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MILITARY HANDBOOK

MICROCIRCUIT ACQUISITION HANDBOOK

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DO NOT CITE THIS DOCUMENT AS A REQUIREMENT.

AMSC N/A FSC 5962

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

1. This military handbook is approved for use by all Departments and Agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Director, US Army Research Laboratory, Physical Sciences Directorate, ATTN: AMSRL-PS-DC, Fort Monmouth, New Jersey 07703-5601, by using the Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

3. Commercial/industrial and commercial (consumer) microelectronic devices, often having advantages in cost, size, weight, performance and availability, have attracted widespread attention for government and military applications. This handbook takes a major deviation from traditional procurement guidelines by assisting military departments and associated contractors in the selection and acquisition of commercial/industrial, commercial (consumer), and traditional military microcircuits for military equipments. The document gives greater flexibility and responsibility to the equipment developer in selecting devices based on cost-effective performance, designed-in reliability, and high quality for a given application. A critically important factor in the selection of a supplier of commercial/industrial or commercial (consumer) quality microcircuits is KNOW YOUR SUPPLIER! Does the supplier have in-line process controls, SPC (EIA 557), incoming material control, in-line process monitors, continuous periodic testing, etc? Does he/she incorporate Best Commercial Practices? These are some of the questions that Figure 1, Vendor Selection Criteria Spreadsheet, is seeking to answer.

4. The handbook introduces two non-military quality systems, commercial/ industrial quality and commercial (consumer) quality (see Definition of Terms pg. 6). Commercial/industrial quality components are normally purchased to an industry (e.g., user) specification and will normally be specified for operation over an extended temperature range such as -40° to +85°C or -40° to +125°C. Commercial/ industrial quality components are currently used in many industrial computer, automotive, telecommunication, avionics and instrumentation applications. Commercial (consumer) quality components are normally purchased to a vendor/manufacturer specification and will be specified over a more limited temperature range such as 0° to 70°C. Commercial (consumer) quality components are used in low-cost driven markets such as video games, VCRs, etc. For military applications, where commercial/industrial quality or commercial (consumer) quality devices meet quality, reliability and operating temperature requirements, a substantial procurement and/or life-cycle cost savings may be realized by procuring to these quality systems.

5. The handbook uses the term "BEST COMMERCIAL PRACTICES" (BCPs) extensively (see Definition of Terms pg. 6). The use of this term in connection with microcircuit technology has the potential for creating some confusion. This handbook uses BCP in association with those components designed, processed, assembled, screened, tested and packaged for industrial customers with requirements for high quality, high reliability and low cost. These products are usually produced continuously on high volume lines. Although BCP will primarily be associated with commercial/industrial quality parts in the handbook, it should be noted that the military's Qualified Manufacturers' List (QML) program was developed to accommodate BCP, to reduce cost and accelerate insertion of new technology.

6. Assurance of highest generic quality and reliability of military, commercial/industrial and commercial (consumer) microcircuits is obtained through the application of BCP systems. The commercial/industrial quality devices are available from mature process lines, which have been qualified by a high volume user and have demonstrated high quality and reliability. Economy-of-scale is realizable through amortization of validation cost over the large number of parts procured.

Commercial/industrial BCP parts are predominately plastic encapsulated and produced in high volume. Although the high volume users of industrial BCP parts require a small variety of part types, the application of "device family" may significantly increase the number of qualified part types regardless of the quality system employed (e.g. commercial/industrial or Qualified Manufacturers' List). The military application of dual use technology is becoming a reality, and plastic encapsulated microcircuits (PEMs) will be part of that trend.

7. The radiation environment is unique to military and space applications. If a system is required to operate in radiation environments (either weapon or natural space) then additional restrictions are placed on the microcircuit selection and application process. It is possible to utilize any of the quality levels described herein in a radiation hardness assured system, if appropriate measures are consistently applied. *The most important* advice is to accurately set your radiation requirements early in contract development, and to NEVER WAIVER from these levels. Back-fitting hardened parts in a system is always much more expensive than doing it right initially.

8. Development of this Microcircuit Acquisition Handbook was recommended to the Office of the Under Secretary of Defense by the Department of Defense (DoD) Defense Science Board (DSB). The DSB made recommendations for a significant change in procurement directed towards increasing DoD's usage of the device manufacturers' best commercial components and practices. Following the DSB recommendations, the Office of the Assistant Secretary of Defense for Production Resources, Standardization Program Division (OASD-MMD/SPD), requested that the US Army Research Laboratory prepare this handbook as an aid in the selection of commercial/military microcircuit components for military equipments. To accomplish the task a military and industry working group, consisting of the three military departments, the Defense Logistics Agency (DLA), system integrators and device manufacturers, was formed. The following organizations played a significant role in the development of this document:

Department of Defense:	US Army Research Laboratory/PSD
	US Air Force Rome Laboratory (RL)
	US Air Force Wright Patterson AFB
	US Naval Surface Warfare Center Crane
	Defense Electronics Supply Center
Industry:	Texas Instruments
	National Semiconductor
	GTE Government Systems

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1. INTRODUCTION

1.1 Purpose. This handbook has been prepared as a guide to assist the various military departments and associated contractors in the selection of microcircuits for military equipments. It provides guidance on how the DoD and its contractors can cooperatively select devices which will result in the lowest total cost of ownership for the DoD. Device selection is to be based on cost-effective performance, designed-in high quality, and reliability for a given application.

1.2 Scope and application. This handbook is intended for guidance, reference, and training for all parties involved in the selection of microcircuit devices for use in military applications. This includes those involved in the application, selection, and handling of microcircuit devices. The handbook will assist the government and associated contractors in identifying and communicating specific application requirements. The handbook is structured for use by the System Program Office (SPO), system integrator and device manufacturer. It is intended to be applied on a contract-by-contract basis. The maximum benefit of this handbook can be achieved if it is used early in contract development and allowed to impact system specifications, statements of work (SOWs), and system design considerations.

1.3 Handbook overview.

a. Chapter 1 - Introduction. This chapter describes the basic purpose of the handbook, explains how to use the handbook, and provides an overview of the handbook on a chapter-by-chapter basis.

b. Chapter 2 - Applicable Documents. This chapter contains the applicable documents referenced in the handbook and where they can be obtained.

c. Chapter 3 - Acronyms, Abbreviations and Definitions. This chapter contains definitions of acronyms, abbreviations and terms used in the handbook.

d. Chapter 4 - Quality Systems and Procurement Documents. This chapter contains information on the quality systems that are available, under which military microcircuits are procured. The chapter also describes the various attributes of each system and its selection criteria.

e. Chapter 5 - Selection Guidance. This chapter contains a selection matrix that provides the information required in each contract category. The matrix identifies acceptable end-use applications for devices from the various quality systems. Also included are guidelines for developing a Parts Control Program Plan (PCPP) and vendor and device selection criteria spreadsheets. Approval of the PCPP and/or the spreadsheets is required in order to use commercial (consumer) quality and some commercial/industrial quality devices.

f. Chapter 6 - Application Practices. This chapter contains information that is intended to raise an awareness of potential problems associated with device application by system integrators and device manufacturers to prevent the misapplication of integrated circuits.

g. Chapter 7 - Selection Process as an Element of Design. This chapter contains selection criteria for the System Program Office (SPO)/Program Manager (PM), system integrator and component manufacturer. The criteria is used to determine the device level requirements of the application as related to the system design, assembly method(s), end use and maintenance requirements. Component manufacturers should make available device capability/limitation data for each selection criteria. The SPO/PM should consider the part costs, total system life cycle cost, performance, and reliability tradeoffs associated with using devices from the different systems.

h. Chapter 8 - System Guidance. This chapter provides a general listing and brief explanation of some potential reliability problems that should be addressed early in the development of all electronic hardware. The SPO/PM and system integrator should discuss these issues to ensure they are adequately addressed in the initial system design and device selection stage. This information should serve as a valuable reference tool for the system integrator.

i. Appendix A - Radiation Hardness Assurance. This appendix provides an overall discussion of RHA considerations including purpose, applicable documents, definitions and acronyms, quality systems, selection guidance, applicable practices, selection process as an element of design and system guidance.

2. APPLICABLE DOCUMENTS

2.1 Government documents.

2.1.1 Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the issue of the Department of Defense Index of Specifications and Standards (DODISS) and supplement thereto.

STANDARDS

MILITARY

MIL-STD-100	-	Engineering Drawing Practices.
MIL-STD-883	-	Test Methods and Procedures for Microelectronics.
MIL-STD-1835	-	Microcircuit Case Outlines.

SPECIFICATIONS

MILITARY

MIL-M-38510	-	Microcircuits, General Specification for.
MIL-H-38534	-	Hybrid (Custom) Microcircuits, General Specification for.
MIL-PRF-38535	-	Integrated Circuits (Microcircuits) Manufacturing, General Specification for.

BULLETIN

MILITARY

MIL-BUL-103	-	List of Standardized Microcircuit Drawings.

(Unless otherwise indicated, copies of federal and military specifications, standards, and handbooks are available from the Standardization Documents Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094).

2.1.2 Other Government documents, drawings, and publications. The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues are those cited in the solicitation.

DODISS - Department of Defense Index of Specifications and Standards.

(Copies of the DODISS are available on a yearly subscription basis either from the Government Printing Office for hard copy, or microfiche copies are available from the DODSSP Subscription Service 700 Robbins Avenue, Building 3D, Philadelphia, PA 19111-5094).

2.2 Non-Government publications.

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted are those listed in the issue of the DODISS cited in the solicitation. Unless otherwise specified, the issues of documents not listed in the DODISS are the issues of the documents cited in the solicitation.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION

ISO-9000 - Guidelines for Selection and Use - Quality Management and Quality Assurance Standards.

ELECTRONIC INDUSTRIES ASSOCIATION

EIA 557 - Statistical Process Control (SPC) Systems

EIA JEDEC Standard No. 47 - Stress Test Qualification Specification

EIA JESD 22-A101 - Temperature Humidity Bias (THB) Test Method

EIA JESD 22-A110 - Highly Accelerated Stress Test (HAST) Test Method.

(Application for copies should be addressed to Global Engineering Documents, 1990 M Street NW, Suite 400, Washington, DC 20036 or telephone 1-800-854-7179.)

American Society for Testing and Materials (ASTM)

ASTM Method 1192 - Standard Guide for the Measurement of SEP Induced by Heavy Ion Irradiation in Semiconductor Devices.

(Application for copies should be addressed to ASTM, 1916 Race Street, Philadelphia, PA 19103 or telephone 215-299-5400.)

AUTOMOTIVE ELECTRONICS COUNCIL

CDF-AEC-Q100 - Stress Test Qualification for Automotive-grade Integrated Circuits

(Application for copies should be addressed to Automotive Electronics Council, Delco Electronics, 1800 E. Lincoln Road M-3, Kokomo, IN 46904-9005.)

3. ACRONYMS, ABBREVIATIONS and DEFINITIONS

3.1 Acronyms and abbreviations. The acronyms/abbreviations used in this handbook are defined as follows:

a. ASIC - Application Specific Integrated Circuit
b. ASTM - American Society for Testing and Materials
c. AQS - Automotive Quality System
d. BCP - Best Commercial Practice
e. CAD - Computer-Aided-Design
f. CADMP - Computer-Aided-Design for Microelectronic Packaging
g. CDL - correlated device list
h. CID - Commercial Item Description
i. CpK - capability index
j. CTE - coefficient of thermal expansion
k. DESC - Defense Electronics Supply Center
l. DIP - Dual In-line Package
m. DLA - Defense Logistics Agency
n. DMPG - Department of Defense Microcircuit Planning Group
o. DMSMS - Diminishing Manufacturing Sources and Material Shortages
p. DoD - Department of Defense
q. DoDI - Department of Defense Instruction
r. DoDD - Department of Defense Directive
s. DODISS - Department of Defense Index of Specifications and Standards
t. DSB - Defense Science Board
u. EIA - Electronic Industries Association
v. EP/TAB - Environmentally Protected Tab Automated Bonding
w. ER - Established Reliability
x. ESD - Electrostatic Discharge
y. ESS - Environmental Stress Screening
z. GFB - Government Furnished Baseline
aa. GIDEP - Government-Industry Data Exchange Program
ab. GM - General Motors
ac. HAST - Highly Accelerated Stress Testing
ad. IC - integrated circuit
ae. IES-ESSEH - Institute of Environmental Sciences-Environmental Stress Screening of Electronic Hardware
af. ISO - International Organization for Standardization
ag. JAN - Joint Army-Navy
ah. JEDEC - Joint Electronic Device Engineering Council
ai. JIT - just-in-time
aj. JQA - Joint Qualification Alliance
ak. LTPD - lot tolerance percent defective
al. MPCAG - Military Parts Control Advisory Group
am. NDI - non-developmental item
an. NGS - non-government standard
ao. OEM - Original Equipment Manufacturer
ap. PCM - process control monitor
aq. PCPP - Parts Control Program Plan
ar. PEM - plastic encapsulated microcircuit
as. PIN - Part Identifying Number
at. PIND - Particle Impact Noise Detection
au. PM - Program Manager
av. PPSL - Program Parts Selection List
aw. PPM - parts per million
ax. PWB - printed wiring board
ay. QCI - Quality Conformance Inspection

az.	QFD	- Quality Function Deployment
ba.	QIT	- quality improvement team
bb.	QML	- Qualified Manufacturers List
bc.	QPL	- Qualified Products List
bd.	RH	- relative humidity
be.	RHA	- radiation hardness assurance
bf.	SCD	- Source Control Drawing
bg.	SEC	- standard evaluation circuit
bh.	SID	- Selected Item Drawing
bi.	SMD	- Standard Microcircuit Drawing
bj.	SMT	- surface mount technology
bk.	SOG	- Spun-on glass
bl.	RHA	- radiation hardness assurance
bm.	SOI	- Silicon on Insulator
bn.	SOS	- Silicon on Sapphire
bo.	SOW	- Statement of Work
bq.	SPC	- Statistical Process Control
br.	SPO	- System Program Office
bs.	THB	- temperature humidity bias
bt.	TRB	- Technical Review Board
bu.	TSMD	- Time Stress Measurement Device
bv.	VHDL	- VHSIC Hardware Description Language
bw.	VHSIC	- Very High Speed Integrated Circuit

3.2 Definition of terms. The terms used in this handbook are defined as follows:

a. Acquisition. The process of bringing methods, knowledge, systems, and equipment into military service.

b. Best commercial practices. This term loosely refers to the best manufacturing and quality assurance provisions that are employed by a manufacturer regardless of the category of products (e.g., consumer, commercial/industrial or military) they are producing. The term encompasses all the design and manufacturing techniques used during the wafer fabrication and assembly and the quality assurance provisions used throughout the processing flow and end item testing regardless of the product category or grade. Best commercial practices produce parts that meet or exceed customer expectations and are frequently produced on high volume lines.

c. Commercial (consumer) products. These products are generally developed for large volume customers and are being produced and sold to the open market and the general public. These products are typically designed for use in benign environments with verified electrical characteristics for room temperature applications. They may have very short product life and may be discontinued without notice as the next generation of consumer hardware is introduced. These products are almost exclusively offered in plastic packaging technology and are used in low-cost consumer products, such as video recorders, desk-top computers, radios, etc. (see 4.1.5).

