverage is limited to five subject areas:

Vol I. - Parameter Variation Analysis describes the techniques for treating the effect of system parameters on performance, reliability, and other figures-of-merit.

Vol. II. - Computation considers the digital computer and where and how it can be used to aid various reliability tasks.

Vol. III. - Testing describes the basic approaches to testing and emphasizes the practical considerations and the applications to reliability.

Vol. IV. - Prediction presents mathematical methods and analysis approaches for reliability prediction and includes some methods not generally covered in tests and handbooks.

Vol. V. - Parts reviews the processes and procedures required to obtain and apply parts which will perform their functions adequately.

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ABSTRACT

Parts reliability and associated problems which are not considered in other volumes of this series are discussed. This includes those functions--selection, specification, verification, review processes, and data sources--which are involved in a successful parts program. Some of the costs associated with these functions are discussed and an attempt is made to define an ideal data bank.

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1. Problems with Parts

The consideration of parts is an important part of practical reliability and intermeshes with all of the other elements--performance variation analysis, computation, testing, and prediction--of reliability to insure mission success. Each of these other subjects of discussion include consideration of and are applicable to parts but the application of parts merits separate consideration. The implementation of every function is effected by an assembly of parts.

A part is distinguished by its use, with other parts, to obtain an assembly with a higher level of usefulness. A given part will normally be common to a variety of assemblies. The manufacture of a part and its use in an assembly are functions most often performed by different organizations. There are millions of different parts ranging from the most simple--such as a nail--to the very complex--such as an integrated circuit.

You and I can buy parts from an electronics supplier and assemble an audio amplifier. It is reasonable to assume that it will work. There are no problems.

An automobile manufacturer buys thousands of parts from hundreds of suppliers using complex procedures to assure success. The suppliers are geographically dispersed and represent diverse skills. This process presents problems, but they are amenable to solution. This has been proven.

A major space venture requires thousands of parts from hundreds of suppliers who are also dispersed and diverse. In this case, however, the long experience of the automanufacturer with parts and the large volume requirements are absent, many of the parts must perform more demanding functions, and maintenance-free operation is often required. For this a recognizable parts program must be set up and operated with finesse. Even then problems do exist.

In modern technology, the space research type of requirement is becoming more common. Aerospace, defense, resources management, business, medicine, and economic planning are all beginning to utilize complex products of our technology and these uses will expand. The need for skilled parts engineering is increasing. In the following chapters, the ingredients of successful parts engineering are examined using as a base the experience obtained in space research programs.

Parts engineering may or may not be a recognizable function in steps toward obtaining a useful system.* For a small system, one design engineer may take care of everything. But, no matter how small, if the system is to be produced in quantity or if it is for a critical application, parts specialists are brought into the action.

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* The common use of the word system will be employed to connote an assembly of parts.

For a medium or large system, the parts function becomes a formal step in the system design and development procedure and may involve many people.

A successful parts program can be classified into five major functions:

(1) selection,

(2) specification,

(3) verification,

(4) review processes, and

(5) data collection.

For various uses the relative importance of these functions will vary, but each is vitally important in obtaining performance of the part in the assembly of which it becomes a part.

There are three organizations with responsibilities for parts; the parts manufacturer, the system manufacturer, and the system user. Each of these participants has unique motivations which govern his actions. In the case of the parts and system manufacturers, the ultimate motivation is profit. For the user the ultimate motivation is a successfully operating system. Difficulties arise in the interpretation of these motives at a practical level.

The classical case of divergent motivations is found when a system manufacturer requires 100 special parts for an important application. The parts manufacturer can not afford to make these since any realistic price for the parts does not provide a profit comparable to that obtained when the same effort is devoted to products sold in large quantities. The only justification for the parts manufacturer to respond to this need is to generate good will or some other high motivation and, if he does too much of this, he loses his shirt.

In any parts program, it is important to assign responsibilities at the proper level. An extreme is the parts specifications which attempts not only to describe the required performance for the part but also delineates in some detail how the part will be made. This can remove the responsibility for manufacturing processes from the parts manufacturer and transfer it to the specification agency. That is misplaced responsibility. It is tempting to follow this course in procuring small numbers of critical parts. It is also a partial answer to the low-bidder-gets-the-job complex. However, it is important to keep the responsibility for making good parts in the hands of the parts manufacturer just as the system manufacturer must be responsible for the design and assembly of systems using these parts. The system user's responsibility to both manufacturers is to adequately describe for what and how he will use the system and then to use it only in that way if he expects it to work.

In our discussion of parts we will assume the existence of the parts and not be concerned particularly with either their design or manufacture per se. The first function in the parts application program is then to select the proper part for the job. To do this requires information on prior experience with the part particularly in applications close to that being considered. Is it mechanically compatible with the system being designed? Has it been previously qualified to criteria similar to those being considered? Is it on a preferred parts list? Will there be any delivery problems? These are the questions which must be faced during the selection process after, of course, being sure that the part will fulfill the functional requirement.

The adequacy of data on the part is important. For example, a part with a very low catastrophic failure rate may not necessarily have a good drift characteristic in a particular application. Adequate data on a part is almost always difficult to obtain. Attempts are being made to solve this data problem but real success is elusive.

If a part has not been qualified or is not on a preferred parts list then it is necessary to qualify it. Qualification procedures are determined by a team usually consisting of testing and design engineers as well as parts specialists. The purpose of the qualification test is to determine whether the part is adequate for a particular application.

Selection involves a comparison of available parts and their characteristics and using past experience, engineering judgement, economic considerations, and existing policy, to choose parts best suited for a particular system application.

In many cases, after a part has been chosen, it must be specified. A selection process identifies certain needed qualities of a part. Specification informs the parts manufacturer as to what these needed qualities are and, in essence, asks him to control his production to obtain these qualities. Specifications may include in addition to the part characteristics, the methods for checking these characteristics, for example, screening tests. In many cases, existing specifications, e.g., MIL-SPECS, may be adequate; in other cases, they may not. These specification systems embody a great deal of knowledge and experience and should not be treated lightly. In formulating new specifications, the parts suppliers to whom they will apply should always be consulted. Simplicity is the key word. Do not over specify or under specify and do not specify anything that cannot be verified.

Verification is as important as specification. It requires inspection and testing to assure that the parts, in fact, meet the criteria on which their selection was based and which were specified. Verification tests are performed by both parts manufacturers and system manufacturers. If the parts manufacturers inspection and quality control procedures are not completely adequate, the system manufacturer must set up receiving inspection and testing programs. In incentive and cost-of-ownership contract programs, the equipment manufacturer usually employs extensive verification procedures.

Review processes, i.e., design and application review are usually performed by a reliability team not directly associated with the project under review. This group's primary function is to review the entire parts program for errors in design and in parts application.

Basically, the selection, specification, and verification processes are tools whereby the equipment manufacturer assures himself that the parts under consideration will do the job. To be successful, each of these functions must be performed conscientiously and comprehensively. Otherwise, one is courting failure.

These various aspects of parts engineering are discussed in some detail in the following chapters. Because data is a sizable portion of the overall parts problem, this is considered toward the end. The cost of parts enter into a number of the discussions and are important. However, even for the most important missions, there is a limit to what money will buy in terms of better parts. The state-of-the-art in scientific knowledge and manufacturing techniques will at any point in time set one limit. Another limit is set by the state-of-the-art in our ability to organize resources and information. It is true that if everything were done in the use of parts that engineers now know how to do, then most system requirements would be met with ease. The optimization of engineering effort to approach this perfect state is our subject.

There is not an excessive amount of sex appeal in the subjects being discussed, they rather fall into the category of what a good engineering organization must do to perform a good engineering job.

2. Part Selection

2.1 General Considerations

How does an engineer select parts? This depends on the situation. At one time, and even now for many non-critical applications, the engineer would use his personal experience, training, and the catalogs he happened to have. But if a system is to be produced in quantity or if it is for a critical application, the engineer must do more, much more. Exactly how far he can go in insuring that the selection will meet all requirements of the application depends on how much effort, i.e., money is available. This in turn usually depends on the value put on the system.

There are several factors which are necessary considerations in the parts selections process. These include:

(1) Applicability--Will the part perform the required system function?

(2) Reliability--Is it sufficient?

(3) Criticality--If the part fails, what is the result?

(4) Availability--Is the vendor qualified and will a sufficient quantity of the part be available when needed?

(5) Qualification--Has the part been qualified for the particular type mission being planned or can it be?

(6) Cost--Is the part cost within the budget limitations?

2.2 Applicability

This is the design engineer's job, matching the part's capability with the system requirement. It is the most important factor in part selection, for the useful functioning of the part is the only basis for giving it attention. Although the functional demands on the part may appear to warrant careful attention, many systems have operated poorly or failed because of misapplied parts.

Whey are parts misused? Actually almost every part is designed with a well defined use in mind. The manufacturer uses all of the information and know-how that he has to insure that the part will do the defined job. Once it is in production, however, the manufacturer seeks to identify the broadest possible market for his part. We usually assume that the manufacturer does know more about the part that he is making than anyone else, and he often does, but when marketing, the manufacturer has a myopic view, profits are the motivation, he should not be trusted to giving an unbiased analysis of his part's applicability.

In determining a part's applicability to a given task, the printed vendor's data is usually the best source of information. It is not, however, without error and is never complete. This dearth of information on the part's applicability is most important, particularly for the more complex parts such as integrated circuits.

Efforts are continually underway to correct it. Manufacturers of parts cooperate closely with users in determining part applicability. The trend is to provide detailed design handbooks describing how and when to use specific parts. Data banks are being organized by NASA and other large users (see Chapter 6).

History is important. If the part has been around for some time, there is a good probability that it has been used in an application similar to the one being used. This information saves the design engineer many headaches. It is the new parts--and many systems require state-of-the-art parts--that we don't know enough about that usually give problems. For these testing is indispensable.

The applicability of a part to a given task may be a complex consideration. Consider as an example, a high reliability switch needed for a ground application. The first consideration is which type of switch to choose for the application and then which particular switch of the selected type.

Before selecting a particular type of switch, all important performance parameters must be considered. This requires a general knowledge of the various switch types available and their characteristics. Sources of information may be the manufacturer or data acquired from past experience.

There are many types of switches available and they are usually classified by the function they perform:

(1) Control switches regulate power to a circuit or device.

(2) Limiting switches regulate the motion limits of moving members, e.g., selector switches.

(3) Safety switches "break" a circuit under conditions where safety to the operator or other equipment may occur.

As stated previously, the type of switch is the most important single decision in selecting a switch. An optimum decision is reached by using general knowledge of all the various kinds of switches and past experience.

The choice of a particular switch is governed by the application. Large knife-blade switches are self-cleaning and have large current handling capacities. These switches, however, can be severly damaged by untrained personnel opening and closing them improperly. For complex low-power electronic circuits, rotary switches are often used because of the large number of poles and switch positions obtained by stacking them. Toggle and push-button switches are commonly used for input and power applications. The switch may be snap-action depending on the type required, its capacity, and application. If light operating forces or precise switching angles are required, snap-action switches are not used. However, snap-action switches are excellent when precise or preadjusted switching times are required.

Switch configuration is governed by available space, mounting dimensions, type of connections, handling of the actuating element, and aspects such as safety and environmental requirements.

The arrangement of switch contacts is governed by the number of separate circuits to be controlled and the number of separate switch positions required.

Switch contact ratings are determined by many factors, e.g., voltage and current to be switched and whether ac or dc, transient currents, temperature rise caused by ohmic drop across contacts, heat dissipation at contact, type of load, and size of contact. Generally, dc loads are more severe than ac loads, the dc currents introduce polarization effects which speed the deterioration of the contacts. Another important factor in contact rating is the speed of making and breaking contact. A high-speed "make" reduces the duration of arc caused by contact closure. A slower "break" minimizes transients which occur in dc and inductive circuits and to some extent in ac circuits.

Keeping the switch contacts clean is another important selection factor since contacts often corrode or pit in normal use. Self-cleaning action is provided by having the contacts slide over each other during switch operation. Knife-blade switch action is excellent for this purpose, but is difficult to use in micro-contact elements. Of course, hermetically sealed units are available for protection against corrosive atmospheres.

Because circuit conditions may vary widely during the instant a switch changes its condition, the switching sequence is often an important selection factor. Make-before-break or break-before-make switches are often necessary to prevent shorting and heavy transients which could damage the equipment. A careful study of the circuit diagram will reveal any need for a predetermined switching sequence.

Other important performance parameters in switch selection are insulation resistance in high impedance circuits, stray capacitance in high frequency circuits, and radio interference caused by switch arcing.

Switches for military use are generally required to meet the same environmental specifications as other component parts, e.g., MIL-STD-202.

The important points in switch selection are [Ref. 2-1]:

(1) Specify the required switch operations and assumptions for the circuit, i.e., type of load, etc.

(2) List the electrical, mechanical and environmental requirements.

(3) Specify snap- or detent-action or momentary contact.

(4) List contact type, i.e., make-before-break or break-before-break.

After the type of switch has been decided upon, it is necessary to select a particular switch within that type. Suppose, for example, that a toggle switch has been selected as the type of switch required. The problem then is obtaining the required switch characteristics at the most economical price. In addition to the selection factors considered previously the following parameters should be considered in selecting the proper toggle switch [Ref. 2-2]:

(1) How much space is available?

(2) What is the envelope size of the switch?

(3) How long a toggle lever is required? Bat or ball handle?

(4) What should the switch weigh?

(5) Who will operate the switch?

(6) Are special safety precautions required?

(7) Should the switch be illuminated or marked in any manner?

(8) Should the toggle level be returned manually or be spring loaded?

(9) How many positions are required of the toggle level?

(10) What forces act on the toggle lever?

(11) How will leads be connected to the terminals?

(12) How accessible are the terminals?

(13) How are terminals identified?

(14) Is terminal strength important?

(15) Is the switch easy to replace or repair?

(16) Will the environment be a problem, i.e., should a hermetically sealed unit be employed?

(17) What is the expected lifetime of the switch?

These questions are most important to proper selection and application. The last question concerning expected frequency of failure is illustrated by an example.*

Electrical requirements: 2 poles, 3A, 45V ac, resistance load

Mechanical requirements: 30 operations/hr

Maximum shock: 30 G's

Maximum vibration: 10G's 5-2000 Hz

Operating temperature - 25°C

Required life - 10^4 operations

Operating environment - ground.

Using MIL-HBK-217A, the expected failure rates for a hermetically sealed and a metal dust protecting case switch are shown below for a Class A (high reliability)

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* A switch has two factors involved in life expectancy, i.e., mechanical and electrical operation. Mechanical life concerns operation without electrical load and electrical life concerns operation with maximum electrical load. Of course, failures also occur randomly with time.

and a Class B (quality conscious but less reliable) manufactured switch [see MIL-HBK 217A, page 7.10-3 for definitions of manufacturer classifications].

Type of Toggle Switch

	Hermetically Sealed	Metal Cover
Class A	4.52 failures/10^6hr.	2.64 failures/10^6hr.
Class B	9.03 failures/10^6hr.	4.60 failures/10^6hr.

Other considerations could well be included here but the above is sufficient to illustrate that even a "simple" component such as a switch may present problems. It is well that experienced engineers are available who know many of the answers to such applicability questions without repeating for every part the laborious process indicated.

2.3 Reliability

The reliability of a brass machine screw is never questioned. The reliability of a diode is. Some parts do not give reliability problems because their function is simple or their design safety margin is large. Other parts, and usually the ones in the more important roles, are susceptable to failure.

The consideration of parts reliability is a difficult part of the selection process. There is a mystic of part failure rates which has been built-up over a period of time which serves a useful purpose. This goes something like this.

Data is available on part failure rates. Take these data for all the parts in the system for the operating environment of the system, combine them and you have a system reliability.

This method, employed properly, is useful. It tells us that, ignoring the quality of the system design and the many variables in determining the part failure rates, there is a reliability number associated with this system which rates it in comparison to other systems for which similar calculations have been made. Similarly, if part failure rates are determined consistently, the numbers obtained are useful for comparison purposes. It is not realistic to expect part failure rates or predictions based on them to give quantitatively useful numbers on any particular system.

In electronic systems, which have been increasing most rapidly in complexity, the parts have been improved to where failure rates have even less meaning. One must instead assure himself that failure mechanisms in the part have been identified and steps taken to eliminate them and that the part manufacture is such that extraneous failures, those which result from not making the part right, are not present. The significant parts reliability data is then that which indicates that a part is being made the way we know it should be made.

Table 2-1

Part Derating Factors [Ref. 2-3]

Part	Derating Factor	X	Y	Stress	Remarks
Capacitors				voltage	The following equation establishes the derating factor for capacitors where values of X and Y are given: $$\text{Derating Factor} = X - \left(\frac{C - C_{min}}{C_{max} - C_{min}}\right)(Y)$$ where C = capacitance value of capacitor for which the derating factor is desired. Cmin = smallest capacitance value available with the same case size and voltage rating as C. Cmax = largest capacitance value available with the same case size and voltage rating as C.
Ceramic Disc	0.7				
Ceramic, Low voltage		0.5	0.2		
Glass	0.5-0.7				
Porcelain		0.7	0.2		
Mica		0.7	0.2		
Plastic Film		0.5	0.2		
Paper		0.8	0.1		
Metalized		0.5	0.2		
Tantalum, Solid		0.7	0.3		
Tantalum, Wet Slug and Foil	0.7				
Connectors				current	Contacts shall be derated to 75% of rating for individual contacts. The average current rating from 1 to 15 contacts shall be decreased linearly to 20%. For more than 15 contacts the rating is 20% of the normal individual contact rating. The applied voltage between contacts or between contacts and shell shall not exceed 250 volts rms.
Silicon Diodes					Current and voltage derating factors shall be applied simultaneously.
Signal and Switching	0.6			I_o	
	0.8			Working inverse voltage	
Power ($I_o \leq 10A$)	0.85			I_o	
	0.75			Peak inverse voltage (PIV)	

Table 2-1 (Continued)

Part Derating Factors [Ref. 2-3]

Part	Derating Factor	X	Y	Stress	Remarks
Power ($10A < I_o \leq 35A$)	0.75			I_o	
	0.75			PIV	
Zener (Power $\leq$ 1W)	0.8			power	
Zener (1W $<$ Power $\leq$ 50W)	0.7			power	
Microcircuits					1. Supply voltages may be reduced to effect lower power consumption, at the price of slower switching speeds and narrower noise immunity margins. 2. Allowable fan-out should be reduced for reliable operation. 3. Operation over wide temperature ranges will generally result in decreased circuit margins and fan-out capability. 4. Operational stability may be improved if power supply voltage tolerances are tightened, especially if the devices employ non-saturating type circuitry.
Relays	0.3			current	
Resistors				power	
Composition	0.7				
Film	0.4				
Wirewound Power	0.5				
Wirewound Precision	0.4				
Transformers	0.4			power	
Silicon Transistors	0.5			power	The voltage applied across any junction or group of junctions shall not exceed 75% of rated voltage.

General statements such as that made in the above paragraph are only generally useful. The reliability of each part being selected for a system must be looked at carefully to make sure it will do the job. Much of the work involved in this can be avoided by intelligent use of the information available.

There is, of course, much written material on parts reliability.* The subjects discussed include:

(1) Information integrity--This analyses the validity of parts reliability data for particular applications.

(2) Costs--The maintenance, testing, effectiveness factors which determine the value of the system must be measured against the costs involved in improving parts reliability.

(3) Design--Redundancy, deratings, effects of degradation, and other design factors determine the effects of part unreliability.

Since part failure rates are increasing functions of the stress applied in actual operation, the maximum part reliability can only be obtained when the part application is controlled within suitable electrical and thermal stress levels. Even the best parts, when operated at maximum stress levels, do not possess sufficiently low failure rates to permit the construction of highly reliable complex systems. Therefore, most parts are derated to some extent in all applications.

The derating factor for a particular part is based on the part reliability at various stress levels. Reliability versus stress curves exist for only a few parts, however, and the remainder of the cases is based on field data obtained from parts operating in systems under conditions similar to those of interest.