d. Commercial/industrial products. Products that are generally developed to operate over broader environmental conditions (temperature range, vibration, humidity, etc.) than consumer products. Usually they are designed for long term quality/reliability considerations and a need for long term availability. These parts are typically used in applications such as industrial computers, commercial avionics, telecommunications, automobiles, etc. (see 4.1.4).

e. Contract categories. Specific phases of the acquisition process.

f. Established reliability. A quantitative maximum failure rate demonstrated under controlled test conditions specified in a military specification.

g. Established reliability parts. Parts that are identified and/or described in military specifications that have met established reliability requirements.

h. Military Parts Control Advisory Group. Department of Defense organization which provides advice to the military departments and military contractors on the selection of parts in assigned commodity classes and collects data on nonstandard parts for developing or updating military specifications and standards.

i. Military products. These products are typically available from the open market and are sold primarily to military customers. These products have electrical performance characteristics specified and verified for operations in harsh environmental applications (i.e., -55°C to +125°C). These products are verified for long-term operations and have been offered primarily in hermetic packages.

j. Parts Control Program Plan. The OEM's description of its internal vendor/part selection procedures based on guidance provided herein (5.3).

k. Physics of failure. A methodology which includes: an analysis of defects and failures; determination of root cause of problem; and based on these analyses recommend corrective actions in design, process, assembly, etc. to eliminate defect or failure.

l. Qualification. A process in advance of, and independent of, an acquisition by which a manufacturer's or distributor's products are examined, tested, and approved to determine conformance with requirements of a specification.

m. Qualified Manufacturers' List. A list of manufacturers' facilities that have been evaluated and determined to be acceptable based on the testing and approval of a sample specimen and conformance to the applicable specification, in accordance with MIL-PRF-38535. The QML includes appropriate products, processes, or technology identification, and test reference with the name and address of the manufacturer's plant.

n. Qualified Products List. A list of products that have met the qualification requirements stated in the applicable specification including appropriate product identification and tests or qualification references with the name and plant address of the manufacturer and distributor, as applicable.

o. Device family. A group of devices representing one supplier, one die manufacturing technology and one package type (e.g. Motorola's digital 3 micron high speed CMOS in PDIP).

p. Radiation Hardness Assurance (RHA). The procedures used to ensure that the radiation hardness capability of a semiconductor device is in compliance with the product specifications. See Appendix A for other RHA definitions.

4. QUALITY SYSTEMS and PROCUREMENT DOCUMENTS

4.1 Quality systems. The quality systems listed herein are candidate systems for DoD parts procurement. Table I is provided for system comparisons.

4.1.1 QML (Qualified Manufacturers' Listing) MIL-PRF-38535. This DOD system was developed in the late 1980s in response to the increasing complexity of digital integrated circuits and the availability of application specific integrated circuits (ASICs) in standard cell, gate array or custom variations. The Qualified Parts List (QPL), formally DoD's primary microcircuit procurement document (see 4.2.1), was then merged into the QML system. The merger allowed the production of qualified parts to the QML, expanding the volume and type of products covered by the QML system. The merging of requirements into one document and the allowance of offshore assembly/test reduces the number of process flows that must be used by the manufacturer. The QML program was selected as the consolidation point for the qualification programs because it allows for and encourages the adoption and implementation of Best Commercial Practices. The Defense Electronics Supply Center (DESC) is responsible for organizing a team of experts who perform a QML validation of the manufacturer's processing flows. The "audit" has been replaced by a "validation". The flow consists of six main activities:

Design	Testing
Fabrication	Customer Service
Assembly	Management

The following features are included in the QML:

Technology Review Board (TRB) System	Statistical Process Control
Conversion of Customer Requirements	Marketing
Quality Management	Continuous Improvement
Design Control	Radiation Hardness Assured Capability Limit

The qualifying activity or its agent validates the manufacturers' process flows. Once validated, the manufacturer may produce all products on that flow as specified on one part Standard Microcircuit Drawings (SMDs), MIL-M-38510 detail specifications, M-level SMDs, DESC drawings, and selected MIL-STD-883 compliant data book parts (see 4.1.2) (released prior to 1 Jun 93) as MIL-PRF-38535 compliant parts. Any new QML devices (released after 1 Jun 93) to be supplied by a QML manufacturer will be released as a one part-one part number SMD. QML also allows for plastic encapsulated and Environmentally Protected Tape Automated Bonding (EP/TAB) parts. Since the process is considered qualified, individual products do not have to be specifically and individually qualified to a standard set of tests. Where standard tests are used by the manufacturer to qualify the process, the use of ASTM, ANSI, EIA, MIL-STD-883 or JEDEC specifications is recommended. The manufacturer may also document and use new tests developed to improve quality and reliability. Formal military coordination was accomplished with the Army, Air Force, Navy and NASA by the preparing activity. Revision B of the document dated 1 Jun 93 contains the QPL/QML merger requirements.

Device performance requirements (electrical, thermal, radiation, and mechanical) are detailed in the device procurement document (e.g. SMD). This document, prepared by the system design house or the device manufacturer, is reviewed, controlled, and coordinated with registered users by DESC. It is the responsibility of DESC to assign a 5962 part number and ensure that only one part number is used for the same function.

Manufacturers are required to identify a Technology Review Board (TRB) system within their company. The TRB evaluates and approves all major changes in the process and product and reports to DESC on a periodic basis. Changes in the process and products are reviewed annually by a team of users, the qualifying activity, and tri-service/NASA representatives. Progress in meeting company established yield, SPC, and reliability goals are reported at this meeting. The manufacturer is also evaluated periodically on meeting Total Quality Management goals using the Malcolm Baldridge criteria or some other similar criteria.

4.1.1.1 System advantages. Some advantages of the QML system are:

a. program focus is on designing and building in quality and reliability and continual improvement;

b. manufacturer is responsible for process changes, allowing for timely improvements to the process which should result in continual improvement of quality, and the reduction of non-value added testing;

c. provides the following services: die banking, traceability, configuration control, end-of-production and product change notification;

d. single standardized dual use manufacturing and QA system which will improve availability and efficiency for all users requiring high quality and reliable parts without the need for large volume purchases;

e. government controls changes to part specification.

4.1.1.2 System disadvantages. Disadvantages of the QML system are:

a. since an infrastructure is required to support a military program, the price of the QML part is higher than the commercial/industrial or commercial (consumer) quality part;

b. there is no guaranteed reliability level provided by the QML system; this is specifically true for plastic components and hybrid devices;

c. availability of part types is limited to the number of qualified suppliers and process flows.

4.1.1.3 Cost savings.

a. should allow ship-to-stock (no user testing required);

b. may result in lower life cycle cost, as opposed to upgrade screening for severe environments;

c. the use of SMDs reduces parts proliferation; the one part-one part number significantly decreases logistics costs.

4.1.1.4 Usage. A variety of parts (e.g., ceramic, plastic, EP/TAB) will be available from various QML manufacturers depending upon which processes are qualified. The user should evaluate the application and type of part required.

4.1.1.5 Manufacturer location. Anywhere in the world covered by the validation system. The QML document also has provisions for the use of third party arrangements for any portion of the process flow (e.g. assembly, test, packaging, design, etc.).

4.1.1.6 RHA provisions. The QML system has extensive provisions to qualify a line as capable of meeting a set of radiation requirements. A sub-set of QML manufacturers have qualified RHA products. The radiation limits set by the vendor are guaranteed as an ongoing part of the SPC system and expressed as a RHACL for a technology or product. If available in appropriate RHA levels, RHA-QML parts are often cost-effective due to reduced part test requirements. (See Appendix A for RHA discussion.)

4.1.2 Class M and MIL-STD-883 compliant devices. This system evolved from various manufacturers' in-house versions of MIL-STD-883 test methods 5004 (Screening Procedures) and 5005 (Qualification and Quality Conformance Procedures). It was an informal and inconsistent system in the late 70s and early 80s known as MIL equivalent or look-alikes. Manufacturers advertised these parts as equivalent to JAN parts. However, some critical JAN requirements (e.g. audits, qualification, QCI tests) were not followed. The Government incorporated a truth-in-advertising paragraph in MIL-STD-883 which requires the manufacturer claiming to meet MIL-STD-883 1.2.1 requirements to self-certify that MIL-STD-883 requirements were met. The primary difference between a Class M product and a MIL-STD-883 compliant product is that DESC manages the procurement document (SMD) for the Class M and approves the sources by accepting their certificate of conformance to the MIL-STD-883 1.2.1 requirements. A MIL-STD-883 compliant product is produced to vendor controlled data books or customer controlled SCDs, and the government has no control over who offers MIL-STD-883 compliant parts, nor does it require notification by such a manufacturer. DESC conducts initial validation audits, on a random basis and at problem companies, of manufacturers offering Class M or MIL-STD-883 compliant product.

4.1.2.1 System advantages. A few system advantages are:

a. the Class M SMD or the MIL-STD-883 compliant parts are generally readily available because DESC certification and qualification is not required, and most products of these manufacturers have all or portions manufactured offshore;

b. these parts generally cost less than QML devices since there is less government oversight and reporting requirements.

4.1.2.2 System disadvantages. A few system disadvantages are:

a. Government does not evaluate the quality systems used to manufacture the parts, as in the QML program;

b. In most cases, Government auditors perform validation audits after the manufacturer is known to be supplying Class M SMD devices and those companies claiming compliance with MIL-STD-883 who are not in the SMD program may never get audited. Therefore, there is a risk that not all testing has been adequately accomplished or correctly interpreted by the manufacturer.

4.1.2.3 Cost savings. A savings can be realized from the following factors: ship-to-stock if customer agrees; qualification testing not required, and use of SMDs reduces parts proliferation and significantly decreases logistics costs. In addition, any cost savings realized through piece-part cost differentials should also include the costs associated with any added screening, device characterization, testing, or other special test and handling that may result from the use of Class M parts.

4.1.2.4 Usage. A variety of parts will be available from various sources. The user should evaluate the application and type of part required.

4.1.2.5 Manufacturer location. Class M and MIL-STD-883 compliant parts can be fabricated, assembled, and/or tested anywhere in the world, and no operation has to be owned by the company selling the parts.

4.1.2.6 RHA provisions. Any claims of RHA are controlled by the vendor. To assure consistent RHA product in Class M devices will require investigation of each vendor's method of certifying and maintaining RHA levels.

4.1.3 Automotive Quality System (AQS). The Automotive Electronics Council, comprised of Chrysler, Ford, and GM Delco, has issued the Stress Test Qualification for Automotive-grade Integrated Circuits, CDF-AEC-Q100, June 9, 1994 and a draft Quality Assessment Supplement for Semiconductors, CDF-AEC-A100 June 9, 1994. The two documents together provide a system which evaluates a supplier's capabilities and details a qualification program which ensures the device to be qualified meets a minimum set of automotive-grade qualification requirements. Together, these requirements provide product comparable to the quality of military approved devices. The supplier evaluation includes assessment of design methodology and validation, process capability and controls, failure analysis and corrective action, and customer satisfaction. Automotive-grade parts are defined as:

Grade 1: -40°C to +125°C
Grade 2: -40°C to +105°C
Grade 3: -40°C to +85°C

Stress-test qualification includes electrical and environmental tests which will assure the product meeting customer's requirements. Qualification of molded and hermetic cavity packages are included in this test scheme. The number of parts produced and qualified to this quality system is large. However, because the DOD equipment developers have many different applications, the identical part type qualified to this procedure would not likely be used. To make use of the quality possible from this procedure, qualification by device family (3.2) will be necessary. This would mean that a part type having the same die manufacturing technology and packaging type as that qualified to AQS would also be assumed to be qualified. A risk exists that a change has occurred in the qualified device which has not been implemented across all products in that device family. The result could be a lesser quality than expected. The AQS is derived from the JEDEC Committee JC14.3 Joint Qualification Alliance (JQA) qualification initiative. A second JQA derivative is the JC14.3 Commercial Qualification Specification (JEDC STD.47). This document, although similar, does not include those requirements necessary for automotive customers. These documents demonstrate high humidity/high temperature capability by requiring EIA JESD 22-A101 and A110 test methods.

4.1.3.1 System advantages. A few system advantages are:

a. provides a qualification system supported by a high volume customer base;

b. this system has the capability of becoming an industry wide standard with extensive application;

c. dominant failure mechanisms are addressed using qualification testing which include MIL-STD-883 and JEDEC test methods;

d. both hermetic and plastic encapsulated parts are included.

4.1.3.2 System disadvantages. Some system disadvantages are:

a. the number of part types could be limited although estimates are greater than 1,000 part types, many of which are custom;

b. screens or lot sample tests are not included;

c. procurement through distributor may be difficult;

d. limited change notification;

e. part construction may be different within family;

f. no assurance of robustness.

g. Cost savings should include any extra costs required for additional screening, testing and/or characterization. These added costs may be significant if a part is to be used in an application that requires radiation hardness.

4.1.3.3 Cost savings.

a. qualification costs will be low as a result of amortization over a large volume of parts procured by the automotive market;

b. high volume results in lower cost per part;

c. additional cost savings may be realized when savings generated at the next level of assembly are included (surface mountability, subassembly manufacturability, size and weight).

4.1.3.4 Usage. May have significant application when parts are obtained from the qualified process and assembly flow. The user should evaluate the type of part required (see Table II).

4.1.3.5 Manufacturer location. Anywhere in the world covered by the audit system.

4.1.4 Commercial/industrial quality systems. These products, hermetic or plastic packaged, are normally produced to meet a particular industry specification. These industrial specifications are restricted to a minimal supplier base, limiting business to those suppliers with the best quality track record. Although, in some cases, these industrial specifications are controlled by individual customers, it is possible to buy these parts for military use. JEDEC-47, Stress Test Driven Qualification Specification, is an industry document developed for users normally requiring high quality and reliability. Because of the special application environments, the requirements are, in some cases, more severe than some of the military application requirements.

CIDs or SCDs will be used to procure commercial/industrial quality devices. The CID/SCD will specify device attributes and will reference applicable industry specifications and standards.

4.1.4.1 System advantages. A few system advantages are:

a. the primary customer (usually large volume, i.e. millions/day) can tailor specification to meet specific application requirements;

b. it provides an extensive quality and reliability database.

4.1.4.2 System disadvantages. A few system disadvantages are:

a. the availability of part types is driven by high volume customers;

b. the Government cannot use restrictive buying methods due to procurement regulations;

c. typically, Government customers cannot tailor specifications because of limited quantity buys;

d. life cycle of part is unknown and uncontrolled.

4.1.4.3 Cost savings.

a. large volumes mean lower unit cost;

b. cost savings include savings generated by part type selection, availability, surface mountability, subassembly manufacturability, size and weight;

c. Cost savings should include any extra costs associated with additional part screening, testing, and characterization. These costs may be significant if a part is to be used in an application requiring very high reliability (e.g. space system) or radiation hardness.