Table 2-1 lists recommended derating factors** for various parts [Ref. 2-3]. These derating factors should yield part failure rates in the range from 0.1 to 0.001%/1000 hours. Of course, part failure rates in actual use vary widely due to the particular circuit's tolerance to drift. Lower failure rates are obtained by designing the circuit to the greatest possible tolerance.

It becomes obvious that part reliability as considered in the part selection process is inseparable from the other factors in selection. Since selection is just one factor in the overall parts activities aimed at providing reliable systems.

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* For a continuing current review of the literature, see "Reliability Abstracts and Technical Reviews", National Aeronautics and Space Administration. Available from Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.

** $$\text{Derating factor} = \frac{\text{Maximum Stress for Reliable Operation}}{\text{Rated Stress}}$$

the necessity for a more rigorous model for considering these becomes obvious. Since we lack this model, a organization in which engineering judgment of many people is combined to achieve the goal is employed for large system jobs.

In summary--on parts reliability--when selecting a part get as much information on its reliability as you can, then use your individual or collective judgment as to how best to meet your design goal.

2.4 Criticality

In any system, some parts are critical, the system fails if they do. Others are not. Among the critical parts, some are tried and true and others entail uncertainty. If we have this information on parts criticality, the part selection effort and the subsequent cost allocations can be apportioned properly. If we don't have this information, we'd better get it.

In discussing parts selection, this subject warrants a section but the essence of part criticality is briefly stated. It is necessary to identify the problem parts and to concentrate on them, other parts can be selected routinely. Just make sure that each class of parts is accurately identified.

2.5 Qualification

Part qualification is a formality that saves much effort. The complexity of information which describes whether a part can perform in a given mission environment is reduced to a statement that this transistor is qualified for earth-orbital space missions, this relay is qualified for ground vehicular control functions, or this transformer is qualified for stationary, controlled environment system applications. Such information represents the synopsis of someone's testing, analysis, and experience. Use it.

If a part is qualified for the type mission or a more demanding mission, then much effort is saved. If it has not been qualified, then it is necessary to determine the mission profile, the environment to be expected, and system design factors and then to run the necessary qualification tests.

Qualification is sometimes evidenced by preferred parts or materials lists or by parts standardization.

Preferred Parts Lists (PPL) and Preferred Materials Lists (PML)

The use of parts and materials lists optimize procurement, reduce test costs and data requirements, and minimize specification preparation. They are usually of two types, i.e., preliminary lists prepared and used during early design stages and breadboarding and approved lists for use during detail design.

The "Preferred Parts List" (PPL) and the "Preferred Materials List" (PML) are used by NASA reserach centers to prepare preliminary parts and materials list for various systems. These are documents which list those parts which should be given first consideration for use during system design and development. The parts in the PPL have been carefully screened and tested by parts specialists. Additions to the list are made only after rigorous application and qualification tests have been performed. Factors considered in choosing a particular part over alternate parts are size, weight, cost, environmental qualifications, previous applications, reliability, delivery schedules, previous vendor performance, and performance versus environment trade-offs. In addition to a listing of the specific part type, the qualified vendors are either listed in the PPL or in another document called out in the PPL. Example pages from a PPL and a PML are shown in Figs. 2-1 and 2-2 respectively [Ref. 2-4].

The advantages of PPL's are many. Perhaps the most important is standardization, i.e., the number of part types that might otherwise be selected is limited to parts of known performance and reliability. Part specialists are familiar with parts on the PPL and can more efficiently aid designers in their choice of parts. Problems of specification, procurement, screening, verification and application are also minimized by the limited number of parts in the PPL. The number of unique part application design problems is also minimized [Ref. 2-4].

Parts for use in high reliability systems may be included in a separate PPL. These Hi-Rel PPL parts have an operational failure rate at least one order of magnitude lower than MIL-spec equivalents. The use of Hi-Rel PPL's increases the system reliability, but trade-offs between less reliable parts may be necessary because of costs [Ref. 2-5].

In space research programs, the use of these PPL's is usually mandatory unless a very good reason for using a nonstandard part exists. There are various rules for qualifying a part, but if a particular part has been qualified by one user, this qualification is usually accepted by others. If the same part is built by two suppliers and only one is approved in a PPL, a separate document must exist with requirements which eliminate one vendor from the PPL. Parts included in the PPL should be checked at various intervals to insure that the part and the vendor still qualify.

Standardization

Standardization of parts usually implies a more restricted parts list than does a PPL. The objective of standardization is to limit the number of possible choices to one or a small number. This standardizing procedure properly performed accrues the following benefits:

(1) Standard parts are readily available, usually from several sources.

(2) Descriptions and performance data and characteristics are well known.

(3) Standard parts are usually competively priced.

(4) Uniformity and quality are usually good and consistent.

The main complaints regarding standardization is that system performance may be compromised and overall cost increased. Standardization involves tradeoffs, i.e., design freedom is lost in return for the advantages of standardization. System designers often complain about standardization because they feel they cannot get optimum performance. While this may be true, a good standardization program may permit the overall usefulness of the equipment to be higher because of better cost, delivery, reliability, and maintenance. In other words, it is possible for standardization to adversely affect one phase of a program while increasing the overall usefulness or performance.

The dual three input NOR gate used in the MIT-Apollo guidance computer is an example of standardization whereby the number of different components used was minimized, i.e., the NOR gate performed all of the logic functions required. It was felt that this minimizing of the number of different components would greatly simplify the process control for production lines thereby enhancing reliability.

2.6 Availability

After a part has been tentatively selected, there must be assurance that it is and will continue to be available in sufficient quantities and the required quality. Vendor evaluation and qualification is most important here. It is necessary to distinguish between vendor reputation (what people think he is or the image he wishes to project) and vendor character (how he really performs under contract). Items to consider are:

(1) Deliver schedules (can the vendor meet them?).

(2) Vendor controls and inspection procedures.

(3) Test facilities.

(4) Previous experience with vendor.

Often, alternate sources of supply are necessary to assure continuous supply. The need for alternate sources of supply is a tradeoff considering engineering judgement, past experience with vendor, cost, reliability, importance of the job, the other factors.

Consider the assessment of the vendor. Factors which are included are [Refs. 2-6 and 2-7]:

(1) Ability to supply devices on schedule.

(2) The institution of component standardization in designs.

Resistors

Note: a. Resistance values shall be selected from the 10% tolerance decade of values listed at the end of this section, regardless of the actual tolerance used.

b. Use carbon composition types only for resistance values outside the range of metal film, RNR types. In such cases derate power an additional 50%.

	SPEC	TYPE DESIGNATION	RESISTANCE RANGE (OHM) b ✓	POWER (WATTS)	MAX CONT. VOLTAGE	APPROX. SIZE (IN.)
1.1	Metal Film, MIL-R-55182. (Tol. 1%(F), T.C. 50 ppm/°C, T_{max} 125°C full load, 175°C zero load)					
	/1	RNR55C----F-	49.9 - 100K	1/10	200	9/64d x 9/32 (max)
	/4	RNR63C----F-	49.9 - 1M	1/4	300	1/4d x 21/32 (max)
	/6	RNR70C----F-	29.9 - 1M	1/2	350	21/64d x 7/8 (max)
1.2	b ✓ Carbon Composition, MIL-R-39008. (Tol. 5%(J), T.C. 2000 ppm/°C approx., T_{max} 70°C full load)					
	/1	RCR07G---J-	10 - 22M	1/4	250	3/32d x 9/32 (max)
	/2	RCR20G---J-	10 - 22M	1/2	350	5/32d x 27/64 (max)
	/3	RCR32G---J-	2.7 - 22M	1	500	1/4d x 19/32 (max)
1.3	Metal Film, Glass, MIL-R-22684A. (*Tol. 2%(G), 5%(J), T.C. 200 ppm/°C, T_{max} 70°C full load, 150°C zero load)					
	/1	RL07S---*	51 - 150K	1/4	250	.098d x 9/32 (max)
	/2	RL20S---*	51 - 470K	1/2	350	.161d x .416 (max)
	/3	RL32S---*	51 - 1M	1	500	.250d x .593 (max)
	/4	RL42S---*	10 - 1.5M	2	500	.328d x .640 (max)
	RLR series is preferred but is not available at this time. Use RL series as substitute temporarily.					

Fig. 2-1. Sample Page--Preferred Parts List [Ref. 2-4]

1100 ALUMINUM SHEET AND PLATE		ALUMINUM ALLOYS DESIGN DATA - SHEET AND PLATE
CURRENT SPECIFICATION QQ-A-250/1c	OTHER SPECIFICATION	SUPERSEDED SPECIFICATION QQ-A-561

DESCRIPTION

Low strength non-heat treatable commercially pure aluminum sheet and plate.

USES

Non-structural and electrical applications where excellent formability, good corrosion resistance, good electrical conductivity, or any combination of these is required and where high strength is not necessary. EC grade is available where electrical conductivity is prime requirement.

PROCUREMENT

Sheet normally procured in -O and -H14 tempers.
Plate normally procured in -F temper.

Note: -H24 temper is considered interchangeable with -H14 and may be supplied at the option of the producer unless the -H24 temper is specifically excluded. Engineering documentation (Material Substitution or DCN) is not required. -H22, -H26, and -H28 tempers are similarly interchangeable with -H12, -H16 and -H18 respectively.

MECHANICAL PROPERTIES[a]

Material Specification	Thickness In.	F_{tu}	F_{ty}	F_{cy}	F_{su}	F_{bru}	F_{bry}	El in 2" % Min.
						e/D = 2		
		1000 psi minimum						
QQ-A-250/1 -O	0.006-3.000	L11	3.5[b]					15-30[c]
-H12/H22	0.017-2.000	L14	11.[b]					3-12[c]
-H14/H24	0.009-1.000	L16	14[b]					1-10[c]
-H16/H26	0.006-0.162	L19						1-4[c]
-H18/H28	0.006-0.128	L22						1-4[c]
-H112	0.250-0.499	L13	7					9
	0.500-2.000	L12	5					14
	2.001-3.000	L11.5	4.5					20
-F	0.250-6.000	No requirements						

L = longitudinal
[a] QQ-A-250/1c
[b] No requirement for thicknesses 0.050 in. and under.
[c] Range of minimum elongation which generally increases with thickness.

OTHER DATA

See Wrought Non Heat-Treatable Aluminum Alloys General Technical Information data 5.1.1

ENGINEERING NOMENCLATURE

ENGINEERING MATERIAL CODE	MATERIAL SPECIFICATION		ABBREVIATED DESCRIPTION
1100A	QQ-A-250/1	1100-O	SH AL
1100P	QQ-A-250/1	1100-H14	SH AL
1100B	QQ-A-250/1	1100-F	PL AL
	QQ-A-250/1	H1100-H112	PL AL

FORM MM-1064 MAY 64

Fig. 2-2. Example of a Standard Entry for the PML [Ref. 2-4]

(3) Ordering procedures.

(4) Method of returning defective material.

(5) Size of quality control group.

(6) Controls and written inspection procedures.

(7) Test facilities.

(8) Size, knowledge, and approach of the engineering organization.

A block diagram of the vendor selection procedures is shown in Fig. 2-3 [Ref. 2-6]. The qualification procurement supplies parts for the qualification testing and engineering evaluations and establishes the manufacturer's device processing. This initial procurement provides an early detection of new failure modes. Conclusions drawn from the failure mode analyses are then fed back to the manufacturer for possible corrective action. This cyclic procedure is repeated until the most obvious problems have been solved. Also, the early detected failure modes together with past experience are used to design the qualification testing.

The formal process of qualifying a particular vendor begins when the vendors under consideration submit devices representative of their final manufacturing process. All qualification and engineering testing must be performed on devices fabricated from the identical process used to supply production devices. The qualification tests subject the parts from the vendors to the extremes of usage conditions and, to some extent, beyond usage conditions in an effort to determine failure modes which could occur in normal use.

Typical qualification requirements list specific test methods, e.g., shock, operating life, etc., as per MIL-SPEC or MIL-STD and define the LTPD* permitted for each test. These qualification requirements are included as part of the final specification to which production parts are brought. The tests are performed on samples from the initial lot and must be completed by the vendor prior to approval as a source of supply. Also, the vendor may be required to run the full qualification tests on certain future lots as a qualification check.

The qualification and engineering evaluations determine which vendors are capable of supplying the parts and those who do not exhibit any major reliability problems. Qualification tests are sometimes insufficient to determine a vendor's ability to control his process, so acceptance tests are used where high reliability requirements must be met.

After qualification tests and engineering evaluations have been made, the final specification and qualified suppliers list are prepared. The qualified suppliers list specifies the vendors from whom the required parts may be purchased.

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* LTPD--Lot Tolerance Percent Defective.

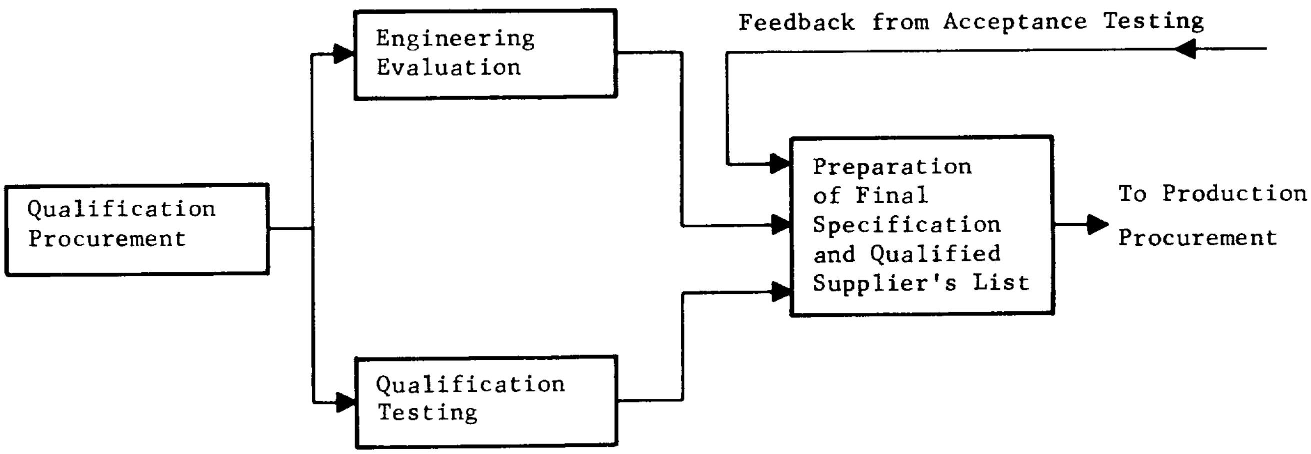

Fig. 2-3. Block Diagram of the Vendor Selection Procedure [Ref. 2-6]

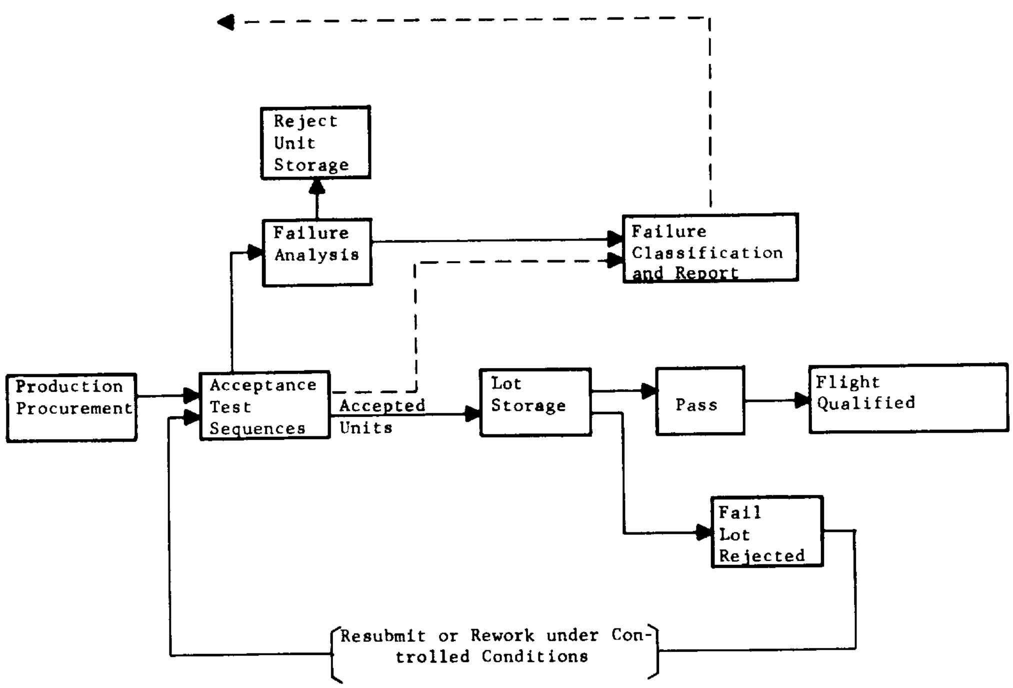

Fig. 2-4. Block Diagram of Flight Qualification Procedure [Ref. 2-6]

The block diagram for the flight qualification procedure used for the Apollo computer NOR gate is shown in Fig. 2-4 [Ref. 2-6]. Here, after a lot passed the initial acceptance tests, it was stored until failure analysis was completed. The failed units were cataloged, analyzed, and classified to complete the lot assessment, followed by a written report. Lots which passed all the test were identified as flight qualified, identified with a new part number, and sent to production. Rejected parts were stored for future study if required.

The vendor's qualification status is constantly checked by accumulated acceptance test data and periodic requalification checks.

Second source availability for a part must be weighed against usage. If the required quantity is small, the additional procedures required to qualify another source may not be feasible. However, in certain cases, a continuous supply of the part must be assured and other vendor sources must be qualified. Such factors as the vendor's reputation, the importance of the project, the amount of money available, and engineering judgement should be considered when deciding whether multiple sourcing is advisable.

The problem of multiple sourcing is sometimes quite complex. If the parts from two vendors are to be used interchangably, they must be identical electrically and mechanically. This may sound simple, but any specification generated for two separate vendors on any complex part usually ends up as a compromise specification [Ref. 2-7].

In-house inspection of the supplier by the user often plays an important part in vendor selection. The inspector inspects or tests actual parameters or views the process operations as they are performed by the supplier. A disadvantage of this procedure is that the source inspector must be at the location at specific times to avoid a delay in shipment of the parts.

Any system of source inspection should be used with a carefully planned system of quality control by the supplier. Otherwise, the system becomes one of detection rather than prevention.

The advantages of a system of source inspection is that the parts shipped have actually been inspected before shipment. It may be the only satisfactory method for a problem suppliers, but even a poor supplier, properly inspected performs a better job than with receiving inspection.

The use of source control and/or inspection is necessary in many instances and should be employed whenever needed. The ultimate goal is to raise the supplier's performance to a level where he can start a new job with the requirements as specified, and perform all functions as if the user's representative were always there to verify proper performance of the job [Ref. 2-8].

The supplier's quality control procedures determine the ultimate reliability of the finished product. Quality cannot be inspected into a part just as reliability cannot be tested into a part. The quality must be included as a part of each manufacturing process.

The two basic areas of controlling a part to assure reliability are:

(1) The supplier must maintain equipment (e.g., tools and gages) control, drawing change control, and follow a general quality system.

(2) The supplier should verify that delivered parts meet the specification requirements.

Consistency is the key word. The major cause of time-oriented failures is inconsistency--inconsistencies caused by engineering or manufacturing changes, changes in inspection methods, or from operating personnel not receiving or following the proper instructions [Ref. 2-9]. Inconsistencies can be minized by assuring that receiving inspection, manufacturing, process assembly, tests and inspections are properly performed the first time.

The most important areas of the supplier's quality control procedures are the methods of test and inspection employed. Questions to be considered are:

(1) Are in-process inspections utilized where inspections or tests at the end of production are not practical?

(2) Have receiving inspection and quality control measures been considered for subcontractors?

(3) Are the inspection and test equipments suitable to check the parameters which they are to measure?

(4) Is testing redundant to the point of being uneconomical?

(5) Has a good statistical basis been formed for any sample testing being employed?

(6) Are all tools and test equipments planned to be available when and where needed?

The responsibility for incorporating quality into the manufacture of a part rests with the supplier. The user then must verify that this quality and hence reliability has been built, not inspected or tested, into the part.

2.7 Cost

Without unlimited funds the costs associated with the part are an important factor in selection. This is more than the direct cost per unit purchased. It also includes:

(1) Cost of assembly into system,

(2) Cost of qualification if required,

(3) Cost of specification,

(4) Cost of testing, and

(5) Stability of vendor.

Each of these must be weighed in the cost considerations. Let's consider several examples of cost factors that may enter into consideration of a part.

Cost-Reliability Tradeoffs

In most cost-reliability tradeoffs, the ratio of increase in equipment MTBF (ΔMTBF) to the increase in cost (ΔC), i.e., the slope, only is considered. This technique usually does not provide the optimum condition of reliability and cost, i.e., the cost increment associated with each slope must also be considered.

In any cost-reliability tradeoff technique, it is important to use current data generated from similar application conditions. The initial step is to make a preliminary reliability estimate for the equipment under consideration. If the prediction does not meet the reliability requirement, then cost-reliability tradeoffs can be made to obtain optimum operating conditions.

The data necessary for predicting the reliability of an equipment are the number of component parts per model, proposed environment, equipment configuration (simplex, redundant, triple modular redundant), delivery schedule of hardware, and component part failure rates. The environment (mission profile) is the most important data input for predicting equipment reliability. The delivery schedule should be known so that the state-of-the-art technology will be incorporated into the equipment at time of delivery. Component part failure rates are estimated from past experience on similar parts (MIL-HBK-217A, for example).

The reference reliability, i.e., the estimated equipment reliability for a serial system is calculated by

$$R_R = e^{\sum_i \sum_j \lambda_i K_{ij} t_j} \qquad (1)$$

where R_R = predicted equipment mission reliability,

λ_i = reference failure rate for the i-th part (typically those from MIL-HBK-217A or similar source),

K_{ij} = derating factors of the i-th part and the j-th mission phase to account for the effect of the application environment, and

t_j = duration of the j-th phase of the mission profile.

Using the predicted reliability from Eq. 1, the cost of the equipment employing the parts used in calculating Eq. 1 is estimated by procurement or cost specialists. A reference cost and reliability now exist. If the reference reliability is lower than the desired equipment reliability, a cost-reliability tradeoff must be performed.

A cost-reliability tradeoff [Ref. 2-10] begins with the calculation of R_R. Each part is upgraded in reliability in various combinations and the new cost associated with each new equipment reliability is calculated. (For example, if three types of parts are available at three levels of reliability, 27 different reliability and cost levels are obtainable.) Each of the points obtained is plotted graphically--MTBF versus cost. The point with the largest slope and the lowest cost increment from the initial conditions that lies above the required reliability level is selected as the optimum choice. (This method lends itself particularly well to computer techniques for large combinations of part types and reliability levels.)

This technique allows for the maximum increase in reliability with the minimum increase in cost. It should be noted that if the reliability level of the chosen system must be demonstrated, it may be necessary to choose a reliability level somewhat higher than the minimum required. Of course, this is easily done from the graph or computer program. Additional discussions of reliability-cost tradeoff analysis are presented in Vol. II - Computation and Vol. IV - Prediction of this report series.

Reliability Screening Cost

Next consider the reliability costs when screening is required. The basic premise for all part screening techniques is providing reliable parts for systems use at an optimum cost.

Several types of screening programs exist, and one or more is used by manufacturers of reliable parts. The basic difference between them is when the screening is done, i.e., during or after manufacture or on the design, materials and processes used in manufacture. Sometimes the screening must be done after the parts have been assembled into units. The most common technique, but least desirable from a cost standpoint, is system burn-in plus replacement of defective parts.

The selection of a particular screening technique is seldom planned. Usually, the screening plan is chosen so that the part can be improved so as to demonstrate the necessary reliability. Technical factors, not proven cost figures, are usually the basis for a choice of screening techniques. Of course, each program attempts to achieve the optimum tradeoffs between cost, reliability, delivery, and supply. The difference in choice of screening programs are related to the relative importance of the above factors. Also, direct comparison of the various screening procedures are often difficult to make because of the absence of proven data under similar project conditions [Ref. 2-11].

One major type of screening program, degradation analysis screening [Ref. 2-12], employs power aging and burn-in on the parts after they have been manufactured and before they are shipped. Parameter drift screening is very similar to the above, but relies on test data generated by the equipment manufacturer. Another widely publicized screening technique, failure mode identification and control, was used by the MIT Instrumentation Laboratory on Project Apollo [Refs. 2-6 and 2-13]. This technique relies heavily on visual inspection during the part manufacturing cycle.

The cost analysis for the screening used by Hughes on the Early Bird Satellite and other projects is shown in Fig. 2-5. Most of the screening costs came from degradation analyses performed prior to start of manufacture. Screening of this type is quite expensive and results in a high total screening cost for high reliability.

The cost analysis for the MIT Apollo visual inspection type of screening is also shown. This technique probably doesn't detect those potential early failures which result from damage during final stages of assembly or undetected material defects. It can, therefore, result in a lower reliability or in a higher cost for the same reliability due to expensive replacement or repair costs or other screening procedures required during later stages of equipment manufacture.

The most expensive approach to reliability achievement is to ignore all control or screening until after the systems have been manufactured. This approach resulted in a multi-million dollar loss for Hoffman Electronics on the ARN-21 project. As shown in the figure, only small sums were spent on reliability at receiving inspection, manufacturing test and system test. The AGREE test then showed the inherent system reliability to be far below contractural requirements. Most of the suppliers had to be changed to vendors who employed adequate reliability control and part screening, resulting in the huge dollar loss.

An optimum cost approach is also shown in Fig. 2-5. Here, a portion of the responsibility for part screening is placed on the manufacturing operation, i.e., some of the reliability screening effort is performed at the unit test level. The important point is that maximum reliability can be achieved at minimum cost if the screening effort is spread throughout the entire project and procurement cycle.

In order to establish an optimum screening program from a cost basis the difficulties of screening and repairing certain units and the advantages of pre-assembly screening on certain types of parts must be considered. By spreading the screening throughout the entire project, savings of one-half or more over a pre-assembly-only screening program can accrue.

The relative cost of the four screening programs (for the same reliability) can be compared as [Ref. 2-11]: Early Bird \$1, Apollo \$1-\$2, ARN-21 \$5-\$100, and the suggested optimum $<$ \$0.50.

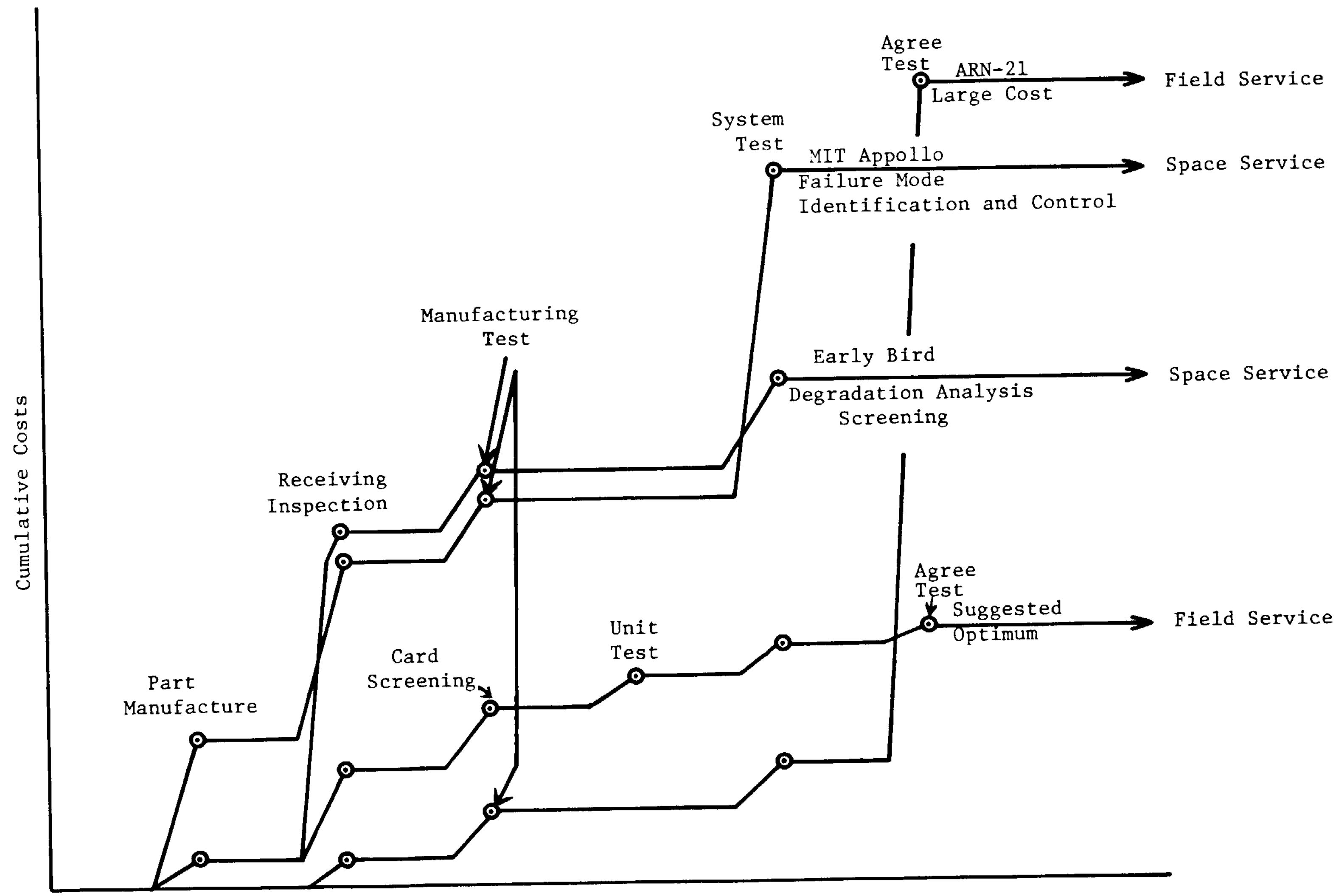

Fig. 2-5. Comparison of Part Reliability Costs for Different Plans [Ref. 2-11]

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3. Specification

A specification for a part may be a six line catalog entry or an encyclopedic compilation which specifies everything from the design of the shipping container to raw materials which will be used in manufacture. There is a place for each type of specification in the parts business and for the many specifications between these extremes. Tailoring the specification to the need is the most important consideration.

A second most important consideration with respect to specification is to use existing documents insofar as possible. Each new specification costs money and detracts from the performance of the parts manufacturer. It is highly desirable to standardize on both general and generic specifications and, in many cases, also on specification sheets for particular parts. Only for specific exceptional needs should the existing hiearchy of specifications be added to. There is rarely any justification for starting a new system for specifications although for every new system, some specific specification sheets for parts will probably be required.

What a specification is not is as important as what it is. It is not, for example, a document telling a parts manufacturer how to make parts. Nor is it to make the parts manufacturer assume system design responsibilities. Specifications should not be used to sole source parts procurement. They should not transfer the responsibility for parts quality out of the manufacturer's hands. Specifications are only for the purpose of describing in whatever detail is necessary, the part that is required, how the manufacturer can be sure that he meets the requirements, and what the buyer will do to make sure he is getting the part he needs.

As noted above, there are many requirements for parts which can readily be met using only catalog descriptions for specification. These include a large number of small quantity non-critical procurements for which the standard products of industry suffice. Critical parts and those being purchased in large quantities involve values which justify more complete specifications. The most important goal is to obtain more reliable parts and the most complex specification systems are for high reliability requirements. These become, therefore, the prime subject of this discussion.

A specification should define exactly what is desired in a part, i.e., the performance characteristics including reliability which are necessary to fulfill the intended use requirements. Whatever the complexity, the specification should reflect the part application requirements to assure the proper margin of reliability at the maximum cost-effectiveness. While it is important to assure a reliable part, it is just as important not to include provisions that are not needed or cannot be verified, i.e., the system requirements should be fully known and understood so that the part is neither overspecified nor underspecified for the application.

Specifications basically cover the following areas [Ref. 3-1]:

A. Performance characteristics
   1. Critical parameters
   2. Applied environmental stresses
   3. Desired reliability
   4. Dimensions, weight, etc.

B. Assurance test procedures
   1. Types of sampling plans
   2. Testing sequence
   3. Degradation analysis

C. Vendor qualification procedures
   1. Administrative requirements
   2. Product-line evaluation requirements
   3. Device test requirements

Most electrical parts have certain critical parameters which signal future device failures. These critical parameters should be carefully covered in the specification. The allowed tolerances on these critical parameters is determined by the intended use application. The tolerance limits must be tight enough to insure proper operation over the desired range at a reasonable cost, but not so tight as to imply a requirement to advance the state-of-the-art.

In some devices, e.g., integrated circuits, it is impossible to specify measurement of all of the electrical parameters because of their inaccessibility. In this case, only the parameters involving the input and output terminals of the device can be specified. Of course, test groups of devices, specially constructed to have elements accessible to measurement, can be used to insure lot quality and stability, since devices produced in the same lot are expected to possess similar characteristics.

The specified environmental stresses should reflect the intended use conditions the part will encounter in the system. Also, any environmental conditions related to known failure modes or mechanisms should be specified regardless of the intended use environment.

The reliability desired in a particular device is often difficult to demonstrate at low-failure rates because of the large number of device-hours involved. High-failure rate devices, however, are usually not a problem.

Because of the inavailability of a direct quantitative method of demonstrating high reliability levels, failure mechanisms rather than failure rates are sometimes specified [Refs. 3-2 and 3-3]. It is assumed that devices containing no known inherent failure mechanisms will have the maximum reliability for the state-of-the-art technology.

After the devices have been manufactured, they must be sampled in some manner to insure that they possess the proper operating characteristics. This sampling may range from testing a few parts to 100 percent screening and burn-in. If the parts are not to be 100 percent screened (non-high-reliability parts), two basic sampling plans are generally used, AQL (Acceptance Quality Level) and LTPD (Lot Tolerance Percent Defective) [Ref. 3-4]. The AQL plan specifies the vendor's risk, but not the customer's, i.e, the vendor has some chance of having a lot rejected even if the percent defective is less than the specified AQL. Also, however, there is a good chance that for small sample size, the lots accepted may have a higher percentage of defectives than the AQL indicates. Under the LTPD plan, the customer is assured that only a small percentage of the time will lots with a poorer quality than specified be accepted.

High reliability screening plans differ according to reliability level and are discussed under the appropriate type of specification.

Degradation analysis is a study of the part performance while it is being tested. It may involve constant monitoring of the part during test or simply a check of the end-point limits before and after test. If end-points only are checked, the specification may require that the end-point limits be the same as the initial limits or allow some relaxation. Also, a maximum allowable shift in any parameter before and after test may be specified. This latter technique assures the delivery of stable devices but is expensive.

The specification should not be concerned with rules concerning the vendor's operation of his business or other nonrelated items. These administrative matters should be handled by separate negotiation with the supplier or by using qualified source-inspection personnel.

Qualification of a vendor may be specified as either part qualification or product-line qualification. In the part qualification concept, a vendor has to qualify separately for each individual part. This implies a continuous demand for a particular item. Because technological improvements and economic factors usually prevent a long constant demand for a particular item, requalification or qualification for other parts is often necessary under the individual-part qualification concept.

The line qualification concept is based on the fact that most production lines produce items that differ only in operational characteristics. The basic quality and inherent reliability levels of parts made from the same materials and processes are essentially the same. The line qualification concept qualifies a vendor to produce a complete class of parts on a single production line.

The line qualification concept has the advantages of producing lower cost parts (because the qualification costs are distributed over a whole class of parts) and shorter delivery times.

The line qualification concept is an especially useful approach to high reliability procurement specifications providing proper controls are maintained. If a vendor is not dependent on particular part types, he can operate at a lower financial risk, thereby providing a class of reliable parts at a lower cost [Refs. 3-1 and 3-5].

The following factors should be considered when constructing a specification [Ref. 3-6]:

(1) The part reliability is best assured by specifying stress tests which adequately control the predominant failure mechanisms.

(2) High reliability levels are best assured by the large continuous production of a part.

(3) Applications requiring low failure rates differ from those requiring long life for individual devices. A single specification providing the required reliability levels for both types is more complex and costly than separate specifications.

(4) Failure mechanisms are very complex and differ from vendor to vendor and over a production cycle, so no two part types made by different vendors or by the same vendor at different periods of time can be assumed to have identical failure mechanisms. Because of this, these parts do not have exactly the same operating characteristics or failure rates.

(5) Failure distributions and acceleration factors should not be specified unless they are supported by adequate test data.

(6) Try to use a specification that the vendor considers standard whenever possible. If the vendor is familiar with the specification, the part desired is more likely to be delivered as specified.

A myriad of specification types exists, with varying degrees of complexity. These are discussed individually.

3.1 High Reliability Procurement Specifications

High reliability part procurement specifications are used to control part quality and to assure reliability as a condition of purchase. A wide variety of approaches to reliability assurance specifications exists because of the differences in operating conditions, reliability requirements, and reliability characteristics of the various component part types.

Procurement specifications should provide reliability assurance by:

(1) removing initial failures;

(2) removing early device failures caused by degradation;

(3) minimizing the probability of random, catastrophic device failure in the field;

(4) assuring adequate device life and margins of electrical characteristics under all operating conditions and environments; and

(5) minimizing the probability that a consistently manufactured part will not be accepted.

Procurement specifications should satisfy each of the above provisions as simply and economically as possible.

The small sample lot acceptance testing and low-stress testing used in most procurement specifications do not adequately fulfill the basic purposes of a procurement specification as stated above. Small samples do not adequately detect random, catastrophic failures or early failures from a device population. Low-stress testing does not determine the device's expected service life. Typical procurement specifications also employ only a small number of stress types and thereby fail to detect certain potential failure mechanisms.

To properly construct a high reliability procurement specification, the suppliers should be carefully selected using product-line evaluation and device testing. Background for specification construction should include generation of stress-testing data. High stress-testing levels provide short stress-screening and life-testing times. The most efficient screen-out of potential failures is accomplished by primarily using those stress types expected to induce device failures thereby reducing the number of stress and sampling tests required. The specification should closely follow the application requirements to assure the proper margin of reliability at the maximum cost-effectiveness [Refs. 3-1 and 3-6].

After a preliminary draft of the proposed specification has been prepared, the suppliers under consideration should be given the complete evaluation-test data on their parts for comments. Any suggestions regarding yield improvement, alternate stress tests or other ideas which might facilitate delivery or reduce cost should be considered and problems resolved by further testing, system design change, or any other appropriate methods. Final agreement between the system designer, the reliability assurance group, and the vendor is necessary before final part procurement can begin. The specification is sometimes renegotiated after the supplier has gained some experience with the manufacture of the part.

The effectiveness of the part procurement specification cannot be completely determined until the system has been built, tested, and operated through the desired life period. Of course, the ability to remove initial and early failures is determined relatively quickly. Deficiencies in the specification may be revealed by the

Table 3-1

Reliability-Cost-Delivery Tradeoffs [Ref. 3-1]

Test	Testing Level	Additional Cost	Delay in Delivery	Aid to Reliability
Power Burn-in	100%	medium	moderate	high
Drift	100%	high	long	medium
	sample	medium	moderate	medium
High Temperature Storage	100%	low	short	small
	sample	low	short	small
Environmental	100%	high	long	high
	sample	low	short	high
Hermetic Seal	100%	low	moderate	high
	sample	low	short	high

initial lot-acceptance test data and, thereby, corrected early in the program. Other deficiencies are pointed out through the need for equipment repair as the program progresses [Ref. 3-5].

A detailed example of procurement specification techniques for high reliability transistors is given in Ref. 3.5.

Table 3-1 lists some reliability-cost-delivery tradeoffs for various screening tests used in high reliability procurement specifications [Ref. 3-1].

TX ("Testing Extra") Specifications and Components

A new class of military-quality components and parts known as "TX" are expected to provide an order of magnitude improvement in aerospace reliability and to have a great effect on equipment manufacturers and their semiconductor suppliers.