4.1.4.4 Usage. May have significant application. The user should evaluate the application and part type.

4.1.4.5 Manufacturer location. Anywhere in the world. Prime customer selects manufacturer.

4.1.5 Commercial (consumer) quality systems. Each supplier has a set of commercial specifications which they use for manufacturing product for general sale. Usually the product specifications are included on a data sheet which is included into a catalog of products for wholesale use. A wide spectrum of performance, quality and reliability can be expected depending on the quality standards applied by the company. The temperature range for these parts is typically specified 0° to 70°C. Commercial Item Descriptions (CIDs)or SCDs will be used to procure commercial (consumer) devices (see 4.3.2).

4.1.5.1 System advantages. Some system advantages are:

a. initial unit cost of product is lowest available;

b. product availability is good;

c. extensive self-audit and periodic assessment test data is typically available.

4.1.5.2 System disadvantages. Some system disadvantages are:

a. additional testing may be required to verify performance, quality, and reliability;

b. part device types may be changed or discontinued without notification, and specifications may be changed without notification;

c. self-auditing may not be equally rigorous across the commercial suppliers;

d. parts may not be interchangeable because of incomplete data sheets;

e. without an industry accepted quality system certification, product quality and operability may require verification at an independent test laboratory (this cost may outweigh the low cost of the parts) and device types may have short life cycles.

f. Process steps which affect radiation hardness are typically unknown and uncontrolled. Consequently radiation hardness may vary widely from lot-to-lot.

4.1.5.3 Cost savings.

a. part cost should be the lowest of the candidate quality systems;

b. these devices should be available from the largest number of sources.

NOTE: The use of commercial electronic parts in military systems must be done with care. Apparent cost savings in initial procurement cost must be weighed against possible additional testing, auditing and reliability testing required to meet the application requirements.

4.1.5.4 Usage. May have limited application in severe environments and weapon systems.

4.1.5.5 Manufacturer location. Anywhere in the world.

4.1.6 RHA in other quality systems. The three commercial quality systems do not incorporate radiation requirements. However, these parts can be radiation tested to define their capability limits (up-screening). The limitation of this method is that no process stability can be assumed since suppliers frequently change and update their process. This requires an ongoing radiation test program for each new lot of devices, or proof of continuity from the vendor. This has a severe impact on total cost of the parts.

4.2. Insufficient/obsolete quality systems for DoD microcircuit procurements. The quality systems listed herein are not to be used for procurement of components on new system designs.

4.2.1 JAN (Joint Army-Navy) MIL-M-38510 Qualified Parts List (QPL) Class B and S. This quality system was developed by the military during the 1960s and came into widespread usage during the late 1970s. The system used a part by part qualification approach. The merger of JAN and the QML allowed JAN manufacturers to adapt their system to the QML approach with the JAN requirements becoming Appendix A of MIL-PRF-38535. As part of this transition from QPL to the QML there is a part number overlap. The QPL part number format (M38510/XXXXXBXX) is maintained for all MIL-M-38510 associated detail specifications. For purposes of this handbook and microcircuit selection, the user need only understand that all part numbers that were available under the QPL system are still available under the QML system. The actual quality system used in the manufacture of these parts has changed, but form, fit, and function are identical. Some QPL manufacturers may not transition to QML or may take time to transition to QML. These manufacturers will continue to meet QPL requirements as outlined in Appendix A of MIL-PRF-38535. The administration of these QPL requirements will be handled by the Defense Electronics Supply Center (DESC). The listing for sources of these parts will be section II of QML-38535. The transition is intended to make better use of Best Commercial Practices in the manufacture of military quality microcircuits.

4.2.2 International quality systems. The ISO-9000 series documents are gaining acceptance as international quality system assurance criteria. The ISO-9000 quality system assurance criteria are applicable to any type of organization. Consequently, these documents are very general and must be interpreted by the applicable assessment body which is typically a third party organization. These third party assessment organizations typically charge fees for their initial and periodic registration services. Numerous organizations will audit and issue ISO-9000 registration to U.S. manufacturers. Several U.S. industry trade associations are studying establishing accreditation schemes for third party auditing organizations as well as determining a mechanism for proper application of these standards within the U.S. community. Direct reciprocity between countries using ISO-9000 documents has not yet been established. This system is not considered adequate for DoD microcircuit procurements, but may be provided as an element of data in the vendor selection spreadsheet (figure 1).

4.2.2.1 System advantages. Some system advantages are:

a. this system is internationally recognized;

b. it provides a basic quality system which can become the building block for future enhancements;

c. if system is acceptable for a particular application, multiple customer audits may not be required;

d. independent third party auditors can periodically evaluate the system.

4.2.2.2 System disadvantages. Some system disadvantages are:

a. it is a generic quality system designed for any industry, therefore, it may not be specific enough for complex technologies;

b. inconsistent applications and audits are possible due to the generic nature of the document (e.g. not specific to microcircuits);

c. third party auditing costs may make this system expensive;

d. this generic quality system may not directly influence outgoing product quality.

4.2.2.3 Cost savings. Potential savings are possible as international acceptance grows because only one audit system may be needed to verify compliance.

4.3 Procurement documents. Military microcircuits are purchased using three procurement documents: Standard Microcircuit Drawings (SMDs), Commercial Item Descriptions (CIDs), and Source Control Drawings (SCDs) also known as Vendor Item Drawings (VIDs).

4.3.1 Standard Microcircuit Drawing (SMD) one part-one part number system. The one part-one part number system described below has been developed to allow for transitions between identical generic devices covered by the three major microcircuit requirements documents (MIL-PRF-38535, MIL-H-38534, and 1.2.1 of

MIL-STD-883) without the necessity for the generation of unique Part or Identifying Numbers (PINs). The three military requirements documents represent different class levels. Previously, when a device manufacturer upgraded military product from one class level to another, the benefits of the upgraded product were unavailable to the Original Equipment Manufacturer (OEM), who was contractually locked into the original unique PIN. By establishing a one part number system covering all three documents, the OEM can acquire to the highest class level available for a given generic device to meet system needs without modifying the original contract parts selection criteria.

Military documentation format	Example PIN under new system	Manufacturing source listing	Document
New MIL-PRF-38535, Standardized Microcircuit Drawings	5962-XXXXXZZ(Q or V)YY	QML-38535	MIL-BUL-103
New MIL-H-38534, Standardized Microcircuit Drawings	5962-XXXXXZZ(H or K)YY	QML-38534	MIL-BUL-103
New 1.2.1 of MIL-STD-883, Standardized Microcircuit Drawings	5962-XXXXXZZ(M)YY	MIL-BUL-103	MIL-BUL-103

The one part SMD (and all SMDs) are controlled by DESC and describe the performance characteristics of a specific device (e.g., 1 megabyte memory). For each quality system the SMD represents that quality system's specific requirements. Under the QML system, the QML device is described by the SMD, written and verified by the manufacturer, but controlled by DESC. The QML quality system assures that the SMD is complete, because the process for generating the SMD has been validated during certification. The manufacturer is held responsible for the quality of the SMD. Under the MIL-STD-883, 1.2.1 compliant system, the manufacturer (or OEM) prepares the SMD and DESC is responsible for ensuring that the SMD is complete. There is less assurance under the MIL-STD-883 system that the part actually meets the requirements of the specification. It is only recently (1990) that DESC has begun spot check verification audits of the Class M/MIL-STD-883 compliant manufacturers. The SMD system is currently being expanded to cover industrial quality devices. The SMD will specify device attributes and will reference the applicable industry specifications and standards.

4.3.2 Commercial Item Descriptions (CIDs). CIDs are short, simple product descriptions or specifications that describe available commercial products that will meet the Government's needs by salient functional or performance characteristics. If a suitable NGS is not available or could not be revised or developed in time to satisfy an acquisition need for a commercial product, then develop a CID. A useful approach is to use an NGS as the basis for the CID, and then make additions or modifications to the NGS in the CID. In the case of microcircuits, CIDs should be used for documenting those commercial (consumer) devices considered acceptable for military use.

4.3.3 Source Control Drawings (SCDs). SCD is a catch-all name commonly used to refer to any contractor-prepared procurement document. These predominantly occur in three forms: the Source Control Drawing (SCD), the Selected Item Drawing (SID), and the Vendor Item Drawing (formerly Specification Control Drawing (SCD)). Vendor Item Drawings are used when it is necessary to limit procurement to one or more sources which exclusively meet critical applications. Selected Item Drawings are used when it is necessary to further limit an existing item by selecting for a characteristic not previously identified. Specification Control Drawings are typically used when the vendor's "off-the-shelf" item is suitable for use.

This document is written by the customer and the contract regulations are controlled in accordance with MIL-STD-100. These documents may vary widely as to completeness. A space systems supplier may have a very high quality SCD. A loosely monitored subcontractor may have little or no control over the SCD and be subject to parts performance surprises (i.e., poor reliability, missing test requirements, etc). The use of SCDs should be carefully worked into the total quality system and be replaced by an SMD if possible.

TABLE I. Quality systems 5/ 6/

	Monolithic				
Requirements	QML (with merged QPL)	Class M/883 compliant	AQS	Industrial	Commercial
	Compliant with MIL-PRF-38535 (class Q/V)	Compliant to MIL-STD-883	Compliant to AQS spec or flow	Compliant to customer specification	Variable per customer
Audit/qual agency	DESC	Self-cert/DESC verifies 4/ SMD suppliers	To be determined	Customer dependent	None/customer dependent
Procurement vehicle	SMD (one part-one part number)	SMD/SCD for 883	CID/SCD	CID/SCD	CID/SCD/PIN
Ambient operating temp range 1/	-55° to +125°C technology dependent	-55° to +125°C technology dependent	-40° to +125°C technology dependent	-40° to +85°C technology dependent	0° to +70°C
Quality/Reliability reqd 2/	MIL-PRF-38535	MIL-STD-883, 1.2.1	CDF-AEC-Q100	Tailored MIL-STD-883/ JEDC-47, etc.	Based on system
Electricals	based on military electricals	SMD based on mil elect; variable for 883	based on CID/SCD or vendor elect	based on vendor electricals	based on vendor electricals
Volume	Expected medium	Medium	High	High	High
Packaging	Hermetic, plastic encapsulated	Hermetic	Hermetic, plastic encapsulated	Hermetic, plastic encapsulated	Per application; majority plastic encapsulated
SPC	Required and effectiveness evaluated	Not required; not evaluated	Not required; but expected	Not required; but expected	Not required; but typically used by industry
Testing	Based on amount in process control	Per MIL-STD-883 para. 1.2.1 control, not evaluated	Per AQS specification	Per specification	Per customer or data sheet
Traceability	Controlled	Controlled	Customer dependent	Customer dependent	Customer dependent
Price	Highest	Highest	Low	Low	Lowest
Delivery time 3/	Short if offshelf; medium otherwise	Short if offshelf; medium otherwise	Expected to be short	Expected to be short	Short if high volume; med otherwise

1/ The operating temperatures listed in the table are maximum ranges only. Each of the quality systems offer parts in a variety of different temperature ranges.

2/ Reliability assessment based on dominant failure mechanism.

3/ Delivery time: medium - 1 month; long - 6 months.

4/ Periodic verification of supplier self-audit.

5/ Part/supplier selection should be approved through SPO/PM acceptance of the PCPP (see 5.3) and the microelectronic selection criteria spreadsheets (see 5.2.1 and 5.2.2).

6/ System risk should be low when selecting parts (from any of the quality systems) when following appropriate handbook guidelines and procedures.

5. SELECTION GUIDANCE

5.1 Selection guidance. Vendors and devices should be selected according to the guidance provided in table II and applicable guidance provided herein.

5.2 Supplier and device selection criteria for commercial (consumer) and commercial/industrial quality product (figures 1 and 2). Figures 1 and 2 and their companion guides, the Vendor Selection Criteria Guide (see 5.2.1) and the Device Selection Criteria Guide (see 5.2.2), are to be used in equipment procurement solicitations. Use of commercial (consumer) devices or commercial/industrial devices requires completion, and at the option of the PM/SPO, submission and approval of the spreadsheets depicted in figures 1 and 2. It is the equipment manufacturer's statement of assurance of microcircuit reliability in the proposed system application.

5.2.1 Vendor selection criteria spreadsheet guide. The information required in each data item of the spreadsheet is explained in a. through f. The descriptions are typical inputs which could meet the data item requirements. Additional inputs which will meet the intent of the data item should be included.

a. Part type and number: Description of devices: microprocessor, memory; controller, amplifier, etc. Identification of parts through catalog numbers, Standard Microcircuit Drawings (SMDs), Source Control Drawings (SCDs), etc.

b. End item applications: What equipment have the devices (part number) been used in, preferably equipment manufactured by the equipment manufacturer? If this is not available, then verifiable data from other government or commercial equipment applications should be pursued and provided. Applicable information would include number of parts used and use history in these systems.

c. Experience factor: This would support category b. above, if the equipment manufacturer has used a vendor's devices in another application. Data could include types of devices used (SMT, DIP, etc), experience at board assembly, and field reliability. What has been the incoming or assembly first test experience? Has cause of reject been determined and is it device design or process related? Vendor outgoing final test data will be acceptable.

d. Volume sold per year: An approximate number of each device per year sold by the supplier over the past five years. This will provide an indication of the maturity of the device. Also, market and production volume trends along with trends in emerging competing technologies should be evaluated to help estimate the obsolescence risk for each component over the life-cycle of the system.

e. Purchased to which qualification system: Provide the qualification system identification to which the microcircuit will be procured. If an accepted military or industry standard, indication of system is the only requirement. If not standard or changes to a standard proposed then detail documentation is required. Commercial part users rely on the suppliers' internal controls and credibility to provide consistently good product. The preferred supplier should have: continuous improvement plans; statistically characterized and controlled processes; rigorous internal qualification procedures; ongoing reliability audit programs.

f. Proposed additional assurance: This category will be for the identification of added value screening or sampled testing required to assure meeting system requirements. Further assurances from the supplier such as certificate of compliance and warranty would be beneficial.

FIGURE 1. Vendor selection criteria spreadsheet 1/

PART TYPE AND NUMBER	END ITEM APPLICATIONS	EXPERIENCE FACTOR	VOLUME SOLD PER YEAR
• Microprocessor • SNJ XXYY	• IBM PC • Ford Radio • AN/PRC-70, etc	• Incoming/assembly first test experience • Vendor test data outgoing • Past experience • Vendor assurance • At incoming or PCB level	• Approximate

PURCHASED TO QUAL SYSTEM	PROPOSED ADDITIONAL ASSURANCE
• Vendor self-audit • ISO-9000 • MIL-PRF-38535 • JEDEC-STD-47 • CLASS M/883 compliant • CDF-AEC-A100 • Baldrige Award • Details required	• Screens • QCI • Certificate of compliance • Warranty • Rad-hard

1/ used with the Vendor Selection Criteria Guide (see 5.2.1)

TABLE II. System environments matrix. 1/

Environment	Category 1 Protected	Category 2 Normal	Category 3 Severe	Category S Space
Special issues	Readily accessible to maintenance	Inhabited Usually accessible for maintenance or replacement	Uninhabited Extreme temperatures High G; high shock	Radiation Non-maintainable
Typical systems	Data processing systems, Test equipment	Air traffic control, Ground radar, ground mobile, Communication facilities, Ground fire control, Cockpit, NAV/COM, Some shipboard, Some munitions	Some avionics High G Some shipboard Tactical missiles, munitions	Space, strategic missiles
Critical trade-off concerns	Controlled environment, air conditioned	Uncontrolled temperature, Moderate-medium vibration, pressure and moisture, long term storage 4/	Extreme pressure, vibration, temperature and moisture, long term storage 4/	Radiation Non-maintainable
Typical temperature	0°to +70°C	- 40°to +85°C	-55°to +125°C	-55°to +125°C
Preferred quality system	QML AQS 2/ Industrial Class M/883 Commercial	QML AQS 2/ Industrial Class M/883	QML (Class Q or V) AQS 2/ Class M/883	QML (Class V)
Preferred procurement document	SMD CID 3/	SMD CID 3/	SMD	SMD
Alternate procurement document	VID/SCD	VID/SCD	VID/SCD	VID/SCD

1/ Inclusion of a device, technology, or supplier in a particular quality system does not relieve the user of the responsibility for determining application suitability. The devices, technologies, and suppliers included in the quality systems have met certain reliability and performance requirements deemed suitable, in general, for usage in a military application. The user is cautioned to examine specific technical, life-cycle, and programmatic considerations when selecting from these quality systems. (see 5.2, figures 1 and 2)

2/ The use of "technology family" parts from this quality system will require monitoring to assure AQS data is applicable.