TX-type devices are subjected to the tests shown in Figure 3-1 in addition to the normal JAN*-type test shown in the figure. The devices so tested are designated JAN-TX devices. Each semiconductor device purchased under the new military specifications undergoes a week (168 hours) of "burn-in" at the suppliers' plant to check for excessive drift of the critical parameters.

* JAN-Joint Army Navy

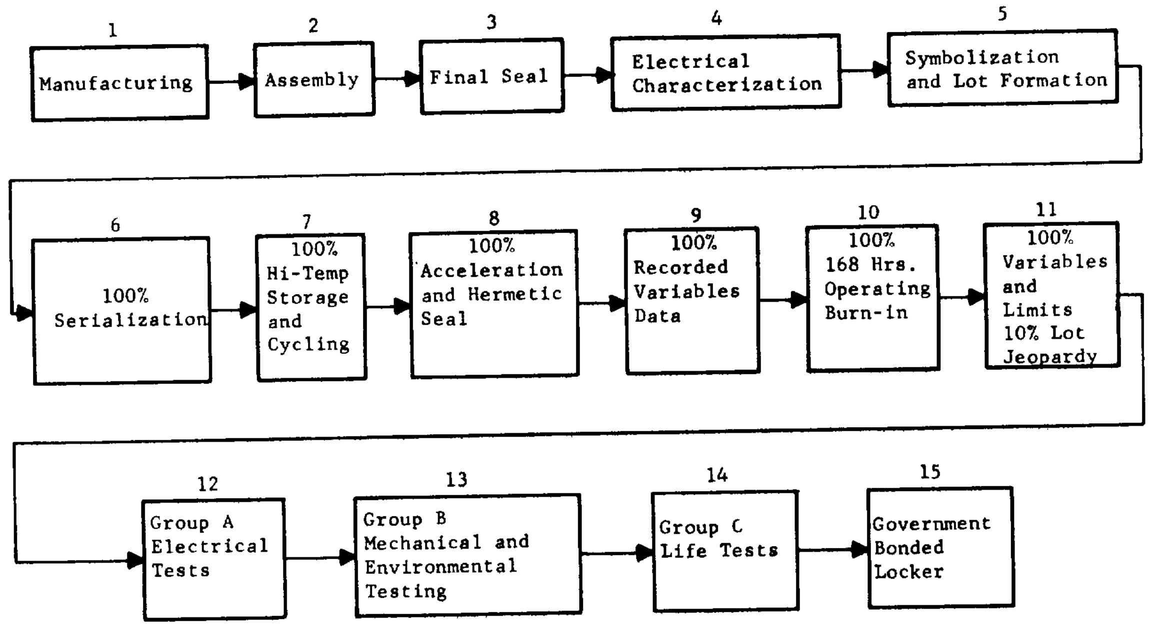


Fig. 3-1. TX Semiconductor Device Production and Testing Procedures (Steps 6 - 11 are unique to TX devices)

TX specifications should eliminate many of the custom specifications which aerospace equipment manufacturers previously felt were necessary to obtain high reliability parts and components. These custom specifications have been a costly bother to the equipment manufacturers, their semiconductor suppliers, and the military.

The new JAN-TX specifications for transistors, diodes, and rectifiers originated from the reliability program for the F-111 at General Dynamics Corporation, but they now have applications beyond that program. TX devices will be widely used in the USAF/Lockheed C-5A and the new Mark II avionics system for later F-111A. If the expected improvement in reliability is achieved, the TX-type devices should gain wide acceptance. At the present time however there is little quantitative field data to show how much improvement in reliability is obtained by using TX devices.

It is estimated that TX devices will cost between 10 and 50 percent more than the JAN equivalent, once suppliers have gained experience in their use. These additional costs (due to the extra testing and resultant rejection of questionable devices) might possibly be absorbed by a reduction in the number of different types of devices which semiconductor manufacturers must now produce for their customers, each with its own special test procedures. The over-all cost of the TX devices will probably be less for aerospace equipment manufacturers that now subject incoming parts and components to 100 percent testing inspection and/or burn-in, since it should be less expensive to test them in the suppliers' plant.

JAN-TX devices are essentially the same as the corresponding JAN semiconductor devices except for the additional testing involved. The additional tests which are performed on each TX part or component are:

(1) Identification of each part or component with a serial number for correlation of results of subsequent tests.

(2) Temperature cycle between -55°C + 200°C.

(3) Temperature baking at 200°C for 48 hours.

(4) Centrifuge tests at a minimum of 20,000 g.

(5) Hermetic sealer tests.

(6) Measurement of key parameters $V_{CE(SAT)}$, I_{CEO}, h_{fe} followed by 168 hours of operation at 80 percent rated voltage.

(7) Repeat measurements of key parameters.

Any part experiencing the catastrophic failure during the testing is discarded in addition to devices which may have drifted out of acceptable operating limits.

If a large number of devices in a given lot exhibit excessive drift, the whole lot is rejected because it indicates errors in the fabrication process. The whole-lot rejection figure is usually 10 percent but may vary according to the particular type of device.

Devices which pass the TX test are subjected to the standard JAN group A electrical test and the group B mechanical and environmental test. However, the percentage of units that can fail before the whole lot is rejected is reduced. Provisions are also made for grade C destructive testing and sample quantities, as with conventional JAN devices.

The response of the semiconductor industry to the new TX specifications has been very favorable, in general [Ref. 3-7].

Established Reliability (ER) Specifications

A total of 22 Established Reliability Military Specifications (ER's) have been issued to date by the military services (see Table 3-1). These ER's are constantly being revised and updated because of advances in the state-of-the-art and changes in military requirements. The basic idea behind ER specs is to obtain a single series of military specifications on electronic parts at specified reliability levels and at costs which are within acceptable limits to users.

ER specs grew out of the AGREE Report (Reliability of Military Electronic Equipment, issued 4 June 1957, by the Advisory Group on Reliability of Electronic Equipment, OASDRE): and the PSMR-1 Report (Parts Specification Management for Reliability, issued

May 1960). The first specification issued under this program was MIL-R-55182 (Resistors, Fixed, Film, Established Reliability).

The military, in cooperation with the Electronic Industries Association (EIA), issued MIL-STD-690, "Failure Rate Sampling Plans and Procedures," in May 1963. This document, which is referenced in all ER specs, provides detailed life test sampling plans and procedures for establishing and maintaining multilevel reliability qualifications.

In addition to MIL-STD-690, each ER spec also references MIL-STD-790 as a prerequisite to qualification. This standard requires each manufacturer to document his in-house reliability program in terms of organization, training programs, process control techniques, failure analysis and reporting, clean room control, etc.

After the first 22 ER specs had been issued, several problems were evident. Each spec contained manufacturer qualification requirements, but manufacturers were reluctant to qualify to these requirements. This reluctance was caused by the fact that users were not specifying ER parts (other service specifications covering the same parts were being used) and the projected prices for the reliable parts were prohibitively high.

The principal reason that ER specs were not readily accepted, however, was the existence of the MIL-R-38100 (USAF) series of specifications on high reliability parts. This series of specs, an outgrowth of the Air Force Minuteman project, provides high reliability parts specifications on resistors, capacitors, and semiconductors. The parts specified under this series of specs were generally also procurable under ER specs, but under slightly different qualification requirements. The existence of MIL-R-38100 (USAF), its widespread use and the similarity to the ER specs caused considerable confusion among manufacturers. The acceptance of ER specs has been further complicated by the "TX" specs.

To eliminate the confusion existing among users and manufacturers and the duplication of effort regarding high reliability specifications, the DOD decided to retain ER specifications as a basis for a single specification system, superseding MIL-R-38100 (USAF) and the "TX" specs. The latter two specification systems were to be reviewed and the best features of each incorporated into the ER specifications. In addition, to reduce the costs of parts procured to ER specs, requirements of ER specs which contributed little to reliability assurance were either eliminated or relaxed considerably.

Certain ER specs have already been revised [Ref. 3-8] and all existing ER specs should be revised by the end of 1967. The success of these specs is not known entirely, although the number of sources already qualified and those expressing interest indicate the ER specs will be accepted. As their use increases, these specifications will be refined into sophisticated reliability documents, providing parts of much higher reliability than those presently available [Ref. 3-8].

3.2 In-House Specifications

Whenever standard or commercial devices cannot be utilized, in-house specifications must be prepared and used as the purchase document. These specifications may range from a simple burn-in requirement imposed on a commercial specification to a complex description of a custom-type circuit or part. The devices described by the in-house specifications usually differ from the commercially specified devices in certain characteristics, e.g., transistor gain at low temperature.

This section describes in-house specification of integrated circuits (IC's) in a standard format.

In most cases, a general product specification is issued before the specific or detailed document is generated (the approach used in the MIL-S-19500 semiconductor device specifications).

The general product specification consists of tests, parameter definitions and basic device requirements common to all IC's and prevents redundancy in the detailed specification. The product specification contains five major sections:

(1) The applicable documents section lists those specifications which are too lengthy to include in the product specification, e.g., MIL-STD-202, Test Methods for Electronic and Electrical Components. Detailed screening processes may also be included.

(2) The general requirements section specifies materials, design and construction, marking, qualification, etc.

(3) The quality assurance section defines qualification inspection, applicable test conditions, responsibility of inspection, and classifies inspection levels (acceptance and failure rate).

(4) The test methods section contains symbols, definitions and test methods of parameters that are common to most integrated circuits [Ref. 3-9]. Examples are switching time and breakdown voltage.

(5) The preparation for delivery section specifies proper packaging and marking requirements for the final shipping containers.

After the product specification has been completed, the detailed specification can be written for any particular type or series of IC's. The detailed specification is usually broken into six sections:

(1) The circuit configuration section specifies the manufacturing process used for the circuit, e.g., monolithic, thin film or hybrid.

(2) The parameter definition section specifies whether the IC should be tested as a black box or at specified points. For specified point testing, the electrical parameters of the IC must be checked between each external lead or each lead and the substrate contact. Black box testing involves only a check of the functional characteristics, i.e., input, output, and transfer. However, since many IC parameters are inaccessible to measurement, usually only those IC parameters involving the input and output terminals of the device and the power supplied in terms of voltage and current are specified.

(3) The parameter measurements section defines the minimum number of measurements necessary to define the IC properly. Parameter tests for many types of IC's are quite complex and must be described completely. The descriptions include minimum and maximum ratings, test paragraphs, a schematic diagram of the test circuit, equipment to use, correct waveforms, etc. Figure 3-2 shows a switching time test circuit and the proper waveforms for a Signetics DTL Dual NAND/NOR Exclusive-OR Gate.

(4) The test classification section classifies the various tests by inspection levels, i.e., the percent of each device to be tested. Certain tests require 100 percent testing for every device, whereas other tests employ sampling procedures whereby only a small number are tested. (MIL-STD-105 lists various sampling procedures and includes sampling tables; Part IV of Ref. 3-4 also discusses sampling procedures.) Careful consideration should be given to those tests requiring 100 percent testing because of the cost factors involved. If sampling procedures can do the job, they should be employed.

(5) The package configuration section defines the dimensions of the IC package. The tolerances should be wide enough to permit the selection of alternate manufacturers. There are many types of packages available, and the size of the package is usually flexible.

(6) The qualified sources section lists information pertaining to qualified sources for the particular IC. Pertinent information includes the appropriate manufacturer's part number and any other information unique to the manufacturer.

The major difference between the standard and high-reliability in-house specifications is the type of quality assurance tests and inspection levels specified in each document. Table 3-2 shows some typcial tests which might be required for the two types of specifications for a moderate level of reliability. The degree of

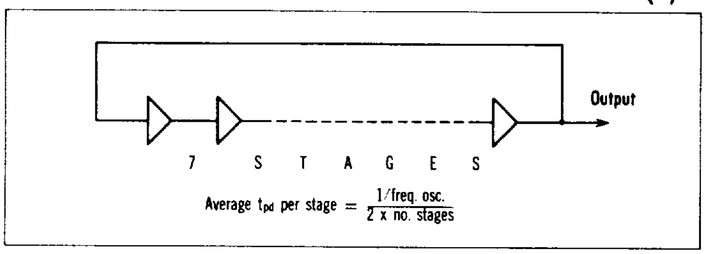
APPLICATION DATA

In any application (e.g. EXCLUSIVE-OR) in which the collectors of two or more SE115 gates are tied in common, the pull-up resistor, Pin 9, should be connected to Pins 2 and 10. Up to five gates may be used in such as configuration, but only one gate in the array need have its pull-up resistor connected. Use of the pull-up in these circumstances assures that at high temperatures, leakage current will not be drawn from the inputs of gates being driven by the SE115.

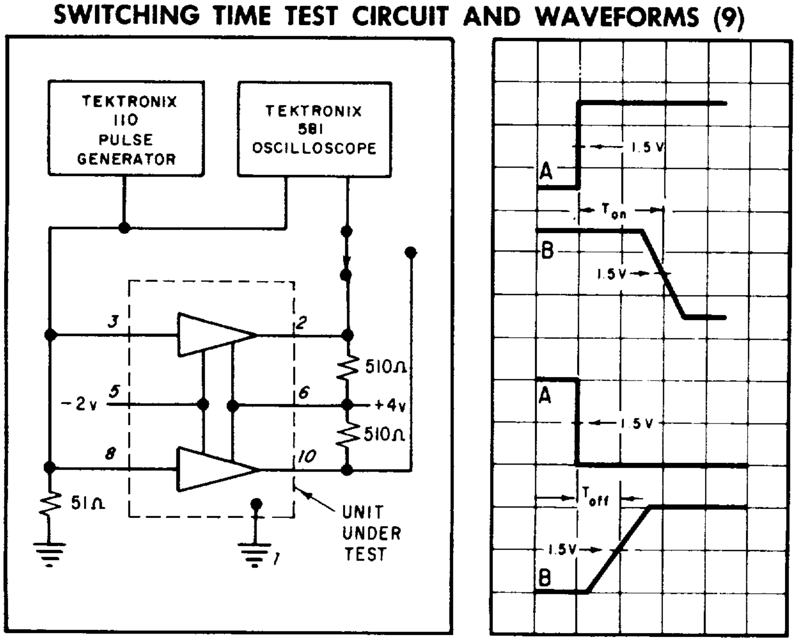
A more general configuration than the EXCLUSIVE-OR shown in the logic diagram on the front page would be one in which A and B are the inputs to one gate and C and D are inputs to the other. The output is then $\overline{AB+CD}$. By appropriate substitutions in this general equation, the EXCLUSIVE-OR function $(\overline{AB+\overline{A}\,\overline{B}} = A\overline{B}+\overline{A}B$, true for $A \neq B$) or the comparison function $(\overline{A\overline{B}+\overline{A}B} = AB+\overline{A}\,\overline{B}$, true for $A = B$) can be generated.

Two or more SE115 gates with the collectors tied in common can also be used in commutation applications. If the signals to be commutated (A,B,C,D. . . .) are connected to one of the two inputs on each gate, and appropriate timing signals $(T_1, T_2, T_3, T_4 \ldots)$ are connected to the other input on each gate, the function $\overline{AT_1+BT_2+CT_3+DT_4}$ is generated.

PROPAGATION DELAY MEASUREMENT CIRCUIT (8)

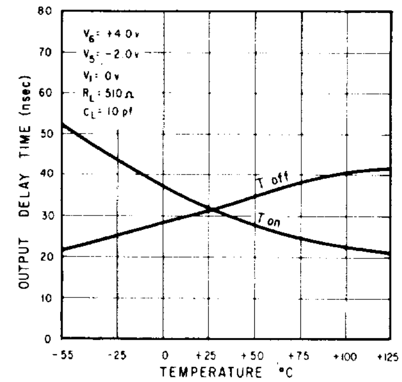


SWITCHING TIME TEST CIRCUIT AND WAVEFORMS (9)

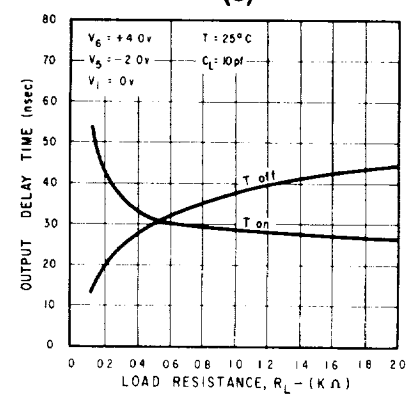


OUTPUT DELAY CHARACTERISTICS

(5)



(6)



(7)

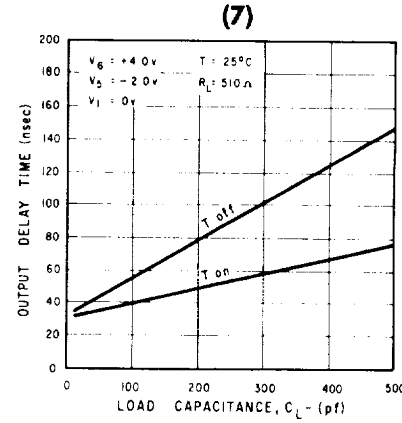


Fig. 3-2. Typical Parameter Measurements for Integrated Circuits

Table 3-2

Typical High Reliability Document Requirements
vs. Standard Document Requirements

High Reliability	Standard
1. High temperature storage 100% inspection	1. High temperature storage 100% inspection
2. Power burn-in 100% inspection - 168 hr. period	2. Power burn-in 100% inspection - 12 hr. period
3. Parameter drift, Analysis - Sample inspection	3. Hermetic seal 100% inspection
4. Hermetic seal 100% inspection	4. Environmental tests sampling inspection
5. Environmental tests 100% inspection for flat packs, sampling for TO-5 packages	

inspection and the tests imposed on the device are, of course, highly dependent on the reliability requirement [Ref. 3-10]. As with any specification, the element of cost is critical. If the specification requires special nonstandard testing techniques and imposes severe selection criteria that reduce yield, the increase in cost may be prohibitive.

Finally, before preparation of an in-house specification is begun, manufacturers should be consulted as to ways of obtaining maximum performance and reliability assurance at lowest possible cost.

References

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4. Verification

Verification is the process whereby a user determines to his own satisfaction whether the parts received, in fact, meet the criteria on which their selection was based and which were specified. This verification may consist of many things, from accepting the manufacturer's word to qualification procedures with in-process inspection to 100% non-destructive acceptance testing and sample destructive testing or combinations of these.

Verification can be costly in time, money and manpower. It requires adequately trained, motivated personnel to perform the required qualification and acceptance tests. It also requires an investment in testing facilities and equipment. In-plant inspectors are usually unpopular and resented by the manufacturer. Because of these factors, if safety and reliability requirements do not necessitate, it may be advantageous to accept the vendor's word with little or no further verification, i.e., the manufacturer's test, inspection, quality control procedures, and character may be adequate. Often, it may also be more economical to replace a defective part than verify it upon receipt.

When reliability requirements are not stringent, the most common verification procedure is line qualification whereby a vendor is qualified to produce a complete class of parts on a single production line. This line qualification concept produces lower cost parts and shorter delivery times. Periodic requalification checks are made on the vendor's product to insure that process controls are being adequately maintained.

High reliability part requirements have led to extensive verification procedures consisting of 100% non-destructive acceptance testing for all parts and destructive tests on a sampling basis [Refs. 4-1 through 4-3]. The basis for all procedures involved in this type of verification must lie in the specification. As stated earlier, the specification should be written simply to avoid unreasonable and unenforceable requirements, i.e., do not specify anything that cannot be verified. In addition, if strict verification procedures are necessary, the user should develop sufficient testing capability so that adequate but reasonable controls can be established. An optimum combination of specification controls and testing capabilities should convince the supplier that the user intends to test for specification conformance whether the supplier does so or not, and that lots can be rejected on this basis.

Suppose, for example, a high reliability silicon integrated circuit is desired for a particular program. What steps should be taken to verify the parts and in what sequence should these steps be performed?

Initially, all possible failure modes of the circuit which may be encountered in manufacture are listed and classified according to basic failure modes (shorts, opens, defective seals, poor workmanship) with sub-classifications according to specific failure mechanisms and causes. This type of information is shown in Table 4-1 for electrical opens (see Ref. 4-3 for complete listing).