3/ Commercial Item Descriptions (CIDs) are to be used for commercial (consumer) and commercial/industrial product whenever possible.

4/ Long term storage is defined as a period of at least ten years. Typical long term storage for weapon systems is 10-20 years with uncontrolled temperature and humidity. OEMs should consult with device suppliers about long term storage reliability issues prior to using parts in this type of application.

5.2.2 Device selection criteria spreadsheet guide. The information required in each data item of the spreadsheet is explained in a. through i. The descriptions are typical inputs which could meet the data item requirements. Additional inputs which will meet the intent of the data item should be included.

a. Part type and number: Description of device: microprocessor, memory; controller, amplifier, etc. Identification of part through catalog number, Standard Microcircuit Drawing (SMD), Source Control Drawing (SCD), etc, with accompanying drawing containing package outline, temperature range, power capability, etc.

b. End item application experience: What equipment has this device (part number) been used in, preferably equipment manufactured by the equipment manufacturer? If this is not available, then verifiable data from other government or commercial equipment applications should be pursued and provided. Applicable information would include number of parts used and use history in these systems. If the equipment manufacturer had used this device in another application; data could include types of devices used (SMT, DIP, etc), experience at board assembly, and field reliability. What has been the incoming or assembly first test experience? Has cause of reject been determined and is it device design or process related? Vendor outgoing final test data may be acceptable.

c. Reliability assurance: How will the equipment manufacturer assure the microcircuit will meet the end item use (reliability) requirement? An approach which implements diagnostics of stress tested parts and field failure returns with feedback to correct problems in design or processing is a technique to assure product reliability. Correct device selection for the circuit design implemented is mandatory. A continuous process improvement methodology for assembly operations will assure the greatest quality, highest yield and lowest defect rate. Assessment could be based on possible failure mechanisms and how the supplier and user will assure any impact is eliminated. PCMs (process control monitors) and SECs (standard evaluation circuits) are test devices used as process control monitors and process validation circuits respectively. Theoretical modeling software programs are available to assess the reliability of a packaged assembly at initial design.

d. Use environment: What is the specific end item this device will be used in? What will be the environmental extremes the device will be subjected to and the frequency of these stresses (cycles per year) if applicable. How have these conditions been addressed in category c. above? (see 6.2.1)

e. Derating: Has the equipment manufacturer's circuit designer provided adequate margin (safety factor) between worst case circuit design and device specification performance limits? Provide comparison of design factors and specification limits.

f. Purchased to which qualification system: Provide the qualification system identification to which the microcircuit will be procured. If an accepted military or industry standard, indication of system is the only requirement. If not standard or changes to a standard proposed then detail documentation is required.

g. Proposed additional assurance: This category will be for the identification of added value screening or sampled testing required to assure meeting system requirements. Further assurances from the supplier should be obtained, such as certificate of compliance and warranty.

h. Guaranteed operating temperature: Provide the vendor guaranteed operating temperature for the device under consideration for use in your equipment application. Using parts outside the manufacturer's guaranteed temperature range is not recommended. Any attempt to use parts outside the specified temperature limits will need to be thoroughly justified.

i. Radiation Hardness Assurance (RHA): RHA is required for all devices intended for operation in a radiation environment and specifies how the equipment manufacturer will ensure that the microcircuit will meet the end item use (radiation hardness) requirements for all specified environments. (See Appendix A for RHA discussion.)

FIGURE 2. Device selection criteria spreadsheet 1/

PART TYPE AND NUMBER	END ITEM APPLICATIONS	RELIABILITY ASSURANCE	USE ENVIRONMENT
• Microprocessor • SNJ XXYY • Drawing with package outline	• IBM PC • Ford Radio • AN/PRC-70, etc.	• PCM • SEC • Life test-need test conditions • Failure rate calculation • CADMP/FEA • Failure mechanism • Field data	• Aircraft, tank, etc • Temperature, RH, temperature cycle, vibration, shock, etc for each environment

DERATING	PURCHASED TO QUAL SYSTEM	PROPOSED ADDITIONAL ASSURANCE	GUARANTEED OPERATING TEMPERATURE	PEM	RHACC
• Worst case operating electrical conditions (1% of spec limits)	• Vendor self-audit • ISO-9000 • MIL-PRF-38535 • JEDEC-STD-47 • CLASS M/883 compliant • CDF-AEC-A100 • Details required	• Screens • QCI • Certificate of compliance • Warranty • Rad-hard 2/			• Environment • Levels • ASIC considerations 2/

1/ used with the Device Selection Criteria Guide (see 5.2.2)
2/ See Appendix A

5.2.3 Spreadsheet submission. The requirements of the procuring activity will dictate the necessity for specific spreadsheet submissions. The spreadsheets are to be used to assess the acceptability of proposed microcircuits for system application and to evaluate the equipment manufacturer's knowledge/investigation of the recommended technology. The procuring activity may want the spreadsheets to also be processed and reviewed by the Military Parts Control Advisory Group (MPCAG). The reporting requirements should be negotiated with the equipment manufacturers and made contractually binding. The spreadsheets are intended to complement and support the information obtained in the PCPP (see 5.3). The following are possible submission/review approaches:

a. The OEM maintains all spreadsheets and supporting data on individual spreadsheets for devices and suppliers. Audits could be conducted at the OEM's facility on individual device and supplier spreadsheets. Reviews may be conducted on the complete set of spreadsheets or some appropriate subset thereof.

b. Government review of vendor and part selection could be limited to approval of the OEM's philosophy and methodology for device and supplier selection as contractually defined in the PCPP. Spreadsheets are required to be completed, but are not formally reviewed by the Government.

5.3 Parts Control Program Plan (PCPP). The OEM should develop a PCPP when designing/developing military equipment and selecting system devices based on MIL-HDBK-179 guidelines. The PCPP should detail the philosophy and methodology for selecting quality suppliers and devices capable of performing in the intended application. The plan should detail all criteria used to evaluate and rate vendors and devices and describe internal procedures that are followed to ensure proper implementation. This handbook provides the framework for developing the PCPP. The PCPP should be a living document that changes, as required, with the growing understanding and experience with the PCPP and selection process.

5.3.1 PCPP submission. When vendor and device selection is based on MIL-HDBK-179, the procuring activity should require the OEM to submit a PCPP for initial review and approval. Review of the PCPP should include the following: rating the OEM's interpretation of handbook guidelines, vendor/device selection procedures, and implementation plan. The plan should be evaluated during proposal phase or shortly after contract award. It should be required that PCPP updates be submitted to the procuring activity for review and approval. The procuring activity may want the PCPP to also be processed and reviewed by the Military Parts Control Advisory Group (MPCAG). (See Appendix A for RHA PCPP requirements.)

6. APPLICATION PRACTICES

6.1 General. Proper application of microcircuits is crucial to the overall effectiveness, functionality, performance, and availability of the system. This chapter will discuss the issues which should be addressed to assure optimum system performance.

6.2 Quality and reliability concerns. The overall system performance is highly dependent on the quality and reliability of its components. The required performance objectives and environmental operating conditions should be communicated by the OEM to the component suppliers at the initial meeting. The establishment of this line of communication between the system designer and the device designer and vendor is crucial to the overall program success as devices get more and more complex. Most standard commercial parts are designed and assembled based on the supplier's internal specifications for a specific environmental window. Customer designed components, such as ASICs and gate arrays, give the system designer the option to optimize device performance and functionality based on the system environmental conditions. Therefore, different approaches need to be taken in each case during the system design and part selection process. The following are some issues which need to be taken into account:

6.2.1 Environmental envelope. Knowing whether the system will experience adverse or extreme conditions in temperature, temperature cycles, vibration, moisture (humidity), radiation, or stress (G-force) has an impact on the features one looks for during the part selection process. However, the process of determining the environmental window is difficult. In most cases, one relies on data from similar systems. Today, there are devices, such as the Time Stress Measurement Device (TSMD), which can be placed in the equipment bay or on the board to give an accurate representation of the operating environment of the system. Table II outlines several environmental conditions and identifies some of the issues that need to be addressed.

6.2.2 Reliability consideration at package design. A software tool has been developed to assure a particular part will provide the reliability necessary to meet application requirements. At package design the software tool has inputs to menus which address materials, form factor, failure mechanisms, use environment, stresses, etc. A reliability assessment is calculated to determine if the proposed design meets the reliability requirements. If not, the parts can be varied, within reason, until the desired reliability is achieved. A system designer can determine if the device supplier has performed such an analysis.

6.2.3 Assembly level reliability goals. As device density grows, so does the silicon chip size. Thus, the choice of packaging style needs to address weight, solderability, heat dissipation, mechanical and thermal integrity, rework, and manufacturability.

6.2.4 Storage. Many systems, such as weapon systems, are placed in storage for long periods of time before they are needed. This is becoming more the norm for many other systems also. Therefore, the conditions under which the system is to be stored in needs to be considered and taken into account before parts are selected for the system. Issues of concern are whether the system is stored in a controlled environment or not.

6.3 Design specifics. A major contributor to system failure, functional and performance related, is inadequate design practices. An essential design practice is to identify all critical limits of the system. This is necessary so that these requirements can be translated into applicable part requirements. Once the part requirements have been defined, a designer must carefully review and evaluate the device vendor's data sheet. This data sheet defines the critical operation and reliability parameters of a device. Caution needs to be exercised during this process since not all applicable part data sheets define all critical parameters that one needs to know. Also, supplier defined parameters may change without notification. Therefore, the device vendor should be kept in the part selection loop. Also, the same device functionality and type manufactured by different vendors are not necessarily the same device. Seemingly insignificant differences between the devices can result in catastrophic system failure. This is particularly critical in the logistic support aspects of the system where part interchangeability needs to be carefully evaluated. The following discussion identifies other design specifics which need to be considered.

6.3.1 Data sheet/performance level. Data sheet limits are measured under specific conditions. System designers should allow for some variations due to absolute temperature tolerances and test setups. In addition, there may be some lifetime speed/parametric degradation which can cause marginal performance compared to the specified limits in the data sheet (some data sheets may only identify typical values without indicating a range). One should be cautious and understand what the vendor means by "guaranteed but not tested." Also, one absolute rule which should always be followed is never to design to the maximum rated limits of the part. Additionally, change control notification may be a significant issue for some applications. For such applications, access to change notifications should be considered when selecting parts from the various quality systems and suppliers.

6.3.2 Technology selection (speed, power, radiation tolerances, geometry). There is generally a trade-off between speed and power. This choice may limit the technology selection. Slower parts are not necessarily replaceable with faster ones. If faster parts are used to replace slower parts in an existing design, circuit re-analysis/testing should be performed to ensure that race conditions or other problems are not engendered by such changes. Faster devices tend to have smaller geometries which can impact certain reliability factors while enhancing others. New technologies may have inherent reliability sensitivities which must be determined and evaluated for the field environment prior to part selection. In regard to radiation tolerance, understand the implications of the various tolerance levels and whether or not the actual device has been tested to that level.

6.4 Plastic Encapsulated Microcircuits (PEMs). A plastic encapsulated package is an enclosure which uses organic material, usually transfer molded for environmental protection. This material is in direct contact with the active element or with an inorganic barrier layer. Since there is no cavity, traditional hermeticity measurements are meaningless and should not be required.

Historically, Plastic Encapsulated Microcircuits (PEMs) have been primarily used in commercial, industrial, automotive, and telecommunication electronics. Consequently, they have a large manufacturing base (97% of world production). With their major advantages in cost, size, weight, and availability (30% more part functions than hermetic), they have attracted widespread attention for government and military applications. Although this is a major opportunity for PEMs, there have been formidable challenges in adapting plastic packages to the high-reliability demanding environment, cost-conscious government, and military markets. While the major impediment to their application has been the perception of lower reliability as a result of moisture related failure mechanisms, the challenges arise as a result of small procurement/production volumes, a conservative approach by SPOs/PMs in the use of these devices, and the defense industry's lack of standards and handbooks for these types of devices.

Some of the first semiconductor devices were encapsulated in plastic. These early encapsulated devices, which employed plastic molding compounds, were plagued by thermal intermittence problems. Because of the coefficient of thermal expansion (CTE) difference between the bond wires and the encapsulant, such devices and circuits produced open circuit failures at elevated temperatures. Returning to a lower temperature, compressive forces restored contact of wire to bond pad. Moisture-induced failures, like corrosion, cracking, fracture and interfacial delamination, were also significant. Early 85°C/85% relative humidity (RH) testing in 1974 produced 25% cumulative failures at 1,000 hours, compared with 0.1% in 1990. Today's nearly exclusive continued use of hermetically sealed microcircuits in military, aerospace, and other high-reliability, highly critical applications is a direct result of the problems associated with early plastic packaging.

The last decade has brought revolutionary changes in electronics technology in general and in plastic packaging in particular. Earlier plastic encapsulation of transistors and diodes was done by dispensing a small amount of material over the die and bond wires (glob topping). Subsequently, various molding techniques were attempted including transfer, injection and potting. Hundreds of molding material variations (epoxies, silicones and phenolics) were evaluated for cost, performance, implementation, shelf life, repeatability, flammability and reliability impact. Included in these evaluations were various additives for heat removal, adhesion, viscosity, mold release, flame retardant, and appearance. Very popular was the protection of the die surface prior to molding by coatings which include silicone elastomers, varnish, and spun-on glass (SOG). To reduce voiding occurring between encapsulant and lead wires, silicone resin was forced, under a vacuum, into these voids using a process known as "backfilling."

The progressive improvement in plastic packaging integrity has been affected by improved materials, increased plastic purity, high-quality device passivation, improved leadframe designs, and device manufacturer's quality programs. In general, the failure rate of plastic packages has decreased from about 100 failures per million device hours in 1978 to about 0.05 per million device hours in 1990. It has become clear that performance must not be compromised by packaging: high-volume controlled processes and materials will be required for quality and reliability; most or all devices must be available in reliable cost-effective packaging; and evaluation, screening, qualification, and test procedures must be developed and managed.

Today the most popular molding compound is epoxy novolac. The basic composition contains, by weight, the following: 15-30% epoxy resin and hardeners, 60-80% fillers, 1-7% pigment, mold release, coupling agent and stress absorber, 1-5% flame retardant, and 1-2% catalyst. Major strides have been made on the corrosive effects of aluminum chip metallization. Reduction of chloride and other halides in the basic epoxy composition, stable flame retardants and ion scavengers have essentially eliminated corrosion problems. Some questions remain regarding toxic fumes liberated from packages exposed to excessive temperatures (>200°C) emanating from flame retardant additives. A serious failure mechanism in memory devices, data loss due to alpha particle impact caused by thorium and uranium elements contained in the filler material, has been greatly reduced. Single bit loss and soft errors have been reduced through reduction of those alpha emitting elements and by barrier coating of the integrated circuit (IC) die.

Delamination or "popcorning" associated with thin package leadless chip carriers, which are surface mounted using various soldering techniques, is understood and can be controlled. Techniques used include baking the finished part and sealing in an airtight plastic bag. Parts removed from this enclosure must be used in a specific time period. At the part level, delamination effects can be reduced by having perforated leadframe die pad, decrease in filler particle size, and stamping of leadframes which eliminate burr formation sites for stress concentration.

Plastic encapsulated microcircuits have been used in many DoD systems, in large quantities. In some applications, military specific materials, processing, and testing was believed necessary. Because of these requirements, cost of parts neared that of hermetically sealed versions. Cost benefits, high quality and reliability, of plastic encapsulated microcircuits can be achieved by realization of the "economies of scale" associated with procurement driven by high volume users.

Plastic product reliability has improved dramatically over the past 15 years. Today they are used in harsh environments, such as automotive under-hood applications and commercial avionics systems. The mechanical ruggedness of plastic can packages makes them superior in high shock and vibration applications that can damage ceramic packages. Even so, the selection of PEMs should be approached cautiously in extremely harsh applications, or where long-term storage is an issue. The user must carefully review the manufacturing process, reliability test results, and customer base of each prospective plastic IC supplier. Some items useful in evaluating the integrity of a supplier of plastic parts include but are not limited to:

a. reduced phosphorus levels in passivation;

b. dual layer passivation in critical cases;

c. perforated frames;

d. benign (non-ionic) cleaning of frames after molding;

e. use of copper frames;

f. reduced stress trim and form;

g. corrosion resistant mold compounds;

h. nitride passivation;

i. ionic contamination;

j. comprehensive reliability program.

In addition to the reliability considerations, the effects of moisture on the long term radiation robustness of a PEM require investigation and characterization. The deleterious effects of moisture (hydrogen) on total ionizing dose hardness have been documented. Hence, the efficacy of the plastic encapsulation concerning this phenomena requires additional effort.

7. SELECTION PROCESS AS AN ELEMENT OF DESIGN

7.1 Scope. This chapter provides a suggested process for the selection of parts with appropriate and adequate function, performance, reliability, and durability characteristics. The selection process requires the application of rigorous engineering methods, disciplined procurement practices, and use of reliability physics-based analytical tools and methods. The goal of this process is to assure that parts are designed to meet function and performance needs while being robust enough to withstand the stress exposure from the circuit application (i.e., bias, output loading, etc) and the use environment (e.g., thermal, vibration, electrical, etc) for a specified minimum period of time.

7.2 General process. The parts selection process begins with a clear understanding of the desired function and performance, as well as intended usage of the equipment being designed. This understanding is derived from an evaluation of the use environment expected during each type and phase of equipment operation or operational support activity. For example, an avionics system should have design criteria based on specific equipment mounting location, number and types of flights, mission mix (training/war-time air-to-air, air-to-ground, etc), mission profiles (e.g., ground cold start, system check, taxi, takeoff, climb, cruise, descent, weapons-release/gun-fire, sprint, climb cruise, descent, landing, taxi, shutdown), total allowable maintenance actions, etc. The goal is to define the field, storage, logistics, manufacturing, transportation, peacetime, and wartime conditions as installed to a sufficient extent that the duration and magnitude of stresses to which parts and materials are to be exposed can be estimated with a reasonable degree of accuracy. Once the sources of stress (e.g., thermal cycles, bias levels, loading, vibration) are known/estimated, principles of reliability physics are applied to determine the suitability of technology families in general and specific device types in particular. This analysis should also consider the impact of allowed/inherent variability in design, materials and structures; and sensitivities, limitations and rate/type of degradation caused by expected stress exposure for each component technology family.

7.3 Determination of stress exposure. The determination of actual stresses begins with a formulation of stress environments. Each environmental element, such as manufacturing, logistics, field use, etc will be made up of particular stresses, stress magnitudes, and duration of exposure at those magnitudes. These stresses include thermal, electrical, vibration, chemical, biological, nuclear, pressure, etc. By determining the magnitude and duration of each type of stress contributed from each environmental element, the stress profile for each stress type is developed. As an example, during manufacturing processes the thermal environment may well be controlled and constant (though severe) and the vibration environment nonexistent. Once fielded, however, the equipment may experience extreme variations in thermal loading and cooling air supply, while at the same time, undergoing extreme G loading and high random vibration levels. In this example, the thermal and vibration environments are constructed as composites of both manufacturing and field environments so the total stress exposure is determined. Other combined stress environments of extreme importance for satellite applications include those caused by the additive effects of electrical stress and irradiation (e.g., total ionizing dose and/or neutron irradiation); operation at cryogenic temperature combined with electrical stressing and irradiation and thermal cycling combined with irradiation.

7.4 Establishing design criteria. Establishing design criteria requires a disciplined method for combining the demands placed on the parts and materials in implementing a circuit function over stress profiles inherent in the expected use environment. This combination establishes a baseline of necessary capability and capacity properties for component evaluation and selection. A particular desired assembly function defines the assemblies boundary conditions such as input/output signal(s) voltage, current, and frequency ranges, transition times, etc. Desired function and performance also define types of processing and processing rates, maximum allowable signal propagation delays, etc. Candidate parts must exhibit a combination of insensitivity to combined (e.g., electrical and radiation) stresses while meeting function and performance needs for a designated period of time. Since design tools based on reliability physics and radiation effects are imperfect in providing exact estimates of a minimum period of acceptable component operation, derating of stressful parameters must be considered. Derating should be reliability physics and process control-based. Worst case component defect characteristics (e.g., grain size and narrowed line widths, etc due to metallization process variability) and impact of failure on safety and mission should be included, for example, when establishing current flow design limits for supply and output terminals. In addition, worst-case radiation response and the impact of this response on mission performance must be addressed.

7.5 Stress reduction. If analysis with respect to stresses and component characteristics, including variability in key characteristics, limitations, and sensitivities (supported by small/coupon testing), indicates a component is not likely to last the entire service life, then design trades aimed at stress reduction should be considered. Adjustments, such as moving a component near the edge of a card (to reduce lead bending stress from vibration) or adding a buffer (to reduce output current demand and power dissipation), can reduce stress exposure and extend component life to a degree that it remains suitable in spite of certain limitations and sensitivities. If practical design adjustments are not enough to assure component survival for the service life, alternate, more robust, components or technology families should be considered. In the situation where the stressing environment is caused by radiation, the use of shielding and systems and circuit design methods should be considered, in conjunction with hardened microelectronics, to achieve cost-effective, balanced designs.

7.6 Quantitative durability analysis. Component suitability and design verification analysis should be performed in a quantitative, deterministic fashion using models for the known wear-out mechanisms of each applied technology family. Microcircuit design is performed with typical electrical and thermal application use conditions applied to establish design criteria. This design criteria, in conjunction with reliability physics, is used to determine or verify the suitability of such features as metallization dimensions, composition and structure, gate oxide material and dimensions, dielectric materials and dimensions, etc. The reliability physics models and various features used to implement a die design provide invaluable and essential data applicable to the design use of the resulting microcircuit. Reliability physics models, using the specific application electrical and thermal stresses and the die and package features as variable inputs, can help predict how long a device will function before catastrophic failure becomes probable. By considering the acceptable range of each key device parameter, according to application environments, a prediction of time-to-failure due to function or performance degradation is also possible. Analyses producing accurate, consistent results are practical for most mature technology families. In fact, measures of technology maturity and suitability for military applications include how well the applicable wear-out mechanisms are understood and the availability and validated accuracy of reliability physics models for deterministic analysis of useful component life under specific application conditions. Because of differences in physical features, materials, manufacturing process suitability and capability, etc from vendor to vendor, models tailored to or developed by a specific vendor are preferred to models applied industry wide. Again, cooperation and communication between vendor and user is very important in achieving accurate analytical results. This is essential in avoiding misapplication of parts in high stress, high performance circuit insertions.

7.7 Suitability evaluation/qualification. Durability depends upon selection of parts that will perform properly for the service life of the equipment. A formal process for determining technology family suitability should be established and applied to all parts regardless of which quality system parts are purchased to. The highest quality part or technology family can be misapplied due to incompatibility with design tools and methods and become a reoccurring failure and logistic support problem.

Top level initial suitability analysis of technology families can be done with respect to bias levels, external temperature, loading conditions, power cycles, and family specific sensitivities and limitations immediately after an estimate of the intended usage, use environment, and assembly level block diagrams is developed. As a design becomes more defined, the effects of specific component power dissipation, internal and external temperature, specific loading conditions, operating signal frequencies, vibration, input signal conditions, etc at specific assembly locations can be evaluated and suitability reaffirmed. Suitability analysis should be carried out as an iterative part of the design process.

Formal equipment designer/manufacturer procedures for qualifying technology families from particular vendors is highly desirable. Such procedures should establish suitability for each design task (desired end function, performance, and use/stress environment) in light of possible vendor to vendor variabilities. This supports a closed-loop design process and will assure highest probability of designing with parts having the necessary characteristics from the very beginning. In addition, the qualification procedure should evaluate the level of supplier technical support and control over key variabilities available as a result of compliance to the applicable quality system(s).

Each vendor technology family should also be evaluated for compatibility with design tools and methods as a part of suitability qualification. Incompatibilities with computer-aided design (CAD) tools for design, analysis and simulation can lead to the misapplication of high quality parts or technology family.

A final element of technology family qualification is evaluating compatibility with equipment manufacturing processes and procedures. The various stress exposures inherent in each manufacturing process should be evaluated in terms of type and duration against technology family sensitivities to assure excessive degradation will not occur. A component should be capable of lasting the service life of the equipment, AFTER exposure to manufacturing and inspection/test stresses (including rework) and environmental stress screening (when applicable).

7.8 Closed-loop design process. A controlled design process with variability reduction is essential to designing high-complexity systems in a timely economic fashion. Variability reduction, as applied to a design process, would drive toward a design environment capable of producing designs with a high probability of first pass success (fewer re-design iterations). An example of such a process would involve the use of a computer-based design and simulation environment to develop and verify a desired assembly function and performance. The design would then be fabricated and electrically tested under various environmental conditions for proper function and performance. Differences in simulation and electrical test results would form the basis for analysis and corrective actions to bring the designed and simulated function and performance into agreement with actual test results. Corrective actions might involve refining CAD tool component models with new and/or more precise parametric limits or central tendency values, or adding CAD routines to accept and utilize data representing such things as parametric drift of specific technology families induced by high or low temperatures.

A disciplined design process would also include a design process suitability verification. The purpose of such a verification is assuring the tools, methods, and procedures used have no inherent limitations or assumptions which will force a less than satisfactory result (assembly design) with respect to short and long-term function, performance, and durability for the kind of assembly/function being submitted to the process.

A typical item to be checked in such a verification would be compatibility (e.g., verify that embedded design rules account for transmission line properties and proper impedance matching of components and interconnecting medium (printed wiring board (PWB), coax)) when assemblies operate at very high frequencies. If the design process consists of an engineer drawing schematics by hand while referring to component data manuals, a suitability verification might consist of assuring the designer is well trained in the proper design application of all proposed component technologies in each new/different type of assembly to be designed. Expertise with the type of function and concepts key to proper functionality and performance (such as, transmission line properties of PWBs for high frequency assemblies) is also a possible consideration.

In both cases, a capabilities demonstration (designing a small assembly requiring the same kind of component technology and same level of operational performance) is an excellent verification tool and provides information about process capabilities and need for corrective actions. Small scale capability demonstration results provide a way of rating potential contractors with respect to a proposed design and development effort providing a criteria appropriate to the desired item of supply. This approach provides more insight into current capabilities as opposed to results of previous design efforts with lower equipment performance levels and different component technologies.

7.9 Characteristics variability. Another consideration in proper design application of a component technology family is an evaluation of the allowed variabilities to determine if any of them will affect proper component function, performance, or durability in a specific circuit insertion. An example of this is the lead dimension limits found in MIL-STD-1835. Mechanical analysis of these dimensions with respect to typical vibration induced bending stresses indicates that life expectations of leads with dimensions at the extremes can vary by as much as 70,000 to 1. With this in mind, the designer must consider the effect on the assembly of worst case lead dimensions.

If analysis shows, for example, that the expected vibration environment is likely to stimulate an early lead failure, design adjustments, such as repositioning the part or adding board stiffeners, can be used to make the design tolerant to lead dimension variations. If service life requirements cannot be met through adjustments, source or specification control may be necessary to assure that installed components have robust leads.

7.10 Specifications and quality system. Variabilities affecting long term function, performance, and reliability are present in every quality system and each technology family. Each application has a unique set of stresses which can turn a particular variability into a source of early failure in the deployed equipment. The specification and quality systems control only a subset of device characteristics. In a specific application, one or more uncontrolled characteristics may be critical to satisfactory component function, performance, or durability. By their nature, these uncontrolled characteristics are likely to vary from vendor to vendor. Identifying these characteristics is not a trivial task and the contractor should have a disciplined "variability affects assessment" procedure to pinpoint them.

Again, the equipment designer should strive to make adjustments so the assembly is tolerant of these characteristics. If this is not possible or practical then specification, source, or item control, or even use of an application specific device may be necessary when safety or mission readiness demand it. It must be recognized that, since these characteristics are uncontrolled by the specification or quality system, it is necessary to document both the characteristics and acceptable limits for each application of the part as identified in the design process. This enables the disciplined procurement of acceptable parts for production and meeting deliverable data item requirements.

The design process must be iterative to assure that, as parameters/properties of the end item become more defined, changes which might render a previously acceptable part less than suitable are identified and addressed. The objective is to have a high probability of first pass success as a design transitions from development to qualification and then to production and deployment. A controlled, closed-loop, iterative design process will minimize the failure events in qualification testing reducing time and cost impacts of design modifications made after assemblies are in production.

7.11 Application Specific Integrated Circuits (ASICs). The primary purpose of application specific devices in equipment design is to achieve a unique function or set of functions at a necessary level of performance in a single device or set of devices. The influences which typically drive use of ASIC devices are unique functionality, space and power constraints, expansion of practical performance limits, radiation requirements (as appropriate) and improving reliability. This last point warrants additional consideration. Typically, discussions of improving reliability through the application of ASIC devices revolve around reducing the statistical probability of a component level failure by replacing several components with a single ASIC. This same consideration applies to a reduction in the number of device/PWB interconnections. The fewer devices or solder joints present in an assembly, the fewer possible failures per unit time. This is a valid method of improving reliability assuming the ASIC is robust enough to withstand the use environment stresses.