After the failure modes have been listed, possible test methods for failure detection should be listed and catagorized. Tests listed in MIL-STD-750 and MIL-STD-202 should be considered. A list of applicable test methods is shown in Table 4-2 [Ref. 4-3].

After the possible test methods and failure mechanisms have been listed, the method or methods most suitable to detect a particular failure mode can be determined. This is done by a series of matrix plots whereby the tests methods are interacted with the failure modes to yield the most applicable and economical methods for failure mode detection [Ref. 4-3].

The important factor in determining adequate verification procedures for high reliability parts is the determination of the effectiveness and applicability of the possible test methods in revealing latent failure mechanisms.

The same general manufacturing processes for integrated circuits are used by all manufacturers. These are [Refs. 4-3 and 4-4]:

(1) Wafer preparation
(2) Circuit fabrication
(3) Electrical probing of wafer
(4) Scribing and dicing
(5) Die mounting into package
(6) Wire bonding
(7) Internal visual inspection
(8) Final sealing
(9) Acceptance tests
(10) Classification, marking, packing, shipping.

Verification procedures, i.e., the screening acceptance test provisions should begin at internal visual inspection. These provisions should be performed in the sequence shown in Table 4-3.

Internal visual inspection is an optical examination of the integrated circuit before sealing to evaluate process techniques and uniformity and reveal contamination and foreign matter. This test requires the user to provide inspection during manufacture.

Table 4-1

Possible Failure Modes for Electrical Opens [Ref. 4-3]

1.0 Electrical Opens or High Resistance

- 1.1 Leads
  - 1.1.1 Lead Fatigue (broken lead)
  - 1.1.2 Nicked or Cut Leads
- 1.2 Wire Bonded to Leader Inside Case
  - 1.2.1 Underbonding
  - 1.2.2 Plague
  - 1.2.3 Overbonding
- 1.3 Bonding Wire
  - 1.3.1 Nicked or Cut Wires
  - 1.3.2 Poor Bonding
  - 1.3.3 Overcurrent
  - 1.3.4 Stretched Wire
- 1.4 Wire Bonded to Metallized Interconnections
  - 1.4.1 Underbonding
  - 1.4.2 Plague
  - 1.4.3 Overbonding
- 1.5 Interconnections
  - 1.5.1 Metal scratches
  - 1.5.2 Oxide steps
  - 1.5.3 Corrosion
  - 1.5.4 Plague
  - 1.5.5 Overcurrent
  - 1.5.6 Overbonding
  - 1.5.7 Masking Defect
- 1.6 Metallized Interconnections Evaporated on Substrate
  - 1.6.1 Poor Adhesion
  - 1.6.2 Misregistration
- 1.7 Substrate (includes components and junctions)
  - 1.7.1 Cracked Chip
  - 1.7.2 Poor Oxide Adhesion

Table 4-2

Applicable Test Methods for Failure Mode Determination [Ref. 4-3]

1.0 Non-Destructive Tests

- 1.1 Visual Inspections
  - 1.1.1 Internal Visual Inspection Before Sealing
  - 1.1.2 Physical Dimensions Test
  - 1.1.3 External Visual Inspection
- 1.2 Electrical Tests
  - 1.2.1 Functional Test
  - 1.2.2 D.C. Parameter Tests
  - 1.2.3 Noise Immunity Tests
  - 1.2.4 Dynamic Parameter Tests
  - 1.2.5 Threshold Tests (Substrate Breakdown Tests)
  - 1.2.6 Power Dissipation Tests
  - 1.2.7 Insulation Resistance Test
- 1.3 Operating and Extended Life Tests
  - 1.3.1 Operating Life Tests (Sampling)
    - 1.3.1.1 Operating Life at Room Temperature (Full Rated Power)
    - 1.3.1.2 Operating Life at High Temperature (Derated Power)
  - 1.3.2 Operating Burn-In Tests (100%)
    - 1.3.2.1 Operating Burn-In Tests at Room Temperature (Full Rated Power)
    - 1.3.2.2 Operating Burn-In Tests at High Temperature (Derated Power)
  - 1.3.3 High Temperature Bake Tests (No Power)
    - 1.3.3.1 High Temperature Storage Life (Sampling)
    - 1.3.3.2 High Temperature Stabilization Bake (100%)
  - 1.3.4 Parameter Drift Tests
    - 1.3.4.1 Can Do as Pre-operating Life and Post-operating Life Tests
    - 1.3.4.2 Can Do as Pre-burn-in and Post-burn-in Tests
    - 1.3.4.3 Can Do as Pre-high Temperature Bak and Post-high Temperature Bake Tests
- 1.4 Environmental Tests
  - 1.4.1 Temperature Tests
    - 1.4.1.1 Temperature Cycling
    - 1.4.1.2 Thermal Shock
    - 1.4.1.3 Dew Point
  - 1.4.2 Mechanical Tests

Table 4-2 (Continued)

- 1.4.2.1 Centrifuge (Constant Acceleration)
- 1.4.2.2 Shock
- 1.4.2.3 Vibration (Monitored or Unmonitored)
    - 1.4.2.3.1 Virbration Fatigue
    - 1.4.2.3.2 Vibration, Variable Frequency
    - 1.4.2.3.3 Random Vibration
- 1.4.3 Barometric Pressure (Altitude)
- 1.4.4 Thermal Vacuum
- 1.5 X-Ray Tests
- 1.6 Hermeticity (Leak) Tests
    - 1.6.1 Oil Bubble (or Hot Glycerin) Tests
    - 1.6.2 Helium Leak (or Radiflo) Tests
    - 1.6.3 Nitrogen Bomb Tests
- 2.0 Destructive Tests
    - 2.1 Internal Visual Inspection After Sealing
    - 2.2 Physical Tests
        - 2.2.1 Bond Tension
        - 2.2.2 Lead Tension
        - 2.2.3 Lead Fatigue
        - 2.2.4 Solderability
        - 2.2.5 Resistance to Soldering Heat
        - 2.2.6 Weldability
    - 2.3 Environmental Tests (Atmospheric)
        - 2.3.1 Salt Atmosphere (Corrosion)
        - 2.3.2 Salt Spray (Corrosion)
        - 2.3.3 Moisture Resistance
        - 2.3.4 Humidity
    - 2.4 Analytical Tests
        - 2.4.1 High Power Microscopic Inspection
        - 2.4.2 Electrical Probing of Circuit Elements
        - 2.4.3 Infrared Scanning
        - 2.4.4 Electron Microprobe X-Ray Analysis
        - 2.4.5 Scanning Electron Microscopy
        - 2.4.6 Anion Reaction Tests
        - 2.4.7 Microsectioning

Table 4-3

Acceptance Test Provisions [Ref. 4-3]

Internal visual inspection before sealing
Marking requirements
External visual and mechanical inspection
Marking permanency test
Stabilization bake
Initial electrical tests
Thermal cycling (shock)
Mechanical tests (centrifuge and vibration)
X-ray
Burn-in
Hermeticity tests
Final electrical tests

Marking requirements provide identification and serialization for each device immediately after sealing. Subsequent test results can then be correlated to specific devices.

External visual and mechanical inspection verify that materials, design, construction, marking, and workmanship are in accordance with all the applicable requirements.

The marking permanency test is used to verify that the identification markings are permanent and cannot be readily removed during use or handling.

Stabilization temperature bake is employed to stabilize electrical characteristics and assure uniformity of testing conditions between manufacturers. Too high temperatures may create long-term failure mechanisms.

Initial electrical tests are performed to verify that the integrated circuits meet system requirements.

Thermal cycling stresses the package materials and lead seals in addition to the active device and attachment areas. This cycling should be followed immediately by centrifuge and vibration tests because mismatches in the thermal expansion coefficients may weaken the device structure causing failures when the mechanical stresses are applied.

All devices should be x-rayed immediately after the thermal and mechanical environmental tests to screen out any deficiencies caused by these stresses.

Burn-in is designed to reduce the percentage of devices that would fail during the initial hours of operation by removing defective units. These tests permit projection of operating life expectancies for the circuits. All failures that occur during burn-in should be carefully analyzed since actual use conditions are usually employed and the failure modes are similar.

Hermeticity tests determine any small leaks (> 10^{-8} std cc/sec) which might degrade future performance. As an example, less than 10^{-6} std cc/sec can cause formations of aluminum hydroxide resulting in time dependent failure modes.

Final electrical tests are performed to evaluate any changes that may have occurred in the electrical parameters during the tests.

The above acceptance tests are a part of the device specification. In addition to these requirements, certain qualification requirements, e.g., destructive tests per MIL-STD-750A, are usually incorporated. Although these qualification requirements are included primarily for initial vendor qualification, certain of these destructive tests usually become part of the acceptance and verification procedure, especially for high reliability devices. These are incorporated on a sampling basis to prevent marginal vendor performance on subsequent lots. Also, if accumulated data warrants, certain of the acceptance tests may be included on a sampling basis only.

The above procedures for acceptance testing may be performed by the vendor or user. If the vendor performs the tests, the user either provides in-house inspection or sets up a receiving inspection team to test the incoming lots on a sampling basis to verify the vendor's results. (Sampling may imply that 100% of the parts are subjected to certain tests [Ref. 4-3].) Since burn-in screening and parts degradation analysis are important verification procedures, they are discussed in more detail below.

4.1 Burn-in Screening

Burn-in is simply a short operating-life test on 100 percent of the devices in a simulated environment at stress conditions. It is designed to reduce the percentage of devices that would fail during the initial hours of operation by removing defective units.

For burn-in screening, all manufactured parts are first subjected to the procurement specification. Those passing the specification are burned-in for specified periods of time and stress conditions. At the end of burn-in each part is retested. All parts outside the specification are removed and the remainder of the parts are ready for shipment.

Burn-in is primarily useful when the area under the new hazard rate curve, i.e., after burn-in, for the mission time is less than the area under the old hazard rate curve, i.e., before burn-in, for the mission time. The hazard rate function is given by

$$h(t) \equiv -\frac{1}{R}\frac{dR}{dt} = -\frac{d(\ln R)}{dt} , \quad (1)^*$$

where R = mission reliability and t = mission time. Equation (1) implies that $R = e^{-\theta}$ where

$$\theta = \int_o^t h(\tau)\, d\tau . \quad (2)$$

An example of useful burn-in is shown in Fig. 4-1 where the area under the hazard rate curve between t_1 and t_2 is less than it would have been in an equal time period beginning at t_0. Situations where burn-in is not applicable are shown in Fig. 4-2. Suppose burn-in has brought the devices to point t_1 in time. Since curve A has an increasing hazard rate function, the area under the hazard rate curve is greater between t_1 and t_2 than it would have been in an equal time period beginning at t_0. For the constant hazard rate of curve B, burn-in has neither helped nor hurt the device's reliability, but has, instead, been a waste of time. However, this does not imply that burn-in may not be useful for devices exhibiting increasing or constant hazard rates. Burning-in the devices under accelerated or other than operating conditions may result in an entirely different hazard rate function in actual operation as shown in Fig. 4-3.

Claims of a decreasing hazard rate function are made for many types of electronic and semiconductor components [Refs. 4-5, 4-6, and 4-7]. The hazard rate functions approximate the familiar "bathtub" curve of Fig. 4-4. Burning-in the parts through Region I ("infant mortality" region) removes early failures and ages the parts to the constant hazard rate region [Refs. 4-7, 4-8, and 4-9]. The same is true for parts whose hazard rate functions can be described by the Weibull distribution when the shape parameter β is less than one.

A rationale for determining whether burn-in is feasible and, if so, what burn-in times are appropriate are difficult problems. A decreased area under the hazard rate function after burn-in is not always the important criteria. If initial failures were critical, curve A of Fig. 4-5 would be preferable over curve B for the total mission time even though any burn-in would decrease the area under the hazard rate function for curve B. If burn-in is desirable, however, the faster the hazard rate

---
* The hazard rate becomes the failure rate when R = 1.

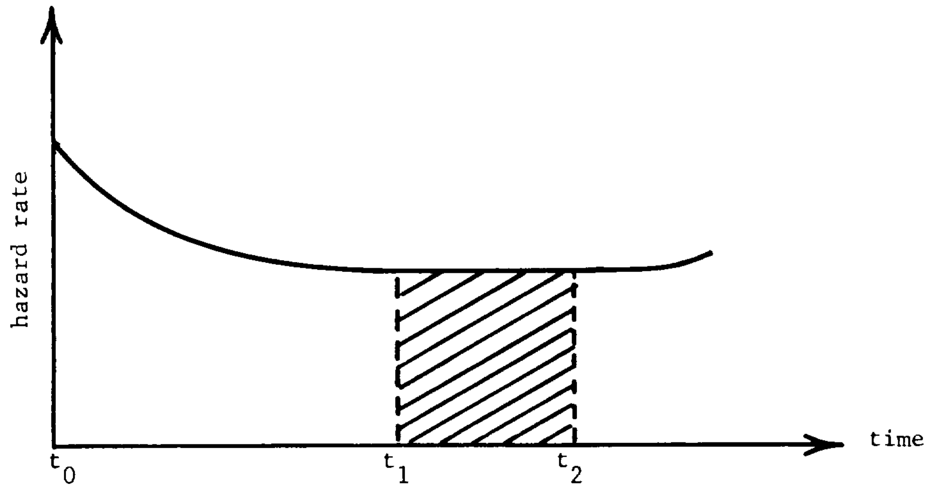

Fig. 4-1. Useful Burn-in

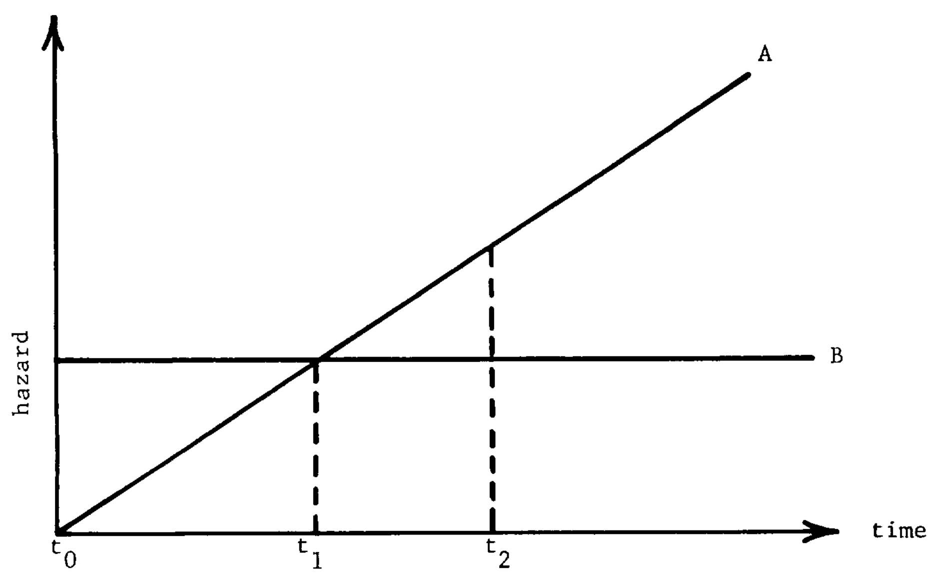

Fig. 4-2. Burn-in Effect on Increasing and Constant Hazard Rate Function

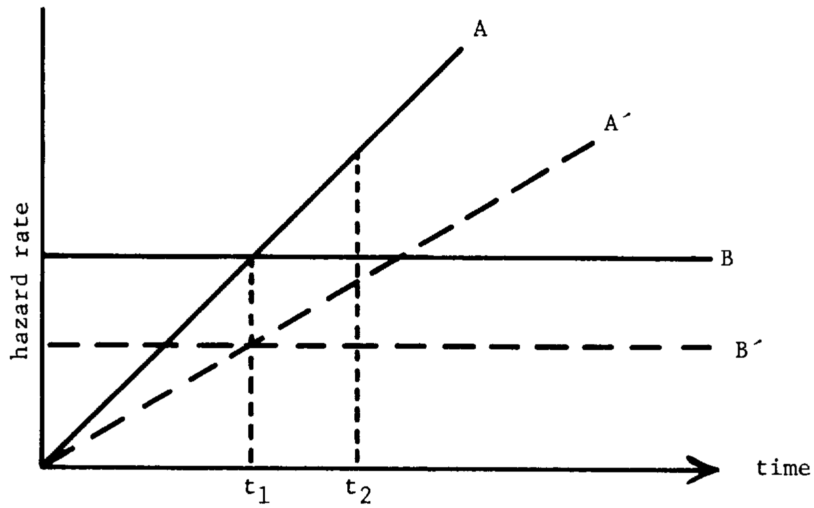

Fig. 4-3. Possible Effects of Burn-in Caused by Accelerated Screening Tests

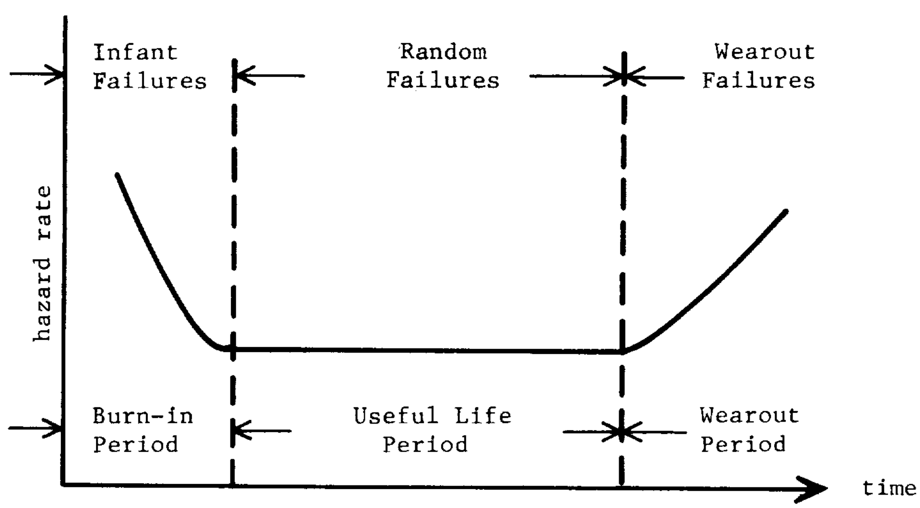

Fig. 4-4. The "bath tub" Curve of Hazard Rate vs. Time

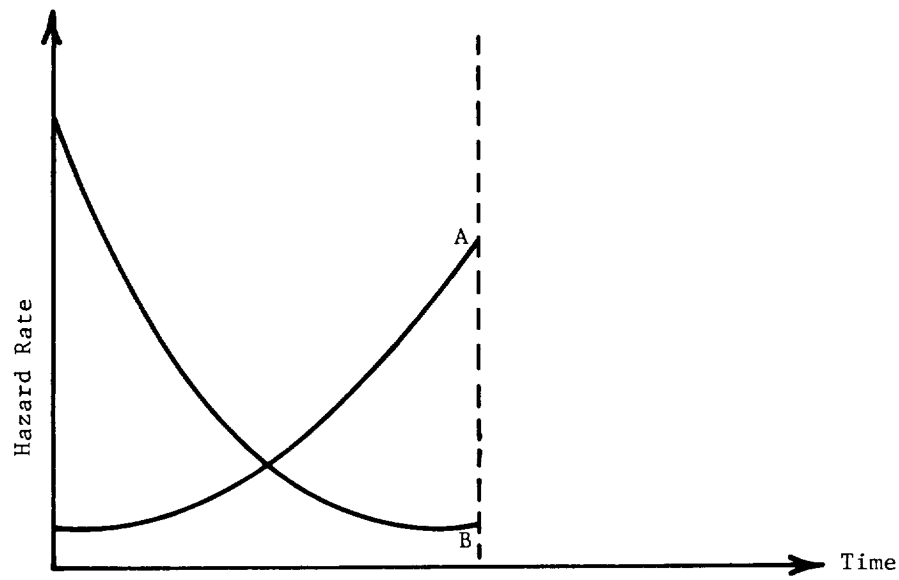

Fig. 4-5. Hazard Rate Curves for Low (A) and High (B) Initial Failure Rates

decreases, in general, the more burn-in will increase the reliability of the delivered parts. One drawback is that the hazard rate function for a particular part is usually not accurately known until a large amount of operating life data is accumulated. Also, the hazard rate function may be altered by changes in fabrication processes, design, or changes in screening tests. The choice of appropriate burn-in tests for the intended application is also difficult.

Because of the problems described above, the choice of burn-in time is usually somewhat arbitrary and is often determined by economic considerations. (Reference 4-5 establishes burn-in conditions by using Weibull statistics.) Of course, if reliability is crucial, economic factors are secondary to any increase in reliability that may be gained. The most common burn-in times are 250 hours, 240 hours, and 168 hours [Ref. 4-10].

Although burn-in conditions may be specified arbitrarily, they are usually difficult to change once they have been specified. Users are often reluctant to permit shorter burn-in times once a period has been specified, even though shorter times may be warranted [Ref. 4-10].

An important by-product of burn-in screening is the large amount of continuous, up-to-date operating life data which can be used for process control in addition to quantitative reliability prediction [Ref. 4-5].

Most burn-in screening has been limited to semiconductor devices and other electronic components. However, it may be used for any part if the conditions warrant.

4.2 Parts Degradation Analysis

Simply stated, a part fails because the stress applied to it at some particular instant exceeds its strength at that instant. The part which failed was not typical in some inherent but unknown manner from the supposedly same parts which did not fail under the same circumstances. Parts degradation analysis is a means of screening entire part lots to remove those parts which may potentially fail. The screening method is based upon the potential modes and mechanisms of failure which can detect and remove those parts from the lot which may fail.

Parts can fail in either or both of two ways. Catastrophic failure occurs when a part suddenly ceases to function, and a degradation failure occurs when parts degenerate in performance beyond certain acceptable limits. Each type of failure is inherent in all parts to a certain extent.

The usual quality screening technique is testing a part to insure that it complies with certain specifications before and after certain stresses have been applied. This type of screening technique is usually less than adequate since every part in even a "poor lot" might perform to specifications from the beginning of the stress test to the end. Parts degradation analysis [Refs. 4-11, 4-12, 4-13, and 4-14] (reliability screening) is a prediction technique to screen items which at the time of testing may not have yet failed, i.e., the part may be rejected even though it is within the specification limits at the end of the test. This screening technique is based on the inherent stability of certain critical part parameters and the degeneration in performance of these parameters caused by operating stresses with time. For reliability screening purposes, the critical indicator parameters do not have to drift out of specification to justify their rejection.

Every type of part possesses certain parameters whose characteristics are related to the circuit design in the inherent quality and reliability of the particular part. Many of these critical parameters are interrelated, i.e., a change in one parameter is often related to changes in one or more other parameters. In cases where the interrelationship is known, it may be necessary to measure only one parameter to determine the condition of the others.

The major part parameters are quite sensitive to internal change or variation and can be excellent indicators of potential or insipiant unreliability. Major critical indicator parameters of certain common parts are shown in Table 4-4. These parameters may vary with a particular part or application.

Table 4-4

Critical Indicator Parameters

Part Type	Test Parameters
Capacitors	Leakage current at 25°C.
	Capacitance at 25°C.
	Dissipation factor at 25°C.
	Leakage current or insulation resistance at 65°C.
	"Q" at 25°C
Resistors	Resistance at 25°C.
	Thermal coefficient.
	Noise at 25°C.
	Noise at 85°C.
Diodes	I_R reverse leakage.
	V_F forward voltage drop.
	T_{CBV} thermal coefficient.
	V_Z Zener voltage.
	V_Z Zener impedance.
Transistors	h_{FE} beta
	I_{CBO} leakage current (collector to base)
	P_g power gain.
	V_{CE}(SAT) saturation voltage.
	h_{FE1} h_{FE2} beta ratio
	I_{DSS} leakage current (drain to source)
	I_{GSS} leakage current (gate to source)
	BV_{CEO} breakdown voltage (collector to emitter)
	V_p gate to source pinch-off voltage, at reverse-biased drain.

Normally one major critical parameter determines a particular part lots acceptance or rejection. This particular major critical parameter may vary from lot to lot of the same type of parts and a different parameter might become important. This variation in critical indicator parameter must be considered in planning the computer program planned for analyzing the degradation data [Refs. 4-13 and 4-14].

It should be pointed out that degradation analysis does not apply only to degradation or degeneration type failure. Degeneration of the critical parameters may reveal impending catastrophic failure. Thus the degradation analysis test can predict both types of failure.

The majority of parts have from 1 to 3 parameters which must not drift beyond certain limits during the degradation analysis test. Degradation failure type limits are set up for operational parameters based on circuit design worstcase analyses. Catastrophic failure type limits are set up on a basis of physics of failure and mechanism of failure analyses for the critical indicator parameters. Frequently only one of the indicator parameters need be measured to control for both types of failure.

During the degradation tests each part is given a serial number so that each measured parameter may be identified with a particular part. Repeated measurement of the critical parameters during a power-on test, carefully noting the time and conditions of measurement, is used to monitor the stability and trends of parameter values under stress.

The degradation curve shown by the repeated stress measurements are the important factor in degradation testing, not the exact values for each parameter at the beginning and end of a test. The degradation curve relative to the upper and lower limits placed on the part parameters defines the inherent stability under stress for the part.

Consider for example the curves of Figure 4-6 which illustrate the density distribution which might be obtained from a measurement of a particular part parameter on a given list of parts at various times. At time T = 0, the peak of the curve is about half-way between the upper and lower acceptable limits with a small percentage of the test lot outside the acceptable limits. After the parts have aged, the curves broaden and the peak shifts to a lower peak level and slightly toward the lower limit. A larger percentage of the parts have shifted in value to be outside the reject limits even though the mean of the curve is still well within the acceptance band. The curves of Figure 4-6 illustrate the fact that the mean value of the density distribution curve does not tell much about the individual reliability of the parts in the test lot. Normally parts having parameter values outside the reject limits after a power aging or burn-in test would be rejected. Pitfalls exist in this method as shown in Figure 4-7.

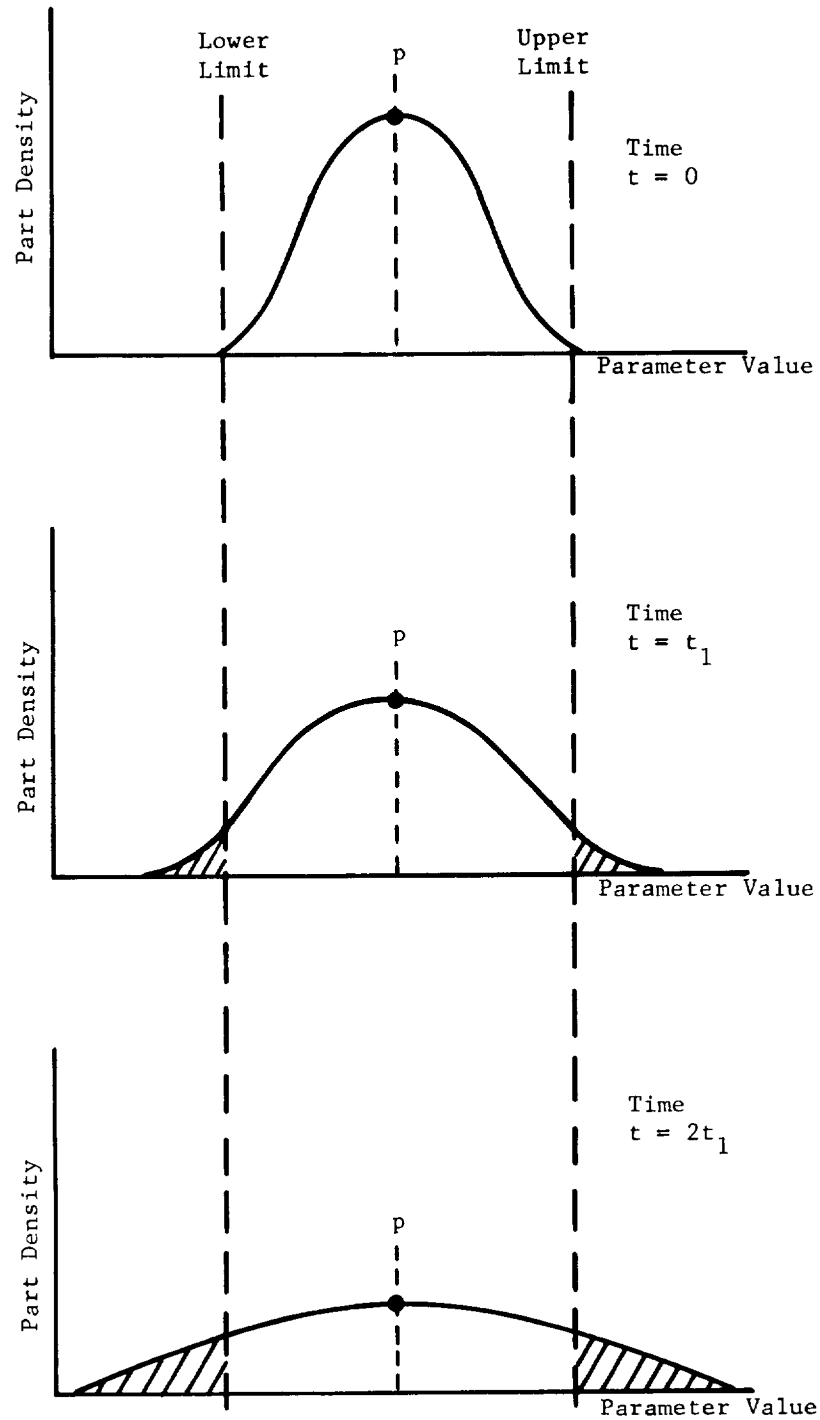

Fig. 4-6. Parts Distribution Variation with Time, Constant Mean Value

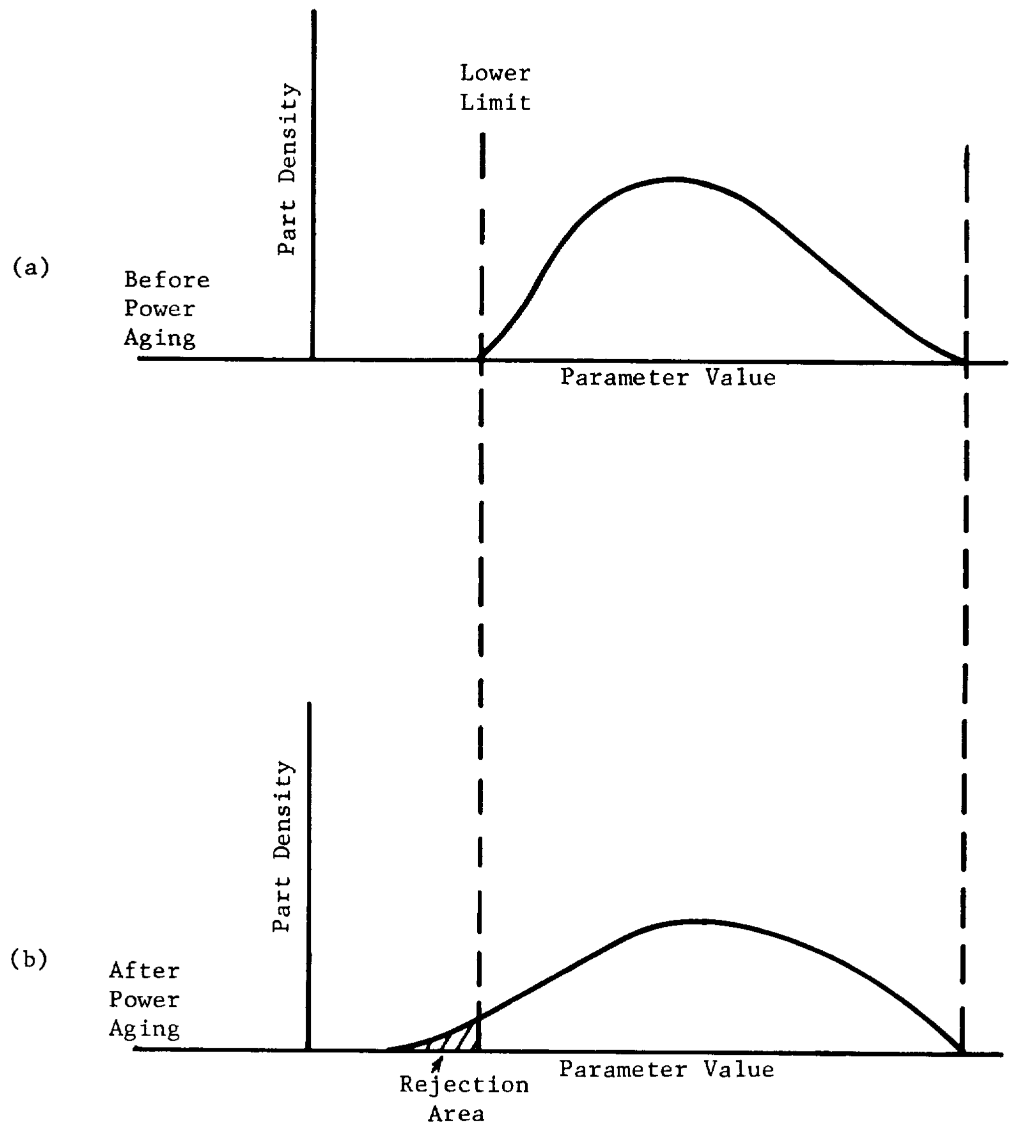

Fig. 4-7. Parameter Distribution Variation with Power Aging

Figure 4-7 shows a density distribution of a critical indicator parameter before and after a power aging test. In the usual quality screening technique the parts whose parameters are below the lower acceptance in Figure 4-7b would be rejected. However, this may be the wrong approach since many of the values in the reject area may have started out just at or slightly above the lower limit, meaning that they exhibited only a small degradation over the power aging period and could be much more reliable parts than those which might have started near the upper limit and varied across the acceptable range between limits.

From the examples in Figures 4-6 and 4-7 it is seen that the value of the mean and the tails beyond the original specification limits tell very little about the individual reliability of the parts of the test lot. Rather, degradation curves must be plotted for each part showing the test data on each parameter for each part at each test interval. The importance of this type of data is shown in Figure 4-8.

Figure 4-8a shows the ideal stable situation where the parameter value stays the same near the center of the limit range during the entire test. A part exhibiting this type of behavior is very likely to remain the same for a considerable length of time under the same or lower stress conditions.

The difference between a reject and a good part is illustrated in Figures 4-8b and 4-8c. Here the parts start out with the same parameter values and end up with the same but lower parameter values. However, the path they trace in reaching their final degradation point illustrates the difference between the good and bad part. The part in Figure 4-8b exhibits the conventional burn-in or stabilizing period common in good parts. Since the part is stabilized it could be as good as the part shown in Figure 4-8a. The characteristic curve for the part in Figure 4-8c shows that it is starting to wear out at Time T_2 and gives every indication of failure some short time after the test (T_3). Although the part should be rejected at T_3 it would be passed along with the part of Figure 4-8b by the conventional quality screening criteria used in Figures 4-6 and 4-7.

The part shown in Figure 4-8d should be rejected as potentially unreliable because of the unstable part characteristics it exhibits. Any part which goes outside the test limits during the reliability test should also be rejected.

Degradation analysis must consider the inherent characteristics of each individual part since the same parameters from identical parts of the same lot may all exhibit different characteristics. Therefore, for any particular parameter the rejection criteria must be devised specifically for the individual part type.

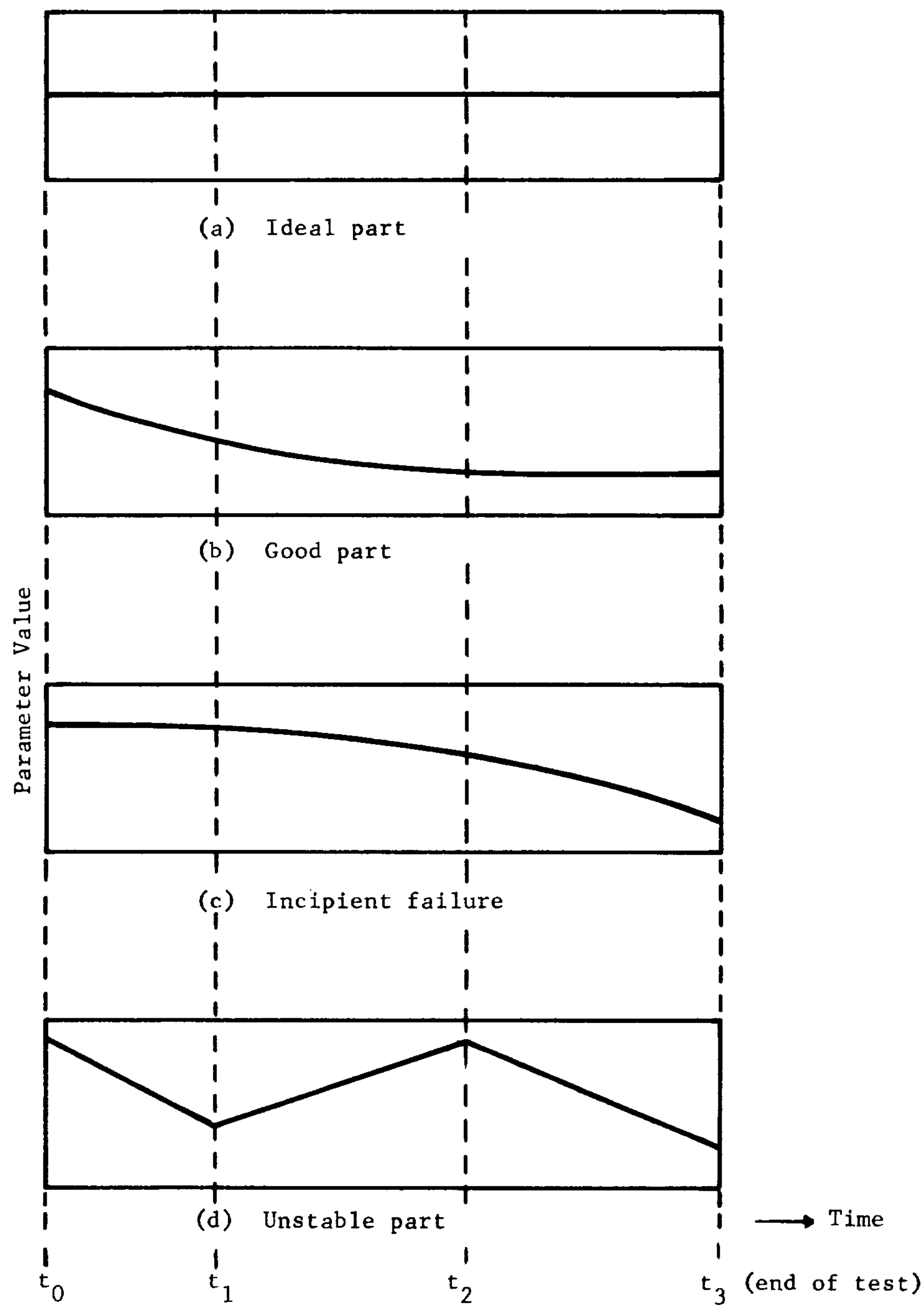

Fig. 4-8. Part Parameter Variation Curves

Evidence indicates that improvement of failure rate by factors of from 10 to 30 can be achieved by using 100 percent degradation analysis on the critical indicator parameters [Refs. 4-11 and 4-12].

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5. Review Processes

The two major types of review processes, application review and design review, are vitally important to the success of any project. The purpose of the application review is to gather and organize data concerning parts and materials selection and specification to determine whether the chosen parts and materials are being applied properly in the system. This data is then fed into an associated design review where corrective measures can be taken on any discrepancies existing in the design or on the parts and materials used in the design. The two types of review are closely related and feedback from one review is used in the other review as the project matures.

Application and design reviews tend to mature a design more quickly, thereby increasing reliability and reducing overall costs. Also, design changes are reduced, especially in later stages of development where any changes are costly.