Application specific devices should be designed for function, performance, and long-term reliability under end item use environment conditions. Reliability physics-based analysis of proposed ASIC designs should be used to evaluate suitability during the equipment service life. Verification of suitability should be done via testing which imposes amounts and types of stress equivalent to the actual use environment and service life.

Another potential avenue of assembly level reliability improvement is the use of an ASIC device designed to provide service life durability (minimize probability of both open/short and parametric degradation). If durability analysis indicates no existing device having the desired function and performance can meet reliability requirements, a durability enhanced ASIC may be necessary to assure safety of flight or mission criticality criteria are met. The use of reliability physics-based design, suitability analysis and verification testing is essential to be successful with this kind of ASIC development. The QML quality system is particularly well suited to meeting equipment designer needs for this type of device. The conversion of customer requirements process must include the use environment in great detail. In selecting a supplier of an ASIC device, consideration should be given to whether or not the device manufacturer is using VHSIC Hardware Description Language (VHDL) tools up front in behavioral level device design VHDL descriptions of the device interactions at the system level. This provides a system designer with the opportunity to redesign or reselect a device based on the interactions before the design is committed to fabrication and/or system insertion. Failure to use these standard design tools can result in high cost, sole source situations both in first time buys and during the remainder of the system life cycle.

7.12 Summary. The design and part selection procedures suggested here are inseparable and much more rigorous than might otherwise be necessary when following traditional methods described in military/industrial/commercial specifications and standards. They are aimed at making the design process (including selection of appropriate components) responsive on a real time basis to the very rapid changes in design tools and component technology. Being rooted in reliability physics, these methods are deterministic and quantitative. From this a more realistic design solution can be reached than with methods applied across the entire vendor base without regard to differences in component reliability, sources and types of variability, and limitations and sensitivities of technology families from different vendors. The quality systems discussed in Chapter 2 are established to allow a designer to select a manufacturer with a defined set of quality standards and practices which should minimize variability of the various technology families produced/shipped, thus minimizing the risk of using their devices in the respective system application. Furthermore, the process discussed in this section requires military equipment designers to consider all aspects of component selection that impact the DoD mission needs, moving beyond questions of compliance to specifications and standards into questions about reliability in specific applications. The reliability physics used in the design of components can be brought to bear on the application of those components. The design rules, tradeoffs, and application assumptions made/used by the device designer can be used to establish design rules for the equipment designer and contribute to reducing misapplications which can severely reduce the useful life of even the highest quality component. The objective of this effort is military equipment that meets all specification requirements and has a very low cost of ownership.

8. SYSTEM GUIDANCE

8.1 Introduction. The competitive nature of today's electronic industry has created an environment suitable to promote, demand, and apply the best manufacturing practices. A manufacturing system capable of producing high quality products must comprehend the basic elements of design, manufacturing, marketing and customer services. The success of this system is based on communication of customer needs and requirements to suppliers. The customer-supplier communication is the key to manufacturing and marketing high quality products. The OEM is responsible for a parts policy and control program which will assure the program performance including reliability of operation on the system specified environment, time, temperature, radiation, etc. There should be a reliability derating to account for application rating studies and end-of-life parameter derating to assure microcircuit application and interchangeability throughout the program life.

8.2 Manufacturing and cycle time. The term manufacturability is used to define manufacturers' ability to produce products with an acceptable quality/cost and it is a function of product maturity for both the supplier and the customer. For new products utilizing new technologies, a yield of 20% may be acceptable in order to supply products ahead of competition. Time-to-market or manufacturing cycle time for introducing new products has become the driving force of many manufacturers. This concept has forced manufacturers to study their cycle time for each operation. In some cases production flows have been streamlined to implement Just-In-Time (JIT). Contracts should require a comprehensive yield improvement program for the new technologies as well as cycle time analysis to reduce cost and obtain continuous improvement.

8.3 Statistical Process Control (SPC). High yield and high quality consistently at the lowest cost is any manufacturers' goal. Statistical process control techniques are tools to achieve this goal. The publication, EIA 557, outlines requirements for an SPC program. This specification requires study of all process nodes, selection of critical nodes, proper use of SPC data, corrective actions based on SPC data, piece parts SPC program, etc. SPC and low yield are not necessarily mutually exclusive. For example, a tester may be under SPC and produce low yield. The low yield is due to incoming material characteristics, not the tester. Contracts should require use of SPC; however, they should avoid selection of critical nodes, CpK, etc. Contracts requiring SPC should provide for some type of detailed review by SPC trained personnel to ensure adequate and effective use of SPC. Under the QML and QPL quality systems SPC is required and is evaluated periodically by the Government for its effectiveness.

8.4 Screening. Data published by the Institute of Environmental Sciences-Environmental Stress Screening of Electronic Hardware (IES-ESSEH) in 1988 and 1990 has shown that the majority of military grade components are defect free. Industrial systems manufacturers have helped drive the increase in quality and reliability by demanding quality levels similar to those imposed by the military. These commercial users consume the largest quantity of IC products and thus have significant impact on the rate of quality improvement. Defects found are typically due to miscorrelation of test hardware/software or ambiguity of specifications. In addition, the above publications show that an active customer-supplier quality improvement team (QIT) can systematically eliminate all defects. A proposed correlated device list (CDL) for the industry to be hosted by the Government-Industry Data Exchange Program (GIDEP) should list components that have reached defect free status based on the correlation effort among specific supplier-user teams. Mandatory 100% rescreening of components must be avoided. Rescreening may be allowed temporarily to give time for quality improvement programs to work or to locate another source. However, screening may be necessary or cost effective when purchasing parts from small volume suppliers. Each program should have as one of its major goals the task of reducing or eliminating costly ESS screening.

8.5 Interchangeability/substitution. One of the most frustrating problems in the field is interchangeability of components. In many cases, a standard component from another manufacturer cannot be used to replace a failed component. This problem has also been found in the list of allowed substitutions. In both cases, designers and the original equipment manufacturers have not fully defined all critical parameters in their application. Contracts should require proper documentation of critical parameters. It is also recommended that OEMs verify the validity of the substitution list.

8.6 Radiation Hardness Assurance and system radiation hardening considerations. Guidelines for RHA issues are addressed in Appendix A of this handbook.

8.7 Obsolescence. Obsolescence or non-availability of items required to support DoD systems has become an increasingly prevalent problem in recent years. This situation may occur among all classes of items and materials, but most commonly affects solid state microelectronics. Various DoD and industry-driven factors may combine to make continued manufacture of selected components uneconomical or otherwise unattractive. Reasons manufacturers cite for ceasing production include rapid technological advances, foreign source competition, federal environmental and safety regulations, and limited availability of items and raw materials. Department of Defense procurement practices further compound the problem. Long design-to-acquisition lead times, uneconomical production requirements, and service life extension programs may all impact profitability and/or availability of specific product lines and thus decrease manufacturers' desire or ability to provide life cycle support for obsolete parts and components. Diminishing Manufacturing Sources and Material Shortages (DMSMS) are defined as the loss or impending loss of manufacturers or suppliers of items or shortages of raw materials. DMSMS cases may occur at any time during the acquisition cycle, from design and development through post production, and have the potential to adversely impact the military's ability to outfit and support critical equipment, components, and parts.

Approaches to limit the impact of obsolescence are: evaluate market trends and the effect on availability, designing at the module level instead of the component level, requiring VHDL at the module or component level, planning for system obsolescence and system re-procurement, requiring contractor logistics support for the life of the system, lifetime buys, and buying components with the longest expected field lifetimes.

8.8 Testability. Integrated circuit designers continue to design circuits that can be made smaller and faster, sometimes using design practices that produce untestable circuits. For the systems of the past this probably was a cost-effective way of bringing systems to the field. However, with continuing decrease in the hardware costs and increase in the field engineering costs, this practice is far from being cost-effective in today's very competitive industry. Today it is necessary to detect, diagnose, and correct problems quickly, accurately, and economically in a mass production environment.

The notion of design and test as two separate activities cannot continue in the future because it will adversely affect the overall cost of integrated circuits and systems. This has been realized by system manufacturers who introduced design for testability techniques in order to essentially minimize the cost for test pattern generation, test pattern validation, and test application. Self-testing techniques are also increasingly being used for functional verification of high performance circuits capitalizing on their advantage of at-speed testing. Finally, when design and test are considered as an integral activity at the component level, system testing can be greatly affected by adopting a system design methodology that takes advantage of "testable" components to create system BIT structures at all levels of design hierarchy so that systems are easily testable.

An important consideration in testing digital microcircuits is the definition of some kind of measure of test "quality." Traditionally, this measure was called fault coverage and is the fraction of detectable faults that are detected using a given test set.

The number of faults detected is relatively easy to determine. A fault simulator is able to count them. The problem is with determining the number of all possible faults. With a structural model, we can define it as the number of interconnections doubled (assuming that we do not allow for bridging faults). At the functional level this measure is relative. The same functional unit can be built in many different ways, each using a different number of gates and, thus, having a different number of interconnections. This means, if we try to use the definition above, we can actually "manipulate" the result, and by adding logically transparent components, such as a noninverter to our functional primitives, we can report a higher percentage of fault coverage without improving the comprehensiveness of the test. An example of cost reduction through the use of increased fault coverage testing is given below:

Example: Assume that the fault coverage of untested ICs is 98%. Assume further that through testing we can improve the fault coverage of the lot to 99.8%. In the intended operation, 50 ICs are used in accordance with PWB, and 10 PWBs are needed to construct a system. The workload is uniform at 1000 systems per month. The company has found that eliminating a fault at the IC level costs $0.75; $7.50 at the PCB level; and $75.00 at the system level. What is the cost savings by high fault coverage assurance?

Let Q_I = fault coverage of ICs,
n = number of ICs on the PWB,
P_B = probability that the PWB is free of bad ICs,
m = number of PWBs in the system, and
P_S = probability that the system is free of bad ICs.

Then, if we do not test ICs, the probability that a PWB is free of bad ICs is

$$P_B = (Q_I)^n = (.98)^{50} = 36.42\%$$

At the system level, we have an unacceptably low probability that the system is free of bad ICs:

$$P_S = (P_B)^m = (.3642)^{10} = .004\%$$

Now, if through testing we bring the fault coverage of the IC to 99.8%, we will have

$$P_B = (Q_I)^n = (.998)^{50} = 90.47\%, \text{ and}$$
$$P_S = (P_B)^m = 36.75\%$$

The cost differential at the board level (CD_B) can be predicted by subtracting the difference in board fault coverage and multiplying it by the quantity and cost of repairing each PWB:

$$CD_B = \$7.50 * (.9047 - .3642) * 10{,}000$$
$$= \$40{,}537.50$$

Similarly, a cost differential (CD_S) exists at the system level:

$$CD_S = \$75.00 * (.36750 - .00004) * 1,000$$
$$= \$27,559.50$$

In this example, it was shown that if the fault coverage of the ICs is only 98%, the probability that the system constructed will be free of IC failures is only 0.004%. If, however, we increase the fault coverage of the ICs to 99.8%, a mere 1.8% increase in IC fault coverage, the probability that the system will be free of IC failures increases to 36.75%. This is nearly a 10,000-fold increase in the probability that the system will work.

It is clear that higher-quality ICs will produce higher-quality systems and, from an economic perspective, will also result in lower costs. Ideally, we would like to have ICs with 100% fault coverage, but we must work within both technical and economic limitations. In order to detect all possible failures that could befall an IC, a very comprehensive test program must be produced. The amount of effort needed to produce such a test program grows exponentially as higher percentages of fault coverage are required. Figure 3 shows how time, cost, and test engineering effort grow with respect to percent fault detection or test effectiveness. An additional substantial cost is that of purchasing, operating, and maintaining an automatic test system.

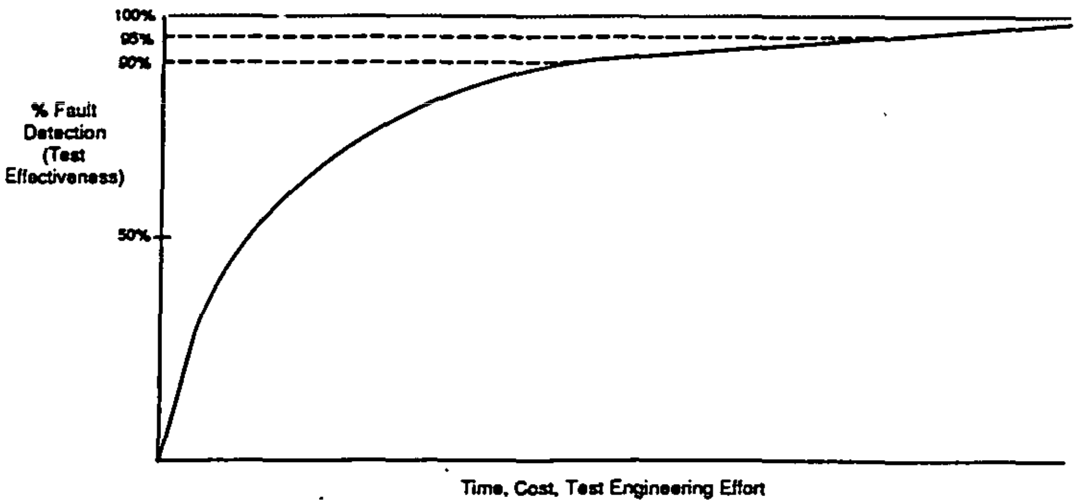

FIGURE 3. Fault coverage as a function of test program development cost.

8.9 Environmental Stress Screening (ESS). Environmental stress screening (ESS) is a process employed by DoD for discovering defective parts and materials at incoming inspection. Effective application of ESS is designed to reduce in-plant rework costs by disclosing defects due to parts, workmanship, and manufacturing process deficiencies. Furthermore, it is designed to decrease maintenance and support costs attributable to early life failures of fielded systems and improves availability during initial deployment. A closed loop corrective action process, dedicated to determining defect cause and instituting corrective action to prevent recurrence is encouraged as an integral part of ESS to assure maximum benefit of instituting this program.

ESS is used at the component, subassembly and system levels to remove quality related defects. Stress screening required of component suppliers, via the quality systems cited, is usually sufficient enough to remove assembly, packaging and workmanship problems. However, many DoD programs specify 100% ESS at receiving inspection. At the component level the most used ESSs are temperature cycle, burn-in, hermeticity and Particle Impact Noise Detection (PIND). An ESS program at the board or higher assembly level should be designed to eliminate workmanship defects resulting from the board or higher assembly processing (solder, contamination, etc) and not due to component defects. These screens include temperature cycle, shock and vibration.

In order to minimize the cost and possible schedule impact when 100% ESS is required, the implementation of government contractor receiving inspection and test is changing to reflect a process for augmenting the component/board supplier control system which in turn will reduce the level of nonconforming product entering the assembly process. The decision to perform electrical and mechanical verification at receiving is based on several factors. These factors may include, but are not restricted to the following: the lack of component/board characterization data, the criticality and/or relative risk of the component/board in its application, demonstrated performance of the component/board, or application specific testing. Decisions regarding receiving inspection and test of components/boards should be made on a supplier and part/board basis. Through implementation of a well thought out receiving inspection program, ESS would be limited to those products meeting the factors cited above. Also, any ESS program should reflect the end use system requirements.