5.1 Application Review

The purpose of a parts and materials application review [Refs. 5-1 and 5-2] is to assure the adequacy of the parts and materials program for a particular project. This review is a documented verification that each individual component meets the specified design requirements with adequate safety margins, based upon a thorough evaluation of every part and material used in the component. This thorough application review of each part and material in relation to mission profile requirements must be performed before the design is finalized. This review and its documentation are essential inputs to the formal design reviews at the various levels of project development. Of course, some form of application review has always been accomplished by individual designers, but the extent of their efforts is a function of their past experience and the requirement for part and material selection in a particular design. Modern systems, however, require a more formal consideration of the effects of parts and materials characteristics upon system performance. This is accomplished with the application review.

Application reviews are assigned and scheduled at logical levels of program development; each consists of the parts and materials in one component or subsystem. In general, the application review provides the basis for performance and reliability prediction. One of its basic functions is to allow for risks brought about by design tradeoffs. The documented application review supports the component through the pertinent design review and establishes the competency of a given application in terms of mission accomplishment.

Large volumes of data from a parts and materials program must be gathered and organized for use in the application and design reviews. This data is accumulated

A disciplined program of parts and materials application reviews can result in lower failure rates and reduced project costs.

5.2 Design Review

Design review [Refs. 5-2, 5-3, 5-4, 5-5 and 5-6] is a formal, documented and systematic study of a particular design by a group of specialists not directly involved with the development of the design. Within economic limits, it speeds the development of all elements of a design, i.e., function, reliability, value and appearance [Ref. 5-3].

Reliability design review is not a duplication of the designer's effort, but is an essential activity, because a feasible design is not necessarily a reliable one. The formal design review is a powerful and economical tool for improving product reliability [Refs. 5-3 and 5-4].

The exact procedures for conducting a design review vary between companies and product groups, but the underlying philosphy is the same. Figure 5-3 shows when design reviews should be scheduled. Design reviews should be started early in the program on a broad general level. As the development approaches the hardware phase, detailed meetings of reduced scope are required. Finally, as components and individual parts are integrated into the system, the review activity is increased [Refs. 5-2 and 5-3].

The personnel in the design review team varies according to the type of review being performed (see Fig. 5-4).

The design review team performs three basic types of design review, i.e., preliminary, intermediate, and final.

Preliminary design reviews are held during product concept and planning, proposal and request for funds, and when contract or authorization is received. This preliminary review establishes early accord between engineering, purchasing and manufacturing. It also exposes divergent requirements and interpretations and confirms the design as representative of the actual requirements.

Intermediate design reviews are held after mechanical design and styling are decided upon and after development model tests have been made. These reviews provide a reevaluation of part performance requirements in view of development and design experience. Several intermediate design reviews are sometimes necessary to measure the progress of the design.

Final design reviews are held when material and parts lists and drawings are complete or when pre-production units have been tested and analyzed. This review permits a final chance to introduce changes to achieve the design objectives without affecting schedules and at a small cost compared to field changes or model changes.

from the product designers, the reliability group, the environmental group and the parts and materials group. The proper documentation of this data is essential to the initial selection of parts and materials, the verification of their application in the system, and to a later evaluation of these or similar parts or materials for future application.

Since the data required for a parts and materials program is the same as is normally recorded during the project, it is necessary to have a standard data recording format for use throughout the project. Typical data recording forms are shown in Figs. 5-1 and 5-2.

As the project develops, failure data and parts and materials application problems which arise must be documented. This documentation permits effective use of the parts and materials in future applications.

The typical steps of an application review are [Ref. 5-1]:

(1) Carefully consider the basis for selection of each part and material (functional data, size, etc.).

(2) Evaluate safety margins on the basis of latest design data or actual measurements.

(3) Review the performance characteristics and operating environments for each item to verify derating and safety factor uses for the particular part or component.

(4) Record and document all discrepancies, omissions or data estimates which are considered unlikely or inadequately verified.

Application reviews are held at appropriate times during a project, i.e., at times beneficial to project activities and at logical program levels. The preparation for these reviews is begun early in the program. The points to consider in organizing the review are:

(1) Appoint the review team. The make-up of the team varies with project complexity. It usually consists of parts and materials specialists and designers who may or may not be directly associated with the project under review.

(2) Assign responsibility for specific data inputs.

(3) Establish documentation requirements. These may consist simply of production drawings, engineering reports, test records, etc. or specialized summary sheets.

(4) Define points in the project at which application reviews are to be performed.

(5) Schedule formal review meetings.

PARTS APPLICATION RECORD—RESISTORS

PROGRAM ________ 'NAME' APPORTIONED FR & CONF. 150/10⁶ HR @ 60% CONF

COMPONENT ________ 263-475-4623 APPORTIONED FR & CONF. 30/10⁶ HR @ 60% CONF

MODULE ________ 263-475-4623-2

THIS FORM IS PARTIALLY FILLED OUT FOR DESCRIPTIVE PURPOSES. THE REMAINING PARTS APPLICATION RECORD FORMS IN THIS EXHIBIT ARE TO BE USED IN A SIMILAR MANNER.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
CIRCUIT DESIGNATION	MFR	MFR P/N	GOVT SPEC	GOVT P/N	RESISTANCE	TOLERANCE	TYPE	RATED PWR	RATED VOLTAGE	RATING TEMP	ESTABLISHED OR GENERIC FR & CONF. LEVEL	APPLICATION TEMP°	% RATED PWR	% RATED VOLTAGE	VIBRATION	SHOCK	OTHER	VERIFIED BY TEST	USE FR & CONF. LEVEL	PARAMETERS FOR TYPE SELECTION
R1	IRC	GEM			1K	1%	METAL FILM	1/10	200	125°C		60°C	50	20				YES		STABILITY REQUIRED

MIL-R-55182 (column 4)

RNR55C1001FM (column 5)

1%/1000 HRS (ESTABLISHED) AT 60% CONFIDENCE (column 12)

20g FROM 0 TO 2000 HZ (column 16)

50g, 11 MILLISEC (column 17)

(THIS COLUMN FOR SPECIAL ENVIRONMENTS SUCH AS STERILIZATION, NUCLEAR RADIATION OR HARD VACUUM) (column 18)

0.44%/1000 HR BASED ON APPORTIONMENT AT 60% CONF.) (column 20)

(THIS COLUMN CITES WHICH OF THE PARAMETERS OR CRITICAL PART PROPERTIES ARE OF FIRST IMPORTANCE IN SELECTING THIS PART.) (column 21)

σ- limit or range

PARTS APPLICATION RECORD—CAPACITORS

PROGRAM ________ ________ APPORTIONED FR & CONF. ________

COMPONENT ________ ________ APPORTIONED FR & CONF. ________

MODULE ________ ________

												APPLICATION REQUIREMENTS DATA									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
CIRCUIT DESIGNATION	MFR	MFR P/N	GOVT SPEC	GOVT P/N	CAPACITANCE	TOLERANCE	TYPE	RATED DC VOLTAGE	RATED AC VOLTAGE	RATING TEMP	ESTABLISHED OR GENERIC FR & CONF. LEVEL	APPLICATION TEMP	DC VOLTAGE	AC VOLTAGE	AC FREQ	VIBRATION	SHOCK	OTHER	VERIFIED BY TEST	USE FR & CONF. LEVEL	PARAMETERS FOR TYPE SELECTION

Legend: FR, failure rate; CONF., confidence; MFR, manufacturer; P/N, part number; PWR, power; DSGN, designation of individual input or output to a specific circuit on a microcircuit chip; TOL, tolerance; COND., electrical-condition (e.g., bias); Θ_{JC}, thermal resistance, junction to case; Θ_{JA}, thermal resistance, junction to ambient; AMB, ambient; PIV, peak inverse voltage; VZ, zener voltage; T_J, junction temperature; V_{CB}, voltage between collector and base; V, voltage; BV_{CBO}, breakdown voltage between collector and base with emitter open.

Fig. 5-1. Sample Parts Application Records [Ref. 5-1]

PARTS APPLICATION RECORD-DIGITAL/LOGIC MICROCIRCUITS

PROGRAM ______ ______
COMPONENT ______ ______ APPORTIONED FR & CONFIDENCE ______
MODULE ______ ______ APPORTIONED FR & CONFIDENCE ______

1	2	3	4	5	6	7	8	9	10	11	11A	12	13	13A	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
IDENTIFICATION							ELEC SUPPLY		INPUT			OUTPUTS				SPEED						APPLICATION DATA							
DESCRIPTION	MFR	MFR'S P/N	GOVT SPEC	GOVT CIRCUIT NO.	TYPE	LOGIC SCHEME	V_{DC}	PWR AT 25°C	NO.	DSGN	LEVEL & TOL	DSGN	LOGIC	LEVEL & TOL	FAN-OUT	CHARAC-TERISTIC	TIME OR FREQ.	COND.	OPER. TEMP. RANGE	TYPE PACKAGE	ESTABLISHED OR GENERIC FR & CONF. LEVEL	V_{DC}	PWR	MAX TEMP.	USE FR & CONF. LEVEL	VIBRA-TION	SHOCK	OTHER	PARAMETERS FOR TYPE SELECTION

PARTS APPLICATION RECORD-LINEAR MICROCIRCUITS

PROGRAM ______
COMPONENT ______ APPORTIONED FR & CONFIDENCE ______
MODULE ______ APPORTIONED FR & CONFIDENCE ______

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
IDENTIFICATION						ELEC SUPPLY					OUTPUT					APPLICATION DATA								
DESCRIPTION	MFR	MFR'S P/N	GOVT SPEC	GOVT CIRCUIT NO.	TYPE	V_{DC}	PWR	FREQ. RESPONSE	GAIN	INPUT IMPED-ANCE	DESCRIPTION	VALUE	COND	OPER. TEMP. RANGE	TYPE PACKAGE	V_{DC}	PWR	MAX TEMP	ESTABLISHED OR GENERIC FR & CONF. LEVEL	USE FR & CONF LEVEL	VIBRA-TION	SHOCK	OTHER	PARAMETERS FOR TYPE SELECTION

PARTS APPLICATION RECORD-DIODES

PROGRAM ______
COMPONENT ______ APPORTIONED FR & CONFIDENCE ______
MODULE ______ APPORTIONED FR & CONFIDENCE ______

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
											APPLICATION DATA					CALC. DATA								
CIRCUIT DESIGNATION	TYPE	PWR RATING 25°C	THERMAL θ_{JC} RESISTANCE θ_{JA}	MAX FULL LOAD TEMP (AMB OR CASE)	ZERO LOAD TEMP (AMB OR CASE)	PIV (VZ FOR REGULATORS)	MFR	MFR'S P/N	GOVT SPEC	GOVT P/N	ESTABLISHED OR GENERIC FR & CONF. LEVEL	AVERAGE POWER	PEAK POWER	PEAK INVERSE VOLTAGE	TEMP-MAX (AMB OR CASE)	PEAK FWRD CURRENT	JUNCTION T_J TEMP (MAX)	% RATED PWR	NORMALIZED TEMP	USE FR & CONF. LEVEL	VIBRATION	SHOCK	OTHER	PARAMETERS FOR TYPE SELECTION

PARTS APPLICATION RECORD-TRANSISTORS

PROGRAM ______
COMPONENT ______ APPORTIONED FR & CONFIDENCE ______
MODULE ______ APPORTIONED FR & CONFIDENCE ______

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
												APPLICATION DATA					CALC. DATA								
CIRCUIT DESIGNATION	TYPE	PWR RATING 25°C	THERMAL θ_{JC} RESISTANCE θ_{JA}	MAX FULL LOAD TEMP (CASE OR AMB)	ZERO LOAD TEMP (CASE OR AMB)	GAIN OR SWITCHING SPEED	BREAKDOWN V BV_{CBO} & AS APPLICABLE	MFR	MFR'S P/N	GOVT SPEC	GOVT P/N	ESTABLISHED OR GENERIC FR & CONF. LEVEL	AVERAGE POWER	PEAK POWER	PEAK VOLTAGE V_{CB} & AS APPLICABLE	TEMP-MAX (CASE OR AMB)	PEAK COLLECTOR CURRENT	JUNCTION T_J TEMP (MAX)	% RATED PWR	NORMALIZED TEMP	USE FR & CONF. LEVEL	VIBRATION	SHOCK	OTHER	PARAMETERS FOR TYPE SELECTION

Fig. 5-2. Sample Parts Application Record [Ref. 5-1]

The main types of application review are the prepackaging application review, the pre-release application review, and the post-qualification application review.

The main objectives of the prepackaging (breadboard stage) application review are:

(1) Verification of performance stress levels. This determines whether the stress level capabilities of the parts and materials are adequate for the application and permits a first examination for derating and safety factors.

(2) Standardization and reduction of the number of parts and materials types.

(3) Rechecking for possible omissions or errors in specifications.

(4) Evaluation of parts and materials data in the preliminary parts and materials lists.

The report from this review may include comments on estimated failure rates, additional data requirements (if any), any special handling requirements for the selected parts and materials, special assembly precautions, etc.

The pre-release application review is the most important review from an economic standpoint because changes after release are costly. This application review is also the most complete, because all design data is available, specifications and approved parts and materials lists are finalized, and suppliers have been selected. This review's primary purpose is as an inclusive audit on all areas of the project. Any remaining deficiencies in the parts and materials program are singled out for prompt action at the associated design review.

A post-qualification application review is sometimes found to be necessary as an input to a post-qualification design review. The degree of effort in this review is usually small because of the reduced hardware development activity. Its primary purpose is to update the documentation from previous reviews and handle any new documentation arising from late design reviews [Ref. 5-1].

A complete and detailed study of application review techniques is found in Ref. 5-1.

The content and scheduling of each application review are governed primarily by decisions made in earlier design reviews. Application and design reviews form a closed loop with decisions in one review affecting the outcome of the other. The application review supplies data for decisive action and the design review initiates corrective measures.

Application reviews unite all of the activities of the parts and materials program and provide complete documented data records useful in system support and in designing future systems.

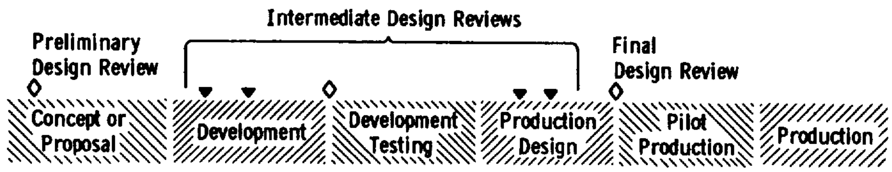

Fig. 5-3. Product Life Cycle and Design Review Schedule

GROUP MEMBER	RESPONSIBILITIES	TYPE OF DESIGN REVIEW		
		PDR	IDR	FDR
Chairman	Calls, conducts meetings of Group and issues interim and final reports.	X	X	X
Design Engineer (s) (of product)	Prepares and presents Design and substantiates decisions with data from tests or calculations.	X	X	X
Reliability Manager or Engineer	Evaluates design for optimum reliability consistent with goals.	X	X	X
Quality Control Manager or Engineer	Ensures that the functions of inspection, control, and test can be efficiently carried out.		X	X
Manufacturing Eng.	Ensures that the design is producible at minimum cost and schedule.		X	X
Field Engineer	Ensures that installation, maintenance, and operator considerations were included in the design.		X	X
Procurement Representative	Assures that acceptable parts and materials are available to meet cost and delivery schedules		X	
Materials Engineer	Ensures that materials selected will perform as required.		X	
Tooling Engineer	Evaluates design in terms of the tooling costs required to satisfy tolerance and functional requirements.		X	
Packaging and Shipping Engineer	Assures that the product is capable of being handled without damage, etc.		X	X
Marketing Representative	Assures that requirements of customers are realistic and fully understood by all parties.	X		
Design Engineers (Not associated with unit under review)	Constructively reviews adequacy of design to meet all requirements of customer.	X	X	X
Consultants, Specialists on components, value, human factors, etc., (as required)	Evaluates design for compliance with goals of performance, cost and schedule.	X	X	X
Customer Representative (optional)	Generally voices opinion as to acceptability of design and may request further investigation on specific items.			X

Fig. 5-4. Design Review Group Responsibilities and Membership Schedule

Table 5-1

Check Lists [Refs. 5-4 and 5-5]

1. Does the design specification meet all user requirements?
2. Does the design meet all functional requirements?
3. Does the design perform properly under specied environments?
4. Have standard parts been used wherever possible? If not, why?
5. Does the device perform more than one function?
6. How many critical and noncritical parts and/or characteristics?
7. If standard parts have not been employed, could they be employed with modifications? What effect would these modifications have on performance?
8. Are drawing and specification tolerances achievable in production?
9. Is the device required to operate at the limits of its strengths or capabilities?
10. If standard parts are being used, are they being used as in previously experienced environments?
11. What are previous hypothesized modes of failure? What are new effective modes of failure? State methods of inspecting and testing for these modes. What can be done to eliminate them?
12. Is the expected or estimated MTBF of the device sufficient to meet the system reliability requirements?
13. Can redundancy be employed and/or the device operated at derated performance levels?
14. Are parts interchangeable between manufacturers? If not, how do the parts differ in their failure experience?
15. Has the device been designed as simply as possible? Have human factors been considered to eliminate error, e.g., reversed wiring?
16. Will the physical location affect performance?
17. How might the design be modified to improve reliability? How would this affect such factors as performance, cost, weight, availability, delivery, maintainability, etc.?
18. Has the device or system been designed for ease of production, assembly, maintenance, and inspection?
19. Have factors such as handling, transportation, packaging, and environments, other than operating environments, been taken into consideration?

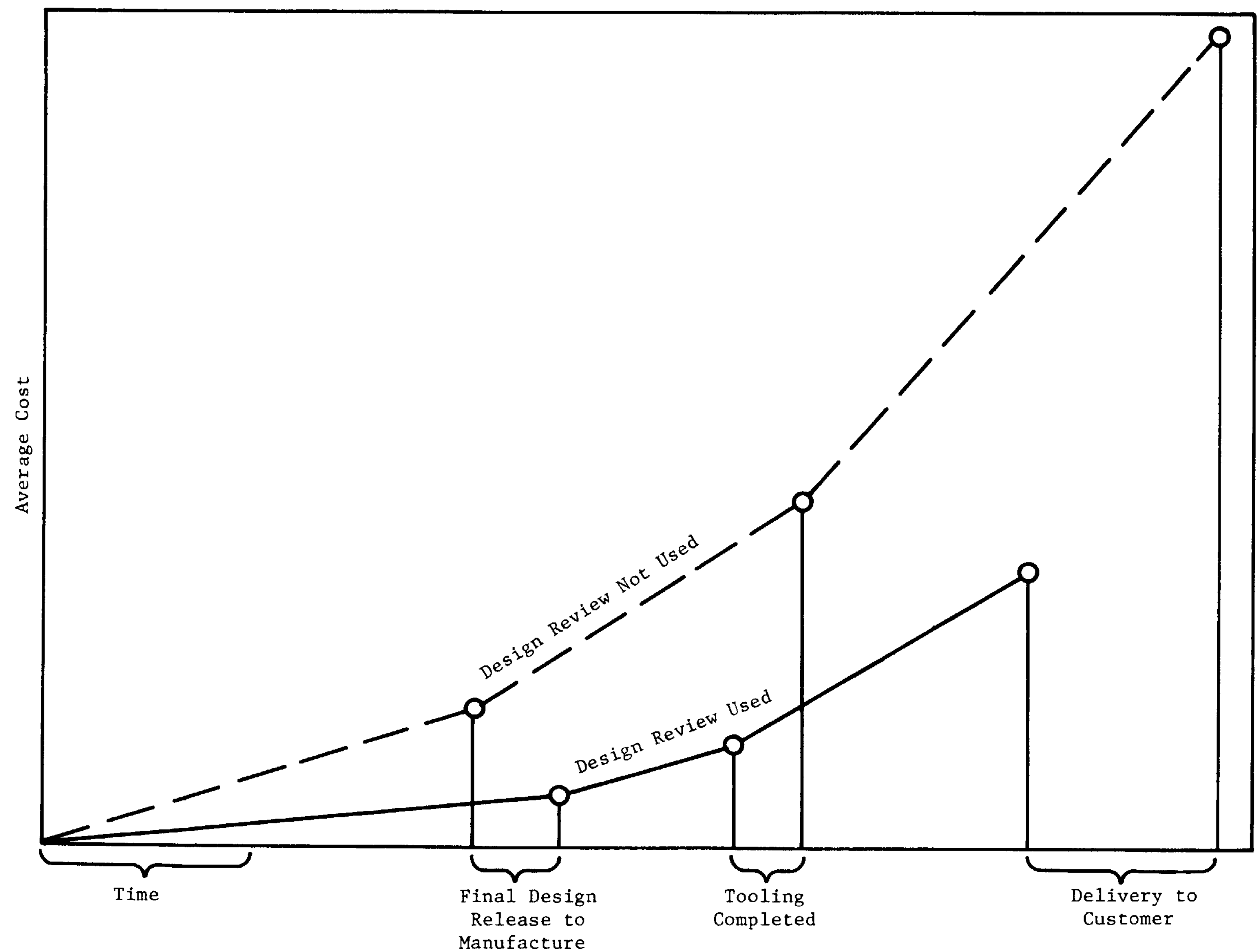

Fig. 5-5. Relative Average Cost of Making Design Changes with Design Reviews vs. Without Design Reviews [Ref. 5-5]

In addition to a complete review of all points previously reviewed, this review studies final performance requirements, critical cumulative tolerances and instruction books for the system. Any questions remaining before final production should be acted upon and disposed of during this review.

A check list should be developed for each type of design review for items considered in that reviw. This list aids the designer by reminding him of important factors that may have been overlooked. Often, a number of reviews are necessary before a check list is complete. A sample general check list is shown in Table 5-1.

The points in the table are just a few items to be considered. Reference 5-2 documents check lists for electrical, mechnical, parts and materials, unit, and system reviews.

The designer is responsible for investigating or incorporating into the design any ideas from the reviews which might optimize it. A final report is made by the designer covering the investigation of suggestions made and the reasons for their adoption or rejection.

Design reviews accelerate the maturity of the design by applying experience and expert opinion from the outset. Design reviews also reduce delivery dates and reduce costs by reducing the number of design changes. Figure 5-5 shows the relative average cost of making design changes versus the design, development and manufacturing cycle for devices using conventional design methods and devices employing design reviews [Ref. 5-5].

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6. Parts Data Sources

6.1 Introduction

The fact that if we did everything that we know how to do with respect to parts then there would be few problems with parts has been noted. A corollary to this is that if we had access to all of the data which has been obtained on parts then the effort necessary to assure optimum parts application would be reduced by at least fifty percent. The resultant savings in time and money would be large, for parts data is the basis of every function in the parts program.

The obvious question is, 'Why do we not have access to the data which is in existence?'. Efforts have been made through ECRC (Electronic Components Reliability Center), IDEP (Interservice Data Exchange Program), APIC (Apollo Parts Information System), and other data collection and dissemination systems to make data accessible. These have had limited success as evidenced by the recent demise of ECRC. The need for effective parts data handling persists. The shortcomings of present systems can partially be discerned by examining the desired functions of a data bank service.

A recent survey (Ref. 6.1) of some desirable functions for a parts data bank revealed the following user requirements:

(1) Complete description of parts and failure rates.
(2) Current awareness of parts available.
(3) Centralized information source accessible to bench-level engineer.
(4) Reports on changes in manufacturing methods for parts.
(5) Screening test data.
(6) Qualification test documentation and reports.
(7) Full-text reports on request.
(8) Local accessibility for user.
(9) Worst-case performance capabilities identified.
(10) Current information--flash notification of changes.
(11) Information screening--quality control of input.
(12) Machine manipulatable data base.
(13) Supplier performance data.
(14) Failure analysis reporting.

While this survey was concerned only with a data bank for microelectronic parts, the user defined data requirements are generally applicable. This defines what is desirable.

Presently existing data banks meet few of these needs. Too often they are described as "garbage in, garbage out operations" implying little confidence in or applicability of the data which is disseminated. Obviously then, the most important need of any data bank is an editorial review of all data deposited in the system and an accurate description of what the data means. Existing data banks do little editing of data.

Later in this chapter some representative parts information operations are described. In almost all cases, their value seems to decrease exponentially with the distance of the user from the operation. Proximity or, at least, rapid and easy accessibility and prompt response are important. Otherwise the service is not used.

What data should be in the data bank? The answer is 'everything that is known about the specific part'. This includes who makes it and how, who uses it and what for, how it has performed in the various applications, and, of course, complete information on selection, specifications, verification, and testing of the part.

To carry this discussion of the ideal data system an additional step, oonsider how it might function. For example, a design engineer needs a power switching transistor. We assume he has considered other types of switches and has determined that only a transistor will do his job. His procedure could be as follows:

(1) The engineer defines the characteristics of the needed device and requests from the data bank, a list of those available.

He receives, in two days, a current listing and a short paragraph describing the major prior applications of each device, its performance, its cost, and other general information.

(2) The engineer tentatively selects a device type and requests a synopsis on it.

He receives from the data bank an information pack describing the manufacture, structure, and performance characteristics. A condensation of use and user experience, failure modes and mechanism analysis, and a comprehensive bibliography of all detailed reports and data in the data bank.

(3) The engineer, if he still thinks he has made the right choice and assuming that his application is critical, selects from the bibliography those reports and test results applicable to his application. These he requests in full text print-outs.

In one week, the reports are delivered to him.

What more can one ask? In many cases of course, the recipient may be dissatisfied by a lack of data, but if the bank has an efficient collection system, then the data does not exist. If the part is important, the data will be generated.

This universal parts data bank does not exist nor will it in the foreseeable future. It is a costly operation, an annual budget of over $20,000,000 would be required to provide the service. The cooperative support of many organizations would be required and, even though the cost to each might be less than now being spent on the existing splintered, ineffectual efforts, the system is such that this cooperation is not encouraged.

The parts data operation which we would like to have does not exist. What can we do? The alert parts engineer who is willing to expend the effort can often obtain a goodly store of data. Between in-house parts information sources which exist in every large user's organization and the general mechanisms for information exchange, much data is available. The existing data banks are, in their limited scope, extremely useful in providing data. Lets examine some of the existing operations.

6.2 Existing Data Sources

There are many public data sources consisting of government and contractor data sources or data banks and reliability and maintainability handbooks which are applicable to the problems of part selection, specification and verification. One source [Ref. 6-2] lists 118 government data sources and provides a brief description of each. In addition, 33 government and contractor reliability and maintainability handbooks are described.

Several data sources (including handbooks) pertaining to the parts application problem are briefly described below:

PRINCE/APIC* is a centralized data bank providing specialized information on parts and materials. It was originally established to serve the information requirements of Marshall Space Flight Center laboratories, but now serves as a parts and materials information center for all Apollo program participants. Its primary purpose is providing support for aerospace projects and coordinating information received from these projects. Significant monetary and time savings are possible because of the rapid access to many types of information. The information available may decrease duplication in design and in the preparation of procurement specifications, permit better test planning and assist in the development of qualification tests for certain items.

Information at PRINCE/APIC is received from NASA centers, manufacturers, contractors and subcontractors, government agencies and research organizations and is contained in more than 50 different types of documents, e.g., drawings test reports, preferred parts lists, specifications and standards material, etc. The data may be submitted by standard printed material, magnetic and punched tape, IBM cards, drawings, and microfilm.

Inquiries to PRINCE/APIC may be made by mail, telephone, datafax, and teletype. The time required to process an inquiry depends on the complexity of the question. If the inquiry can be answered by a computer, the reply can be prepared in minutes. However, if manual retrieval of data or report preparation is required, the reply may take several days. Replies to inquiries may include computer printouts, datafax copy, microfilm print, or copies of reports. Often, telephone replies are made when the information is relatively brief.

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* PRINCE/APIC (Parts Reliability Information Center/Apollo Parts Information Center).

Examples of information obtainable through PRINCE/APIC are:

Life test information.
Failure rate information.
Qualified vendor lists.
Extent of usage of various parts.
Performance data on transistors in various environments.

The PRINCE/APIC Index contains general information about the system and lists parts and materials which have been entered in the files and the available information on each item. Parts and components are grouped by part class and name. The part classes are arranged in alphabetical order with individual entries in each class arranged in alphabetical order with individual entries in each class arranged by vendor part number.

FARADA* is sponsored by the three services and NASA. Its basic function is the collection, summarization, analysis, compilation, and distribution of failure-rate and failure-mode data for use in reliability and maintainability prediction.

Participants include 190 prime and major subcontractors and 80 government agencies engaged in the design, development, manufacture and assessment of military and space hardware.

The FARADA Information Center is located at the Fleet Missile Systems Analysis and Evaluation Group (FMSAEG) at Corona, California. The information supplied by FARADA is divided into handbooks (SP-63-470) of five volumes, which are updated quarterly. The volumes are classified as follows:

Volume 1A - Tabular failure-rate data for electrical-electronic parts including vendor and part name and applicable environment and stress levels.
Volume 1B - Similar to Vol. 1A except for mechanical and other type parts.
Volume 2 - Failure-rate data curves for failure rate vs. environment.
Volume 3 - Background data on each source of failure-rate data or failure-mode data contained in the handbooks, e.g., system description, failure reporting system, maintainance concepts involved, etc.
Volume 4 - Tabulation of failure-mode distribution data for all part types.

The FARADA part failure-rate and failure-mode data is obtained from all types of military and space systems. For each reliability event, the failure rate, failure mode, vendor, part number, and environmental and stress level information is listed and correlated.

IDEP** contains parts and components information consisting of qualification reports, engineering analyses, contractor high-reliability specifications, material reports, failure analyses, and general technical reports.

The IDEP program, under joint sponsorship for the three services and NASA, provides for the voluntary automatic interchange of parts and components test data among government contractors and agencies, reducing duplication efforts in parts testing and improving system reliability. The participating contractors are parts users, not manufacturers or vendors.

Reports submitted to IDEP are processed and the reports forwarded on microfilm to all contractors interested in that topic. The file consists of approximately 20,000 reports with about 300 being added monthly.

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* FARADA (Failure Rate Data).

** IDEP (Interagency Data Exchange Program).

A Reliability Analysis Central is being developed at Rome Air Development Center. The objective is obtaining reliability information on parts and devices expected to be used in the future design of Air Force equipment. Initially only semiconductor transistor and diode data will be included. Later plans call for expansion to include integrated circuits, mechanical, and electromechanical parts. The system should be fully operational by mid-1969. Information to be available includes failure rates, failure-modes and mechanisms vs. time and stress, characteristic drift data, failure distributions, part application data and environmental limitations. Also included would be established reliability parts lists, principal characteristics of parts, correlation between reliability and part characteristics, comparison of parts reliability in the field and under laboratory conditions, and summaries of part test programs planned and in progress.

RATR* is published monthly by NASA. Reliability articles in the literature pertaining to aerospace research, development and operation are abstracted and subjected to a critical review. An average of 50 articles per month are covered. RATR is available at no charge to reliability and quality assurance officers of government agencies and their contractors, industrial librarians and engineering faculty members.

MIL-HDBK-217A: Reliability Stress and Failure Rate Data for Electronic Equipment (December 1965) is directed toward reliability prediction. While it is not a complete guide to reliability engineering, it provides a common basis for predicting and comparing reliability predictions on military contracts and proposals. It includes environmental effects, design considerations, application, failure modes, failure rates, operating factors, mathematical concepts, probability tables and graphs, preferred parts lists, and other data necessary to reliability engineers.

The major sections of the handbook cover the following areas:

Fundamentals of reliability	Capacitors
Part failure rate characteritics	Transformers, magnetic amplifiers
Failure rate calculations	Inductors and coils
Electron tubes	Relays and Switches
Resistors	Rotary electrical devices
Semiconductor devices	Minuteman part failure rates
Wires and cables	Micromodule reliability

Other sections of the handbook include:

Data sources	Hybrid circuits
Reliability models	Integrated circuits
MIL-STD-756A techniques	Reliability calculations
NAVSHIPS 93820 techniques	Redundancy techniques
Reliability prediction techniques	Degradation factors
Microelectronics	
Parts manufacturers reliability ratings	

There are several changes in MIL-HDBK-217A over MIL-HDBK-217. These include:

(1) The failure rate data in MIL-HDBK-217A has been restricted to controlled test data failure rates, i.e., vendor, laboratory and qualification tests on parts. Assembly data, system qualification data and field data which were used in 217 have been excluded.
(2) Field data was used only to generate K-factors.
(3) More data based on more recent experience is found in 217A.
(4) Failure rates for transistors, diodes, motors, transformers, and connectors are calculated using a newer, more time consuming, method.

A comparison of MIL-HDBK-217 with MIL-HDBK-217A is given in Ref. 6-2.

* RATR (Reliability Abstracts and Technical Reviews).

MIL-STD-756A: Reliability Prediction (May 1963) establishes procedures for making quantitative reliability predictions of electronic systems, e.g., satellites, missiles, aircraft, and subsystems within these systems.

The reliability prediction procedures are divided into two types, i.e., feasibility prediction (before the design is finalized) and design prediction (after design is finalized). Steps are identified for each type of prediction together with required assumptions, information sources, and suggested derating, environmental factors.

Reliability MTBF values based on the number of electron tubes, etc., expected to be used in the system are included in the feasibility predictions procedure.

NAVSHIPS 93820: Handbook for the Prediction of Shipboard and Shore Electronic Equipment Reliability contains techniques for predicting the reliability of certain Naval electronic equipment. Illustrative examples are given based on the degree of accuracy required of the prediction and the amount of detailed information available for the system.

Parts failure rates are tabulated for various electronic parts, e.g., capacitors, diodes, electron tubes, etc. These tables are based on actual measurements, and, in some cases, are extrapolated on the basis percent of full load or other parameters.

STAR* is a NASA sponsored journal devoted to scientific and technical information on aerospace research and development. These reports cover unclassified report literature on 34 major subject areas. Issues are indexed according to subject, corporate source, author, report number, and NASA accession number. Reports from NASA, NASA contractors, government agencies, universities, and research organizations are included.

IAA** is published twice monthly by the Institute of Aeronautics and Astronautics under NASA sponsorship. Coverage includes books, periodicals, conference proceedings, and other media in aeronautics and aerospace technology. IAA has worldwide coverage and includes works in original languages as well as translations. The subject headings and indexing system used in IAA are the same as those used in STAR.

CASE*** is a program designed to pool the vendor evaluation reports made by a number of companies into a central source. This concept provides savings of time and money for participating companies and reduces the duplication-of-efforts problem of many companies in evaluating sources of supply. Also, suppliers are not being constantly bothered by dozens of overlapping quality evaluation teams.

In the early 1940's the United States Government produced scores of quality regulations and product/process specifications to assure the quality of purchased defense items. These documents placed the final responsibility for product quality up on the Government. Prime contractors desiring government business had to use subcontractors that had been approved by a government agent. Government approval of a suppliers facilities and processes meant that he was qualified to do business with the Government, either as a prime contractor or as a subcontractor.

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* STAR (Scientific and Technical Aerospace Reports).

** IAA (International Aerospace Abstracts).

*** CASE (Coordinated Aerospace Supplier Evaluation).

In recent years under the reorganized Defense Supply Agency the burden of quality has been placed upon the prime contractor rather than the government. This action means that a subcontractor no longer deals with a single government agency or inspector but rather with evaluation teams from every prime contractor with which it hopes to do business.

CASE was originated by Aerojet-General who recognized several important factors:

(1) Most contractors had evaluation teams performing similar tasks of supplier evaluation.
(2) All contractors had similar although not necessarily identical objectives.
(3) Evaluations varied in completeness due to individual needs.
(4) An exchange of information between contractors provided prospects of mutual savings.

The members of CASE are primarily interested in special process services and contract-designed parts. Special processes include heat treating, plating and casting. These services are evaluated in accordance with a particular specification or compilation of specifications. Contract-designed parts are assemblies or components designed by a prime contractor but manufactured by a subcontractor. In these cases, the subcontractor is evaluated for his compliance with a quality system, e.g., the requirements of MIL-Q-9858A, NPC-200-2, MIL-Q-21549A, or in individual companies, private compilation of these requirements. CASE members share their list of approved suppliers and provide back-up data upon request. The information is processed by computer at Aerojet-General.

Information which concerns a disapproved supplier is not used in the CASE program. If a supplier is not approved, no record exists. Suppliers who have been approved by one aerospace manufacturer, however, share the possibility of doing business with other aerospace companies.

CASE does not replace or eliminate contractor responsibility for the evaluation of a particular supplier. It only makes supplier information available to participants which may or may not meet the requirements of an individual contractor. CASE provides the opportunity for participating contractors to save time and money by using whatever portions of their requirements are available through member contributions.

At present, Aerojet-General is bearing the cost of collating and processing the information necessary for the CASE program. The savings accrued by the company have more than borne the cost of the program [Ref. 6.3].

These information sources and the many others in existence have their strengths and weaknesses as previously discussed. A system which has been discontinued represented a good effort toward solving some of the problems and is examined below for the lessons it may offer.

ECRC (Electronic Component Reliability Center) at Battelle Memorial Institute was sponsored by a group of government and industrial organizations to provide electronic parts reliability information to participating members. Sources of data were reports describing the results of tests conducted by the member organizations for their own purposes, e.g., parts qualification or incoming inspection.

Technical Memoranda were written for frequently used parts. These documents summarized data from many test reports in a concise compact form which enabled ECRC members to scan a large amount of data quickly. A series of documents and

Data Summaries provided rapid scan capability in addition to increased detail and were the major product of the ECRC Data Center. Member organizations submitted a report (Data Summary) to ECRC which summarized the results of a test on the parts of a particular manufacturer. In the heading, the part was identified, and the number of parts passing or failing the tests were noted. Both a brief review of the test results and detailed results were presented. Manufacturer's comments on the Data Summary are often included and sometimes provided helpful suggestions as to part usage.

Copies of the test reports are furnished the user if more detailed information is required. Also, contact between the user and the organization which conducted the test may be arranged if necessary. In addition, the ECRC will conduct special brief studies or tasks at a member's request.

All the data in the ECRC Data Center is generated by test reports submitted by the member organizations and not the parts manufacturers.

The ECRC was in almost continuous process of change and evolution since its beginning in 1958 to its termination in 1967, and its long experience, will be useful for future data bank operations.

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services offering access to any selected material in increasing detail was then provided. In order of increasing detail, these were:

(1) Technical Memorandums,

(2) Index,

(3) Data Summaries,

(4) Reports,

(5) Contact, and

(6) Special Services.

This effort was supported by participant fees and evidently did not attain the participation level which was required to survive. Many of the techniques however were well throughout and the experience of ECRC should be useful. Looking in more detail at this operation, we will examine the output forms.

Technical Memorandums presented electronic part data in chart form. The column headings listed the parameters tested and the row headings listed the various tests to which the parts have been subjected. The figures in the chart gave the percentage of parts, subjected to a particular tests, which failed in the parameter listed in the column heading. The largest percentage of failures for any type of test was enclosed in a rectangle and the second largest in an oval.

The first column in the chart gave the sample size tested. Subscripts in the blocks of the chart indicated the sample size for each parameter if all of the parts were not tested for a particular parameter. For example a subscript of 8 indicated that 80 percent of the sample size subjected to that tests was measured for the particular parameter. A large number of rectangles or ovals in a given column indicated that the parameter in question was expected to exceed the specification values under a wide range of conditions.

Similar charts were prepared for various categories of parts, e.g., general purpose diodes, fast switching diodes, etc. A one page summary listed all the available information on a particular part for each category. Data from a particular manufacturer on that category of parts was presented after the summary.

Technical Memoranda provided a rapid means of determing whether available parts are adequate for a particular application and permit a comparison of the reliability of different types of parts and of parts from different manufacturers.

A parts data index, which was updated three times a year, listed all parts on which data had been processed by the center. The parts were catagorized by part type, including information on the rating and manufacturer. It was planned that the index would also categorize the parts by manufacturer and provide cross-referencing information.