8.10 Quality Function Deployment (QFD). QFD is a structured system for designing product or service based on customer demands and involving all members of the producer or supplier organization that assures product characteristics equate to customer requirements. QFD can be used to clarify an identifiable supplier/customer interface. It should be used in any new systems contract to assure that the final system meets or exceeds all the customer expectations.

Briefly, in a matrix format, it lists the customer's "wants" with priority ratings on one side of the matrix and the "how to" across the top of the matrix. In a system design this process is reiterated through a Requirements Matrix, a Design Matrix, a Product Characteristics Matrix, a Manufacturing/Purchasing Matrix, a Control/Verification Matrix, and a Control/Verification of Product Matrix.

In the context of this handbook, QFD should be used by the parts supplier with the system's builder to assure that all the customer application and performance requirements are properly communicated to the parts supplier so that the capability of the part may be matched to the system's environment (electrical, thermal, mechanical). For instance, it would be inappropriate to use plastic parts in an exposed wing tip avionics pod, but unfortunately, it was done on one system at a considerable retrofit/redesign cost. QFD would have established the structured communications link between the supplier and the customer.

CONCLUDING MATERIAL

Custodian:
Army - ER
Navy - EC
Air Force - 17

Review activities:
Army - CR, AR, MI
Navy - NW
Air Force - 19, 85, 99
DLA - ES

Preparing activity:
Army - ER

Agent:
DLA - ES

(Project 5962-1402)

APPENDIX A - RADIATION HARDNESS ASSURANCE

1. INTRODUCTION

1.1 Purpose. The purpose of this appendix is to provide guidance to assist the various military departments and their contractors in the selection of microcircuits for systems and equipment that must operate and survive in a radiation environment. As previously stated, device selection should be based on selecting the most cost-effective solution to provide adequate system/equipment radiation hardening and survivability considering both semiconductor piecepart hardness and system hardening techniques. Examples of system hardening approaches include the use of shielding, redundancy, error detection and correction, circumvention, and several other system architecture and circuit design methods. In general the objective is to provide the requisite radiation hardness consistent with established targets for electrical performance, cost, availability, reliability, etc.

1.2 Scope and Application. This appendix is intended to provide guidance, reference, and training for those persons involved in radiation hardened/tolerant microcircuit device selection.

2. APPLICABLE DOCUMENTS

2.1 Government Documents.

2.1.1 Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the Department of Defense Index of Specifications and Standards (DODISS) and supplement thereto, cited in the solicitation.

STANDARDS

MILITARY

MIL-STD-883 - Test Methods and Procedures for Microelectronics.

HANDBOOKS

MILITARY

MIL-HDBK-814 - Ionizing Dose and Neutron Hardness Assurance Guidelines for Microcircuits and Semiconductor Devices
MIL-HDBK-815 - Dose Rate Hardness Assurance Guidelines
MIL-HDBK-816 - Guideline for Developing Radiation Hardness Assurance Specifications.
MIL-HDBK-817 - System Development Radiation Hardness Assurance

2.2 Non-Government Publications. The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted are those listed in the DODISS cited in the solicitation. Unless otherwise specified, the issues of documents not listed in the DODISS are the issues of the documents cited in the solicitation.

ELECTRONIC INDUSTRIES ASSOCIATION

EIA 557 - Statistical Process Control Systems
JEDEC Publication 22 - Plastic Package Test Methods

American Society for Testing and Materials (ASTM)

ASTM Method 1192 - Standard Guide for the Measurement of SEP Induced by Heavy Ion Irradiation in Semiconductor Devices.

3. DEFINITIONS AND ACRONYMS

3.1 Acronyms. The acronyms used in this handbook are defined as follows:

a. FXR - flash X-ray
b. RHA - radiation hardness assurance
c. RHACL - radiation hardness assured capability limit
d. RLAT - radiation induced latchup
e. SEE - single event effects
f. SEU - single event upset
g. SEB - single event burnout
h. SEDR - single event dielectric rupture
i. SEGR - single event gate rupture
j. SEH - single event hard errors
k. SEL - single event latchup
l. TID - total ionizing dose

3.2 Definitions of Terms. The terms used in this handbook are defined as follows:

a. Radiation Hardness Assured Capability Level (RHACL). This is the radiation exposure level for a semiconductor at which the manufacturer warrants that it will continue to meet specifications. It is typically based on data obtained from exposing devices or test structures to radiation in accordance with MIL-STD-883 or Mil-PRF-38535.

b. Radiation Hardness Assurance (RHA). The procedures used to ensure that the radiation hardness capability of a semiconductor device is in compliance with the product specifications.

c. Design Margin. The parts "overdesign" factor expressed as the ratio of either environmental levels or parametric values.

d. Single-Event-Effects. The radiation response of a semiconductor device caused by the impact of galactic cosmic rays, solar enhanced particles and/or energetic neutrons and protons. The range of responses can include both nondestructive (e.g., upset), and destructive (e.g., latchup or gate-rupture) phenomena.

e. Dose-Rate-Upset/Survivability. The response of a semiconductor device to the prompt emanations of a nuclear weapon, i.e. gamma or x-ray pulse, which can result in the transient upset and/or destruction of the device.

f. Total Ionizing Dose Effect. The response of a semiconductor device to ionizing radiation that can occur due to the x-ray and gamma emanations of a nuclear weapon or due to electrons/protons trapped in the earth's magnetosphere, occurring in space, or surrounding other planets. The effects of ionizing radiation include device degradation and/or failure.

g. Displacement Damage. The damage to the bulk structure of a semiconductor device caused by the impact of energetic neutrons and/or protons. This effect can be engendered by either a nuclear weapon detonation (neutrons) or solar activity (neutrons and protons). The result of this irradiation is either device performance degradation or failure.

h. Hardness Maintenance. Procedures applied during the operational phase to ensure that the system's operation, logistics support, and maintenance do not degrade the system's designed and fielded radiation hardness.

i. Hardness Surveillance. Scheduled tests and inspections performed during the operational phase to ensure the system's designed radiation hardness is not degraded through operational use, logistics support, maintenance actions, or natural causes.

4. QUALITY SYSTEMS

The various quality systems and the RHA implications of each system are discussed in Chapter 4 of the handbook. The primary message is that for an RHA device, the entire cost of ownership (i.e., purchase price, cost of additional supplier data, radiation characterization costs, radiation test and screening costs, subsequent radiation acceptance test costs, increased radiation hardness assurance costs, maintenance and surveillance costs, increased system design costs, etc.) should be considered in any acquisition.

5. SELECTION GUIDANCE

5.1 Selection Guidance. Vendors and devices should be selected according to the guidance provided in Section 5 of the document.

5.2 Radiation Hardness Assurance (RHA). RHA is required for all devices that must operate in a radiation environment. Three distinct situations are possible and each must be addressed separately as follows:

(1) QML Vendor Technology: Pieceparts are accepted as qualified for the specified RHA level with no additional testing required when die are procured from a qualified QML vendor and application parameter limits lie within the die specification (a QML qualified die fabrication technology). The parts used in the equipment must pass all TCI/QCI test for the specified RHACL of the QML fabrication technology.

When the specified RHA levels and parameter limits for the qualified die and planned circuit application do not match, additional specification controls are needed. These may best be accomplished with a selected item drawing (SID).

(2) Vendor RHA Product Qualification: When pieceparts are procured from a vendor where the supplier maintains die fabrication technology change control the parts shall be qualified to the RHA level for the required RHA environment. The qualification test requirements shall be based on the requirements of Mil-PRF-38535, Appendix A, for Class B or Class S devices as appropriate for the application. Group "C" steady state life test shall be performed on a sample of each lot of die to establish parameter deltas. Post rad temperature and end-of-life deltas shall be established and documented. Qualification shall be reperformed as a result of a major change of the die vendors die fabrication technology.

(3) Commercial Vendor Lot Qualification: When pieceparts are procured from a commercial semiconductor supplier who does not guarantee change control of the fabrication process, the equipment supplier shall develop and document a plan to assure fabrication lot uniformity (i.e., same wafer lot, homogeneous lot process,

etc.) The plan shall identify a lot sample plan and qualification test for each lot based on the RHA requirements for the equipment. The qualification test requirements shall be based on the requirements of Mil-PRF-38535, Appendix A, type of requirement for Class B or Class S devices as appropriate for the application. Group "C" steady state life test shall be performed on a sample of each lot to establish parameter deltas. Post rad temperature and end-of-life deltas shall be established and documented. Any fabrication lot exceeding initial established deltas shall be scrapped.

5.3 Parts Control Procurement Plan for RHA Devices. Since radiation requirements impose additional requirements on the parts control process the basic PCPP will have to be augmented to reflect these requirements. In addition to the normal controls, additional controls are required to establish both the radiation hardness of the device, and the maintenance of this level through the duration of the program. Assurance that the initial hardness level has not changed is a larger effort than establishing the initial level, particularly for the commercial quality system devices. As indicated in the Vendor Selection Criteria Spreadsheet (Section 5.2.1) and Device Selection Criteria Spreadsheet (Section 5.2.1), additional information is required for RHA devices and applications requiring equipment to operate in a radiation environment.

6. APPLICATION PRACTICES

6.1 General. The correct application of microcircuits is essential to overall performance, hardening and survivability for nuclear and space environments, reliability and cost/availability of systems. This chapter provides a discussion of the issues that must be addressed to ensure correct part selection for systems with a radiation hardening requirement.

6.2 Radiation Hardness Assurance. The proper operation of microelectronics in a radiation environment require knowledge and understanding of the radiation environment (e.g., nuclear weapons engendered, earth's magnetosphere, space, man-made commercial, etc.), the performance required of the microelectronics in the environment (e.g., operate-thru, etc.), the equipment configuration (e.g., shielding, shadowing, circumvention, etc.), the response of the actual device and the device response in the intended circuit application. The last point is especially important in a nuclear weapons environment (NWE) due to dose-rate and internal electromagnetic pulse (IEMP) effects. A brief discussion of these radiation environments, some general considerations, and supplier requirements is provided in the following sections.

6.2.1 Environments. Device radiation hardness capability shall be compared to the radiation environment levels associated with each application. The environments associated with natural space, NWE, and other man-made sources (e.g., nuclear reactors) include:

(1) Single-Event-Effects (SEE). The sources of SEE are galactic cosmic rays (GCR), solar enhanced particles (SEP), energetic neutrons, and protons, and alpha particles.

The effects to be considered include single-event-upset (SEU), single-event-latchup (SEL), single-event-burnout (SEB), single-event-gate-rupture (SEGR), and single-event-hard-error (SEH).

(2) Total Ionizing Dose. Environmental sources considered for ionizing total dose include radiation belts (protons and electrons), solar radiation, nuclear reactors, and nuclear weapons. The characteristics of these sources in terms of dose rate and total dose expected over the life of the part is particularly important. Specific

total ionizing dose effects include: functional failure, increased leakage and standby currents, timing degradation, and decreased I/O drive capability. The specification of the piecepart shall encompass the mission life and the worst case dose rate and total dose characteristics for the included pieceparts.

(3) Neutron & Proton (Bulk displacement damage). Environmental sources considered for neutron irradiation include radiation belts, solar radiation, nuclear reactors, and nuclear weapons. The particle environment is specified in terms of fluence. Specific bulk damage effects include gain degradation, increased noise, increased dark current for charge coupled devices, and secondary circuit effects from these.

(4) Dose-Rate and Internal Electromagnetic Effects (IEMP). Environmental sources considered for ionizing dose rate and IEMP effects are limited to nuclear weapons threats. The dose rate environment includes the amplitude, spectrum, and risetime of the dose rate event. Specific dose rate and IEMP effects to be considered include current and voltage transients, upset, latchup, snapback, and high dose rate burnout. Particular attention must be given to combined IEMP effects and input/output (I/O) photocurrent effects among interconnected pieceparts. Where the designer has a capability to use shielding to achieve a modified environment, he must demonstrate procedures to model the shield's effectiveness and consider the effects of the environment as modified by the shield.

6.2.2 Qualification Requirements. For the case of the QML supplier the RHACL shall be used to determine the margin between the actual radiation levels and the device capability. For those suppliers who are not QML certified but maintain stringent SPC of the critical design and process parameters, report all design and process changes and have characterization data concerning device, the application of devices use shall be based on radiation test results.

A proposed method to derive the required data base would consist of radiation testing using MIL-PRF-38535, Appendix A, Class B or Class S requirements (as appropriate to the application), performing steady state life tests on a sample of each lot of die to establish parameter deltas and finally establishing post-radiation temperature and end-of-life deltas.

In addition, this process should be reperformed following any major change of the vendor's fabrication methodology.

For those vendors who provide commercial parts without any guarantee of change control, a lot sample plan or equivalent would have to be developed by the equipment manufacturer to assure fabrication lot uniformity (i.e., same wafer lot, homogeneous lot process, etc.). The plan must identify a lot sample plan and qualification testing procedures. A more detailed description of these requirements is provided in Appendix A Section 5.2.

7. SELECTION PROCESS FOR RHA MICROCIRCUITS AS AN ELEMENT OF DESIGN

7.1 Scope. This section provides a suggested process for selecting microcircuits with the required performance, reliability and radiation hardness capabilities. The goal of this process is to ensure cost effective designs that satisfy all of the above noted requirements.

7.2 General Process. The parts selection process, as in the non-radiation environment situation, must begin with a clear understanding of the application including electrical performance and environment (e.g. temperature, atmosphere, vibration, etc.). However, for device applications in systems that must operate and survive in radiation environment, these radiation effects must be superimposed upon the other natural environment conditions.

This later task is especially significant since the effects of the ambient environment (e.g. temperature, atmosphere, etc.) will impact on the radiation response of the microcircuits. A more complete discussion of these interactions is contained in Section 7.3. below.

7.3 Radiation Response Variability.

One of the major issues concerning the use of microelectronics for applications which require radiation hardness is the variability of the radiation response of a specific technology and the designs emanating from that technology.

Two specific issues must be considered:

(1) The sensitivity of the response of a circuit to a particular environment or failure mode (e.g., total ionizing dose, dose-rate, SEE, displacement damage, etc.) due to otherwise acceptable process variations.

(2) The statistical process controls (SPC) and qualification conformance inspection (QCI) procedures used by a specific semiconductor supplier to maintain critical process/design parameters for radiation hardness.

In general total ionizing dose response is the most sensitive of the radiation effects to processing parameters. The processing parameter associated with gate oxide and field oxide growth are the most critical. Moreover, relatively small changes in temperature, time, pressure, contamination, and atmosphere (e.g., Argon vs. Nitrogen; steam vs. dry) can have a dramatic effect on final process robustness. Circuit design rules and layout also are important, but not to the same degree as processing parameters.

Dose-rate-upset, SEE and displacement damage are less affected by process parameters than electrical design rules and layout. However, individual transistor response (e.g., current drive and propagation delay) plays an important role concerning dose-rate and SEE response.

In general, total ionizing dose affects both MOS and bipolar technologies; dose-rate upset and SEE affect MOS, bipolar and GaAs technologies and neutron irradiation (displacement damage) affects bipolar technology and MOS technologies associated with electro-optical devices (e.g., charge-coupled and charge-integrating devices).

Concerning semiconductor supplier SPC and QCI the following can be stated:

- QML Suppliers with specified RHACL's: For these suppliers the radiation sensitive process and design parameters have been identified and kept under strict control. Consequently, minimal variability in circuit (technology) response is the standard.

- RHA Suppliers: These suppliers are typified by the application of stringent post-fabrication screening and characterization procedures as a method of supplying in-specification products. These suppliers may or may not have identified all critical processing/design parameters, since post-fabrication screening is relied upon to meet specifications. Hence, in some cases, greater variability in radiation response can be anticipated and precautions should be taken to ensure that circuit performance is not compromised when using these circuits.

- Non-RHA/QML Suppliers: Products provided by these suppliers can be anticipated to have significant variability concerning their radiation response. Hence, stringent characterization, screening and testing is mandatory.

Section 5.2 of this appendix provides additional discussion concerning the RHA procedures required for the different classes of semiconductor suppliers.

7.4 Application Specific Integrated Circuits (ASICs). The use of ASICs in a radiation environment provides a number of unique challenges for a circuit designer. This occurs since, in addition to the standard effects on radiation response caused by process and design variations, specific personalizations can also impact radiation hardness capability.

Thus, although a robust set of process and design rules may be available for a QML manufacturer, it still may be necessary to perform radiation testing on every personalization of a gate array.

The requirement to perform testing for specific environments and the complexity of the testing will depend on the margin between the radiation levels of the operating environment and the capability of the technology.

The need for the testing is, as previously stated, due to the effects the layout, physical interconnections, and the die have on the radiation hardness of a specific ASIC. In the following discussion each of the radiation environments will be discussed.

(1) Total Ionizing Dose: The effects of TID in an MOS circuit are in general to reduce operating speed, increase leakage current, reduce individual transistor current drive, and reduce transconductance. Concerning these effects, leakage current and operating speed must be dealt with by the basic process and layout rules.

However, to ensure satisfactory IC operation circuit design rules that govern transistor fan-in and fan-out, signal and clock routing, etc. must be considered.

Depending on the design margin, changes in transistor operating speed can result in "race" conditions for specific personalizations.

In general, simulation and analysis can be used to identify and investigate worst-case signal paths, and based on the design margins, a decision to perform total ionizing dose testing for a specific personalization determined.

(2) Dose-Rate-Upset/Survivability: There are two specific issues which strongly suggest that each individual personalization be subjected to dose-rate upset testing. These issues include:

- The effects of the die power distribution on the upset level of circuits interior to the die. Circuits which are furthest from the input power pins suffer the greatest IR (voltage) drop caused by the dose-rate engendered photocurrents and will be more prone to upset due to rail-span collapse. Thus, these sensitive areas must be identified to ensure worst-case testing.

- The effects of transistor location on charge collection. The proximity of a transistor or circuit to the edge of a die or to other transistors can significantly affect the amount of photocurrent collected at critical junctions/nodes.

In addition, circuit design rules concerning fan-out/fan-in and I/O loading can also influence upset levels both at internal nodes and at the outputs.

Thus, the dose-rate upset performance of a complex ASIC can be significantly affected by the actual layout of the transistors which comprise that circuit.

The sensitivity of the ASIC to layout will of course be a function of the performance capability of the process/design to the actual threat level or the so-called design margin.

Here again, the need to perform comprehensive testing can be identified through analysis and simulation. However, the issues of identifying sensitive areas of a die and the input vector set required to exercise those sections of the circuit personalization greatly increase the difficulty associated with both simulation and testing.

Proprietary simulation codes exist (e.g. BUSNET, a product of Mission Research Corporation) to accomplish this type of analysis and should be used to support any dose-rate upset testing. Also, for testing of this complexity, pretest analysis is mandatory to ensure worst-case situations are accurately identified.

(3) Single-Event-Effects: Specific ASIC personalizations can also affect SEE performance and complicate establishing a simple quantifiable metric (e.g., errors-per-bit/day for a memory) for a particular design.

Some of the factors that would influence the SEE performance include:

- The specific operation (i.e., input excitation vectors, and mode of operation, etc) of the circuit in progress at the time of the ion strike will determine the nature of the single event effect. The complexity of this factor can be appreciated if we consider the SEE sensitivity of a microprocessor such as a 486. The specific operation in progress, the data being operated-on, etc. will all affect the overall IC response.

- The propagation path of an upset. Specifically, a heavy ion strike can result in the creation of a spurious signal at some location in a combinatorial circuit. This signal or glitch can propagate through the circuit until it is attenuated to a level where the signal is no longer capable of causing an upset or until it reaches (i) an output pin and propagates off chip with to-be-determined (TBD) consequences or (ii) reaches an internal latch with sufficient amplitude and duration to reset the circuit. Once "latched" this spurious signal will then be interpreted as a "real" signal with TBD consequences.

Here again the basic concerns are somewhat similar to those engendered by dose-rate upset with the exception that the spurious signal is local rather than global. Also, the same type of simulation methods can be used to determine worst-case situations.

In addition, non-nuclear types of testing such as laser probing can be used to identify sensitive areas within a die and worst-case conditions (e.g., bias voltage, input vector, mode of operation, etc.).

Thus, for certain critical ASICs, a comprehensive analysis and test qualification program is required to support operation in a radiation environment (e.g., space, etc.). The level of detail and completeness of these tasks will be governed by the technology design margin and criticality of the application.

7.5 Radiation Hardness Considerations. Proper application of microcircuits requires a thorough understanding of the radiation environment, the system functions which must be performed and the hardness of the semiconductor devices which are available.

The effects of radiation on various semiconductor technologies is summarized in Table 1.

The specific radiation environments as a function of device application are summarized in Table 2.

Finally, Table 3 provides a summary of threat environments vs. threat mitigation methods.

In general, device design margin can be traded-off against considerations such as shielding, circuit and system design complexity (e.g., circumvention, EDAC, voting, etc.), RHA requirements (e.g., lot testing, individual device screening, etc.) and overall system design complexity. Obviously, the "best" solution is the one which simultaneously achieves the required system performance (including reliability or MTBF) and minimizes total cost of ownership.

Table 1. Radiation Effects on Semiconductor Technologies.

Category	Cause(s)	Mechanism	Affect
Total Ionizing Dose Irradiation	Natural Environment: Trapped electrons and protons in the earth's magnetosphere NWE: X-Rays γ-Rays	Charge buildup in the oxide and other materials used to fabricate semiconductor devices	Metal Oxide Semiconductor (MOS): - Increased leakage current - Changes in operating speed - Parametric and functional failures Bipolar Transistors: - Reduced gain - Increased leakage current - Parametric and functional failures GaAs: - Insensitive FO and EO: - Increased attenuation
Single-Event-Effects	- Galactic Cosmic Rays - Solar Enhanced Particles - Energetic protons and neutrons	- Deposition of charge in semiconductor devices through impact of heavy ions from GCRs or SEPs) - Nuclear Reactions caused by protons and neutrons	MOSs: - Upset - Burnout - Gate rupture - Latchup Bipolar: - Upset - Burnout - Latchup EO: - Increased CCD dark current Solar Cells: - Degradation in efficiency GaAs: - Upset
Displacement Damage	Natural: Energetic protons and neutrons NWE: Neutrons	- Lattice Damage in Semiconductor material	FO and EOs: - Increased attenuation - Loss of efficiency (CTE) - Increased dark current Solar Cells: - Loss of efficiency GaAs: - Gain Degradation FET (Si & GaAs): Relatively Insensitive Bipolar (Si & GaAs): - Power & Low ft devices more sensitive
Dose-Rate	Prompt Radiation	- photocurrent generation	MOS, Bipolar & GaAs: - Upset - Burnout - latchup FO & EO: - Darkening - Upset

TABLE 2. Application/Threat vs. Device Requirements.

Application	Threat Environment	Representative Device Requirements
ICBM & Strategic Interceptor Missiles (NWE)	• Primary: - Neutron Irradiation - Dose-Rate upset/Survivability • Secondary - Total Ionizing Dose	• Neutron Irradiation $>10^{13}$ n/cm^2 • Dose-Rates > 10^8 rad/s • Total Dose < 10 Krad(Si)
Military Surveillance, Navigation & Communications Satellites (GEO & 1/2 GEO) (Natural & NWE)	• Primary - Total Dose - SEE - Dose-Rate-Upset • Secondary - Displacement Damage (neutrons & protons)	• Total Dose ≥ 300 Krad(Si) • SEE < 10^{-10} errors/bit-day • Dose-Rate < 10^8 rad/s • Neutrons < 10^{12} n/cm^2
Commercial Communications Monitoring Satellites (natural & NWE)	• Primary - SEE - Total Dose (NWE) • Secondary - Total Dose (natural) - Displacement Damage (protons/neutrons)	• SEE < 10^{-9} errors/bit-dag • Total Dose ~ 30 Krad(Si) NWE (LEO) ~ 10 Krad(Si) Natural
	• Primary - Neutron irradiation - Dose-rate (upset & latchup) • Secondary - Total dose - SEE (for avionics)	• Dose-Rate: 10^9 rad/sec • Neutron irradiation: 10^{12} n/cm^2 • Total Dose: < 5K rad(Si) • SEE: < 10^{-9} errors/bit-daY
Nuclear Reactor Control & Scientific Systems	• Primary: - Neutron irradiation - Total dose	• Neutron irradiation: > 10^{13} n/cm^2 • Total dose: > 100 Krad(Si)

TABLE 3. Threat Environment vs. Mitigation Method.

Threat Environment	Mitigation Methods
• Total Ionizing Dose	• RH Parts • Shielding - Note that for high energy electrons & proton environments shielding is minimally effective due to bremstrahling effects • Circuit Design - Bias for max. gain
• SEE - Upset - Latchup - Gate Rupture - Burnout	• RH Parts (design, layout & material) • Shielding for protons & neutrons only • System Design - EDAC, voting, etc.
• Dose-Rate Upset & Survivability	• RH Parts • Shielding - shield until X-Ray = γ limit • Subsystem Design - Circumvention - Power Strobing - Operate-thru
• Displacement Damage - NWE (Neutrons) - Natural (protons & neutrons)	• RH Parts (high ft Bipolar transistors or FET technology) • Shielding - for protons • Circuit Design - bias for minimum neutron degradation

8. SYSTEM GUIDANCE

8.1 Introduction. This section in conjunction with the information contained in Chapter 9 of this document provides guidance concerning RHA, RHM, and RHS on system development issues.

These activities should be initiated as early as possible in the system development cycle to minimize cost and effort. Moreover, these efforts should be integrated to the maximum extent practicable in the system's testability requirements.

Indeed, if an aspect of an overall system development activity entails the development and demonstration of a "new" technology, this development effort should also extend to qualification, RHA, RHM, and RHS tasks as appropriate.

One example of such a situation would be the need to develop a radiation hardened cryogenic microelectronics technology to support a system development. Since the areas of radiation hardening and testing, reliability testing, process qualification, etc. are ill-defined for this type of technology, it would be highly desirable and cost effective to initiate technology qualification, reliability characterization testing, and RHA efforts in conjunction with the basic development tasks.

Clearly such a proactive approach is also appropriate for devices without radiation requirements. However, the imposition of this additional set of constraints greatly exacerbates the situation.

8.2 Radiation Hardness Assurance and System Radiation Hardening Considerations. RHA progrm - The microcircuit RHA program must include an allocation of radiation design margin in the part acceptance specification limits which can be combined with other parameter degradation stresses, such as time and temperature, to assure each system relevant parameter has tolerable end-of-line (EOL) limits.

As previously stated, the selection of devices for a particular application requires knowledge of the radiation response of that device, a description of the environment, an understanding of the specific device application, and a description of the system/subsystem where the device will be used.

Electronic pieceparts are normally obtained for a system through the implementation of a parts control plan (see Section 5.3) and an integral part of such a plan is the radiation hardness assurance (RHA) program. The RHA program refers to all of the methods and procedures which control the acquisition to specified radiation performance levels. Specific RHA requirements for various classes of semiconductor suppliers are discussed in Section 5.2.2.

RHA activities are most apparent during the production phase of a program. However, RHA considerations (e.g., parts selection, parts control, etc.) should begin during the initial stage of a program (i.e., concept definition) and pervade all phases of a program. Such an approach should preclude the need to retrofit radiation hardening into a system which can be extremely costly. If radiation hardening is addressed during the initial stages of a systems development the cost of hardening can be less than 5% of the entire satellite cost.

In addition to RHA, hardness maintenance and surveillance programs are required to ensure that the robustness of a system is not compromised during its operational phase due to incorrect maintenance.

For suppliers that provide radiation hardened parts in general all RHA SMDs require devices to be characterized to indicate device capability (not to system survivability) using the following MIL-STD-883 Test Methods 1017, 1019, 1020, and 1021; and ASTM Test Method 1192.

RHA designators have been developed to allow for the categorization of total ionizing dose capability levels, as follows:

M = 3 X 10^3 rad(Si)	G = 5 X 10^5 rad(Si)
D = 1 X 10^4 rad(Si)	R = 1 X 10^5 rad(Si)
L = 5 X 10^4 rad(Si)	H = 1 X 10^6 rad(Si)
F = 3 X 10^5 rad(Si)	

For example, if a part is characterized to 5 X 10^4 rads(Si) the part would be listed as a D level part, but if that same part from a different manufacturer shows a capability to 5 X 10^5 rads(Si), the part would be listed as an R level on the same SMD.

The other test methods are handled within the Mil-PRF-38535, Group E paragraphs in each detailed specification as required by design or by the purchase order. The Mil-PRF-38535, Group E Table designates the test method, sample size, identify specific technology types that allow certain tests to be eliminated or retained and contains a variety of caveats concerning radiation testing in general.

It should be noted that the utmost care must be exercised before a specific test is eliminated. This warning is important since some technologies contain parasitic structures sensitive to radiation effects which don't offect the primary structure but are capable of affecting the overall circuit performance. An example of such a situation would be a combined MOS digital circuit and CCD device. In general, an MOS digital structure is insensitive to neutron irradiation, but neutrons can dramatically degrade the operation of a CCD. Thus, the deletion of neutron testing which is normally allowed for MOS technology would be inappropriate for this case.

By providing a fully characterized detailed device specification the user knows the device capability and can make a better judgment on which part best suits his particular application. However, for the situation where a device without an RHA specification is used in a situation where radiation hardness is required, as is often the case, a complete characterization of the device is required for those applicable environments (e.g., total ionizing dose, SEE, etc.) at the anticipated radiation levels. Also, any decisions concerning the appropriateness of the device must include the statistical variations associated with the device response, anticipated/statistical variations in the operating environment (e.g., solar max, solar min, solar flares, etc.) and the actual system parameters (e.g., shielding, shadowing, end-of-life performance needs, allowable number of upsets, etc.).

Specific RHA requirements for the various classes of semiconductor suppliers are discussed in more detail in Section 5.2.2.